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Sharks and their Relatives

Ecology and Conservation

Merry Camhi, Sarah Fowler, John Musick,
Amie Bräutigam and Sonja Fordham

Occasional Paper of the IUCN Species Survival Commission No. 20

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The Department of the Environment Transport and the Regions, UK (DETR) supports a Red List Officer post at the SSC Centre in Cambridge, UK, where the SSC Trade Programme staff are also located. The DETR also supported the work of the Shark Specialist Group on CITES issues in 1996, including preparation of the original Shark Specialist Group report to the CITES Animals Committee, on which this Occasional Paper is based. Together with two other Government-funded agencies, Scottish Natural Heritage and the Royal Botanic Gardens, Kew, the DETR is also financing a specialist plants officer. Further support for the SSC Centre is being offered by two NGO members of IUCN: the World Wide Fund for Nature – UK and Conservation International, US.

The National Audubon Society (NAS) through their ***Living Oceans Program***, provides staff and logistical support to the Shark Specialist Group, including the preparation of the original report and this revision. Living Oceans is dedicated to the conservation and restoration of the oceans' giant fishes, including sharks, tunas, and billfishes, and is a major sponsor of *Shark News* and other IUCN Shark Specialist Group activities.

The Center for Marine Conservation (CMC) provides financial and in-kind support to the work of the SSC Shark Specialist Group and other SSC marine species specialist groups and to the broader marine activities of the Species Survival Commission.

The Nature Conservation Bureau Limited supports the work of the Shark Specialist Group through donation of staff time and office facilities.

The Virginia Institute of Marine Science has supported this Occasional Paper through Contribution #2167.

The IUCN Species Survival Commission

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Ecology and Conservation

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Amie Bräutigam and Sonja Fordham**

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Published by: IUCN, Gland, Switzerland, and Cambridge, UK

Citation: Camhi, M., Fowler, S.L., Musick, J.A., Bräutigam, A. and Fordham, S.V. (1998) *Sharks and their Relatives – Ecology and Conservation*. IUCN/SSC Shark Specialist Group. IUCN, Gland, Switzerland and Cambridge, UK. iv + 39 pp.

ISBN: 2-8317-0460-X

Cover photo: Grey reef shark, by Jeremy Stafford-Deitsch

Produced by: The Nature Conservation Bureau Ltd, Newbury, UK

Printed by: Information Press, Oxford, UK

Available from: IUCN Publications Services Unit
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Tel: +44 1223 277894, Fax +44 1223 277175
E-mail: iucn-psu@wcmc.org.uk
WWW: http://www.iucn.org
A catalogue of IUCN publications is also available.

The text of this book is printed on 115 gsm Zone Silk, which is rated as 5-star under the Eco-Check system and is made from 100% sustainable fibre sources using chlorine-free processes.

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Executive Summary

Sharks and their relatives – the rays and chimaeras – are the diverse group of cartilaginous fishes (Class Chondrichthyes) that have evolved over 400 million years. Historically considered of low economic value to large-scale fisheries (and therefore neglected by fishery management agencies), today many of these fishes have become the target of directed commercial and recreational fisheries around the world, and are increasingly taken in the bycatch of fisheries targeting other species. Unfortunately, most sharks and their relatives are characterised by K-selected life history traits, including slow growth, late sexual maturity, low fecundity and long life, resulting in low rates of population increase. Such life histories make these species highly vulnerable to overexploitation and slow to recover once their populations have been depleted.

Shark fisheries have expanded in size and number around the world since the mid-1980s, primarily in response to the rapidly increasing demand for shark fins, meat and cartilage. Despite the boom-and-bust nature of virtually all shark fisheries over the past century, most shark fisheries today still lack monitoring or management. For example, only a handful of the 125 countries that are now involved in shark fishing and international trade have even the most minimal management in place, and there is still no management for sharks fished on the high seas. As a result, many shark populations are now depleted and some are considered threatened.

Shark fishery management has been hampered by a lack of biological and fishery data. Growing international concern over the status of these species, however, has improved this situation in recent years. This report emphasises the widely acknowledged need to improve shark fishery monitoring, expand biological research and take management action. Yet while species-specific data are still needed, lack of information should not be used to justify the lack of management for these vulnerable animals. If any marine species demand precautionary management, as set out by the United Nations Food and Agriculture Organization (FAO) Precautionary Approach (1995), it is the sharks and their relatives, because of their well-documented vulnerability to overexploitation.

This report serves as an introduction to the ecology, status and conservation of the sharks and their relatives for a general audience. It draws attention to their unique biology and makes the case for expanded political and financial investment in research, monitoring and precautionary management for all fisheries taking sharks, skates, rays and chimaeras as part of their catch. Shark fisheries cannot be managed sustainably, nor shark populations remain viable, in the absence of new conservation and management initiatives.

Acknowledgements

Much of the original content of this report was written and compiled by Merry Camhi and Sarah Fowler in August and September 1996, with substantial assistance from several members of the Shark Specialist Group and other elasmobranch biologists. It was revised by the present authors for publication as an IUCN Species Survival Commission Occasional Paper. Two years after the completion of the original, unauthored paper, it is difficult to recall all those who had generously contributed, directly or indirectly, to the original version, or helped to review it. We apologise if anyone who helped with the preparation of this publication has been omitted below.

We would particularly like to thank Alberto Amorim, Charles Anderson, Ramón Bonfil-Sanders, Steven Branstetter, Barry Bruce, George Burgess, Greg Cailliet, José Castro, Christine Chan-A-Sing, Gustavo Chiaramonte, Leonard Compagno, Sid Cook, Enric Cortés, Dominique Didier, Jim Ellis, Ian Fergusson, Malcolm Francis, Manoel Gonzalez, Samuel Gruber, Hajime Ishihara, Peter Last, Rosangela Lessa, Mark Marks, Henry Mollet, Madeleine Oetinger, Andrea Oliver, Debra Rose, Alison Rosser, Carl Safina, Glenn Sant, Colin Simpfendorfer, Malcolm Smale, Susan Smith, John Stevens, Carolus Vooren, Paddy Walker, Terry Walker, Keith Wolf and George Zorzi.

Finally, our late colleague Sid Cook, former regional vice-chair of the Shark Specialist Group's North East Pacific Region, was always extremely generous with his time and advice. We dedicate this publication to him.

Chapter 1

Introduction

1.1 Conservation issues

Chondrichthyan fish (shark, ray and chimaera) populations around the world are being affected both directly and indirectly by a wide array of human activities. As a result, many populations are depleted, and some species are considered to be threatened with extinction as a result of several factors:

- life history strategies that make chondrichthyans especially susceptible to over-exploitation and impede recovery of depleted populations;
- rapid growth in fisheries that are for the most part unregulated and partly driven by unrestricted international trade in shark products;
- very high levels of mortality from bycatch (incidental take) in marine and freshwater fisheries; and
- degradation of important nursery grounds and other critical coastal, estuarine, and freshwater habitats from development, alteration, overfishing, and pollution.

Investment in research and management of the world's chondrichthyan populations has historically been a low priority. Elasmobranch fisheries have had low levels of production relative to those targeting bony (teleost) fishes; the products have mostly been less valuable; and significant numbers are taken as bycatch in other fisheries. In the few cases where fisheries have targeted high-valued species, stocks have often collapsed before management was introduced.

Today, few shark fisheries are managed, and most of those are inadequately controlled, due in part to a lack of understanding of the limitations of traditional teleost fisheries management models when applied to elasmobranchs. The major difficulties faced by researchers and managers attempting to evaluate and manage shark and ray populations are the lack of available quality data, management tools, and political will. Elasmobranch biology is generally poorly understood and little fishery-independent or taxonomic research is under way. Fishing mortality is not adequately calculated and monitored because most fisheries generally do not identify or record their shark landings or bycatch, and landings may occur at a great distance from the catch source. The origin of shark products and numbers of sharks entering international trade are almost completely unrecorded. There are few published taxonomic or distribution guides to enable the identification of all species taken in fisheries (no comprehensive batoid or chimaeroid catalogues exist, and many species are still undescribed). Records are rarely kept to enable the identification of products to species or even genus level, and to monitor changes in trade and catch patterns. Finally, few existing management models take into account the unique biology and state of knowledge of chondrichthyans.

Even with excellent data and management tools, the particularly vulnerable nature of chondrichthyan fishes necessitates a very conservative approach to management if populations are to remain viable, fisheries sustained, and threatened species not driven to extinction. In the absence of basic data, however, it is difficult for biologists and managers to assess the impacts of fisheries and international trade on elasmobranch populations, reverse declining population trends, achieve effective management, and ensure that fisheries can continue to supply products to domestic markets and international trade. A precautionary approach to management must, therefore, be stringently applied.

Taxonomy and terminology

The term 'shark' is often used generically to refer to all of the chondrichthyan or cartilaginous fishes, taxonomic Class Chondrichthyes. 'Shark' is used in this sense by the Convention on International Trade in Endangered Species (CITES), in the present FAO Technical Consultation, and in the Shark Specialist Group's name.

This report deals with all members of the Class Chondrichthyes, but endeavours to distinguish between the three main groups of chondrichthyan fishes: sharks, rays (also known as batoid fishes) and chimaeras.

The higher systematic organisation of the chondrichthyan fishes is:
Class Chondrichthyes: sharks, rays, and chimaeras.
Superorder Elasmobranchii: sharks and rays. (Elasmobranch means literally 'strap gill'; 'rays' include the sawfishes, guitar fishes, electric rays, skates and stingrays.)
Superorder Holocephali: chimaeras. (The chimaeras are a more distantly related, poorly known group of mostly deepwater fishes that do not appear in as wide a range of target and bycatch fisheries as the elasmobranchs.)

1.2 Background

The Shark Specialist Group was established by IUCN – The World Conservation Union as part of its Species Survival Commission in 1991. The Group was formed to assess and address the conservation needs of sharks, rays and chimaeras (the cartilaginous or chondrichthyan fishes).

Its members are completing a Status Report (Fowler *et al.* in press b) and preparing an Action Plan for these groups (Fowler *et al.* in preparation). The Status Report briefly reviews the status of regional populations and fisheries, the regional and global conservation status of a selection of species, and the current and potential threats to their survival. The Global Action Plan will identify the actions needed to ensure the maintenance of healthy chondrichthyan populations and the recovery of depleted and threatened species.

This report is drawn in part from the Status Report. It provides a summary of the biological characteristics and status of chondrichthyan fishes as well as implications for their conservation and management. The first version of this report was submitted by the Shark Specialist Group (SSG) to the 13th meeting of the Animals Committee for the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) in 1996, and has since been revised and updated.

At their ninth biennial meeting in 1994, the CITES Parties directed the CITES Animals Committee to compile a review of data on the biological and trade status of shark species subject to international trade for the Parties' consideration at their next meeting. The CITES Animals Committee presented their review (Anon. 1997) to the tenth CITES meeting in Harare, Zimbabwe (June 1997). This report recognised the vulnerable nature of chondrichthyans, danger of rapid population collapse, lack of accurate fisheries data, and paucity of information on international trade. It presented a series of recommendations, including a request that the UN Food and Agriculture Organization (FAO) undertake an inquiry on the availability of biological and trade data on chondrichthyans, and undertake a consultation of experts to develop a programme to implement shark fishery data collection and management.

This FAO assessment is under way, under the auspices of a Technical Consultation on the Management of Shark Fisheries mandated at the 1997 session of FAO's Committee on Fisheries (COFI), and will culminate in an intergovernmental meeting in October 1998. This Consultation has developed guidelines for sustainable global and regional shark management as part of a Plan of Action for Sharks for promoting and implementing shark conservation and management (FAO 1998), and has produced the overview of chondrichthyan fisheries requested by CITES. Draft reports of the FAO Regional Workshops held in preparation for the consultation are also available (Oliver and Walker 1998 a, b, c).

In addition to the present paper, two other reports were submitted to the CITES Animals Committee in 1996 and are now available. An examination of shark fisheries around the world was prepared by the US National Marine Fisheries Service (NMFS) (Oliver 1997) and a summary paper by TRAFFIC Oceania and TRAFFIC USA (1996) (based on several regional studies summarised in Rose 1996) addressed international shark trade. Subsequently, a report prepared by the Center for Marine Conservation and TRAFFIC (Weber and Fordham 1997) presented options for regional and international shark management. Since then, a series of regional reports on international trade in sharks has been published by TRAFFIC, and regional summaries of the status of chondrichthyan fisheries and their management, commissioned by FAO from national experts, will be published later in 1998. Many SSG members have contributed to these studies.

Chapter 2

The Biology of the Chondrichthyan Fishes

2.1 Chondrichthyan diversity

The over 1,000 species of chondrichthyan (cartilaginous) fishes include the sharks (*c.* 400 species, not all described), batoid fishes (including skates, stingrays, guitarfishes and sawfishes – *c.* 600 species, not all described), and chimaeroid fishes (*c.* 30+ species, poorly known with confused taxonomy) (Compagno in press b). Chondrichthyans occupy a wide range of habitats, including freshwater riverine and lake systems, inshore estuaries and lagoons, coastal waters, the open sea, and the deep ocean. Although sharks are generally thought of as wide-ranging, only a few (including many commercially important species) make oceanic migrations. Most species of chondrichthyan fishes have a more restricted distribution (Last and Stevens (1994) identify 54% of the Australian chondrichthyan fauna as endemic), occurring mainly along continental shelves and slopes and around islands, and some are also confined to narrow depth ranges. Overall, some 5% of chondrichthyan species are oceanic (found offshore and probably migrating routinely across ocean basins), 50% occur in shelf waters to *c.* 200 m depth, another 35% are found in deeper waters (200–2,000 m), 5% occur in fresh water, and 5% have been recorded from several of these habitats.

The chondrichthyans are predominantly predatory; however, some are also opportunistic scavengers, and some of the largest (whale, basking and megamouth sharks, and manta rays) filter-feed on plankton and small fishes, like the baleen whales. Predatory sharks are apex predators, found at or near the top of marine food chains. Wherever they occur, therefore, their numbers are naturally limited by the carrying capacity of the ecosystem and are relatively low compared to those of most teleost fishes.

The biology of the chondrichthyan fishes is among the least known and understood of that of any major marine faunal group. Information on life history, reproductive biology and population dynamics is available only for those few species that are of importance for fisheries. Logistically, it is extremely difficult, if not virtually impossible, to collect these sorts of data for most populations, particularly those that are restricted to deepwater habitats or that are sampled only at certain times of the year or stages in the lifecycle. The ecological importance of sharks, such as their role as predators in complex fish communities, is virtually unknown. It is likely that sharks, like apex predators on land, play an important role in the structure and function of marine communities.

2.2 Life history characteristics

The life history of an organism is determined by the biological features of its lifecycle (e.g. fecundity, growth rate, mortality) and the strategies that influence its survival and reproduction. The size and growth (rate of increase) of a population of the species can be calculated if life history parameters such as rates of birth, recruitment (taking into account immigration and emigration) and mortality are known. In general, chondrichthyans have life histories characterised by:

- low fecundity;
- large, precocious young;
- slow growth;
- late maturity;
- long life; and
- high survival of all age classes.

This suite of life history characteristics results in low reproductive potential and low capacity for population increase (Pratt and Casey 1990). This is because sharks, generally top predators with few natural enemies, need to produce very few young capable of reaching maturity in order to maintain population levels at the carrying capacity of the ecosystem. Species with life histories such as these have often been called 'K-selected'. These life history characteristics have serious implications for chondrichthyan populations, as they limit the capacity of populations to recover from over-fishing or other negative impacts (Holden 1974).

Of the chondrichthyan fishes for which age and growth data are available, many are very long-lived – up to 70 years in the spiny dogfish *Squalus acanthias* (Ketchen 1975, Nammack *et al.* 1985, Beamish and McFarlane 1987) – and very slow to reach maturity. Age to maturity ranges from the exceptionally short one and three years in the sharpnose sharks *Rhizoprionodon taylori* (Simpfendorfer 1993) and *Rhizoprionodon terraenovae* (Branstetter 1987a) respectively, to 20–25 years in the dusky shark *Carcharinus obscurus* (Natanson *et al.* 1995). Most species, however, have not been aged, and cannot be aged reliably except through the use of detailed tagging and recapture or with the study of validated growth rings on vertebral cartilage (Cailliet *et al.* 1986).

Annex 1 summarises available information (including literature sources) on life history traits and geographical distributions for 41 species of elasmobranchs. The species' actual or potential exposure to fisheries is also noted. Most of the species are featured here because they are taken in large-scale fisheries or are important in international trade. A few species, however, are included because of their rarity, dependence on a very restricted habitat, or some other distinguishing trait that means they are of particular conservation concern.

There are three main patterns of embryonic development in chondrichthyans, all of which involve considerable maternal investment to produce small numbers of large, fully-developed young with relatively high natural survival rates (Hamlett 1997). Internal fertilisation of relatively few eggs is followed by either:

- attachment of the embryo by a placenta (placental viviparity);
- development of unattached embryos within the uterus, with energy supplied by large egg yolks (ovoviviparity); ingestion of infertile eggs (oophagy) and, very rarely, smaller embryos (embryophagy); or fluids secreted by the uterus; or
- development of the young within large leathery egg cases that are laid and continue to develop and hatch outside the female (oviparity).

