AQUATIC CONSERVATION: MARINE AND FRESHWATER ECOSYSTEMS
*Aquatic Conserv: Mar. Freshw. Ecosyst.* **18**: 459–482 (2008)
Published online 22 May 2008 in Wiley InterScience
(www.interscience.wiley.com) DOI: 10.1002/aqc.975

# *You can swim but you can't hide: the global status and conservation of oceanic pelagic sharks and rays*

NICHOLAS K. DULVY[a,*], JULIA K. BAUM[b], SHELLEY CLARKE[c], LEONARD J. V. COMPAGNO[d], ENRIC CORTÉS[e], ANDRÉS DOMINGO[f], SONJA FORDHAM[g], SARAH FOWLER[h], MALCOLM P. FRANCIS[i], CLAUDINE GIBSON[h], JIMMY MARTÍNEZ[j], JOHN A. MUSICK[k], ALEN SOLDO[l], JOHN D. STEVENS[m] and SARAH VALENTI[h]

[a] *Centre for Environment, Fisheries and Aquaculture Science, Lowestoft Laboratory, Lowestoft, NR33 0HT, UK* and *Department of Biological Sciences, Simon Fraser University, Burnaby, BC V5A 1S5, Canada*

[b] *Scripps Institution of Oceanography, University of California, San Diego, 9500 Gilman Drive, La Jolla, California 92093-0202, USA*

[c] *Division of Biology, Imperial College London, Silwood Park Campus, Manor House, Buckhurst Road, Ascot, Berkshire SL5 7PY, UK*

[d] *Shark Research Center, Iziko—South African Museum, P.O. Box 61, Cape Town, 8000 South Africa*

[e] *NOAA Fisheries Service, Panama City Laboratory, Panama City, FL 32408, USA*

[f] *Dirección Nacional de Recursos Acuáticos, Recursos Pelágicos, Constituyente 1497, CP 11200, Montevideo, Uruguay*

[g] *Ocean Conservancy and Shark Alliance, c/o Oceana, Rue Montoyer, 39 1000 Brussels, Belgium*

[h] *IUCN SSC Shark Specialist Group, Naturebureau International, 36 Kingfisher Court, Hambridge Road, Newbury, RG14 5SJ, UK*

[i] *National Institute of Water and Atmospheric Research, Private Bag 14901, Wellington, New Zealand*

[j] *Escuela de Pesca del Pacifico Oriental (EPESPO). Los Esteros, Avenida 102 y calle 124, P.O. Box 13053894, Manta, Ecuador*

[k] *Virginia Institute of Marine Science, Greate Road, Gloucester Point, VA 23062, USA*

[l] *Centre of Marine Studies, University of Split, Livanjska 5, 21000 Split, Croatia*

[m] *CSIRO Marine and Atmospheric Research, PO Box 1538, Hobart, Tasmania 7001, Australia*

All authors contributed equally to this work.

*Correspondence to: N. K. Dulvy, Department of Biological Sciences, Simon Fraser University, Burnaby, BC V5A 1S5, Canada. E-mail: nick_dulvy@sfu.ca

## ABSTRACT

1. Fishing spans all oceans and the impact on ocean predators such as sharks and rays is largely unknown. A lack of data and complicated jurisdictional issues present particular challenges for assessing and conserving high seas biodiversity. It is clear, however, that pelagic sharks and rays of the open ocean are subject to high and often unrestricted levels of mortality from bycatch and targeted fisheries for their meat and valuable fins.

2. These species exhibit a wide range of life-history characteristics, but many have relatively low productivity and consequently relatively high intrinsic vulnerability to over-exploitation. The IUCN — World Conservation Union Red List criteria were used to assess the global status of 21 oceanic pelagic shark and ray species.

3. Three-quarters (16) of these species are classified as Threatened or Near Threatened. Eleven species are globally threatened with higher risk of extinction: the giant devilray is Endangered, ten sharks are Vulnerable and a further five species are Near Threatened. Threat status depends on the interaction between the demographic resilience of the species and intensity of fisheries exploitation.

4. Most threatened species, like the shortfin mako shark, have low population increase rates and suffer high fishing mortality throughout their range. Species with a lower risk of extinction have either fast, resilient life histories (e.g. pelagic stingray) or are species with slow, less resilient life histories but subject to fisheries management (e.g. salmon shark).

5. Recommendations, including implementing and enforcing finning bans and catch limits, are made to guide effective conservation and management of these sharks and rays.


Received 26 November 2007; Revised 17 January 2008; Accepted 12 February 2008

KEY WORDS: biodiversity conservation; demography; elasmobranch; life histories; blue shark; white shark; porbeagle; thresher shark; tuna; billfish

## INTRODUCTION

The current rate of biodiversity loss is several orders of magnitude higher than the background historic extinction rate (Baillie *et al*., 2004; Mace *et al*., 2005). Much of the known species loss has occurred on land, and there have been few documented marine species extinctions to date (Carlton *et al*., 1999). However, the increasing scale of human exploitation of the seas, coupled with evidence of declines and population extinctions, may forewarn of increasing loss of coastal and oceanic biodiversity (Verity *et al*., 2002; Dulvy *et al*., 2003; Hilborn *et al*., 2003; Myers and Worm, 2005). The conservation and management of open-ocean biodiversity is generally hampered by two key issues. First, oceanic ecosystems lie far from land, making it difficult to monitor the consequences of human activities for biodiversity. Second, these species range primarily in the high seas outside countries' Exclusive Economic Zones (EEZ), beyond the remit and immediate concerns of national jurisdictions. Oceanic sharks and rays face additional threats associated with lack of management and low conservation priority.

Twenty-one oceanic pelagic shark and ray (Subclass Elasmobranchii) species range widely in the enormous habitat of the oceans' upper pelagic waters, largely beyond the continental margins of the world (Table 1). These species also are widely distributed, occurring in multiple oceans, with many found circumglobally (Compagno, 2001). In common with other shark and ray species, these oceanic pelagic elasmobranchs exhibit life history traits that confer on most a low intrinsic rate of population increase (Hoenig and Gruber, 1990; Smith *et al*., 1999; Cortés, 2000, 2002; Frisk *et al*., 2005). They mature late (average = 11, range = 2–21 years) and have long life spans (8–65 years). After a long gestation period (typically 9–18 months) they give live birth to few well-developed offspring with a relatively high probability of surviving through to adulthood (Table 2). The slow life-history characteristics and low population growth rates of sharks render them less able to withstand fishing mortality than the earlier-maturing,



DOI: 10.1002/aqc

shorter-lived bony (teleost) fishes with which they are frequently captured (Musick, 1999; Stevens *et al*., 2000; Schindler *et al*., 2002). There is, however, considerable intrinsic variation in demographic rates among species and populations of pelagic sharks and rays which has consequences for their relative response to exploitation and threatened status (Cortés, 2000).

Oceanic pelagic sharks and rays are threatened by over-exploitation in high seas fisheries, which is exacerbated for sharks by the high value and demand of their fins (Clarke *et al*., 2007). Many of these species are caught regularly as bycatch in widespread longline, purse seine, and gillnet fisheries targeting more productive tuna, swordfish and other billfish, as well as midwater trawl fisheries for small pelagic fish in boundary current systems (Baum *et al*., 2003; Zeeberg *et al*., 2006). Most shark species have valuable fins, which are traded internationally to meet the burgeoning demand for a delicacy 'shark fin soup'. This demand is driven by rapidly growing Asian economies (Rose, 1996; Clarke, 2004; Clarke *et al*., 2006a, b). The fins of sharks are generally worth more than their meat, which creates an economic incentive to retain the fins and discard the carcass at sea — a practice known as 'finning'. Of the species identified in the Hong Kong shark fin market ( ~45%), a large proportion ( ~70%) were pelagic sharks (Clarke *et al*., 2006a). The median number and biomass of sharks entering the shark fin trade each year have been estimated at 38 million individuals and 1.7 million mt, respectively (Clarke *et al*., 2006b). These figures suggest that shark catches may be 3-4 times as large as those recorded in the United Nations Food and Agriculture Organization (FAO) fisheries landings database (Clarke *et al*., 2006b). In the past, only a few oceanic pelagic shark species were targeted, primarily shortfin mako (*Isurus oxyrinchus*) and porbeagle (*Lamna nasus*), which have high-value meat. However, due to the high and growing demand for shark fins and

Table 1. Taxonomic list of all 21 oceanic pelagic sharks and rays considered in this paper and their global IUCN Red List status and the year of assessment

| Family | Species | English common name | Global Red List status[a] | Assessment year |
|---|---|---|---|---|
| Rhincodontidae | *Rhincodon typus* | Whale shark | VU A1bd + 2d | 2000 |
| Odontaspididae | *Odontaspis noronhai* | Bigeye sand tiger | DD | 2000 |
| Pseudocarchariidae | *Pseudocarcharias kamoharai* | Crocodile shark | NT | 2000 |
| Megachasmidae | *Megachasma pelagios* | Megamouth shark | DD | 2000 |
| Alopiidae | *Alopias pelagicus* | Pelagic thresher | VU A2d + 4d | 2008 |
| Alopiidae | *Alopias superciliosus* | Bigeye thresher | VU A2bd | 2008 |
| Alopiidae | *Alopias vulpinus* | Thresher shark | VU A2bd + 3bd + 4bd | 2008 |
| Cetorhinidae | *Cetorhinus maximus* | Basking shark | VU A1ad + 2d | 2000 |
| Lamnidae | *Carcharodon carcharias* | Great white shark | VU A1cd + 2cd | 2000 |
| Lamnidae | *Isurus oxyrinchus* | Shortfin mako | VU A2abd + 3bd + 4abd | 2008 |
| Lamnidae | *Isurus paucus* | Longfin mako | VU A2bd + 3d + 4bd | 2005 |
| Lamnidae | *Lamna ditropis* | Salmon shark | LC | 2008 |
| Lamnidae | *Lamna nasus* | Porbeagle shark | VU A2bd + 3d + 4bd | 2006 |
| Carcharhinidae | *Carcharhinus falciformis* | Silky shark | NT | 2008 |
| Carcharhinidae | *Carcharhinus longimanus* | Oceanic whitetip shark | VU A2ad + 3d + 4ad | 2006 |
| Carcharhinidae | *Prionace glauca* | Blue shark | NT | 2000 |
| Dasyatidae | *Pteroplatytrygon violacea* | Pelagic stingray | LC | 2008 |
| Mobulidae | *Manta birostris* | Manta ray | NT | 2006 |
| Mobulidae | *Mobula japanica* | Spinetail devilray | NT | 2005 |
| Mobulidae | *Mobula mobular* | Giant devilray | EN A4d | 2006 |
| Mobulidae | *Mobula tarapacana* | Chilean devilray | DD | 2006 |

[a]Species were categorized as EN — Endangered, VU — Vulnerable, NT — Near Threatened, LC — Least Concern and DD — Data Deficient.
In addition to the threat categories, the detailed criteria from the assessment are presented. Criteria A1–4 refer to different time scales of population decline (A1 — past and ongoing threat, A2 — past and threat ceased, A3 — future and A4 — past and future) and a–d refer to different forms of evidence for population decline (for further detail see IUCN, 2004a).



DOI: 10.1002/aqc

Table 2. Summary of biological parameters and demographic information for 21 oceanic pelagic sharks and rays collated from primary and secondary scientific literature