Depending on the species, female sharks may bear from one to, exceptionally, as many as 300 young (in the case of the whale shark *Rhincodon typus*, Chang *et al.* 1997). Litter number in most species, however, falls within the range of two to 20 pups. Gestation periods are unknown for most species, but range from less than three months to as long as 24 months for the ovoviviparous spiny dogfish *Squalus acanthias* (Compagno 1984, Nammack *et al.* 1985; the longest gestation period known for any living vertebrate); most are around 10–12 months. Breeding does not always occur annually in females; not only may gestation exceed 12 months, but some species have at least one 'resting' year between pregnancies (Branstetter 1990, 1997, Pratt and Casey 1990).

Following this high initial investment in the production of large eggs or pups, many chondrichthyan fishes give birth in sheltered coastal or estuarine nursery grounds (Musick and Colvocoresses 1988, Castro 1993), where predation risks to the pups (primarily from other sharks) are reduced (Branstetter 1990), or deposit their eggs in locations where they are most likely to survive undamaged until the pups emerge. There is no known post-birth parental care.

2.3 Life history constraints on exploitation

The life history strategies of elasmobranchs have developed over some 400 million years and are appropriate and successful for an environment where the main natural predators of these fishes are larger sharks. Such a K-selected life history strategy, however, poses limits on reproductive productivity and the ability of populations to sustain fisheries and recover from depletion caused by human exploitation or other impacts (Hoenig and Gruber 1990). In addition, the tendency of many chondrichthyan species to aggregate by age, sex and reproductive stage can make them particularly vulnerable to fisheries.

In comparing life histories across a number of vertebrate taxa (Table 1), it is immediately apparent that sharks are among the latest-maturing and slowest-reproducing of vertebrates. Their reproductive strategies contrast markedly with those employed by most teleosts (bony fishes), which support most fisheries. Teleost fishes produce thousands to tens of millions of tiny eggs annually and, although only very few young survive to maturity, recruitment to the adult population is broadly independent of the size of the spawning stock (until the latter declines to extremely low levels). This is partly due to the operation of density-dependent factors that compensate for adult population decline. Almost all traditional fisheries management is based on these typical teleost life history strategies (Hillborn and Walters 1992).

In contrast to teleosts, the recruitment of sharks to the adult population is very closely linked to the number of mature, breeding females (Holden 1974), although some density-dependent factors (for example, improved survivorship of small elasmobranchs in the absence of large adult sharks) may also operate for their stocks (Musick *et al.* 1993, van der Elst 1979). The result is that, as mature animals are caught, the production of offspring that will support future generations also declines, which in turn limits future productivity of the fishery and the ability of elasmobranch populations to recover from overfishing. In this respect, the reproductive potential and strategies of the chondrichthyans are more closely related to those of the cetaceans, sea turtles, large land mammals and birds than to the teleost fishes (Table 1). Therefore, a very different management regime to that employed for teleosts is required to prevent the overexploitation of elasmobranchs and sustain fisheries over a long period of time.

Although the large majority of chondrichthyan species is slow-growing with low reproductive potential (see Table 1), a few sharks and rays, especially some smaller species, are not as extreme in their life histories. For example, the Australian sharpnose shark *Rhizoprionodon taylori* matures at an age of one year, lives to an age of six or seven years, and has a natural mortality coefficient of about 0.56 (Simpfendorfer in press a). This means that, on average, 56% of each age-class in the population dies every year from natural causes (predation, disease etc.) and only 44% survive. By contrast, an average natural mortality coefficient for the very slow-growing sandbar shark is *c.* 0.10–0.05, or 90%–95% survival (Sminkey and Musick 1996).

In general, smaller-sized elasmobranch species have a tendency to mature earlier, be shorter-lived, and have higher rates of population increase. Many dogfishes,

Table 1. Comparative life-history traits of sharks with other long-lived and/or wide-ranging taxa.

Scientific and common names	Age to maturity (years)	Size (cm) (total length maximum or at maturity)	Life span (years)	Litter size	Annual rate of population increase	Reproductive periodicity (years)	Gestation time (months)	CITES listing (Appendix I, II, III)
Carcharhinus plumbeus Sandbar shark[1]	13–16 (29 in another study)	M: 170 (mat), F:>180 (mat), ~235 max (in US)	35	8–13 pups	2.5%–11.9% (5.2% if maturity is 29 years)	2	9–12	none
Prionace glauca Blue shark[1]	M: 4–6 F: 5–7	M: 182 (mat), F: 221 (mat); 383 (max)	20	40 pups; 135 max.	6.25%	females? males annually?	9–12	none
Squalus acanthias Spiny or piked dogfish or spurdog[1] (NW Atlantic population)	M: 6 F: 12	M: 60 (mat), 100 (max); F: 70 (mat), 124 (max)	M: 35 F: 40 (70: NW Pacific)	2–15 pups	2.3%	2 (but no resting stage)	22–24	none
Thunnus macocyii Southern bluefin tuna[2]	10–11	225 (max TL)	40	14–15 million eggs	?	annual	n/a	none
Xiphias gladius Swordfish[3] (N. Atlantic)	M: 1–5 F: 5–9	M: 165 FL F: 209 FL	25 (max)	1–9 million eggs/batch	4.3%	annual	n/a	none
Gadus morhua Atlantic cod[4] (New England stock)	2–4	32–41 (mat), 130 (max)	20+	2–11 million eggs	?	annual	n/a	none
Paralichthys dentatus Summer flounder[4]	1	27 (at mat)	F: 20 M: 7	0.5–5 million eggs	50%	annual	n/a	none
Tursiops truncatus Bottlenose dolphin[5]	M: 11 F: 12	M: 381 F: 367	50 (min)	1	?	3–6	12 (lactation 12–18)	I
Balaenoptera musculus Blue whale[6] (Antarctic)	5	3,100 (max)	110 (max)	1	5.1% (N. Atlantic)	2–3	11	I
Caretta caretta Loggerhead sea turtle[7]	12–30	92–122	~50+	116 eggs/clutch 76.5/year	2%–6%	2–5 in SE US	n/a	I
Panthera tigris Asian tiger[8]	3–7	140–280 (w/o tail)	26	1–7 per litter	?	2–3	3.3	I
Loxodonta africana African elephant[9]	8–13	M: 320–401 F: 220–260 (shoulder ht.)	55–60	1	4%–7% (favourable conditions)	2.5–9	22	I/II
Dromedea epomophora Royal albatross[10]	6–11	122 (max)	58–80	1/clutch	?	2	n/a	

References: [1] See Annex 1; [2] [3]Arocha 1997, Hoey *et al*. 1990, ICCAT 1996; [4]National Marine Fisheries Service 1995; [5] Klinowska and Cooke 1991; [6]Best 1993, Laurie 1937, Lockyer 1984, Ohsumi 1979; [7]Camhi 1993, Crouse *et al*. 1987, Frazer and Ehrhart 1985, Richardson and Richardson 1982; [8]Nowell and Jackson 1996; [9]Laursen and Bekoff 1978; [10]Gales 1993.

particularly deepwater species, are an exception to this rule (Walker 1998a). Species with the highest capacity to rebound from overexploitation tend to be the smaller, inshore species, which have evolved shorter generation times as an adaptation to higher rates of predation (Smith *et al.* in press). These species may be able to sustain commercial fisheries with careful conservation and management. For example, the gummy shark *Mustelus antarcticus* in southern Australia, which reaches maturity at 4–5 years of age (for females) and a maximum age of 16, has sustained a carefully managed fishery for more than 25 years (Walker 1996 and in press).

In contrast, larger, longer-lived species have less capacity to sustain exploitation or recover from depletion (Smith *et al.* in press). Fisheries for these species, such as sandbar, dusky and leopard sharks, and deepwater sharks with exceptionally low metabolic rates, require even more cautious management if they are to be sustained.

Chapter 3

Overview of Exploitation and Other Threats

3.1 Fisheries

Chondrichthyans are exploited for their meat, fins, cartilage, leather, oil, teeth, gill rakers and jaws (Rose 1996). They are directly targeted in some commercial and recreational fisheries and are caught incidentally as bycatch in many other fisheries (Anderson 1990a, Bonfil 1994). While fisheries are the major factor affecting shark populations, beach netting and drum lining for swimmer protection may also lead to shark mortality (1,000 to 1,500 large sharks *per annum*) in localised areas of South Africa and Australia (Paterson 1990, Cliff and Dudley 1992, Krough 1994, McPherson *et al.* 1998), or *c*. 2,500–3,000 sharks annually, worldwide.

Although sharks are the most widely recognised group of the chondrichthyans taken in fisheries and entering international trade (particularly their fins), the trade and population status of the other chondrichthyans, particularly the batoids (skates and rays), is also of considerable concern. From the fisheries data reported to the UN Food and Agriculture Organization (FAO) over the last 15 years, sharks comprised 60% of the world chondrichthyan catch, and skates and rays comprised almost 40% (Bonfil 1994). There are only a few target or utilised bycatch fisheries for chimaeras, mainly in the southern hemisphere: New Zealand, Australia, South Africa and South America (Didier in press), comprising about 0.7% of chondrichthyan fish catches reported to FAO. This section, therefore, primarily covers elasmobranch exploitation.

FAO has published a comprehensive overview of world elasmobranch fisheries, including regional trends in landings and bycatch, patterns of exploitation, and an appraisal of their problems and management needs (Bonfil 1994). This report documents how growth in shark fisheries in the past was limited by their low economic value and relatively low abundance. Yet there has been steady growth in shark fisheries since World War II, the result of an overall intensification of marine fisheries and increasing human populations worldwide. Most recently, the growing demand for shark fins (and, to a lesser extent, meat) has further stimulated shark fisheries in some parts of the world (e.g. USA, Central America, and Indonesia, as noted by TRAFFIC in Rose (1996 and 1998), Chen 1996, and Phipps 1996). Nonetheless, commercial catches of chondrichthyans still comprise only about 1% of the reported world fisheries catch.

It is important to note that the upward trend in world elasmobranch catches since the early 1980s reported by FAO does not take increasing fishing effort into account. Also, the general pattern of declining elasmobranch landings in many areas are masked by increased landings from newly-established elasmobranch fisheries elsewhere.

Bonfil (1994) reports that 26 major fishing countries caught more than 10,000 metric tonnes (t) per year of elasmobranchs. His minimum estimate of the world commercial elasmobranch catch in 1991 was 714,000 t, representing approximately 71 million animals. This figure significantly underestimates the actual annual catch because FAO statistics do not include recreational or incidental catches and discards, and many landings are under-reported. Therefore, Bonfil (1994) concludes that the total level of world elasmobranch catches in 1991 may have been twice the official statistic, or nearly 1,350,000 t. Close monitoring of catches in selected countries would help to verify such estimates.

Data on the utilisation of shark landings are poor because most countries do not report statistics on shark products or local consumption. Fresh shark meat is consumed locally in many parts of the world, but, because some shark meat is difficult to process due to its high urea content (which taints the flesh if not bled, rinsed and chilled quickly), it has been of low value for export markets. In contrast, dried shark fins (used for shark fin soup) and dried shark meat are easy to process and supply to distant markets. In the mid-1980s, a surge in demand for shark fins in Asia caused a rapid increase in fin prices. Although data on the fin trade are substantially incomplete because many countries do not report fin exports, trade in fins certainly increased dramatically in the 1980s (Rose 1996, 1998, Chen 1996, Phipps 1996, Chen *et al.* 1996, Sant and Hayes 1996, Fleming and Papageorgiou 1997, Hanfee 1997, and Marshall and Barnett 1997).

The continuing emphasis on elasmobranch fisheries appears to be the result of several factors, including:

- the increased world demand for fish protein;
- a related rise in shark exploitation (target and bycatch) to replace declining catches from many depleted teleost stocks (as reported in FAO statistics); and
- the rising demand for and value of shark fins in international trade.

Certainly, FAO reports that world elasmobranch landings have been stable in the 1990s, while many teleost fish catches have been level or declining and some established shark fisheries have undergone declines. This continued or increasing exploitation is exceeding the capacity of some shark populations, resulting in documented stock depletions where data exist (Musick 1995, NOAA 1998a), and presumably also in regions where fisheries are not monitored.

As close relatives to the sharks, the batoid fishes (skates, rays, and sawfishes) have very similar life history characteristics and hence vulnerability to overfishing. They are taken by directed and multi-species fisheries for their meat (highly valued in many areas), represent a significant component of fisheries bycatch, and are also widely discarded.

The fins of guitarfishes and sawfishes and the wing tips of some rays are processed and traded as 'shark fin', with the former two groups providing some of the most highly valued fins in the world. Some ray species are also utilised for their skin. The saws (rostra) of the rare sawfishes are also traded as curio items and for traditional Chinese medicine (in very small numbers, due to their increased rarity). The gill rakers of plankton-feeding manta rays and whale sharks are reported to be as valuable as whale shark fins. Other ray species may be of low value, but are taken in large numbers as bycatch and often fully utilised in artisanal 'catch-all' fisheries.

Unfortunately, batoid fisheries and trade are even less effectively monitored and reported than those for sharks, not least because of the difficulty of identifying a great many species in the absence of an adequate identification guide and investment in taxonomic research. Indeed, in some regions, such as South-east Asia, some of the common stingrays landed by fisheries have not been scientifically described or named (Fowler *et al.* in press a).

3.1.1 'Boom and bust' and collapsed fisheries

There is a well-documented history of shark stocks that have undergone a brief period of fisheries exploitation followed by a sudden collapse in yield. Often-cited examples of collapsed shark fisheries include the porbeagle *Lamna nasus* fishery in the North Atlantic, the soupfin shark *Galeorhinus galeus* fishery in California, various basking shark *Cetorhinus maximus* fisheries, and spiny dogfish *Squalus acanthias* fisheries both in the North Sea and off British Columbia (e.g. Anderson 1990b). Indeed, many of the unregulated target shark fisheries for which data exist have been 'boom and bust' endeavours. These are remarkable for the relatively short period for which they 'boom', which is followed by a very rapid decline in catches and a long period of either very slow recovery (usually only possible under fishery closure) or continued low yield at a small fraction of the original catches. Examples of a few such fisheries are provided below.

Norwegian porbeagle *Lamna nasus* fishery

Annual Norwegian landings of porbeagle shark from the North-east Atlantic increased rapidly from 279 metric tonnes (t) in 1926 to a high of 3,884 t in 1933, then declined to 2,213 t in 1939. Catches were greatly reduced for five years during World War II when fishing effort was very low, presumably resulting in some stock recovery. The fishery resumed in 1945, reached a high of 2,824 t in 1947, then again began to decline. In 1961, the Norwegian fleet began to target the porbeagle stock in the North-west Atlantic. Longline catches increased from 1,824 t in 1961, when catch per unit effort (CPUE) was 9.1 sharks per 100 hooks, to 8,060 t in 1964, but then declined to only 207 t, with a CPUE of 2.9 sharks per 100 hooks in 1968 (Gauld 1989). Total landings in Norway have not exceeded 100 t since the late 1970s and averaged 33 t per year in the decade ending in 1994. The fishery is now of little significance to the Norwegian fleet (Anon. 1995). This declining trend has been observed elsewhere in European waters.

Market prices cannot explain these low landings; the porbeagle remains one of the highest-value food fishes landed in northern Europe and is still sought-after where it occurs. Rather, the decline can be attributed to the overfishing of a species which does not reach maturity until over seven years of age (for females), lives to 30 years, and produces between one and five pups per litter (see Annex 1).

California soupfin *Galeorhinus galeus* fishery

California shark landings during 1930–1936, of which soupfin *Galeorhinus galeus* comprised a high proportion, were relatively low and stable at *c.* 270 t/year. Following the establishment of a new market for liver oil in 1937 the fishery expanded enormously, with catches peaking at 4,185 t in 1939. Prices rose from some $50/t in 1937 to $2,000/t in 1941. Soupfin landings (identified separately from 1941 onwards) declined from 2,172 t in 1941 to 287 t in 1944. CPUE in one region declined from 55.4 fish/1,000 fathoms of gillnet fished for 20 hours in 1942 to 7.7 fish from the same fishing effort in 1945 (Roedel and Ripley 1950). This trend was probably indicative of the whole US west coast (Leet *et al.* 1992).

More than 50 years later, it is uncertain whether the soupfin stock has recovered; there are no fisheries specifically targeting the species, and catches are fluctuating. Although the fishery was intensive and expanded rapidly, it spanned only eight years. Similar landings over a similar period have occurred in New Zealand and Australia without causing the collapse of the fishery, but management was introduced in the 1980s to reduce effort and reverse declining trends (Stevens in press d). Since soupfin sharks were targeted by the fishery at a relatively large size in California (their longevity is 60 years), and since small juveniles were essentially unfished and would take several years to recruit to the fishery (females mature at 10–15 years of age), in the absence of other negative factors the stock would have been expected to rebuild once fishing ceased. Soupfin sharks are, however, dependent on pupping and nursery grounds, often in sheltered inshore areas. Deterioration and/or loss of this habitat could be a factor contributing to delayed recovery for this stock and in other populations (Stevens in press d).

Basking shark *Cetorhinus maximus* fisheries

There are several examples of collapsed fisheries for the basking shark. Information about the life-cycle of this species is scarce, but females may not reach maturity until 18–20 years of age and live to perhaps 50 years (Pauly 1978). (Parker and Stott's (1965) estimates of maturity at 4–5 years following growth rates of about 1 m/year from perhaps 1.7 m total length at birth are no longer widely accepted.) Basking sharks probably do not pup every year and the only known litter consisted of just five very large young (Sund 1943).