| Common name *Species* | Population | Sex | Size[a] at maturity (cm)[b] | Age at maturity (years)[b] | Longevity (years)[c] | Max size (cm)[c] | Size at birth (cm)[d] | Gestation period (months) | Reproductive cycle (years) | Average litter size[e] | Annual survivorship (age 0+)[f] | Annual survivorship (ages 1+)[f] | Generation time (years)[f] | Annual rate of increase[g] | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Whale shark *Rhincodon typus* | Global | F | > 800 | > 22 | — | ca 2000 | ca 55–60 | — | — | — | — | — | — | — | (Chen *et al*., 1996; Compagno *et al*., 2005; Joung *et al*., 1996; Kukuyev, 1996; Wintner, 2000; Wolfson, 1983) |
| | | M | > 600 | < 20 | — | — | — | — | — | — | — | — | — | — | |
| Bigeye sandtiger *Odontaspis noronhai* | Global | F | ca 325 | — | — | 326 | — | — | — | — | — | — | — | — | (Amorim *et al*., 2005; Compagno, 2001) |
| | | M | ca 225–300 | — | — | 367 | — | — | — | — | — | — | — | — | |
| Crocodile shark *Pseudocarcharias kamoharai* | SW Indian Ocean | F | 89–102 | — | — | 105 | 40–43 | — | — | 4 | — | — | — | — | (Bass *et al*., 1975; Compagno, 1984) |
| | | M | 74 | — | — | 98 | | — | — | — | — | — | — | — | |
| Megamouth shark *Megachasma pelagios* | Global | F | ca 500 | — | — | 709 | < 177 | — | — | — | — | — | — | — | (Compagno, 2000; Wang and Yang, 2005) |
| | | M | ca 400 | — | — | ca 550 | — | — | — | — | — | — | — | — | |
| Pelagic thresher shark *Alopias pelagicus* | NW Pacific Ocean | F | 282–292 | 8–9 | 16 | 375 | 158–190 | — | 1 | 2 | 0.77–0.87 | 0.77–0.90 | 13 | 0.033 | (Liu *et al*., 1999; 2006; Otake and Mizue, 1981) |
| | | M | 267–276 | 7–8 | 14 | 353 | — | — | — | — | — | — | — | — | |
| Bigeye thresher shark *Alopias superciliosus* | NW Pacific Ocean | F | 332–341 | 12–13 | 20 | 422 | 138–149 | 12 | 1 | 2 | 0.75–0.89 | 0.77–0.89 | 17 | 0.002 | (Chen *et al*., 1997; Liu *et al*., 1998) |
| | | M | 279–288 | 9–10 | 19 | 357 | — | — | — | — | — | — | — | — | |
| Common thresher shark *Alopias vulpinus* | NE Pacific Ocean | F | 315 | 3–4 | 15 | 573 | 117–155 | 9 | 1 | 4 | 0.35–0.83 | 0.56–0.93 | 8 | 0.254 | (Cailliet and Bedford, 1983; Hixon, 1979) |
| | | M | 333 | 4–5 | — | — | — | — | — | — | — | — | — | — | |
| Basking shark *Cetorhinus maximus* | Global | F | 700–800 | 5–18 | — | 1043 | 150 | 18 | — | 6 | — | — | — | — | (Cheeseman, 1981; Francis and Duffy, 2002; Kunzlik, 1988; Matthews, 1950; Matthews and Parker, 1950; Pauly, 1978; Pratt and Casey, 1990) |
| | | M | 700–800 | — | — | 900 | — | — | — | — | — | — | — | — | |
| Great white shark *Carcharodon carcharias* | Global | F | 450–500 | 18 | 25 | ca 700 | 120–150 | — | — | 8 | 0.63–0.90 | 0.71–0.96 | 22 | 0.051 | (Compagno, 2001; Francis, 1996; Malcolm *et al*., 2001; Mollet and Cailliet, 1996a, b) |
| | | M | 360–380 | 10 | – | 550 | | | | | | | | | |
| Shortfin mako shark *Isurus oxyrinchus* | NW Atlantic Ocean | F | 280–298 | 18–19 | 32 | 375 | 70–80 | 15–18 | 3 | 12.5 | 0.75–0.91 | 0.79–0.94 | 24 | 0.047 | (Campana *et al*., 2005; Mollet *et al*., 2000; Natanson *et al*., 2006; Pratt and Casey, 1983) |
| | | M | 201 | 8 | 29 | 298 | — | — | — | — | — | — | — | — | |
| | SW Pacific Ocean | F | 300–311 | 19–21 | 28 | 380 | 66 | 15–18 | 3 | 12.5 | 0.76–0.91 | 0.79–0.93 | 23 | 0.034 | (Bishop *et al*., 2006; Francis, 2007; Francis and Duffy, 2005) |
| | | M | 196–202 | 7–9 | 29 | 295 | — | — | — | — | — | — | — | — | |

Table 2 (*continued*)

| Common name *Species* | Population | Sex | Size[a] at maturity (cm)[b] | Age at maturity (years)[b] | Longevity (years)[c] | Max size (cm)[c] | Size at birth (cm)[d] | Gestation period (months) | Reproductive cycle (years) | Average litter size[e] | Annual survivorship (age 0+)[f] | Annual survivorship (ages 1+)[f] | Generation time (years)[f] | Annual rate of increase[g] | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Longfin mako shark *Isurus paucus* | NW Atlantic Ocean | F | 245 | — | — | 417 | 92–122 | — | — | 2–4 | — | — | — | — | (Compagno, 2001; Gilmore, 1983; Guitart-Manday, 1966) |
| | | M | — | — | — | — | — | — | — | — | — | — | — | — | |
| Salmon shark *Lamna ditropis* | NE Pacific Ocean | F | 205 | 6–9 | 20 | 261 | 84–96 | 9 | 2 | 4 | 0.59–0.82 | 0.67–0.91 | 13 | 0.081 | (Goldman, 2007; Goldman and Musick, 2006; Nagasawa, 1998; Tanaka, 1980) |
| | | M | 158 | 3–5 | 17 | 230 | — | — | — | — | — | — | — | — | |
| Porbeagle shark *Lamna nasus* | N Atlantic Ocean | F | 230–260 | 13 | 24 | 357 | 65–77 | 8–12+ | 1 | 4 | 0.81–0.91 | 0.82–0.93 | 18 | 0.081 | (Aasen, 1961; Campana *et al*., 2002; Francis *et al*., 2008; Natanson *et al*., 2002) |
| | | M | 180–215 | 8 | 25 | 295 | — | — | — | — | — | — | — | — | |
| | SW Pacific Ocean | F | 198–209 | 15–18 | ca 65 | 240 | 72–82 | 8–9 | 1 | 3.75 | 0.75–0.94 | 0.78–0.94 | 26 | 0.086 | (Francis *et al*., 2007; Francis and Duffy, 2005; Francis and Stevens, 2000) |
| | | M | 164–175 | 8–11 | ca 65 | 236 | — | — | — | — | — | — | — | — | |
| | Central Pacific | F | 193–200 | 6–7 | 13 | 286 | 65–81 | | | 6 | 0.52–0.77 | 0.64–0.90 | 10 | 0.058 | (Oshitani *et al*., 2003) |
| | Central Pacific | M | 180–187 | 5–6 | 8 | 222 | | | | | | | | | |
| Silky shark *Carcharhinus falciformis* | Gulf of Mexico | F | 225–245 | 7–12 | 22 | 308 | 70–76 | 12 | 2 | 11 | 0.70–0.86 | 0.75–0.90 | 16 | 0.067 | (Bonfil, 1990; Bonfil *et al*., 1993; Branstetter, 1987) |
| | Gulf of Mexico | M | 210–225 | 6–10 | 20 | 314 | — | — | — | — | — | — | — | — | |
| Oceanic whitetip shark *Carcharhinus longimanus* | Pacific & Atlantic Ocean | F | 175–200 | 4–7 | 17 | 272 | 63–77 | 12 | 2 | 5–7 | 0.66–0.82 | 0.72–0.92 | 11 | 0.110 | (Branstetter, 1990; Lessa *et al*., 1999; Seki *et al*., 1998; Stevens, 1984) |
| | | M | 175–190 | 4–7 | 14 | 251 | — | — | — | — | — | — | — | — | |
| Blue shark *Prionace glauca* | N Atlantic Ocean | F | 221 | 4–7 | 15 | 374 | 35–44 | 9–12 | 1–2 | 37 | 0.53–0.84 | 0.65–0.91 | 10 | 0.287 | (Castro and Mejuto, 1995; Pratt, 1979; Skomal, 1990; Skomal and Natanson, 2003; Stevens, 1975) |
| | | M | 215 | 4–6 | 16 | 340 | — | — | — | — | — | — | — | — | |
| **Pelagic rays** | | | | | | | | | | | | | | | |
| Pelagic stingray *Pteroplatytrygon violacea* | NE Pacific Ocean | F | 40–50 | ca 3 | ca 12 | 100 | 19 | 2–3 | ca 0.5 | 6 | 0.47–0.71 | 0.68–0.88 | 6 | 0.311 | (Mollet *et al*., 2002; Mollet, 2002; Neer, 2008) |
| | | M | 40–50 | ca 2 | ca 10 | 68 | — | — | — | — | — | — | — | — | |
| Manta ray *Manta birostris* | Global | F | 375–425 | — | 20 | 701 | 120–150 | 9–14 | 1–3 | 1 | — | — | — | — | (Marshall *et al*., 2006; White *et al*., 2006) |
| | | M | 325–400 | 6–8 | — | 408 | — | — | — | — | — | — | — | — | |
| Spinetail devilray *Mobula japanica* | Global | F | ca 207 | — | — | 310 | 70–85 | — | — | 1 | — | — | — | — | (Compagno and Last, 1999; Notarbartolo di Sciara, 1987; Paulin *et al*., 1982; White *et al*., 2006) |
| | | M | 198–205 | — | — | 240 | — | — | — | — | — | — | — | — | |

Table 2 (*continued*)

| Common name *Species* | Population | Sex | Size[a] at maturity (cm)[b] | Age at maturity (years)[b] | Longevity (years)[c] | Max size (cm)[c] | Size at birth (cm)[d] | Gestation period (months) | Reproductive cycle (years) | Average litter size[e] | Annual survivorship (age 0+)[f] | Annual survivorship (ages 1+)[f] | Generation time (years)[f] | Annual rate of increase[g] | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Giant devilray *Mobula mobular* | Mediterranean Ocean | F | — | — | — | 520 | 166 | — | — | 1 | — | — | — | — | (Notarbartolo di Sciara and Serena, 1988; Serena, 2000) |
| | | M | — | — | — | — | — | — | — | — | — | — | — | — | |
| Chilean devilray *Mobula tarapacana* | Pacific Ocean | F | 270–280 | — | — | 370 | >105 | — | — | 1 | — | — | — | — | (Compagno and Last, 1999; Notarbartolo di Sciara, 1987; White *et al.*, 2006) |
| | | M | 234–252 | — | — | 304 | — | — | — | — | — | — | — | — | |

[a] Size measurements refer to total length for shark and disc width for rays.
[b] Size or age at maturity was reported in the literature as the size or age at which maturity is first reached, the median size or age at maturity, or simply a range. The values presented (generally a range) may thus reflect different criteria for defining maturity or a range of estimates from different studies.
[c] Maximum age and size are the greatest reported values.
[d] Size at birth was generally reported as a range for both sexes combined.
[e] Litter size is given as the arithmetic mean.
[f] The probability of annual survival was reported separately for age-0 and age-1+ sharks to reflect higher mortality in the first year of life when animals are smaller and thus more vulnerable to predation. A range of estimates was reported corresponding to the lowest and highest values obtained from applying five methods based on predictive equations of life history traits (as described in Cortés, 2002).
[g] The annual rate of increase (r) and generation time (T, time required for the population to increase by $R_0$, the net reproductive rate) were obtained from an age-structured life table using the discrete form of the Euler equation based on a prebreeding survey and a yearly time step applied only to females, and using the maximum estimate of age-specific annual survivorship.

declines in traditional food fish, others such as the blue shark (*Prionace glauca*), are increasingly targeted for both meat and fins (Clarke *et al*., 2007; Hareide *et al*., 2007).

Despite this widespread exploitation, oceanic pelagic shark and ray catches have been poorly reported in fisheries records (Bonfil, 1994; Barker and Schluessel, 2005; Lack and Sant, 2006). This is due to the incidental nature of most catches of these species and their traditionally low value relative to the tuna and billfish with which they are typically caught. These factors have translated into these species having low priority for fisheries management. Although this situation has improved over the last decade in some countries, notably Australia, New Zealand and the USA, in general there are very few effective domestic or international regulations for reporting shark and ray catch and bycatch. Even when catches are reported they are usually not recorded to the species level. For example, only 15% of all shark catches reported to the FAO have been recorded by species (Lack and Sant, 2006). This lack of species-specific data poses a significant challenge to quantifying the impacts of exploitation on these species and may mask declines and local extinctions (Dulvy *et al*., 2000).

Here we present the first assessment of the global status of 21 oceanic pelagic shark and ray species using IUCN Red List Categories and Criteria. The threats to, challenges of, and opportunities for conserving these species are illustrated and management recommendations are given.

## METHODS

There are 30 oceanic pelagic species in total; however, this analysis is limited to only those species usually caught in high seas fisheries. This paper is based on an evaluation of the global threatened status of 21 oceanic pelagic sharks and rays occurring in the top 200 m of the ocean. The term pelagic refers to highly mobile species that are not closely associated with the sea bottom (Compagno, 2008). Truly oceanic species primarily inhabit ocean basins away from the submerged shelf edge of continental land masses. Some oceanic species enter waters over continental and insular shelves (shallower than about 200 m) to feed, breed, or partake in other activities, including social interactions (Compagno, 2008).