The oldest fishery records for this species are from the Sunfish Bank, west Ireland, in the late 18th century. Probably due to its artisanal nature, this fishery spanned several decades. Rising demand for shark liver oil, however, led to serious declines by 1830 and fishery collapse in the second half of the 19th century. Basking sharks were not targeted actively again off west Ireland until 1947, when a new, very localised fishery started at nearby Achill Island. Between 900 and 1,800 sharks were taken each year from 1950 to 1956, with a significant decline in catch records occurring from 1955 onward. Average annual catches declined from 1,067 per year in 1949–58, to 119 per year in 1959–68, and then 40 per year for the remaining seven years of the fishery. Even increasing shark oil prices and capital investment during the last few years of the fishery did not reverse the steady decline in catches, and the fishery ended in 1975. A total of 12,360 individual fish had been taken in 29 years, with 10,676 of these caught in the ten peak years of the fishery starting in 1949 (McNally 1976). Basking sharks are still only rarely sighted in the area today (Berrow and Heardman 1994).

A Norwegian fleet was also fishing basking sharks over a large area of the North-west Atlantic during the same period. Catches were high (>1,000 sharks and up to >4,000 in some years) between 1959 and 1980. Landings subsequently declined and have not exceeded 1,000 sharks per year since 1981 (Kunzlik 1988). This collapse has been attributed to an ageing fleet and a decline in value of basking shark liver oil, but because the precise location from which the fish were taken is uncertain (data reflect a large sea area), it is difficult to detect and evaluate trends in catches. The fishery is still profitable only as a result of the very high prices paid for the huge fins, now among the most valuable sold in Singapore.

A number of other small-scale fisheries for the basking shark have taken place. There is, however, generally insufficient information on catches (hundreds rather than thousands of animals), trends in CPUE, and changes in frequency of basking shark sightings to determine population declines resulting from these fisheries. An exception is the 1950s basking shark eradication program implemented in Barkley Sound, Vancouver Island (aimed at preventing damage to salmon nets). The Canadian Department of Fisheries and Oceans had killed several hundred sharks by 1959 (Clemens and Wilby 1961) and appears to have removed the majority of the population; the species is still only rarely sighted, some 35–40 years later (Darling and Keogh 1994).

3.1.2 Future trends in fisheries

Despite the static or declining trend in fisheries landings identified by FAO in most parts of the world, an increasing demand for fish products will likely lead to continuous increases in already heavily subsidised fishing activity. The record of 'boom and bust' shark fisheries described above suggests that the most recent increase in shark landings, most of which result from unmanaged fisheries, is unlikely to be sustainable beyond the next few decades. Similar patterns of declining landings are seen in some skate and ray fisheries for which adequate data exist (e.g. Walker and Heessen 1996, Walker and Hislop 1998, Dulvy *et al.* in prep.).

One anticipated result of the present and expected declines in traditional fisheries yields will be the development of pioneer fisheries to exploit previously unfished populations and species, almost certainly including sharks, rays and chimaeras. This trend is already apparent for deepwater fisheries, now explored in many regions worldwide. Nearly 35% of chondrichthyan species are confined to deep water and will likely be affected by these new fisheries. Deepwater fisheries are generally conducted by very large, modern vessels from major industrialised fishing nations and supply international trade as well as domestic markets. They take place mainly in international waters, off the continental shelf, or around oceanic islands.

There is well-founded concern that deepwater sharks, adapted to a very stable environment of low productivity in comparison with the shelf seas, are less able to withstand commercial fisheries than the sharks and rays that have up to now supported pelagic and demersal elasmobranch fisheries. The biology of these deepwater species has been poorly studied, but they are believed to be very slow-growing, even in comparison with other elasmobranchs. Metabolic rates of some deep-sea teleosts have been calculated to be only 10% of their coastal counterparts (Smith 1978, Smith and Brown 1983). Since the deep-sea shark fauna is dominated by squaloids related to the coastal spiny dogfish *Squalus acanthias*, their intrinsic rates of population increase must be near the lowest of any known vertebrate (that for the spiny dogfish is only 2%–3% per year – see Table 1 – which means that the number of dogfish in the population can only rise by 2%–3% each year). Additionally, there is no information about stock size or distribution of these species. In some cases, deepwater fisheries are taking chondrichthyan species that have not yet been described.

Not only does a lack of biological information hamper management of these fisheries, but politicians and managers have little or no incentive to regulate their country's activities when these fisheries occur largely outside national waters. Indeed, international fisheries policy remains inadequate even for teleost species and few marine animals have lower international fisheries management priority than the unfamiliar, relatively low value, deepwater chondrichthyans.

Some small and/or unusual elasmobranchs are being increasingly targeted for the public and private aquarium trade. This is of particular concern for species with restricted distributions and small population numbers, such as small freshwater rays, endemic species, possibly sawfishes, and other rarities. As demand for the exotic fish trade (both by hobbyists and public aquaria) increases in the years ahead, it is important that vulnerable populations of elasmobranchs should not be overexploited. The educational value of elasmobranchs in public aquaria, however, can be crucial to changing negative public perception of sharks, thereby building political will to conserve them. Certainly, though, capture for display should not be allowed to threaten species survival in the wild.

3.2 Bycatch

Elasmobranchs are caught incidentally, as bycatch, in most fisheries world-wide. The extent of bycatch and discards, both in domestic fisheries and on the high seas, is poorly documented (Alverson *et al.* 1994). While some elasmobranchs are landed and reported in official statistics, a large proportion is estimated to be discarded unreported. Mortality of incidentally caught sharks and rays is believed to be significant, especially from trawl nets, gillnets, purse seines, and longlines, and may exceed mortality from directed fisheries (Bonfil 1994). Some fisheries for oceanic teleost species (tuna and billfishes) catch more sharks as bycatch than they do target species (e.g. Francis and Griggs 1997). In addition, an increase in fin prices has encouraged the practice of 'finning' sharks that were previously discarded intact or released alive. Fins are easily air-dried and stored, whereas retention of whole shark carcasses would compete for freezer space with more valuable species like tuna (Rose 1996, Sant and Hayes 1996). Finned sharks tossed overboard invariably die.

Most countries do not require reporting of shark bycatch in fishing logbooks; therefore, few bycatch data are incorporated into national and international (e.g. FAO) statistics. Although observer programmes provide the best available information, observer coverage of high seas fisheries is minimal. Virtually any species of shark taken as bycatch in multi-species fisheries may enter regional or international trade, but there is very little tracking of this trade, particularly that resulting from artisanal fisheries. Rare species of elasmobranchs taken as bycatch and entering trade (e.g. sawfishes) are of particular concern.

Although there are many gaps in available bycatch data, Bonfil (1994) estimated that, at the end of the 1980s, approximately 12 million elasmobranchs (up to 300,000 t) were taken as bycatch each year on the high seas alone. About 4 million were taken in driftnet fisheries and more than 8 million on longlines (mainly in the tuna fisheries of Japan, Korea, and Taiwan). The species composition of these catches is virtually unknown, other than that most were sharks. Still, with an estimated nearly 6.5 million individuals caught incidentally each year, the blue shark *Prionace glauca* is believed to be the most common species of elasmobranch in high-seas fisheries bycatch (Bonfil 1994). Although most high seas drift net fisheries ceased at the end of 1992, fishing effort has been redirected towards longlining, which also affects elasmobranch populations.

Batoids and small coastal shark populations are seriously affected by bycatch in bottom trawl fisheries. These impacts are rarely monitored but are thought to be significant locally, particularly for regional endemics (Casey and Myers 1998, Dulvy *et al.* in prep., Notarbartolo di Sciara in press). In some parts of the world, many inshore fisheries do not intentionally target any particular group of species, but land and utilise everything they catch. In such cases, shark catches would not be considered incidental, but still may go unrecorded and will contribute significantly to the overall mortality of the population.

3.3 Habitat loss and degradation

All chondrichthyan fishes depend on properly functioning ecosystems in order to sustain growth, reproduction and survival. Habitat requirements vary for different species during different stages of their lifecycles. Critical shark habitats range from shallow estuarine sloughs and coastal bays to coral reefs, kelp forests and the deep sea. As a result of their K-selected life history, sharks are generally unable to adapt to rapidly changing environmental conditions. The use of inshore coastal nursery grounds, or complete dependence throughout the lifecycle on coastal, estuarine, or freshwater habitats, has become a particular liability during the second half of the 20th century as direct and indirect fishing pressures have intensified and coastal habitat loss and degradation have accelerated.

Adults of many shark species are known to visit inshore pupping and nursery grounds on a seasonal basis, usually in the spring and summer (Musick and Colvocoresses 1988, Branstetter 1990, Castro 1993, Simpfendorfer and Milward 1993). Newborns and juveniles may remain year-round in tropical waters, as these productive shallow areas provide both abundant food and shelter from predators (Morrissey and Gruber 1993). Less is known about the location and characteristics of offshore over-wintering areas inhabited by many species of coastal sharks, both adults and juveniles, and of the offshore pupping grounds of pelagic sharks.

Coastal habitat is being destroyed and degraded at an alarming rate. Human activity threatens coastal and estuarine habitats through development, fisheries activities, chemical and nutrient pollution, freshwater diversion from incoming rivers, and dumping of plastic and other man-made garbage known to entangle and choke a wide variety of marine life.

In the United States, for example, human population growth in coastal areas averages four times the national rate, and coastal habitat is being lost in direct proportion to population density. By the mid-1970s, over half of US mangrove stands and salt marshes had been destroyed. The state of California has lost over 90% of its coastal wetlands. Louisiana is losing 40 square miles of wetlands per year and precipitous declines in Gulf of Mexico fisheries are anticipated as a result. In Chesapeake Bay, the east coast's largest estuary and a critical nursery area for coastal sharks and rays, increased algal growth and turbidity from agricultural run-off, sewage plant effluent and atmospheric deposits led to a 90% loss of native bay grasses between 1950 and 1980 (Hinman and Safina 1992). Similar trends are apparent in most countries.

Around the world, coral reef specialists report increased damage and serious global decline in this habitat over the past two decades. The World Resources Institute, the International Centre for Living Marine Aquatic Resources, and the World Conservation Monitoring Centre report that 58% of the world's reefs are at risk from human activities, with about 27% at high or very high risk. Reefs of South-east Asia, the most diverse in the world, were also the most threatened, with more than 80% at risk including 55% at high or very high risk (Bryant *et al.* 1998).

Scientists have just begun to study the effects of fishing on the marine environment. Recent research suggests that intensive bottom trawling may reduce demersal fish productivity by reducing the complexity of the benthic substrate (Auster and Langton 1998, Dayton 1998). Other studies are attempting to quantify the impact of 'ghost fishing' from lost or abandoned fishing gear on fish populations.

Efforts to improve water quality and benthic complexity contribute to the protection of shark mating, pupping and nursery grounds. Additional protection for shark populations may be gained by limiting fishing activity at times when sharks are aggregated in these areas or otherwise vulnerable to fishing. Demographic models reveal that increasing the survivorship of juvenile sharks can yield great benefits in terms of population growth (Cortés in press a).

As top marine predators, long-lived elasmobranch species are significant bioaccumulators of pollutants, more so than most other groups of marine organisms (Walker 1988b, Forrester *et al.* 1972). Indeed, adult sharks accumulate such high levels of mercury that some Australian shark fisheries have maximum size limits on sharks landed for human consumption – for example, the sale of sharks with a carcass weight of over 18 kg is prohibited in Western Australia, and the South Australian shark fishery also limits landings of larger sharks.

Overall, documentation of how altered and contaminated habitats and bioaccumulation of pollutants affect the health and productivity of sharks or the overall dynamics of the marine food web remains scarce. Those species restricted to freshwater and estuarine habitats but with very small populations (for example, some sawfishes, the Borneo river shark and other large freshwater species) are likely to be the most vulnerable, although also some of the least-studied (Thorson 1982, Compagno and Cook 1995).

Chapter 4

Conservation Status

4.1 Extinction risk

No marine fish species is yet known to have been driven to biological extinction by fishing (Musick 1998). Regional stocks of some species, however, have been extirpated (Brander 1981, Beverton 1990, Casey and Myers 1998, Huntsman in press). Because of their life history strategies, many sharks are highly vulnerable to over-exploitation leading to population depletion. Some are particularly susceptible to extinction as a result of these factors because of their restricted distribution, small population sizes, or other characteristics, including dependence on nursery grounds or specific habitats, behaviour and morphology. For example, all species of sawfishes *Pristis* spp. are considered to be threatened with extinction (Table 2), because they occupy restricted freshwater, estuarine or shallow inshore habitats that are subject to increasing human disturbance and exploitation, and are highly vulnerable to bycatch in fishing gear at all life stages. Their toothed rostrum (saw) makes sawfishes extremely

Table 2. IUCN Red List assessments for elasmobranchs (updated from *The 1996 Red List*).

Common name	Scientific name	Stock	Red List Assessment[1]
Bluntnose sixgill	*Hexanchus griseus*	World	Lower risk, near threatened
Whale shark	*Rhincodon typus*	World	Data Deficient
Sand tiger shark	*Carcharias taurus*	World SW Atlantic Eastern Australia	VU A1a,b, A2d EN A1a,b, A2d EN A1a,b, A2d
Great white	*Carcharodon carcharias*	World	VU A1b,c,d, A2c,d
Porbeagle	*Lamna nasus*	World NW Atlantic NE Atlantic	Lower risk, near threatened Lower risk, conservation dependent VU A1b,d, A2d
Basking shark	*Cetorhinus maximus*	World	VU A1a,d, A2d
Blacktip shark	*Carcharhinus limbatus*	World	Lower risk, near threatened
Dusky shark	*Carcharhinus obscurus*	World NW Atlantic	Lower risk, near threatened VU A1d, A2d
Sandbar shark	*Carcharhinus plumbeus*	World NW Atlantic	Lower risk, near threatened Lower risk, conservation dependent
Ganges shark	*Glyphis gangeticus*	World	CR A1c-e, A2c-e, C2b
Blue shark	*Prionace glauca*	World	Lower risk, near threatened
Kitefin shark	*Dalatias licha*	World	Lower risk, near threatened
Freshwater sawfish	*Pristis microdon*	World SE Asia	EN A1a,b,c, A2c,d CR A1a,b,c, A2c,d
Smalltooth sawfish	*Pristis pectinata*	World NE Atlantic SW Atlantic	EN A1a,b,c, A2c,d CR A1a,b,c, A2c,d CR A1a,b,c, A2c,d
Largetooth sawfish	*Pristis perotteti*	World	CR A1a,b,c, A2c,d
Common sawfish	*Pristis pristis*	World	EN A1a,b,c, A2c,d
Brazilian guitarfish	*Rhinobatos horkelii*	World	CR A1b,d, A2b,d
Deepsea skate	*Bathyraja abyssicola*	World	Data Deficient
Common skate	*Raja batis*	World	EN A1 b-d, A2 b-d
Giant freshwater stingray	*Himantura chaophraya*	World Thailand	VU A1b-e, A2c,e CR A1b-e, A2c,e

[1]The categories of threat are: CR=critically endangered, EN=endangered, VU=vulnerable. See Annex 2 for explanation.

vulnerable to entanglement in fishing gear at all ages, and very difficult to release alive even if not wanted in the catch (Compagno and Cook 1995, in press d). The tendency of the white shark *Carcharodon carcharias* to investigate human activities makes it very easy to approach by trophy hunters (Fergusson *et al.* in press).

There is debate over the potential for fisheries (or other factors) to drive wide-ranging marine fishes (both teleosts and chondrichthyans) to extinction (Musick 1998). Some argue that a species will become commercially extinct before going biologically extinct and, therefore, will be relieved of fishing pressure, which should allow the species to recover. It may be true that targeted fisheries will collapse of their own accord when stocks become so reduced that they are no longer profitable to pursue. However, the notion that a fish will reach economic extinction before biological extinction is not certain in cases where the value of the product is so high that it is economical for fishers to continue to pursue an extremely small surviving stock, or where economic yields are not a controlling issue (e.g. for recreational trophy fishing). Similarly, in a mixed-species fishery where all species are subject to the same fishing effort and similar fishing mortality rates, less abundant species subjected to fishing activity throughout their range could be driven to extinction, while numerically dominant species continue to support the fishery (Musick 1995). Species caught extensively as bycatch may be, indirectly, even more vulnerable than target species taken in a mixed fishery, because discards and landings are generally poorly monitored and signs of declining catches and collapsing stocks may thus be overlooked. Such was the case for the North-west Atlantic barndoor skate *Raja laevis*, a large, late-maturing species taken as bycatch in the bottom trawl groundfish fishery. Casey and Myers (1998) found that *R. laevis* appears to have become extinct in northern Canadian waters and currently survives only in small numbers off Georges Bank at the southern edge of its range (where warmer water temperature allows faster growth and presumably earlier maturity).

Cosmopolitan and wide-ranging species may become locally depleted in some parts of their ranges even as their global abundance remains high. It is difficult, however, to assess the cumulative effect of localised depletions on the viability of a species at a global level, as unregulated and unmonitored shark fisheries crop up around the world. Some argue that immigration from source populations will offset these depletions, thereby reducing extinction risk, but very little is known about population dynamics and structure or migratory behaviour in most chondrichthyans.