The global threatened status of oceanic pelagic sharks and rays has been assessed using the IUCN—World Conservation Union Red List Categories and Criteria (Mace, 1995; IUCN, 2004a). Threat assessments for all of the chondrichthyan fish (sharks, batoids and chimaeras) were conducted by the IUCN Shark Specialist Group (www.flmnh.ufl.edu/fish/organizations/ssg/ssg.htm), an international network of 200 members. The SSG will conclude its 10 year programme to complete Red List assessments for the world's ~1200 species of chondrichthyan fish at the end of 2007, for publication in 2008. This will be the first complete assessment of all members of a major marine taxonomic group, and will provide an important baseline for monitoring the global health of marine species and ecosystems (Butchart *et al*., 2006; Dulvy *et al*., 2006). The results will be published in the web-based IUCN Red List of Threatened Species™ (www.iucnredlist.org) which is widely recognized as the most comprehensive, scientifically based source of information on the global status of plant and animal species. IUCN Red List Categories and Criteria are applied to individual species assessments (which contain information on ecology and life history, distribution, habitat, threats, current population trends and conservation measures) to determine their relative threat of extinction (IUCN, 2001, 2004a). Species listed as Critically Endangered (CR), Endangered (EN) or Vulnerable (VU) are considered 'threatened'. Taxa that do not qualify for the threatened thresholds, but are either close to meeting or are likely to meet a threatened threshold in the near future are classified as Near Threatened (NT). Taxa evaluated to have a low risk of extinction are classified as Least Concern (LC). Also included within the Red List are taxa that cannot be evaluated because of insufficient knowledge, and are therefore assessed as Data Deficient (DD). This category does not necessarily mean that the species is not threatened, only that its risk of extinction cannot be assessed with the current available data (IUCN, 2006).

 
DOI: 10.1002/aqc

Table 3. Details of IUCN SSG's Red List workshops up to February 2007, including the FAO areas covered, workshop location, date, number of participants and number of countries represented

| Regional or thematic workshop | FAO areas | Location | Date | Participants | Countries |
|---|---|---|---|---|---|
| Australia and Oceania | 57, 71, 81 | Queensland, Australia | March, 2003 | 26 | 5 |
| South America | 41, 87 | Manaus, Brazil | June, 2003 | 26 | 9 |
| Subequatorial Africa | 47 | Durban, South Africa | September, 2003 | 28 | 9 |
| Mediterranean | 37 | San Marino | October, 2003 | 30 | 14 |
| North-west and Central America | 21, 31, 77 | Florida, USA | June, 2004 | 55 | 14 |
| North-east Atlantic | 27 | Peterborough, UK | February, 2006 | 24 | 11 |
| West Africa | 34 | Dakar, Senegal | June, 2006 | 24 | 14 |
| Deep sea Chondrichthyans | N/A | New Zealand | November, 2003 | 36 | 14 |
| Batoids | N/A | Cape Town, South Africa | September, 2004 | 30 | 15 |
| Pelagics | N/A | Abingdon, UK | February, 2007 | 15 | 11 |

The SSG is the IUCN's Red List Authority for chondrichthyan assessments and considers full consultation with its membership to be essential for the preparation of accurate assessments (Fowler, 1996). In recent years the SSG has undertaken most of its Red Listing work through a series of regional workshops which have facilitated detailed discussions and the pooling of resources and regional expertise. As of February 2007, the SSG had conducted IUCN Red List Assessments at seven region-specific and two habitat or taxon-specific workshops (Table 3). Once draft assessments have been produced and consensus achieved at the workshops, a summary of the assessment is provided to the entire SSG membership for comment. This process of consultation has led to consensus being reached on each Red List assessment before it is submitted to the IUCN Red List and ensures consistency across assessments (Cavanagh *et al.*, 2003; Cavanagh and Gibson, 2007). Synthesizing the global status of pelagic sharks required input from experts from all regions. Therefore in February 2007, the SSG held its third thematic workshop to complete Red List assessment documentation and to determine the global threatened status of pelagic species that occur across multiple ocean regions. This workshop was convened near Oxford, UK, and was attended by the 15 co-authors of this paper. Overall, however, the pelagic species assessments presented here result from the work of 62 experts from 26 countries. This paper was based on, and summarizes, the outcomes of the assessments that were completed before the writing of this manuscript. Full details of each species assessment will be published both as an IUCN Shark Specialist Group report available from the IUCN SSG website and on the IUCN Red List website (www.iucnredlist.org).

## RESULTS

Eleven oceanic pelagic species were assessed as globally threatened (one Endangered, 10 Vulnerable) and five as Near Threatened (Figure 1(a); Table 1). Two species were categorized as Least Concern; the remaining three were Data Deficient. The proportion of oceanic pelagic sharks and rays that are threatened (52%) is considerably higher than the proportion of all chondrichthyans that are threatened (21.3%). To date, of the 591 chondrichthyans assessed globally 126 species are considered threatened and 107 species (18%) are Near Threatened (Figure 1b). All of the threatened species were listed on the basis of population declines over 10 years or three generation spans, whichever is greater. Some population reductions were observed, estimated, inferred or suspected using direct observation (e.g. basking shark, (*Cetorhinus maximus*)), an appropriate index (typically standardized catch per unit effort (CPUE) estimated from fishing vessels) or actual or potential levels of exploitation (Table 1). Without exception, fishing is the main activity threatening oceanic pelagic sharks and rays.

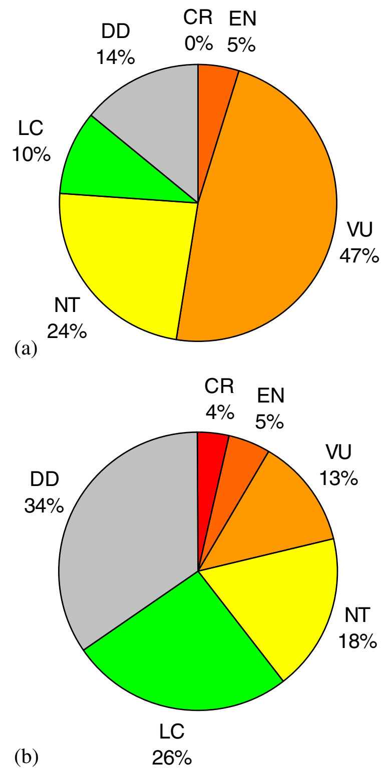


Figure 1. Percentage of (a) oceanic pelagic elasmobranchs ($n=21$) and (b) globally assessed chondrichthyan fishes ($n=591$) within each IUCN Red List category in 2007. Of the globally assessed chondrichthyans 126 (21.3%) are threatened; comprised of 22 (3.7%) Critically Endangered, 29 (4.9%) Endangered and 75 (12.7%) Vulnerable species.

The giant devilray (*Mobula mobular*) is currently the only globally Endangered oceanic pelagic elasmobranch (Table 1). This planktivorous ray is highly vulnerable to capture and over-exploitation by fisheries because of its life-history characteristics: it has large body size with a wingspan up to 5 m and gives birth to a single pup with unknown breeding frequency (i.e. annually or only biennially) (Notarbartolo di Sciara, 1987). This species has a relatively small geographic range compared with most other oceanic pelagic species, it is found only in the Mediterranean Sea and adjacent North Atlantic waters of southern Europe and Northwest Africa (Notarbartolo di Sciara, 2005; Cavanagh and Gibson, 2007). It is known to suffer high mortality from bycatch in the intensive pelagic longlines, driftnets, purse seines and traps targeting tuna and swordfish in the Mediterranean Sea (Muñoz-Chapuli *et al*., 1993; Cavanagh and Gibson, 2007).

The threat status of oceanic pelagic sharks and rays is highly dependent on the interaction between the intrinsic demographic capacity to withstand fishing mortality and the intensity and scale of fishing pressure (Figure 3). Of the species assessed, blue shark and pelagic stingray (*Pteroplatytrygon violacea*) have the highest annual rates of population increase–more than three times greater than the other species (29 and 31% $yr^{-1}$; Table 2, Figure 2).

Found throughout the world's oceans, the blue shark is (or was) arguably the most widespread and abundant chondrichthyan fish and is the most frequently caught shark species (Bonfil, 1994; ICCAT, 2005; Hareide *et al*., 2007; Rogan and Mackey, 2007). While not considered by traders to be the most sought after of fins, blue shark fins are the most prevalent on the Hong Kong shark fin market (Clarke *et al*., 2006a).



DOI: 10.1002/aqc

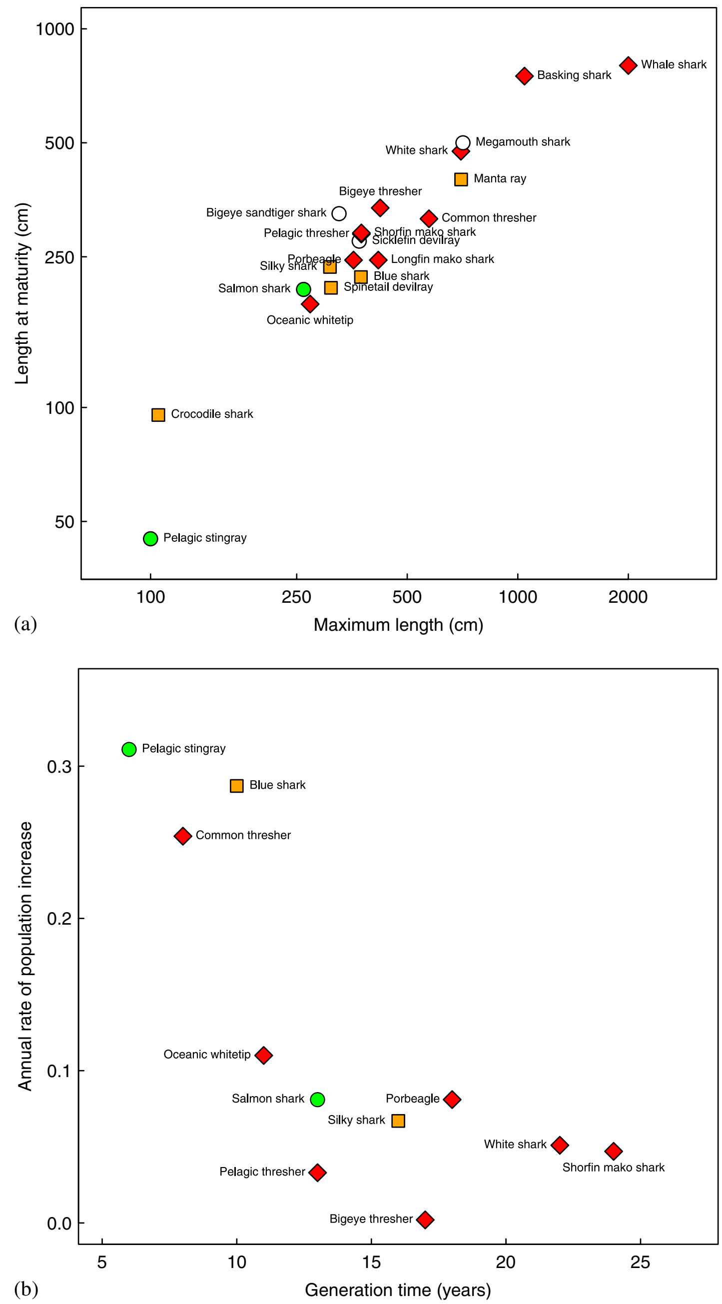


Figure 2. Life histories, demography and IUCN Red List status of oceanic pelagic sharks and rays. (a) Maximum length and length at maturity for 20 of the 21 species, the Endangered giant devilray was excluded as length at maturity is not known. Length is reported as total length for sharks and disc width for rays. Note that the pelagic thresher shark and shortfin mako shark data points overlap. (b) Generation time and the annual rate of population increase for 11 species. The data are average values from Table 2. The shape and colour of each point represents global IUCN Red List status: Threatened — red diamond, Near Threatened – orange square, Least Concern — green circle and Data Deficient — white circle.



DOI: 10.1002/aqc

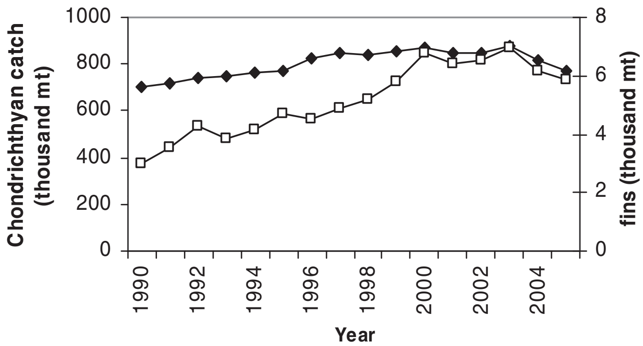


Figure 3. FAO capture production (landings) for all chondrichthyan catches (◆, left axis) and adjusted Hong Kong imports of shark fin (□, right axis), 1990-2005 (FAO, 2007; HKSARG, 2007).