The assumption that marine fish populations are not vulnerable to extinction because they are 'open' with large geographic ranges and unlimited immigration is unfounded. Coastal stocks of even large migratory species such as sandbar sharks have discrete geographic boundaries (Musick 1995). Catch per unit effort (CPUE) data from some beach-netting programmes and historic examples of collapsed stocks, such as North Atlantic porbeagle sharks *Lamna nasus*, suggest that migration between stocks, or even within a single stock (where individual fish tend to return seasonally to the same coastal area throughout their life), may be limited. Overfishing of the large and long-lived common skate *Raja batis* this century has led to its extinction in the Irish Sea (Brander 1981) and most of the North Sea (see case study below). The fact that the common skate still occurs in the nearby waters of the Celtic Sea and North-east Atlantic, but is not recorded in landings from the former areas, suggests that recovery of depleted or extirpated populations through local immigration is not guaranteed, or would be extremely slow, even if all skate landings ceased.

Similarly, even if the North-west Atlantic shark fishery were completely closed, stock recovery of the sandbar shark *Carcharhinus plumbeus* and other large coastal species in the region would take several decades because of the very low rate of population increase for the species (see Table 1).

In general, the rate of recovery of an elasmobranch population following localised depletion is species-specific. It will depend not only on the species' reproductive capacity, but also on migration patterns, the level of depletion, the rate of population increase (taking into account possible density-dependent factors), and changes in habitat and prey population structure.

The biological vulnerability of most chondrichthyans suggests that extinction resulting from fisheries is possible. For targeted species, this risk is largely dependent on market forces and the economics of the fishery. This is not necessarily the case for bycatch species, regardless of their economic value; their extinction risk will be related to overall fisheries effort and will increase if the species has a restricted range or other specialised ecological requirements. It is noteworthy that commercial whaling extirpated all but a few individuals of some regional whale stocks, and that these are still threatened with extinction despite a cessation in whaling activity many decades ago. Given that there are greater life history similarities between sharks and marine mammals than between sharks and most teleost fishes (Musick 1997), such a scenario is also possible for some shark populations.

Finally, biological extinction is a process that can have detrimental and irreversible ecological effects long before a species disappears. If a species' abundance drops too low, it may no longer perform its function as predator or prey in the ecosystem – a situation often referred to as 'ecological extinction'. It is unclear what effect the large-scale removal of sharks may have on the food webs of marine communities. Off south-eastern Africa and in the North-west Atlantic, however, heavy fishing of large sharks may have resulted in the proliferation of smaller sharks, skates and rays (van der Elst 1979, Musick *et al.* 1993).

Because intensive target and indirect fisheries for elasmobranchs have only started during the present life span of long-lived mature sharks, the effect of a very large decline in species abundance on extinction risk or other impacts on populations and marine communities is still largely unknown.

4.2 IUCN Red List assessments for sharks

Although the subject of extinction risk in marine fishes is not new, only recently have attempts been made to evaluate it. The Shark Specialist Group (SSG) is now systematically assessing the global conservation status of the chondrichthyan fishes using the revised IUCN Red List Categories and Criteria, summarised in Annex 2. These criteria endeavour to provide a more objective assessment of a species' extinction risk. They have, for the first time, enabled a wide range of marine fish species to be classified in the IUCN threatened species categories, largely on the basis of estimates of recent and projected population declines (criterion A, see Annex 2).

These efforts have pointed to a problem with the use of the population decline criterion; it can lead to a significant over-estimate of extinction risk in the case of widely distributed species, or those with high reproductive potential or fecundity. This is particularly true for a species with a very high initial abundance; a very large population decline (50% or 80%) does not necessarily equate to the very high extinction risk implied by the Endangered or Critically Endangered IUCN Categories (Fowler 1996a, in press a, Musick 1998). The IUCN Criteria are currently under revision to address this and other issues.

The SSG has identified an initial list of over 100 species of elasmobranchs, some of which may be threatened by exploitation or habitat loss, and is in the process of evaluating their extinction risk using the IUCN Criteria, while taking into account the above drawback in the Criteria and adjusting the evaluated extinction risk accordingly. The resulting assessments will be published in forthcoming IUCN publications (including Fowler *et al.* in press b and the IUCN Red List). The remaining species are still to be evaluated, but it is expected that additional at-risk species will be identified as more species-specific information becomes available.

It should be noted that, for most species, there is a significant lack of baseline data on historic stock sizes, as well as current abundances or changes in catch per unit effort, to use as a basis for these assessments. In such cases, it has been necessary to extrapolate from the biological information available for other, closely related species, or from what is known of overall fisheries trends in a region.

The results of the Shark Specialist Group's 1996 threatened species assessments for chondrichthyan fishes are presented in Table 2. (This is updated from the published IUCN Red List (IUCN 1996) and should be read in conjunction with the summarised IUCN Red List Categories and Criteria presented in Annex 2.) Most of these classifications result from application of Red List Criterion A, which is a measure of decline in numbers of mature individuals in the population calculated over the past three generations or projected into the future for the next three generations. Because most chondrichthyans are relatively long-lived, with generation times of often more than a decade long (see Annex 1), the period over which the decline in population must be considered will most often be 30 years or longer.

4.3 Species case studies

Brief species conservation status accounts for a few examples of elasmobranchs are presented below. These animals were selected to illustrate some characteristic aspects of the life history, habitat requirements, and biological status of chondrichthyans that make them particularly vulnerable to over-exploitation. The following accounts are summarised from much longer species reports in the IUCN Status Report (Fowler *et al.* in press b).

Two examples of carcharhinids are presented: the sandbar shark *Carcharhinus plumbeus*, a wide-ranging, very slow-growing, well-studied coastal species, important in directed fisheries, but seriously depleted in the US Atlantic; and the blue shark *Prionace glauca*, an abundant and relatively fecund, cosmopolitan, oceanic species that is subjected to extremely high fishing pressure as bycatch in high-seas fisheries.

The soupfin or school shark *Galeorhinus galeus* is a species with a long history of exploitation: one population has collapsed while a separate, steadily fished population is recently showing signs of depletion. Despite its rarity, the white shark *Carcharodon carcharias* is an important marine macro-predator. Although it has protected status in parts of its range, the white shark is still threatened by mortality from bycatch, sports angling, and some other directed fisheries for its jaws, teeth and fins.

The kitefin shark *Dalatias licha* is an example of the rather poorly known deepwater species. Deepwater chondrichthyans have been subject only to relatively small-scale directed fisheries, but are now likely to come under increased fishing pressure as traditional fisheries decline.

Examples of three batoid fishes (skates and rays) are included. Although not 'true' sharks, many batoids are also important in fisheries and international trade and are equally vulnerable to over-exploitation. They are primarily taken for their meat, which is highly valued for human consumption in many regions, but the wingtips of some rays may also be dried and sold as 'shark fin'. Their skin is sometimes used for leather. Most batoids are strongly

K-selected species, and overfishing can severely deplete populations, if not regionally extirpate or threaten some species with extinction.

Sawfishes (family Pristidae) are dependent on very restricted coastal, freshwater, and inshore/estuarine habitats and are now very scarce as a result of fishing pressure (they are extremely vulnerable to bycatch in nets), but still highly valued in the international trade for shark fin, curios and traditional Chinese medicine.

The Brazilian guitarfish *Rhinobatos horkelii* has a restricted geographic range, being endemic to the continental shelf of the south-western Atlantic Ocean. Its entire range is very heavily fished, particularly those areas used by pregnant females and juveniles. As a result, the species has suffered a severe population depletion over the past decade. The giant or 'common' skate *Raja batis* was formerly an important component of the Northern European catch, but is now extirpated from or very rare in most of its former centres of abundance.

4.3.1 Status of the sandbar shark *Carcharhinus plumbeus* (Nardo, 1827)

The sandbar shark *Carcharhinus plumbeus*, a medium-to-large-sized shark reaching a maximum reported size of *c.* 230 cm total length (TL), is a wide-ranging coastal species typical of other common coastal sharks in many aspects of its biology. It is characteristic of the requiem sharks (Carcharhinidae), which are subject to fisheries worldwide because of their wide distribution and importance for human consumption (they have good-quality flesh and valuable 'white' fins that fetch a premium price in international trade). The history of the fishery in the North-west Atlantic (described below) illustrates how high catches can continue for a decade or more when the original stock is very large, even when the stock has declined drastically and recruitment is slow. If left unchecked, however, such overexploitation willeventually cause a population crash, with very slow subsequent recovery.

The sandbar shark is the most abundant large coastal shark in the western North Atlantic and eastern Gulf of Mexico. The species exhibits strong seasonal movements in this region, with segregation of adult males and females, neonates and juveniles in different geographic areas and habitats. Adult female sandbar sharks use temperate, estuarine waters as pupping grounds in summer, where neonates and juveniles (age 1–4 years) are also found. Larger juveniles use shallow coastal habitats and adult females move offshore immediately after pupping. Sandbar sharks of all ages migrate south to warmer waters in winter. In contrast, island populations, such as those in Hawaii, appear to be seasonally resident.

Sandbar sharks are K-selected species. They grow very slowly and mature at a relatively late age (calculations range from 13–16 to 29 years, and 150 to 180 cm). These sharks are viviparous with a yolk sac placenta. Gestation has been estimated at 9–12 months, with females breeding only every other year. Litter size is variable (1–14) and depends in part on the size of the mother, but averages 5.5–9.3. The size of newborn pups averages 60–65 cm TL in most areas.

Sandbar sharks feature prominently in coastal shark fisheries worldwide. Along the US Atlantic coast, this species comprises up to 60% of the total shark catch and 80% of the landings in the directed longline fishery. In addition, it is second only to the blue shark in importance in the US Atlantic recreational shark fishery. During the last 20 years, the recreational and commercial fisheries for sharks along the west Atlantic Coast and in the Gulf of Mexico have expanded rapidly, with commercial landings rising dramatically between 1985 and the implementation of a Fisheries Management Plan (FMP) in 1993. Sandbar shark stocks in the western Atlantic were reduced by 85%–90% in just ten years as a result of overfishing. In addition, the age structure of the population has shifted dramatically toward younger age classes; adult females are now only very rarely observed. The species continues to support a substantial fishery after this severe population decline only because of the very large size of the original stock and recently implemented conservative landings quota. Habitat degradation in nursery areas is also a threat to the recruitment of this species.

Although the US fishery is now regulated under the FMP, there was concern that managers had considerably under-estimated the extent of stock depletion and used an unrealistically high annual rate of replacement (r) based on a model more appropriate for fast-growing teleost fishes. In 1996, an FMP Scientific Review Panel recommended that the total allowable catch (TAC) should be significantly reduced or the fishery closed to enable recovery. Under the FMP, the target fishery mortality ($F = 0.25$) could only lead to continued population decline. Consequently the TAC was reduced by 50% in 1997. Further reductions and size restrictions have since been proposed to enhance the chances for population recovery. Even if the fishery were completely closed, the population dynamics of these sharks is such that stock recovery of the sandbar shark and other large coastal species in the North-west Atlantic could take several decades.

This species has been classified globally as "Lower Risk, near threatened" according to the IUCN Red List Criteria. This assessment takes into account the very wide-ranging nature of the world population of this species, the history of the North-west Atlantic fishery described above, the high value of the species in fisheries and trade, and the strong likelihood that similar trends exist or will occur in other regions (where there is no fisheries management) within the next 60 years (the three-generation period for this species). These factors are tempered by the lack of data on populations and past and projected catches from other regions. The US Atlantic and Gulf of Mexico stocks, which are well studied, were considered to be "Vulnerable (A1b,d, A2d)" in 1996, but have now been reassessed as "Lower Risk – conservation dependent".

[Summarised from Musick 1995 and in press.]

4.3.2 Status of the blue shark *Prionace glauca* (Linnaeus, 1758)

The blue shark *Prionace glauca* is a member of the requiem shark family, Carcharhinidae. It is representative of the oceanic (pelagic) sharks that are common in the world's oceans and subject to an extremely high level of bycatch in high-seas longline and driftnet fisheries for other species. Because it is not a valued fishery species, the bodies (with low-value meat) are usually discarded but the fins are generally retained for trade. With increasing fin prices, the distinction between bycatch and directed catch in many fisheries is becoming less clear. There are some directed fisheries for sport angling and to provide meat and fins for domestic markets and international trade.

The blue shark is a large, slender shark reaching *c.* 380 cm TL. It is one of the most wide-ranging of all sharks, being found throughout tropical and temperate seas from about 60°N to 50°S latitude. It is found from the surface to about 350 m depth and occasionally occurs close inshore where the continental shelf is narrow. This is a highly migratory species, with complex movement patterns related to reproduction (there is segregation of the population by age and sex for much of the year) and the distribution of prey. Trans-Atlantic migrations have been demonstrated from tagging studies, and more limited tagging in the Pacific has shown movements of up to 4,000 km annually.

About 50% of males in the Atlantic are sexually mature by 218 cm (4–6 years), and females are fully mature from 221 cm (5–7 years), although pregnant fish as small as 183 cm have been recorded from the Pacific. The species is viviparous, usually producing litters in spring or summer that average about 30 young (although a litter of 135 has been recorded) after a gestation period of 9–12 months. The females can store sperm for a year after mating before fertilisation. At birth the pups are 35–50 cm long. Pupping takes place in offshore nursery areas in the Mediterranean and off the Iberian peninsula in the Atlantic, and in the sub-Arctic boundary of the Pacific where there is a large prey biomass for the juveniles. Juvenile blue sharks remain in the nursery areas and do not take part in the extensive adult migrations until they reach a length of *c.* 130 cm.

The main threat to blue sharks is from bycatch in high-seas fisheries (Bonfil 1994). Very few data on the scale of these catches are recorded, as there is virtually no observer coverage on the high seas. Some observer data have been collected from fisheries operating in national fishing zones. Blue shark catch rates by longliners vary considerably, with some exceptionally high rates of 70–83 per 1,000 hooks obtained from longlining during research, to a minimum of 3.2 per 1,000 hooks. Logbook records, where available, are generally in single figures per 1,000 hooks, but these usually under-report catches. A conservative estimate of five blue sharks per 1,000 hooks would give a global bycatch from Japanese and Korean longliners of 2.8 million blue sharks. Bonfil (1994) estimated total worldwide longline effort in 1989 as 750 million hooks taking a bycatch of 4 million blue sharks on the high seas. An estimated 2.2–2.5 million blue sharks were taken as bycatch by driftnet fisheries in the same year. Driftnet fishing effort is now much reduced, but the amount of longlining has increased and Francis and Griggs (1997) report that the blue shark bycatch in the tuna longline fishery off the New Zealand coast considerably exceeds the catch of the target species.

Because of their high abundance, blue sharks are likely a keystone species in the oceanic ecosystem. Nothing is known, however, of their stock structure or population sizes and it is impossible to determine the effects of removing six million blue sharks annually on either blue shark populations or ocean ecology. Although blue sharks are among the most widespread, fecund, and fastest-growing elasmobranchs, their general life history characteristics still severely limit their ability to withstand such heavy fishing pressure.

The IUCN Red List assessment for this species is "Lower Risk, near threatened" globally.

[Summarised from Stevens in press c.]

4.3.3 Status of the white shark *Carcharodon carcharias* (Linnaeus, 1758)

The white shark *Carcharodon carcharias* is a member of the family Lamnidae and related to other mackerel sharks (makos and porbeagles). It is a marine macro-predator reaching a maximum size of *c.* 700 cm TL. The white shark has a cosmopolitan distribution, occurring in coastal and pelagic waters, but has also been recorded in small numbers from mid-ocean fisheries. As an apex predator, it is generally rare, even in favoured locations where the species may reliably be found and studied. Despite this low population density, this shark is considered to be of significant ecological importance. Although the white shark has protected status in parts of its range (see Table 4, page 20), it is threatened by bycatch, sports angling, and some directed fisheries.

The white shark is a relatively fast-growing but late-maturing K-selected species, reproducing by aplacental viviparity (the embryos are nourished in the uterus by unfertilised eggs). Litter size is 2–10 and length at birth ranges from 120 to 150 cm TL. Maturity is reached at the very large size of 450–500 cm TL (probably 12–15 years of age) for most females and 350–380 cm TL (8–9 years) for males. There is, therefore, a high probability of immature white sharks being fished before they can breed. Mature females are particularly scarce. Frequency of litter production is unknown, but if gestation exceeds one year (as is the case for some related sharks), females may only produce young every 2–3 years.

Because this is a rare species, the main targeted fishery is by recreational anglers, with the jaws and teeth being highly valued as trophies. Some other directed fisheries also supply the international curio trade. A large set of jaws may be worth US$10,000 to a collector and there is reportedly also a market for neonates. This fish tends to actively investigate human activity, making it a relatively easy target. The main source of mortality, however, is through bycatch in commercial fisheries, including accidental take in areas where it is protected. Habitat degradation as a result of pollution and overfishing (particularly of prey species) also threatens the white shark. These impacts may largely exclude the species from feeding or pupping areas where it was historically more abundant.

The IUCN Red List assessment for this species is "Vulnerable A1b,c,d, A2c,d".

[Summarised from Fergusson *et al.* in press.]

4.3.4 Status of the kitefin shark *Dalatias licha* (Bonnaterre, 1788)

The kitefin shark *Dalatias licha* is a relatively common, deeper-water dogfish unevenly distributed on continental and insular shelves and continental slopes from warm temperate to tropical areas. It represents one of the very large number of poorly known, deepwater elasmobranchs that have been subject only to relatively small-scale directed fisheries until very recently, but are now likely to come under increased fishing pressure as more fisheries move into deeper water.