Blue shark fins comprise at least 17% of the overall market, and an estimated 10.7 million individuals (0.36 million tonnes) are killed for the global fin trade each year (Clarke *et al*., 2006a, b). Despite being one of the best-studied of the world's elasmobranchs, assessment of the global status of the blue shark was hindered by its wide geographic range throughout the world's oceans and by the paucity and/or poor quality of demographic and catch data (ICCAT, 2005; Aires-Da-Silva and Gallucci, 2007; Hareide *et al*., 2007; Pilling *et al*., 2008). Official FAO statistics underestimate the true magnitude of catches: landings estimated from blue shark fin exports from the Atlantic Ocean alone are known to greatly exceed the reported catches from this area (ICCAT, 2005; Campana *et al*., 2006; Pilling *et al*., 2008). Demographic models, catch-rate analysis, age-structured models, food web and ecosystem models have been applied or attempted for blue sharks, mainly in the North Atlantic and North and Central Pacific, and these yield a conflicting picture of blue shark sustainability (West *et al*., 2004). Different catch-rate analyses generate diverging trends even for the same ocean: the North-west Atlantic data suggest significant declines in abundance (Simpfendorfer *et al*., 2002; Baum *et al*., 2003), while those for international waters of the North Atlantic suggest little change (Nakano, 1998; Matsunaga *et al*., 2001). Increasing fin prices, further depletion of less-productive sharks and lack of management (particularly on the high seas) will lead to greater pressure on blue shark stocks (Clarke *et al*., 2007). In the past decade high seas fleets (especially Spanish and other European fleets) in the Atlantic, Pacific, and Indian Oceans have also increasingly targeted blue sharks for their previously low-valued meat (Mejuto *et al*., 2006a, b; Hareide *et al*., 2007). Given the current state of knowledge it is difficult to determine the status of global blue shark stocks with a high degree of confidence, but it was evaluated as Near Threatened.

Only two species were categorized as Least Concern; the pelagic stingray and salmon shark (*Lamna ditropis*). There are contrasting reasons for the Least Concern classifications: the pelagic stingray's productive life-history should allow it to withstand relatively high fishing mortality, whereas the salmon shark is now subject to reduced fishing pressure on the high seas and management measures in the small part of its range where it is fished (Figure 2). The pelagic stingray is frequently caught by tuna and swordfish longliners (Mollet, 2002; Domingo *et al*., 2005; Forselledo *et al*., in press; Ribeiro-Prado and Amorim, in press) and to a lesser degree in pelagic gillnet and demersal trawl fisheries (Hemida *et al*., 2003). It has little commercial value and is usually discarded, but chances of survival are low. The jaws are often damaged during hook removal and in an effort to avoid being stung fishermen may smash the rays against the rail (Domingo *et al*., 2005). The pelagic stingray is one of the most productive of the live-bearing elasmobranchs and therefore more resilient to fishing pressure than most sharks and rays. In captivity it produces two litters of 1–13 pups each year resulting in an annual rate of increase of $\sim 31\%\ yr^{-1}$ (Table 2).



DOI: 10.1002/aqc

In contrast to the pelagic stingray, the salmon shark has low productivity with an annual rate of increase of $\sim 8\%$ $yr^{-1}$ and potentially low capacity to withstand fishing mortality (Table 2, Figure 2). From the 1950s and 1960s salmon sharks were taken in relatively large numbers (105 000–155 000 individuals $yr^{-1}$) in open ocean gillnet fisheries for Pacific salmon (*Oncorhynchus* spp.) and flying squid (*Ommastrephes* spp.) mostly by Canadian, Japanese, and Russian vessels (Robinson and Jamieson, 1984; Blagoderov, 1994). Salmon shark populations now appear to be rebuilding after cessation of these fisheries, suggesting that there have been significant declines in fishing mortality (Nagasawa *et al*., 2002). There is currently a small directed commercial fishery for salmon sharks in the North-west Pacific, and in the North-east Pacific directed catch is limited to a tightly controlled recreational fishery (Goldman and Musick, 2008).

The Least Concern status of the salmon shark contrasts with the Vulnerable listing of its sister species — the porbeagle shark. These two species have similar demography with the porbeagle perhaps being slightly more resilient (Stevens, 1999). The higher threat status of the porbeagle is a result of intense fisheries in the North Atlantic and Mediterranean Sea since the early 1960s (Campana *et al*., 2002; Cavanagh and Gibson, 2007). Over-exploitation and collapse of porbeagle populations in the North-east Atlantic in the 1960s led to intensive directed and largely unregulated fishing in the North-west Atlantic, where most of the virgin biomass was removed in just six years. Porbeagles continued to be taken as bycatch in the Mediterranean and targeted in the North-east Atlantic even from depleted populations, whereas the North-west Atlantic population was able to begin rebuilding after fisheries collapsed. In the 1990s, renewed target fishing in the North-west Atlantic led to another population decline to 11–17% of virgin biomass (Campana *et al*., 2002). Age- and sex-structured life-history models project that this population will most likely require 70–100 years to recover to maximum sustainable yield [$B_{MSY}$] (Gibson and Campana, 2005). Little is known of porbeagle shark population trends in the remainder of its range (i.e. the Southern Hemisphere), where they are also taken primarily as bycatch in the pelagic and demersal longline fisheries. However, the even slower growth rates and greater longevity of this stock (Francis *et al*., 2007) indicate that it is biologically more vulnerable to over-exploitation than the depleted North Atlantic stocks.

The combination of very low capacity to withstand fishing mortality and intense exploitation is shared by other species. For some species, regional variation in the intensity of fishing mortality is an important factor determining their global threatened status. The shortfin mako shark, for example, is considered Vulnerable globally but is classified as Critically Endangered in the Mediterranean Sea and Near Threatened in the North-east Pacific. Like porbeagles, shortfin makos are sought for both their meat and fins; thus unlike many other oceanic pelagic sharks, they are frequently targeted by the large longline fleets in the Atlantic, Pacific and Indian Oceans. The shortfin mako comprises up to $\sim 7\%$ of total catches (weight) in the Atlantic swordfish fishery and $\sim 10\%$ (weight) of all North Atlantic shark catches (Mejuto *et al*., 2006a, b; Hareide *et al*., 2007). This species is also a highly-prized recreational gamefish, particularly in the North-west Atlantic. Major declines in shortfin mako abundance have occurred, notably in the eastern Mediterranean Sea where they are now rarely seen. In the North Atlantic Ocean, population declines of up to 70% have been documented (ICCAT, 2005). In the North-east Pacific, the combination of domestic management of the US swordfish fishery, the lack of a target fishery for shortfin makos, and the absence of adult makos from the region, appears to have limited the effect of fishing on the population in this area, although its exact status is uncertain (Taylor and Bedford, 2001).