The kitefin shark is primarily a solitary, bottom-dwelling species, which can range well off the seabed. It feeds on a broad range of bony fishes, other elasmobranchs, and invertebrates. Its maximum size is at least 120 cm TL for males and 160 cm for females. As for most deepwater species of elasmobranchs, there is no information available on growth rates, age at maturity, and life span, but because of the low productivity of very stable deepwater habitats, they are assumed to be particularly slow to grow and reproduce. The kitefin shark is known to be ovoviviparous, giving birth to litters of 10–16 pups *c.* 30 cm long.

The kitefin shark has been the subject of directed, deepwater line fisheries, but these appear to be of limited potential, with rapid degradation of stocks reported when large catches are taken in a fishing season. It is feared that deepwater sharks are even less able to sustain fisheries than species from more productive shallow-water environments. The increasing need for commercial fisheries to move off the continental shelves to sustain catch levels and recent trends in the development of deepwater trawling gear, however, indicate that this and other poorly known deep-sea elasmobranchs will undoubtedly come under increased pressure in the future.

The IUCN Red List assessment for this species is "Lower Risk, near threatened". This takes into account the difficulties of projecting the effects of future deep-sea fishing pressure on populations of such a vulnerable, but poorly-known species.

[Summarised from Compagno and Cook 1996 and in press c.]

4.3.5 Status of the largetooth sawfish *Pristis perotteti* (Müller and Henle, 1841)

The sawfishes are a very unusual group of highly modified large rays that probably evolved from ancient sharks. There are three to eight species of sawfishes in the Family Pristidae (the taxonomy requires revision). All possess a long, blade-like snout studded with lateral teeth. All live in shallow coastal, estuarine and/or freshwater habitats in warm-temperate to tropical regions.

The restricted habitat range of sawfishes and their great vulnerability to fisheries have resulted in very serious population declines for most, if not all, known species over the past 50 years. The largetooth sawfish *Pristis perotteti* was once relatively common in warm, shallow, nearshore marine, estuarine and freshwater habitats in the Pacific and Atlantic oceans, where it had a wide but disjunct distribution. It is now only rarely recorded.

Adult largetooth sawfish reach a size of up to 600 cm TL with a possible maximum age of *c.* 30 years. Maturity probably occurs at about ten years and a length of 240–300 cm. All sawfish species are ovoviviparous; the largetooth sawfish gives birth after a five-month gestation to between one and 11 fully developed young of *c.* 76 cm TL.

Intensive fishing pressure at most locations within the species' range has resulted in a dramatic decline in local stocks of this and other sawfishes. Unfortunately, even a very serious reduction in stocks does not cause a cessation in fishing effort: because of the long tooth-studded saw, all sawfish species are extremely vulnerable from birth to incidental capture in net gear set for other species. Sawfishes also yield valuable fisheries products, so are landed when caught rather than released.

The fins of all sawfish species are very highly priced in the shark fin trade (some also have valuable flesh). The saw is used in traditional Chinese medicine and appears in trade as a curio. In addition, aquaria collect sawfishes from the wild for display (there is no known record of successful captive breeding) and there is also limited sports fishing (for trophies). Since sawfishes occur in areas where human activities are particularly intensive, habitat loss and degradation are also significant threats to the species' survival.

The IUCN Red List assessment for this species is "Critically Endangered (A1a,b,c, A2c,d)".

[Summarised from Compagno and Cook 1995 and Cook *et al.* in press a.]

4.3.6 Status of the Brazilian guitarfish *Rhinobatos horkelii* Müller & Henle, 1841

The Brazilian guitarfish *Rhinobatos horkelii* is a viviparous ray with a maxium recorded total length of 142 cm, distributed along the coast of southern Brazil. Until 1985, the species was highly abundant and constituted an important resource for the artesanal beach seine fishery in summer, when gravid (pregnant) females formed dense concentrations in shallow coastal waters. This case study illustrates the extent to which a fishery can rapidly deplete a species which has a restricted geographic range and is caught at all stages of the lifecycle, both as a target species and at the same time as part of a multi-species fishery.

Females reach maturity at 7–9 years old and *c*. 110 cm TL; males at 5–6 years of age. The species segregates by age and sex and carries out marked seasonal migrations during its annual reproductive cycle. Pregnant females are found in shallow coastal waters for the five summer months before birth of their litters of four to 12 pups (dependent on size of mother) and subsequent mating. Adult males come inshore only briefly during the pupping and mating season. All adults then disperse into deep water over the continental shelf, but the newborns and juveniles remain in the inshore pupping grounds year round.

From about 1960, this species was caught by otter and pair trawlers in depths of 10–100 m, and by beach seine net in depths of up to 10 m in summer, with the latter taking 98% pregnant females. Annual landings increased from 100 t in 1960 to 2,029 t in 1984 and 1,927 t in 1989, then decreased continually (with falling catch per unit effort) to 254 t in 1992 and 178 t in 1995. As trawl catches decreased, bottom gill nets became the main fishing method. Guitarfish abundance fell by 96% between 1984 and 1994, but landings continued because of increased gillnet fishing effort.

This species is extremely vulnerable to over-exploitation because the inshore areas where pregnant females and adult males congregate and juveniles remain year-round are so heavily fished. Juveniles are first taken by the fishery at the age of four, two to three years before they reach maturity. Because the fishery targets several species and is not dependent on *R. horkelii*, the extirpation of this species will not cause the fishery to close.

The IUCN Red List assessment for this species is "Critically Endangered (A1b,d; A2b,d)".

[Summarised from Lessa and Vooren (in press).]

4.3.7 Status of the common or gray skate *Raja batis* (Linnaeus, 1758)

The common or gray skate is one of more than 160 skates in the family Rajidae and is the largest European skate species, attaining a length of 285 cm (females) and 205 cm (males). A bottom-dwelling species, it is found primarily on the outer shelf, at depths of 200 m or greater, although historically it was common in coastal waters in the North-east Atlantic and adjoining seas. Males mature at an age of *c.* 11 years and length of 125 cm, and females presumably at a rather larger size. Maximum age is *c.* 50 years. Fecundity is estimated at 40 large eggs per year, with young hatching at a size of up to 21–22 cm.

Rajids are an important component of the demersal fisheries of north-west Europe, and the common skate has traditionally been landed because of its large size and high-quality meat. At the end of the last century it was considered one of the more common elasmobranchs in Scottish waters, comprising nearly 40% of landings. In the 1930s, it comprised nearly 40% of the tonnage of skates landed by Dutch fishermen from near the Dogger Bank in the North Sea, although only juveniles of 20–60 cm were landed. This figure had dropped to 10% in 1970, the last year in which this species was recorded separately. It appears to have been absent from the southern and central North Sea since then. Catches elsewhere in the region have declined. The disappearance of the Irish Sea population (Brander 1981) is notable as the first reported case of a fish being brought to the brink of extinction by commercial fishing (albeit only on a regional basis).

The life history of this species, particularly its age and very large size at maturity, makes the common skate especially vulnerable to over-exploitation when compared to other rajids. Most size classes are taken in fishing nets, and mortality of the large juveniles is high. Fishing pressure on skates from target and multi-species fisheries in the North-east Atlantic is so intense that few of this species can survive to maturity. Fishing pressure in the North Sea, probably representative of other heavily fished areas, is calculated to result in a 34%–37% decrease in numbers of *R. batis* annually. The species has been replaced in much of its former range in the southern and central North Sea by smaller, faster-maturing and more fecund *Raja* species.

The common skate is still taken by French, British, and Icelandic fishermen, with landings appearing to be increasing in France, probably as a result of expanding deepwater fisheries. Because most countries do not record skate and ray landings to species, analysis of trends and stock status is difficult.

The IUCN Red List assessment for the world population of this species is "Endangered (A1b,c,d; A2b,c,d)". Inshore European populations are "Critically Endangered" under the same criteria.

[Summarised from Ellis and Walker (in press).]

Chapter 5

Management of Chondrichthyan Fishes

5.1 Fisheries management

As the previous discussion of chondrichthyan biology suggests, the life history strategy of these fishes requires conservative, risk-averse management if their populations and fisheries are to remain viable. Regardless, on a global basis, most shark fisheries are completely unmonitored, unregulated and unmanaged.

Historically, chondrichthyan fishes have generally been of low economic value. They make only a small contribution to the overall world fisheries catch. Consequently, they are a low priority for research and management funds compared with more valuable teleost and invertebrate resources. This has been compounded by the traditionally negative image of sharks as malevolent creatures responsible for attacks on humans and damage to fish catch. In addition, incidental capture, particularly of batoids in bottom trawl fisheries and pelagic sharks in tuna and billfish fisheries, has led to large and poorly documented mortality. More recently, certain chondrichthyan products, especially shark fins and cartilage, have escalated in price – dramatically increasing the value of the catch and the incentive to retain them. The result is a very poorly documented global catch that is estimated to be twice that reported (Bonfil 1994).

In addition to increasing value and catches, a further compelling reason for the implementation of management plans for chondrichthyans stems from their specialised life-history strategy and role in the ecosystem. Most chondrichthyans are predators at or near the top of marine (and some estuarine and freshwater) food chains and, as such, tend to be naturally low in abundance (Hoff and Musick 1990). They typically grow slowly, mature late in life, have low fecundity and are long-lived. Unlike most bony fishes in which the survival of millions of eggs and larvae are often largely dependent on environmental variables, chondrichthyans exhibit a much closer relationship between the number of young produced and the number of breeding adults. This 'K-selected' life history strategy makes them particularly vulnerable to fishing pressure and, once depleted, stocks can take many years to recover (Hoenig and Gruber 1990). Maintenance of biodiversity and ecosystem structure is another reason for controlling the indiscriminate destruction and fishing of chondrichthyans. The complex interactions between species in marine ecosystems are poorly understood and removal of top predators may well trigger undesirable consequences for other fishery resources, as well as ecosystem function.

Historically, most targeted chondrichthyan fisheries have been unregulated and have rapidly become unsustainable (Anderson 1990b). In 1994, about 105 countries reported chondrichthyan landings to FAO. Twenty-six nations are considered to be major shark-fishing nations, each landing more than 10,000 metric tons of chondrichthyans a year. Only four of these – Australia, New Zealand, the United States, and Canada – have established integrated research and management plans for some of their shark fisheries. One is also in development in South Africa. Apparently only about 11 countries in the world have any federal management at all for their elasmobranch fisheries. Table 3 presents a summary of the management measures implemented for shark fisheries around the world. Unfortunately, fishery regulations can only be effective with adequate enforcement. In many areas where fishery regulations have been implemented, there has been little or no enforcement to ensure compliance. A few additional countries protect one or more chondrichthyan species (Table 4, page 20), but do not actually manage any fisheries.

Efforts to enhance management for sharks are complicated by many factors. Most fundamental is the lack of basic needs such as adequate identification guides for the numerous batoid species or for elasmobranch species by region, and baseline data on species-specific abundances, life history characteristics, fishing effort, catches, and discards at sea. Some highly migratory shark species cross jurisdictional boundaries, which complicates management action and makes aggregation of relevant data difficult. An exceptional lack of data, fleet structure and control makes management of artisanal fisheries even more challenging than that for commercial fishing operations. In addition, the long life span and slow maturation of many sharks often means the effects of fishing and management will not be apparent until 15 to 20 years after initiation. In mixed-species fisheries, which are common for sharks, less abundant and incidentally caught species can become depleted long before there are signs of trouble in the catches of the dominant species. Improved data on the trade in elasmobranchs and their products would significantly increase our understanding of levels and trends in the exploitation of these fishes.

In those very few cases where shark fisheries are managed, regimes have sometimes failed to prevent overfishing or to promote population recovery. This has been the result, *inter alia*, of controls having been implemented too late, or not being sufficiently restrictive.

Table 3. Management tools currently implemented for domestic shark fisheries by shark fishing nations.

Country	Management plan	Quotas	Licences/ limited entry	Habitat/area closures: adult/ nursery [1]	Closed seasons	Minimum sizes	Gear restrictions [1]	Prohibition on finning	Recreational bag limits	Bycatch monitoring (species-specific)
Australia – Southern Shark Fishery (of Victoria, Tasmania, South Australia)	1988		X	X		X	X	Finning in EEZ by domestic vessels discouraged, but not prohibited	X	Limited
South Western Shark Fishery (of Western Australia)	1988, 1998		X				X	Finning within EEZ discouraged but not prohibited	X	X
Northern Australia Fishery (of Queensland, Northern Territory, and N. of W. Australia)	?	X	X	X (area within 15 miles of coast closed)			X	Finning discouraged but not prohibited within EEZ		Minimal
Brazil							Proposed for drift nets	Proposed		
Canada	1995	X	X					X		X
European Union		X [2]								
Ireland						Recreational only (self-regulated)				Limited
Maldives				X			X			
Mexico	In development		X	X [3]		X				
New Zealand		X [4]	ITQs			Recreational	X			Limited
Norway						Only for spiny dogfish *Squalus acanthias*				
Oman								Prohibited		
Portugal (Azores)							Net length for kitefin shark *Dalatias licha*			
South Africa	In development [5]	X [6]	Pelagic & demersal longline permits in Cape Province. Gillnet licences				X commercial only	X	X	Minimal
United Kingdom						For rays, some Sea Fisheries Districts				
United States – Atlantic and Gulf coasts, State [7] & Federal waters	1993	On large coastals (22 spp) small coastals (7 spp) & pelagics (10 spp) [8]	Proposed		X	Proposed		X	X	Limited
Pacific Coast (California, Oregon, and Washington)	X [9]		*Alopias vulpinus* only	*Alopias vulpinus* only		*Triakis semifasciata* in California only		California only	For seven shark species in California (1992)	Limited
Mediterranean Sea	X [10]									

1 Area closures and gear restrictions specific to shark fisheries only.
2 Quotas of 400 metric tonnes (t) liver weight for basking shark *Cetorhinus maximus* and 200 t porbeagle *Lamna nasus* by Norwegian vessels in EU waters. 125 t porbeagle quota for Faeroese vessels. North Sea quota for all skates (*Raja* spp.) is based on previous catches, not stock assessments.
3 Nursery areas protected for bull shark *Carcharinus leucus*, blacktip shark *C. limbatus*, bonnethead shark *Sphyrna tiburo*, lemon shark *Negaprion brevirostris*, and others in Campeche and Quintana Roo.
4 Quota management system (est. 1986) sets quotas for some species, including tope *Galeorhinus galeus*, rig *Mustelus lenticulatus*, elephant fish *Callorhinchus milii*, spiny dogfish *Squalus acanthias*, and *Raja* spp.
5 Research and management plan will focus on tope *G. galeus*, smoothhound *Mustelus mustelus*, and St Joseph *Callorhinchus capensis*.
6 Spotted gully shark *Triakis megalopterus*, sand tiger shark *Carcharias taurus*, Pyjama shark *Poroderma africanum*, and leopard catshark *P. pantheriunum* to be decommercialised-restricted to sport fisheries.
7 For details of Atlantic and Gulf State shark fishery regulations see Camhi 1998.
8 Excludes management quotas for spiny dogfish *Squalus acanthias* despite large increase in landings for export markets.
9 No federal management, but Tri-State Monitoring Plan in California, Oregon, and Washington for thresher shark *Alopias vulpinus*.
10 Mediterranean populations of shortfin mako *Isurus oxyrinchus*, porbeagle *Lamna nasus*, blue shark *Prionace glauca*, white skate *Raja alba* and angelshark *Squatina squatina* are listed on Annex III of a protocol to the Barcelona Convention and (with devil ray *Mobula mobular*) on Appendix III of the Bern Convention on Conservation of European Wildlife and Natural Habitats. Once ratified, these listings will require the exploitation of these species to be regulated.

Table 4. Legally protected elasmobranch species.

Protected species	Country or region	Legislation	Date	Other information
White shark	Australian EEZ	Federal Endangered Species	1997	Extends throughout 200 mile EEZ
Carcharodon carcharias	All Australian range states	State legislation	1984–98	
	USA Atlantic & Gulf Coasts	Fishery Management Plan	1997	Recreational catch-&-release permitted
	South Africa			
	Namibia		1993	
	California	Calif. legislature (SB 144)	1997	AB 522 gave temp. protection in 1993
	Maldives			
	Mediterranean Sea	Barcelona Conv. Annex II	1995	Protocol signed, but not ratified
Whale shark *Rhincodon typus*	Western Australia	State Fisheries Legislation		
	USA Atlantic & Gulf Coasts	Fishery Management Plan	1997	
	Maldives	Fisheries regulation	1995	
	Philippines	Fishery Admin. Order 193	1998	
Grey nurse/sand tiger shark	Australia	Federal Endangered Species	1997	
Carcharias taurus	NSW Australia	State legislation	1984	
	USA Atlantic & Gulf Coasts	Fishery Management Plan	1997	
Bigeye sandtiger *Carcharias norohai*	USA Atlantic & Gulf Coasts	Fishery Management Plan	1997	
Shortfin mako *Isurus oxyrinchus*	Canada	Fishery Management Plan	1995	Target fisheries prohibited, landing of bycatch permitted
Basking shark	USA Atlantic & Gulf Coasts	Fishery Management Plan	1997	
Cetorhinus maximus	Florida State waters	Florida Administrative Code		
	Great Britain	Wildlife & Countryside Act	1998	Extends to the 12 mile territorial limit
	Guernsey, UK	Fisheries legislation	1997	
	Isle of Man, UK	Wildlife Act, Schedule 5	1990	Protected species
	Mediterranean Sea	Barcelona Conv. Annex II	1995	Protocol signed, but not ratified
		Bern Conv. Appendix II	1997	Reservation lodged by EU
	New Zealand [1]	Fishery legislation		Target fisheries prohibited, landing of bycatch permitted
Sawsharks	USA Atlantic & Gulf Coasts	Fishery Management Plan	1997	
Order Pristiophoriformes	Florida State waters	Florida Administrative Code		
Sawfishes *Pristis* spp.	Indonesia	Protected species legislation		Species found in Lake Sentani, Irian Jaya
	USA Atlantic & Gulf Coasts	Fishery Management Plan	1997	
	Florida State waters	Florida Administrative Code		
Spotted eagle ray	USA Atlantic & Gulf Coasts	Fishery Management Plan	1997	
Aetobatis narinari	Florida State waters	Florida Administrative Code		
Giant devil ray *Mobula mobular*	Mediterranean Sea	Barcelona Conv. Annex II	1995	Protocol signed, but not ratified
Manta ray *Manta birostris*	Philippines	Fishery Admin. Order 193	1998	
All chondrichthyans	Israel			

[1] Many elasmobranchs are prohibited target species in New Zealand, but bycatch can be quite high, so effective protection may be minimal.

For management to be effective, it must be based on the biological constraints of the species rather than the short-term economics of the fishery. Past shark management has been particularly ineffective because managers relied on techniques developed for much more productive and resilient teleost fishes (Musick 1995). Until recently, few shark fisheries models have been used as the basis for management.

For example, in the United States, large coastal sharks in the north-western Atlantic and Gulf of Mexico had already been overfished by the time a US Federal Fishery Management Plan (FMP) was implemented in 1993. Management actions have apparently stemmed the rapid decline in catch per unit effort experienced during the 1980s. Some populations, however, are still reduced to only 10%–50% of their 1970s abundances (Musick *et al.* 1993). A 1996 biological assessment concluded that fishing mortality would have to be cut by 50% or more for there to be a "strong probability of stock rebuilding" (NOAA 1996). The subsequent assessment in 1998 has suggested that even further restrictions on catch are needed for recovery to take place (NOAA 1998a). The fact that virtually no commercial shark fishery in the United States has been managed sustainably, despite considerable investments in shark fishery research and management, emphasises the extreme vulnerability of shark populations to overfishing.

Management is even more difficult for the many species that exhibit wide-ranging movements and have a complex population structure. These resources are often shared between states or nations, and require cooperative management at an intergovernmental level (FAO Fisheries Department 1994). Oceanic shark resources extend into international waters, yet there are few regulatory bodies collecting shark data, much less implementing shark management measures. International efforts to establish such data collection and conservation programmes have just recently begun. For example, in September 1998, the Northwest Atlantic Fisheries Organization (NAFO) agreed to improve the reporting of elasmobranch catch statistics and carry out analyses of the distribution and abundance of elasmobranchs in the NAFO Regulatory Area (international waters in FAO Statistical Area 21). A Plan of Action for Sharks, including guidelines for improved monitoring, recording and management activities, is being discussed at the inter-governmental FAO Committee on Fisheries meeting in October 1998.

The UN Agreement on Straddling and Highly Migratory Fish Stocks could be used as a framework for promoting the conservation of oceanic sharks by expanding the role of intergovernmental bodies, such as the Inter American Tropical Tuna Commission (IATTC), the International Commission for the Conservation of Atlantic Tunas (ICCAT), the South Pacific Commission (SPC) and the Forum Fisheries Agency (FFA), or the establishment of new regional management regimes for sharks where none currently exist. Yet, this agreement currently remains 12 signatories short of coming into force. As a matter of priority, countries should accede to and ratify this Agreement and become active members of treaty organisations relevant to chondrichthyans.

5.2 Species protection

In recent years, a number of countries have begun to enact protective legislation or regulation for a few species of sharks as concern over the threats to these species has increased. White sharks *Carcharodon carcharias*, for example, have been afforded varying levels of protection in Australia, Israel, Namibia, South Africa and the United States. Basking sharks *Cetorhinus maximus* and whale sharks *Rhincodon typus* are now also protected to varying degrees in a few countries (see Table 4). It is unfortunately only the largest and most 'charismatic' sharks that are receiving the benefits of such protection. Many other species, including some skates and rays, are in as great, if not greater, need of conservation action and legal protection.

Unfortunately, a declaration of protected status without implementation of enforceable regulations – while reassuring to governments and international bodies – will result in little effective protection. For example, several Mediterranean populations of sharks and rays listed as protected on the Barcelona and Bern Conventions receive no real protection because these agreements are not ratified or enforced. The protection of the basking shark in UK coastal waters may not have any effect in stemming the apparent decline in numbers there if target fisheries and bycatch continue to remove significant numbers of individuals from the same population elsewhere in its range.

Finally, the loss or deterioration of critical habitats, which may be a strong contributory factor to a population decline, is not halted by species protection legislation alone.

Chapter 6

Conclusions

6.1 Summary

The life histories of chondrichthyan fishes make them highly vulnerable to over-exploitation and therefore inappropriate targets for large-scale commercial fisheries in the absence of effective management. Shark fisheries and landings, however, continue to grow in directed fisheries seeking fins, cartilage and meat, and in 'take-all' fisheries. In most places, exploitation occurs in the absence of even the most basic monitoring and management.

Effective conservation and management of sharks must address the array of factors affecting their populations, including directed fisheries, bycatch and discard mortality, loss of habitat, and changes in marine trophic structure, among others. In the context of fisheries, there is an urgent need to develop and implement management regimes that take into account the biological constraints and life histories of sharks. For example, fishing mortality cannot continually exceed the ability of the population to replace itself through reproduction if the fishery is to persist long-term.

To develop effective fisheries management regimes for sharks and address their broader conservation needs, greater attention is needed to improve the quality of ecological and fisheries data and to develop and apply management mechanisms and tools, including to control and monitor trade. Specific data and other requirements are set out below. Addressing these needs will require increased investment of human and financial resources in research and management, in developing the necessary policy, legal and institutional frameworks, and in training and other capacity-building to implement management measures.

Given the biological vulnerability of sharks and their relatives, these species clearly demand a precautionary approach to their management. The United Nations Food and Agriculture Organization has made a strong case for such an approach in capture fisheries, noting the need to take management action even where there are uncertainties and gaps in knowledge (FAO 1995), as is the case for most shark fisheries today. A truly precautionary approach to shark fishery development would dictate that fisheries only be conducted where stock assessments are available and stringent monitoring and management regimes are in place. However, few biological and long-term fisheries data are available, even for species that are abundant in fisheries and/or of considerable value in trade. While management is hampered by the lack of data on most species' population status and productivity, shark biology and fisheries dynamics are now sufficiently well understood to enable precautionary management to be introduced wherever such fisheries occur.

6.2 Ecological data needs

If shark fishing is to be sustainable, management must be driven by the biological capacity of the sharks themselves. This will require better knowledge of the biology, ecology and life history of the populations being exploited, and of rarer species that may be taken as bycatch.

1. Basic taxonomic knowledge is lacking for some groups of chondrichthyans, particularly the batoids and chimaeras, many of which are very important in fisheries. Greater taxonomic research effort is needed, including species description and genetic research into stock structure.
2. Models used to assess elasmobranch fisheries should be appropriate for long-lived animals with low productivity and a close relationship between stock and recruitment. Optimal models require species-specific data on:
   - reproductive characteristics (age at maturity, gestation period and average annual pups per female);
   - critical habitats at different life stages, including mating, pupping and nursery grounds;
   - growth rates and age structure;
   - mortality (natural and in fisheries) for all age classes;
   - stock and relative species abundance; and
   - stock structure and migration patterns.
3. Assessment of the global and regional status of all species.

6.3 Fisheries data needs

Because much of the assessment and monitoring of shark populations relies on fisheries data, there is a need to develop and implement mechanisms to collect and enhance the reliability of these data, at national and sub-national, as well as regional and international, level, through fisheries management and other bodies. Particularly important are:

1. Data on shark fishing mortality by species, gear type and region, including current and historical records of:
   - commercial, artisanal and recreational catches;
   - size and age structure and sex composition of catch;
   - landings (including number and weight of fishes);
   - bycatch, discards and discard mortality; and
   - catch per unit effort (CPUE).
2. Socio-economic data on shark fisheries – commercial, recreational and artisanal – including fleet and vessel size, gears used, areas fished, numbers of fishers, markets and values for different products, and the structure of trade.
3. Fishery-independent data.
4. Standardised data collection and reporting methods, for comparison of trends between regions and over time.

6.4 Management measures

With the exception of a few countries that have instituted national measures for their shark fisheries or protection for individual species, there are virtually no controls on shark fisheries around the world. There is an urgent need for management and monitoring to be instituted at the national, regional and international levels to prevent fisheries collapse and the extirpation of species and populations. Each shark fishery is unique, but FAO's Precautionary Approach (1995) provides guidance on the minimal management actions needed for both new and existing fisheries. Cooperation is necessary among all parties interested in the long-term productivity of shark populations.

The biology of sharks requires a particularly conservative approach to fisheries management. Ideally, shark fisheries should not be established or proceed in the absence of a management plan, which should *inter alia*:

1. Focus on individual populations (stocks) if possible, or on species or groups with similar life-history characteristics.
2. Provide a precautionary buffer by maintaining biomass above levels associated with maximum sustainable yields.
3. Address the need to avoid recruitment overfishing by ensuring that adequate numbers of fish survive to maturity.
4. Where adequate data exist, use assessment models relevant to sharks (i.e. stage- or age-based demographic matrix models) rather than traditional models for teleosts (surplus production or biomass dynamic models).
5. Encourage commercial fishing practices that reduce chondrichthyan bycatch and/or facilitate live release and discourage wasteful practices such as finning.
6. Take into account the vulnerability of less common chondrichthyans taken as a bycatch that may be rapidly driven to stock collapse or extirpation while more common species support fisheries.
7. Encourage live release of recreational catches and participation in tagging programmes.
8. Include international bi- or multi-lateral agreements, based on the precautionary approach and other elements of sound fisheries management.

Effective management measures include the following:

1. Limited entry (instituted as early as possible in the development of the fishery).
2. Commercial, recreational and artisanal catch quotas or bag limits (incorporating bycatch).
3. Size limits (so that enough fish mature and reproduce).
4. Closed seasons (to reduce overall fishing mortality or protect vulnerable aggregations on mating, nursery or pupping grounds).
5. Closed areas (e.g. fishery reserves or sanctuaries, to serve as refugia for fisheries productivity, or to protect critical habitats or threatened species or populations).
6. Gear restrictions (to protect certain species or age classes and reduce bycatch).
7. Selective take of males only.
8. Protection of threatened species.
9. Prohibition of finning and requirement to land whole carcasses (which will also improve recording of accurate fisheries statistics and enforcement of regulations).

The recent growth in shark fisheries has been driven, in part, by the expansion of international trade in shark fins and other products. Better understanding of the quantities, sources and utilisation of shark fishery products is necessary to inform management of shark fisheries. Management will benefit from:

1. Improved documentation on international shark trade, including:
   - monitoring of species, products, and volumes in trade, and their value; and
   - details of importing/exporting countries and oceans/areas of origin.
2. Controls on trade in rare chondrichthyan fishes threatened by over-exploitation for trade (e.g. for the fin, curio or aquarium markets).
3. Evaluation of elasmobranch species for possible listing on the Convention on International Trade in Endangered Species (CITES) Appendices (to help provide needed trade data).

In addition to the controls to reduce the risk of overfishing, investment in a number of management tools is needed to address the data collection and monitoring needs outlined above, including:

1. Preparation of regional and global identification guides for species and products.
2. Preparation of a procedures manual to help standardise data collection, which will facilitate international management measures.
3. Training programmes within fisheries agencies to apply management measures and standardised data collection techniques.
4. Mechanisms for involving commercial, recreational and artisanal fishers in monitoring and management decision-making.
5. Increased enforcement capability.

Finally, despite frequent reference to the limitations of available data, enough is known about shark biology and the dynamics of shark fisheries to begin implementing basic management measures wherever these fisheries exist. That is, lack of data must not be used to justify lack of management. Increasing human-induced pressures are rapidly intensifying the risk of shark population collapse, species endangerment and even extinction. Increased commitment to shark research, management and conservation at the national, regional and international levels is crucial to the future viability of these exceptionally vulnerable animals.

Annex 1. Life-history traits of some chondrichthyan species.[1]

Scientific and common names	Age to maturity (years)	Size (cm TL) (at birth, maturity, and maximum)	Life span (years)	Litter size	Annual rate of population increase	Reproductive periodicity (years)	Gestation time (months)
Notorynchus cepedianus Broadnose sevengill shark	M: 4–5 M: 11–21 F: 16–20	Birth: 40–45 Mat: M: 150 F: 220 Max: 290–300	M: 23–32 F: 35–49 32	20, 82–95 (max)	2.6%	2	10–12
Rhincodon typus Whale shark	?	Birth: 60 Mat: F: >560 Max: ~1370	?	300	?	?	?
Ginglymostoma cirratum Nurse shark	?	Birth: 27–30 Mat: 150 Max: 425	?	20–30	?	?	?
Carcharias taurus Sand tiger, spotted raggedtooth, or gray nurse shark	6–12 8	Birth: 95–105 Mat: 220 Max: 318	32 (NE Pacific)	1–2	4.6%	2	12
Carcharodon carcharias White shark	M: 9–10 F: 12–14	Birth: 120–150 Mat: M: 350–410 Mat: F: 400–430 Max 594	36	2–10	4.1%	2?	>12?
Isurus oxyrinchus Shortfin mako	M: 3 F: 7–8 av. 5	Birth: 60–70 Mat: M: 195 Mat: F: 280 Max: 394	28	4–16	5.2%	2–3	12–18
Lamna nasus Porbeagle shark	4–8 F: 7.5	Birth: 60–75 Mat: M: 165 F: 152–225 Max: 300–365	30	1–5	?	1–3?	9–18?
Cetorhinus maximus Basking shark	M: 12–16 F: 20	Birth: 150–170 M: 500–700 F: 810–980 Max: 1000–1300	50	5–6	?	2?	>12?
Alopias vulpinus Thresher shark	7	Birth: 114–150 Mat: M: 319 F: 376 Max: 491	?	2–6	7.2%	?	9
Mustelus antarcticus Gummy shark	4–5	Birth: M: 30–40 Mat: F: 85 M: 80 Max: 175	16	10–38 (mean=14)	12%	annually in W. Australia 2 year in Bass Strait	11–12
Mustelus henlei Brown smoothhound	2–3	Birth: 19–21 Mat: M: 51–63 F: 52–66 Max: 95	15	3–5	13.6%	1	10–11
Galeorhinus galeus Tope, school, or soupfin shark	F: 10–15 M: 8–10	Birth: 30–40 Mat: F: 134–140 Mat: M: 125–135 Max: 155–200	40–60	8–50 (mean=28)	3.3%	1–3	12
Carcharhinus falciformis Silky shark	M: 10 F: >12	Birth: 76–87 Mat: M: 187–225 Mat: F: 213–245 Max: 330	M: >20 F: >22	2–15	?	1–2	12
Carcharhinus leucas Bull shark	6–8 or 15	Birth: 56–81 Mat: 200 Max: 300–320	M: 16 F: 12–27	1–13	2.7%	?	10–11
Carcharhinus limbatus Blacktip shark	M: 4–5 F: 6–8	Birth: 53–65 Mat: M: 130 F: >155 Max: M: 175 F: 193	10–18	2–4 4–7	2.2%–13.6% 5.6%	2	11–12

[1] Most of the data presented here are from Compagno (1984) and Smith *et al*. in press, with updates for a small number of species.

Distribution cosmopolitan, wide-ranging, regional, country endemic, localised, restricted	pelagic, demersal	Habitat information insular, oceanic, bathyal (>200m), coastal (shore-200m), reef, mangrove, estuarine	pupping/nursery grounds (estuarine, near-/offshore)	Fisheries pressure Directed (high, some, low, none)	Incidental (high, some, low, none)	References
wide-ranging, temperate waters	demersal	coastal	estuarine-nearshore	high	high	Compagno in press a, Ebert 1990, Ebert 1989, Van Dykhuizen & Mollet 1992
cosmopolitan, warm temperate and tropical	pelagic	coastal-oceanic	?	low	low	Joung *et al.* 1996, Norman in press
regional (Atlantic and E. Pacific)	demersal	coastal	nearshore	low	low	Castro 1997, Carrier 1991, Clark & von Schmidt 1965
wide-ranging, temperate to sub-tropical	demersal	coastal	nearshore-estuarine	low	high	Branstetter & Musick 1994, Gilmore 1993, Gilmore *et al.* 1983, Goldman 1998, Pollard *et al.* 1996, Pollard & Smith in press, Sminkey 1996
wide-ranging, temperate to boreal waters	pelagic	coastal-oceanic	probably coastal	low (high in some trophy fisheries)	low (high in beach netting areas)	Cailliet *et al.* 1985, Fergusson 1996, Fergusson *et al.* in press, Francis 1996, Uchida *et al.* 1996
cosmopolitan, tropical, sub-tropical and temperate	pelagic	oceanic, sometimes coastal	probably coastal	high [in some recreational fisheries]	high	Cailliet & Mollet 1997, Cailliet *et al.* 1983, Cliff *et al.* 1990, Mollet *et al.* 1997, Pratt & Casey 1983, Stevens in press b
wide-ranging demersal	pelagic and oceanic	coastal and oceanic	offshore	high	high	Aasen 1963, Ellis & Shackley 1995, Gauld 1989, Stevens in press a
wide-ranging, temperate to boreal waters	pelagic	coastal	offshore?	some	some	Fowler in press b, Kunzlik 1988, Pauly 1978, Parker & Stott 1965, Sund 1943
cosmopolitan, warm waters	pelagic	coastal-oceanic	inshore	high?	some?	Goldman in press
endemic (temperate Australia)	demersal	coastal	?	high	high?	Lenanton *et al.* 1990, Moulton *et al.* 1992, Walker 1996, 1983, 1994a, b, & in press
localised	demersal	coastal	?	some	some	Yudin & Cailliet 1990
wide-ranging sometimes pelagic	demersal, (but down to 800 m)	coastal and estuarine	nearshore	high	some	Capape & Mellinger 1988, Grant *et al.* 1979, Olsen 1954, Peres & Vooren 1991, Ripley 1946, Stevens in press d, Walker *et al.* 1995
wide-ranging in temperate and tropical waters	pelagic	coastal-oceanic	offshore	high	high	Bonfil 1990 & in press, Bonfil *et al.* 1993, Branstetter 1987b
wide-ranging in subtropical to tropical waters	pelagic	coastal into estuaries and freshwater	estuarine	high	high	Burgess *et al.* in press, Branstetter & Stiles 1987
cosmopolitan in warm-temperate to tropical waters	pelagic	coastal	estuarine	high	low	Branstetter 1987c, Burgess & Branstetter in press, Castro 1996, Dudley & Cliff 1993, Killam & Parsons 1989, Wintner & Cliff 1996

Annex 1. ... continued

Scientific and common names	Age to maturity (years)	Size (cm TL) (at birth, maturity, and maximum)	Life span (years)	Litter size	Annual rate of population increase	Reproductive periodicity (years)	Gestation time (months)
Carcharhinus longimanus Oceanic whitetip shark	4–5	Birth: 60–65 Mat: F: 180–200 M: 175–195 Max: 310	22	1–14	6.9%	?	12
Carcharhinus melanopterus Blacktip reef shark (Eastern hemisphere)	?	Birth: 30–35 Mat: 95–110 Max: 140–180	?	2–4	?	1 or 2	8–9 or 10–11 or ?16
Carcharhinus obscurus Dusky shark	M: 19 F: 21	Birth: 80–100 Mat: F: 280 Max: 365	40–50	3–14 (mean 607)	2.8% 2%	2 or 3	12 or 22–24
Carcharhinus plumbeus Sandbar shark	13–16 [29 in another study]	Birth: 60–65 Mat: M: 170 F: >180 Max: >239 (in USA)	25–35	8–13	2.2%–11.9% 3.4%, or 5.2% if mat=29 years	2	9–12
Galeocerdo cuvier Tiger shark	8–10	Birth: 59–90 Mat: M: 226–290 F: 250–350 Max: 450–600	50	10–80 av. 35	4.3%	probably 2 yrs	12–16
Glyphis sp. Borneo river shark	?	?	?	?	?	?	?
Negaprion brevirostris Lemon shark	11–13	Birth: 60 M: 224 (mat) Mat: M: 224 F: 239 Max: M: >279 F: >285	27	4–17	1.2%	?	?
Prionace glauca Blue shark	F: 5–7 M: 4–6	Birth: 35–50 Mat: M: 180–218 Mat: F: 180–220 Max: 383	20	40 av. (4–135)	6.25%	females? males annually?	9–12
Rhizoprionodon terraenovae Atlantic sharpnose shark	3–4	Birth: 30–35 Mat: M: 80–85 F: 85–90 Max: 110	10	4–6 1–7	4.5% 8.8%	annual	10–12
Triaenodon obesus Whitetip reef shark	5 or 8–9	Birth: 52–60 Mat: 105 Max: 170	16–25	1–5 2–3	4.9%	?	>5?
Sphyrna lewini Scalloped hammerhead	M: 4–10 F: 4–15	Birth: 31–55 Mat: M: 140–280 Mat: F: 150–300 Max: 329–420	35	15–40 12–38	2.8%	?	9–12
Sphyrna tiburo Bonnethead shark	F: 2–3 M: 3	Birth: 35–40 Mat: M: 68–85 F: 80–85 Max: M: 124 F: 150	12	4–16	0.01–0.27	annual?	?
Dalatias licha Kitefin shark	?	Birth: 30 Mat: M: 100 F: 120 Max: M: 120 F: 160	?	10–16	?	?	?
Squalus acanthias Spiny or piked dogfish or spurdog NW Atlantic population (NW Pacific population)	M: 6–14 F: 10–12 (F: 12–23)	Birth: 20–30 Mat: M: 60 F: 70 Max: 100–125	M: 35 F: 40–50 (70)	2–15 av. 4–9	2.3%–3.5% (1.7%)	2 (but no resting stage)	18–24
Squatina californica Pacific angelshark	8–13	Birth: 21–26 Mat: M: 75–80 Mat: F: 86–108 Max: M: 114 F: 152	35	1–11 mean 6	3.9%–6%	1	10–12
Pristis microdon Greattooth or freshwater sawfish	?	700 (max)	?	?	?	?	?

Distribution cosmopolitan, wide-ranging, regional, country endemic, localised, restricted	pelagic, demersal	Habitat information insular, oceanic, bathyal (>200m), coastal (shore-200m), reef, mangrove, estuarine	pupping/nursery grounds (estuarine, near-/offshore)	Fisheries pressure Directed (high, some, low, none)	Incidental (high, some, low, none)	References
cosmopolitan	pelagic	oceanic; insular	oceanic	high	high	Backus *et al*. 1956, Seki *et al*. undated, Smale in press a
widespread	demersal	insular (reefs)	insular	high	high	Heupel in press, Last & Stevens 1994, Stevens 1984
wide-ranging in sub-tropical and temperate oceans	coastal-pelagic	coastal	offshore in Australia inshore USA	high (in USA & Australia)	high	Branstetter & Burgess 1996, Camhi *et al*. in press, Cortés in press a, Goldman 1998, Natanson *et al*. 1995
wide-ranging tropical and temperate oceans	pelagic	coastal, oceanic	nearshore	high	some, moderate	Casey & Natanson 1992, Casey *et al*. 1985, Sminkey & Musick 1995, 1996, Musick in press
cosmopolitan in tropical and subtropical waters	coastal-pelagic	coastal	wide-ranging, may enter estuarine areas	locally high	low	Branstetter *et al*. 1987, Clark & von Schmidt 1965, De Crosta *et al.* 1984, Randall 1992, Simpfendorfer in press b, Sminkey 1996, Tester 1969
restricted to rivers in Borneo?	localised	demersal	freshwater-estuarine	low	low-moderate (bycatch)	
regional	demersal	coastal, insular and reefs	nearshore	high	high	Brown & Gruber 1988, Sundstroem & Gruber in press
cosmopolitan	pelagic	oceanic, sometimes coastal	offshore	low	high	Amorim 1992, Cailliet *et al*. 1983, Castro & Mejuto 1995, Hazin 1993, Nakano 1994, Pratt 1979, Stevens 1976 & in press c, Tanaka *et al*. 1990
wide-ranging in warm temperate to tropical Atlantic	demersal	coastal	estuarine	high	high	Branstetter 1987a, Cortés 1995, in press a, b, Parsons 1983, 1985
wide-ranging (in Indo-Pacific)	demersal	coastal	nearshore	some	high	Anderson & Ahmed 1993, Fourmanoir 1961, Last & Stevens 1994, Smale in press b
wide-ranging in warm temperate to tropical waters	pelagic	coastal-oceanic	nearshore	high	high	Branstetter 1987b, Kotas in press, Stevens & Lyle 1989
regional	demersal	coastal and reefs	?	some	high	Carlson & Parsons 1997, Cortés in press c, Cortés & Parsons 1996, Parsons 1993a, 1993b
wide-ranging, warm temperate to tropical waters	demersal	bathyal	bathyal	high in some locations	high in some locations	Compagno & Cook in press c
cosmopolitan, temperate to subarctic waters	demersal	coastal	offshore	high	high	Fordham in press, Gauld 1979, Jensen 1965, Jones & Geen 1977, Ketchen 1975, Nammack *et al*. 1985, NOAA 1998b, Saunders & McFarlane 1993
localised, cold to warm temperate waters	demersal	coastal	coastal	high	high	Cailliet in press b, Cailliet *et al*.1992, Natanson & Cailliet 1986, 1990
localised in tropics	demersal	freshwater	?	high	high	Compagno & Cook in press b, Last & Stevens 1994

Annex 1. ... continued

Scientific and common names	Age to maturity (years)	Size (cm TL) (at birth, maturity, and maximum)	Life span (years)	Litter size	Annual rate of population increase	Reproductive periodicity (years)	Gestation time (months)
Pristis pectinata Smalltooth or wide sawfish	?	760 (max)	?	15–20	?	?	?
Rhynchobatus djiddensis Giant guitarfish	?	M: 110 (mat) >300 (max)	?	?	?	?	?
Rhinobatos horkelii Brazilian guitarfish	F: 7–9 M: 5–6	Mat: 90–120	?	4–12	?	1	11–12
Bathyraja abyssicola Deepsea skate	?	M: 110 (mat)	?	? (eggs)	?	?	n/a
Raja batis Common skate	11	Birth: 21–22 Mat: M: 125 Max: 254	50	40 eggs	?	annual?	n/a
Raja (Dipturus) binoculata Big skate	M: 8–11 F: 12	Mat: M: 100–110 F: 130 Max: 168–240	?	1–7 embryos per egg case	?	?	n/a
Raja (Raja) clavata Thornback skate or ray	9–12	M: 69 (mat) F: 72 (mat)	M: 36–43 F: 39–46	52 eggs/ year	0 or less in North Sea	annual	n/a
Raja (Dipturus) rhina Longnose skate	M: 7–8 F: 8–10	Mat: M: 60 F: >70 Max: 137	?	?	?	?	n/a
Myliobatis californica Bat ray	M: 4, F: 5	Birth 20 (DW) Mat: M: 60 F: 88 (DW) Max 180 (DW-disk width)	M: 10 F: 25	2–5	?	1	~12
Himantura chaophraya Giant freshwater stingray or whipray	?	Mat: 100 (disk width) Max: 200 (disk width)	?	?	?	?	?

Distribution		Habitat information		Fisheries pressure		References
cosmopolitan, wide-ranging, regional, country endemic, localised, restricted	pelagic, demersal	insular, oceanic, bathyal (>200m), coastal (shore-200m), reef, mangrove, estuarine	pupping/nursery grounds (estuarine, near-/offshore)	Directed (high, some, low, none)	Incidental (high, some, low, none)	
wide-ranging (disjunct)	demersal	coastal and freshwater	?	high	high	Adams in press, Bigelow & Schroeder 1953
wide-ranging in tropical waters	demersal	coastal	?	high	high	Simpfendorfer in press c, Last & Stevens 1994
regional	demersal	coastal	nearshore	high	high	Lessa 1982, Lessa *et al*. 1986, Lessa & Vooren in press
regional	demersal	bathyal	?	none (too rare)	some	Cook *et al*. in press b, Zorzi & Anderson 1988
regional, boreal to cool temperate (NE Atlantic)	demersal	coastal	?	high	high	Ellis & Walker in press, Du Buit 1972 & 1976, Brander 1981, Fahy 1991
regional (NE Pacific)	demersal	coastal	nearshore and offshore	high	high	Ellis & Dulvy in press, Martin & Zorzi 1993, Zeiner & Wolf 1993, DeLacy & Chapman 1935, Hitz 1964
wide-ranging in temperate water	demersal	coastal	estuarine-nearshore	high	high	Brander & Palmer 1985, Capape 1977, Ellis & Shackley 1995, Ellis in press, Holden 1975, Holden & Vince 1973, Nottage & Perkins 1983, Ryland & Ajayi 1984
regional (NE Pacific)	demersal	coastal	nearshore and offshore	high	high	Zeiner & Wolf 1993
west coast USA	demersal	coastal	estuaries	some	some	Cailliet in press a, Martin & Cailliet 1988 a & b
localised	demersal	freshwater-estuarine	freshwater	some	some	Compagno & Cook in press a, Last & Stevens 1994

Annex 2. Summary of the 1994 IUCN Red List Categories and Criteria.
This table should be used in conjunction with Table 2, to help explain the basis of the Red List assessments applied to various chondrichthyan fishes by the IUCN/SSC Shark Specialist Group.

Use any of the **A-E** criteria	**Critically Endangered**	**Endangered**	**Vulnerable**
A. Declining Population			
population decline rate at least:	80% in 10 years	50% in 10 years	20% in 10 years
using either	or 3 generations	or 3 generations	or 3 generations
1. population reductions observed, estimated, inferred, or suspected in the past or			
2. population decline projected or suspected in the future based on:			
a) direct observation			
b) an index of abundance appropriate for the taxon			
c) a decline in area of occupancy, extent of occurrence and/or quality of habitat			
d) actual or potential levels of exploitation			
e) the effects of introduced taxa, hybridisation, pathogens, pollutants, competitors, or parasites			
B. Small Distribution and Decline or Fluctuation			
Either extent of occurrence:	< 100 km^2	< 5,000 km^2	< 20,000 km^2
or area of occupancy:	< 10 km^2	< 500 km^2	< 2,000 km^2
and 2 of the following 3:			
1. either severely fragmented (isolated subpopulations with a reduced probability of recolonization, if one extinct) or known to exist at a limited number of locations:	+ 1	≤ 5	≤ 10
2. continuing decline in any of the following:	any rate	any rate	any rate
a) extent of occurrence			
b) area of occupancy			
c) area, extent and/or quality of habitat			
d) number of locations or subpopulations			
e) number of mature individuals			
3. fluctuations in any of the following:	> 1 order/mag.	< 1 order/mag.	< 1 order/mag.
a) extent of occurrence			
b) area of occupancy			
c) number of locations or subpopulations			
d) number of mature individuals			
C. Small Population Size and Decline			
Number of mature individuals:	< 250	< 2,500	< 10,000
and 1 of the following 2:			
1. rapid decline rate	25% in 3 years or 1 generation	20% in 5 years or 2 generations	10% in 10 years or 3 generations
2. continuing decline	any rate	any rate	any rate
and either a) fragmented	all sub-pops ≤ 50	all sub-pops ≤ 250	all sub-pops ≤ 1,000
or b) all individuals in a single subpopulation			
D. Very Small or Restricted Population			
Either:			
1. number of mature individuals:	< 50	< 250	< 1,000
2. population is susceptible:	(not applicable)	(not applicable)	area of occupancy < 100 km^2 or no. of locations < 5
E. Quantitative Analysis			
Indicating the probability of extinction in the wild to be at least:	50% in 10 years or 3 generations	20% in 20 years or 5 generations	10% in 100 years

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Annex 1. Summary of the 1994 IUCN Red List Categories and Criteria.

This table should be used in conjunction with Table 2, to help explain the basis of the Red List assessments applied to various chondrichthyan fishes by the IUCN/SSC Shark Specialist Group.

Use any of the **A-E** criteria	**Critically Endangered**	**Endangered**	**Vulnerable**
A. Declining Population			
population decline rate at least	80% in 10 years	50% in 10 years	20% in 10 years
using either	or 3 generations	or 3 generations	or 3 generations
1. population reductions observed, estimated, inferred, or suspected in the past or			
2. population decline project or suspected in the future based on:			
a) direct observation			
b) an index of abundance appropriate for the taxon			
c) a decline in area of occupancy, extent of occurrence and/or quality of habitat			
d) actual or potential levels of exploitation			
e) the effects of introduced taxa, hybridization, pathogens, pollutants, competitors, or parasites			
B. Small Distribution and Decline or Fluctuation			
Either extent of occurrence	< 100 km²	< 5,000 km²	< 20,000 km²
or area of occupancy	< 10 km²	< 500 km²	< 2,000 km²
and 2 or the following 3:	= 1	£ 5	£ 10
1. either severely fragmented: (isolated subpopulations with a reduced probability of recolonization, if one extinct) or known to exist at a number of locations			
2. continuing decline in any of the following:	any rate	any rate	any rate
a) extent of occurrence			
b) area of occupancy			
c) area, extent and/or quality of habitat			
d) number of locations or subpopulations			
e) number of mature individuals			
3. fluctuating in any of the following:	> 1 order/mag.	< 1 order/mag.	< 1 order/mag.
a) extent of occurrence			
b) area of occupancy			
c) number of locations or subpopulations			
d) number of mature individuals			
C. Small Population Size and Decline			
Number of mature individuals	< 250	< 2,5000	< 10,000
and 1 of the following 2:			
1. rapid decline rate	25% in 3 years or 1generation	20% in 5 years or 2 generations	10% in 10 years or 3 generations
2. continuing decline	any rate	any rate	any rate
and either a) fragmented	all sub-pops £ 50	all sub-pops £ 250	all sub-pops £ 1,000
or b) all individuals in a single subpopulation			
D. Very Small or Restricted			
Either			
1. number of mature individuals or	< 50	< 250	< 1,000
2. population is susceptible	(not applicable)	(not applicable)	area of occupancy
		< 100 km² or	
			no. of locations < 5
E. Quantitative Analysis			
Indicating the probability of extinction in the wild to be at least	50% in 10 years or 3 generations	20% in 20 years or 5 generations	10% in 100 years

Annex 2. Life-history traits of some chondrichthyan species.[1]

Scientific and common names	Age to maturity (years)	Size (cm TL) (at birth, maturity, and maximum)	Life span (years)	Litter size	Annual rate of population increase	Reproductive periodicity (years)	Gestation time (months)
Notorynchus cepedianus Broadnose sevengill shark	M:4-5 M:11-21 F:16-20	Birth: 40-45 Mat: M:150 F:220 Max: 290-300	M:23-32 F:35-49 32	20, 82-95 (max)	2.6%	2	10-12
Squalus acanthias Spiny or piked dogfish or spurdog NW Atlantic population (NW Pacific population)	M:6-14 F:10-12 (F:12-23)	Birth: 20-30 Mat: M:60 F:70 Max: 100-125	M:35, F:40-50 (70)	2-15 av.4-9	2.3-3.5% (1.7%)	2 (but no resting stage)	18-24
Dalatias licha Kitefin shark	?	Birth: 30 Mat: M:100 F:120 Max: M:120 F:160	?	10-16	?	?	?
Squatina californica Pacific angelshark	8-13	Birth: 21-26 Mat: M:75-80 Mat: F:86-108 Max: M:114 F:152	35	1-11 mean 6	3.9-6%	1	10-12
Ginglymostoma cirratum Nurse shark	?	Birth: 27-30 Mat: 150 Max: 425	?	20-30	?	?	?
Rhincodon typus Whale shark	?	Birth: 60 Mat: F>560 Max: ~1370	?	300	?	?	?
Carcharias taurus Sand tiger, spotted raggedtooth, or gray nurse shark	6-12 8	Birth: 95-105 Mat: 220 Max: 318	32 (NE Pacific)	1-2	4.6%	2	12
Alopias vulpinus Thresher shark	7	Birth: 114-150 Mat: M:319 F:376 Max: 491	?	2-6	7.2%	?	9
Cetorhinus maximus Basking shark	M: 12-16 F: 20	Birth: 150-170 M:500-700 F:810-980 Max: 1000-1300	50	5-6	?	2?	>12?
Carcharodon carcharias White shark	M: 9-10 F: 12-14	Birth: 120-150 Mat: M:350-410 Mat: F: 400-430 Max 594	36	2-10	4.1%	2?	>12?
Isurus oxyrinchus Shortfin mako	M: 3 F: 7-8 av. 5	Birth: 60-70 Mat: M:195 Mat: F:280 Max: 394	28	4-16	5.2%	2-3	12-18
Lamna nasus Porbeagle shark	4-8 F: 7.5	Birth: 60-75 Mat: M:165 F:152-225 Max: 300-365	30	1-5	?	1-3?	9-18?
Galeorhinus galeus Tope, school, or soupfin shark	F: 10-15 M: 8-10	Birth: 30-40 Mat: F:134-140 Mat: M:125-135 Max: 155-200	40-60	8-50 (mean=28)	3.3%	1-3	12

1 Most of the data presented here are from Compagno (1984) and Smith *et al*. in press, with updates for a small number of species.

Distribution		Habitat information		Fisheries pressure		References
cosmopolitan, wide-ranging, regional, country endemic, localized, restricted	pelagic, demersal	insular, oceanic, bathyal (>200m), coastal (shore-200m), reef, mangrove, estuarine	pupping/ nursery grounds (estuarine, near-/offshore)	Directed (high, some, low, none)	Incidental (high, some, low, none)	
wide-ranging, temperate waters	demersal	coastal	estuarine-nearshore	high	high	Compagno in press, Ebert 1990, Ebert 1989, Van Dykhuizen & Mollet 1992
cosmopolitan, temperate to subarctic waters	demersal	coastal	offshore	high	high	Fordham in press, Gauld 1979, Jensen 1965, Jones & Geen 1977, Ketchen 1975, Nammack *et al*. 1985, NOAA 1998, Saunders & McFarlane 1993
wide-ranging, warm temperate to tropical waters	demersal	bathyal	bathyal	high in some locations	high in some locations	Compagno & Cook in press
localized, cold to warm temperate waters	demersal	coastal	coastal	high	high	Cailliet in press, Cailliet *et al*.1992, Natanson & Cailliet 1986, 1990.
regional (Atlantic and E. Pacific)	demersal	coastal	nearshore	low	low	Castro 1997, Carrier 1991, Clark & von Schmidt 1965
cosmopolitan, warm temperate and tropical	pelagic	coastal-oceanic	?	low	low	Joung *et al*. 1996, Norman in press.
wide-ranging, temperate to sub-tropical	demersal	coastal	nearshore-estuarine	low	high	Branstetter & Musick 1994, Gilmore 1993, Gilmore *et al*. 1983, Goldman 1998, Pollard *et al*. 1996, Pollard & Smith in press. Sminkey 1996.
cosmopolitan, warm waters	pelagic	coastal-oceanic	inshore	high?	some?	Goldman in press.
wide-ranging, temperate to boreal waters	pelagic	coastal	offshore?	some	some	Fowler in press, Kunzlik 1988, Pauly 1978, Parker & Stott 1965, Sund 1943.
wide-ranging, temperate to boreal waters	pelagic	coastal-oceanic	probably coastal	low (high in some trophy fisheries)	low (high in beach netting areas)	Cailliet *et al*. 1985, Fergusson 1996, Fergusson *et al*. in press, Francis 1996, Uchida *et al*. 1996.
cosmopolitan, tropical, sub-tropical and temperate	pelagic	oceanic, sometimes coastal	probably coastal	high [in some recreational fisheries]	high	Cailliet & Mollet 1997, Cailliet *et al*. 1983, Cliff *et al*. 1990, Mollet *et al*. 1997, Pratt & Casey1983, Stevens in press.
wide-ranging demersal	pelagic and oceanic	coastal and oceanic	offshore	high	high	Aasen 1963, Ellis & Shackley 1995, Gauld 1989, Stevens in press.
wide-ranging sometimes pelagic	demersal, (but down to 800 m)	coastal and estuarine	nearshore	high	some	Capape & Mellinger 1988, Grant *et al*. 1979, Olsen 1954, Peres & Vooren 1991, Ripley 1946, Stevens in press, Walker *et al*. 1995.

Annex 2 continued

Scientific and common names	Age to maturity (years)	Size (cm TL) (at birth, maturity, and maximum)	Life span (years)	Litter size	Annual rate of population increase	Reproductive periodicity (years)	Gestation time (months)
Mustelus antarcticus Gummy shark	4-5	Birth; M:30-40 Mat: F:85 M:80 Max: 175	16	10-38 (mean=14)	12%	annually in W. Australia 2 year in Bass Strait	11-12
Mustelus henlei Brown smoothhound	2-3	Birth: 19-21 Mat: M:51-63 F:52-66 Max: 95	15	3-5	13.6%	1	10-11
Carcharhinus falciformis Silky shark	M:10 F:>12	Birth: 76-87 Mat: M:187-225 Mat: F:213-245 Max: 330	M:>20 F:>22	2-15	?	1-2	12
Carcharhinus leucas Bull shark	6-8 or 15	Birth: 56-81 Mat: 200 Max: 300-320	M: 16 F: 12-27	1-13	2.7%	?	10-11
Carcharhinus limbatus Blacktip shark	M: 4-5 F: 6-8	Birth:53-65 Mat: M:130 F:>155 Max: M:175 F:193	10-18	2-4 4-7	2.2-13.6% 5.6%	2	11-12
Carcharhinus longimanus Oceanic whitetip shark	4-5	Birth: 60-65 Mat: F: 180-200 M:175-195 Max: 310	22	1-14	6.9%	?	12
Carcharhinus melanopterus Blacktip reef shark (Eastern hemisphere)	?	Birth: 30-35 Mat: 95-110 Max: 140-180	?	2-4	?	1 or 2	8-9 or 10-11 or ?16
Carcharhinus obscurus Dusky shark	M: 19 F: 21	Birth: 80-100 Mat: F:280 Max: 365	40-50	3-14 (mean 607)	2.8% 2%	2 or 3	12 or 22-24
Carcharhinus plumbeus Sandbar shark	13-16 [29 in another study]	Birth: 60-65 Mat: M: 170 F:>180 Max> 239 (in USA)	25-35	8-13	2.2-11.9% 3.4%, or 5.2% if mat=29 years]	2	9-12
Galeocerdo cuvier Tiger shark	8-10	Birth: 59-90 Mat: M:226-290 F:250-350 Max:450- 600	50	10-80 av. 35	4.3%	probably 2 yrs	12-16
Glyphis sp. Borneo river shark	?	?	?	?	?	?	?
Negaprion brevirostris Lemon shark	11-13	Birth: 60 M: 224 (mat) Mat: M:224 F:239 Max: M:>279 F:>285	27	4-17	1.2%	?	?
Prionace glauca Blue shark	F:5-7 M:4-6	Birth: 35-50 Mat: M:180-218 Mat: F:180-220 Max: 383	20	40 av (4-135)	6.25%	females? males annually?	9-12
Rhizoprionodon terraenovae Atlantic sharpnose shark	3-4	Birth: 30-35 Mat: M:80-85 F:85-90 Max: 110	10	4-6 1-7	4.5% 8.8%	annual	10-12

Distribution: cosmopolitan, wide-ranging, regional, country endemic, localized, restricted	Distribution: pelagic, demersal	Habitat information: insular, oceanic, bathyal (>200m), coastal (shore-200m), reef, mangrove, estuarine, fresh	Habitat information: pupping/ nursery grounds (estuarine, near-/offshore)	Fisheries pressure: Directed (high, some, low, none)	Fisheries pressure: Incidental (high, some, low, none)	References
endemic (temperate Australia)	demersal	coastal	?	high	high?	Lenanton *et al*. 1990, Moulton *et al*. 1992, Walker 1996, 1983, 1994a, b, & in press.
localized	demersal	coastal	?	mod	mod	Yudin & Cailliet 1990.
wide-ranging in temperate and tropical waters	pelagic	coastal-oceanic	offshore	high	high	Bonfil 1990 & in press, Bonfil *et al*. 1993, Branstetter 1987b
wide-ranging in subtropical to tropical waters	pelagic	coastal into estuaries and freshwater	estuarine	high	high	Burgess *et al*. in press, Branstetter & Stiles 1987
cosmopolitan in warm-temperate to tropical waters	pelagic	coastal	estuarine	high	low	Branstetter 1987a, Burgess & Branstetter in press, Castro 1996, Dudley & Cliff 1993, Killam & Parsons 1989, Wintner & Cliff 1996.
cosmopolitan	pelagic	oceanic; insular	oceanic	high	high	Backus *et al*. 1956, Seki *et al*. (MS), Smale in press.
widespread	demersal	insular (reefs)	insular	high	high	Heupel in press, Last & Stevens 1994, Stevens 1984.
wide-ranging in sub-tropical and temperate oceans	coastal-pelagic	coastal	offshore in Australia inshore USA	high (in USA & Australia)	high	Branstetter & Burgess 1996, Camhi *et al*. in press, Cortés in press, Goldman 1998, Natanson *et al*. 1995,
wide-ranging tropical and temperate oceans	pelagic	coastal, oceanic	nearshore	high	some, moderate	Casey & Natanson 1992, Casey *et al*. 1985, Sminkey & Musick 1995, 1996, Musick in press.
cosmopolitan in tropical and subtropical waters	coastal-pelagic	coastal	wide-ranging, may enter estuarine areas	locally high	low	Branstetter *et al*. 1987, Clark & von Schmidt 1965, De Crosta *et al.* 1984, Randall 1992, Simpfendorfer in press, Sminkey 1996, Tester 1969.
restricted to rivers in Borneo?	localised	demersal	freshwater-estuarine	low	low-moderate (bycatch)	
regional	demersal	coastal, insular and reefs	nearshore	high	high	Brown & Gruber 1988, Sundstroem & Gruber in press.
cosmopolitan	pelagic	oceanic, sometimes coastal	offshore	low	high	Amorim 1992, Cailliet *et al*. 1983, Castro & Mejuto 1995, Hazin 1993, Nakano 1994, Pratt 1979, Stevens 1976 & in press, Tanaka *et al*. 1990
wide-ranging in warm temperate to tropical Atlantic	demersal	coastal	estuarine	high	high	Branstetter, 1987b, Cortés 1995, in press a, b, Parsons 1983, 1985,

Annex 2 continued

Scientific and common names	Age to maturity (years)	Size (cm TL) (at birth, maturity, and maximum)	Life span (years)	Litter size	Annual rate of population increase	Reproductive periodicity (years)	Gestation time (months)
Triaenodon obesus Whitetip reef shark	5 or 8-9	Birth: 52-60 Mat: 105 Max: 170	16-25	1-5 2-3	4.9%	?	>5?
Sphyrna lewini Scalloped hammerhead	M: 4-10 F: 4-15	Birth: 31-55 Mat: M:140-280 Mat: F:150-300 Max: 329-420	35	15-40 12-38	2.8%	?	9-12
Sphyrna tiburo Bonnethead shark	F: 2-3 M: 3	Birth: 35-40 Mat: M:68-85 F:80-85 Max: M:124 F:150	12	4-16	0.01-0.27	annual?	?
Pristis microdon Greattooth or freshwater sawfish	?	700 (max)	?	?	?	?	?
Pristis pectinata Smalltooth or wide sawfish	?	760 (max)	?	15-20	?	?	?
Rhynchobatus djiddensis Giant guitarfish	?	M: 110 (mat) > 300 (max)	?	?	?	?	?
Brazilian guitarfish *Rhinobatos horkelii*	F: 7-9 M: 5-6	Mat: 90-120	?	4-12	?	1	11-12
Bathyraja abyssicola Deepsea skate	?	M: 110 (mat)	?	? (eggs)	?	?	n/a
Raja (Raja) clavata Thornback skate or ray	9-12	M: 69 (mat) F: 72 (mat)	M: 36-43 F: 39-46	52 eggs /year	0 or less in North Sea	annual	n/a
Raja (Dipturus) binoculata Big skate	M: 8-11 F: 12	Birth: Mat: M:100-110 F:130 Max: 168-240	?	1-7 embryos per egg case	?	?	n/a
Raja batis Common skate	11	Birth: 21-22 Mat: M:125 Max: 254	50	40 eggs	?	annual?	n/a
Raja (Dipturus) rhina Longnose skate	M: 7-8 F: 8-10	Birth: Mat: M:60 F:>70 Max: 137	?	?	?	?	n/a
Bat ray *Myliobatis californica*	M:4, F:5	Birth 20 (DW) Mat: M:60 F:88 (DW) Max 180 (DW-disk width)	10M, 25F	2-5	?	1	~12
Himantura chaophraya Giant freshwater stingray or whipray	?	Birth: Mat: 100 (disk width) Max: 200 (disk width)	?	?	?	?	?

Distribution		Habitat information		Fisheries pressure		References
cosmopolitan, wide-ranging, regional, country endemic, localized, restricted	pelagic, demersal	insular, oceanic, bathyal (>200m), coastal (shore-200m), reef, mangrove, estuarine	pupping/ nursery grounds (estuarine, near-/offshore)	Directed (high, some, low, none)	Incidental (high, some, low, none)	
wide-ranging (in Indo-Pacific)	demersal	coastal	nearshore	some	high	Anderson & Ahmed 1993, Fourmanoir 1961, Last & Stevens 1994, Smale in press.
wide-ranging in warm temperate to tropical waters	pelagic	coastal-oceanic	nearshore	high	high	Branstetter 1987b, Kotas in press, Stevens & Lyle 1989.
regional	demersal	coastal and reefs	?	some	high	Carlson & Parsons 1997, Cortés in press, Cortés & Parsons 1996, Parsons 1993a, 1993b.
localized in tropics	demersal	freshwater	?	high	high	Compagno & Cook in press, Last & Stevens 1994.
wide-ranging (disjunct)	demersal	coastal and freshwater	?	high	high	Adams in press, Bigelow & Schroeder 1953.
wide-ranging in tropical waters	demersal	coastal	?	high	high	Simpfendorfer in press, Last & Stevens 1994.
regional	demersal	coastal	nearshore	high	high	Lessa 1982, Lessa *et al*. 1986, Lessa & Vooren in press.
regional	demersal	bathyal	?	none (too rare)	some	Cook *et al*. in press, Zorzi & Anderson 1988.
wide-ranging in temperate water	demersal	coastal	estuarine-nearshore	high	high	Brander & Palmer 1985, Capape 1977, Ellis & Shackley 1995, Ellis in press, Holden 1975, Holden & Vince 1973, Nottage & Perkins 1983, Ryland & Ajayi 1984.
Regional (NE Pacific)	demersal	coastal	nearshore and offshore	high	high	Ellis & Dulvey in press, Martin & Zorzi 1993, Zeiner & Wolf 1993, DeLacy & Chapman 1935, Hitz 1964.
regional, boreal to cool temperate (NE Atlantic)	demersal	coastal	?	high	high	Ellis & Walker in press, Du Buit 1972 & 1976, Brander 1981, Fahy 1991.
Regional (NE Pacific)	demersal	coastal	nearshore and offshore	high	high	Zeiner & Wolf 1993.
west coast USA	demersal	coastal	estuaries	some	some	Cailliet in press, Martin & Cailliet 1988 a & b.
localized	demersal	freshwater-estuarine	freshwater	some	some	Compagno & Cook in press, Last & Stevens 1994.

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