For many oceanic species, there is major regional variation in the quality and quantity of data available for assessment. The global classification of some of these species reflects a balance between higher threat categories in 'data-rich' regions, and lower threat or Data Deficient classification in 'data-poor' regions where fisheries impacts are suspected but are unquantifiable. For example, the oceanic whitetip (*Carcharhinus longimanus*) and the bigeye thresher (*Alopias superciliosus*) shark are regionally assessed as Critically Endangered and Endangered, respectively, in the North-west and Western Central Atlantic Ocean, but Vulnerable globally. Similarly, the silky shark (*Carcharhinus falciformis*) is regionally assessed



DOI: 10.1002/aqc

as Vulnerable in the South-east and Central Pacific as well as in the North-west and Western Central Atlantic, yet Near Threatened globally. These three species are taken incidentally in fisheries worldwide and, along with blue shark, other thresher sharks (*Alopias* spp.) and hammerhead sharks (*Sphyrna* spp.), make-up the bulk of the fins sold in the global shark fin trade (Clarke *et al*., 2006b). Their status requires careful monitoring and these species might be upgraded to a higher threat category when more data and knowledge become available from other regions.

The white shark (*Carcharodon carcharias*) is one of the largest, most widespread apex ocean predators, yet it is one of the least demographically resilient species. Despite its almost global distribution, this species is extremely rarely recorded in high seas fisheries (Springer, 1963; Beerkircher *et al*., 2004; Baum *et al*., 2005), although small numbers move inshore seasonally or year-round to aggregate in a few coastal regions or islands (Goldman and Anderson, 1999; Bonfil *et al*., 2005; Domeier and Nasby-Lucas, 2007). Where white shark populations go unprotected, their iconic status and high value jaws and fins mean that they are subject to exploitation. This includes target recreational and trophy fisheries, beach meshing operations (although in South Africa all sharks retrieved alive are released) and possible positive or negative disturbance by non-consumptive ecotourism operations. White shark bycatch in high seas fisheries is likely to be finned unless legal protection or finning prohibitions are enforced.

The white shark was listed as globally Vulnerable (Table 1). This species is afforded the highest level of protection of any elasmobranch and in the absence of this protection the threatened status could be worse. Indeed this species is listed as Endangered in the Mediterranean Sea (Cavanagh and Gibson, 2007). The white shark is listed on the appendices of a range of regional and international conventions (UNCLOS, CITES, CMS, Barcelona and Bern treaties; Appendix 1) as well as being protected under fisheries or biodiversity conservation legislation of a growing number of States.

## DISCUSSION

Despite perceptions to the contrary, wide-ranging highly migratory marine fishes can be threatened. Globally, three-quarters (16 of 21) of oceanic pelagic sharks and rays have an elevated risk of extinction due to overfishing, based on this analysis (Figure 1(a)). The proportion of threatened oceanic pelagic elasmobranchs (52%) is more than double that of all assessed chondrichthyans (21%). This reflects the widespread intense effort of open ocean fisheries for highly-valued large pelagic fishes (primarily billfish and tuna), the lack of limits on pelagic shark catches, and the rising value of shark fins and meat. Fisheries have rapidly spread across the world's oceans over the last 50 years and it is increasingly likely that there are no more unexploited open ocean areas (Myers and Worm, 2003; Roberts, 2007). High seas shark fishing continues unabated because of the relatively high productivity of the primary target species (Schindler *et al*., 2002; Sibert *et al*., 2006) and the limited interest in managing sharks (Lack and Sant, 2006).

Sharks are among the top predators in ocean ecosystems and continued depletion of their populations through overfishing could also have cascading effects for high seas biodiversity (Stevens *et al*., 2000; Kitchell *et al*., 2002; Ward and Myers, 2005; Myers *et al*., 2007). ECOSIM models of the Venezuelan shelf, the Alaska Gyre and the French Frigate shoals in Hawaii suggest the removal of sharks results in changes in the abundance of some prey species (Stevens *et al*., 2000). Similarly, the proliferation of cownose rays (*Rhinoptera bonasus*) in coastal North-west Atlantic waters may stem primarily from over-exploitation of the great sharks (Myers *et al*., 2007). However, ECOSIM models of the open-ocean Central North Pacific ecosystem, which is more relevant to this study, suggest oceanic pelagic sharks do not have a keystone role because of their relatively low consumption rates, low production-to-biomass ratios and a wide range of prey types consumed compared with tuna and billfish (Kitchell *et al*., 2002). While the over-exploitation of sharks and rays may have minor ecosystem effects in oceanic pelagic systems, the intrinsic biodiversity value



DOI: 10.1002/aqc

and long evolutionary history of these species provides strong argument for appropriate management and conservation (Kitchell *et al.*, 2002).

Though not considered in detail here, semi-oceanic pelagic sharks may face similar or greater threats. Some species have valuable fins and they suffer considerable fishing mortality both in the oceanic and shelf edge habitats from commercial and artisanal pelagic fishing fleets using surface gillnets and longlines. The semi-oceanic hammerheads (*Sphyrna* spp.) are the second most commonly traded shark fins. All species together comprise at least 4–5% of the fins in the Hong Kong market representing an annual catch of between 1.3 and 2.7 million individuals (49 000–90 000 mt) (Clarke *et al.*, 2006a, b). Although hammerheads are moderately productive, they are estimated to have suffered considerable population declines of up to an order of magnitude since the mid-1970s in the North-west Atlantic; one of the few areas where data are available to assess their status (Baum *et al.*, 2003; Myers *et al.*, 2007). One hammerhead species, the scalloped hammerhead (*Sphyrna lewini*), was categorized as globally Endangered. Like many fully oceanic species little is known of the biology, fisheries and status of many semi-oceanic sharks. For example the bignose shark (*Carcharhinus altimus*) was categorized as Data Deficient globally as it is presumably misidentified and not reported worldwide. It shares similar life-history characteristics with its close relative, the sandbar shark (*Carcharhinus plumbeus*), which has been assessed as Vulnerable globally.

The high value of shark fins, coupled with poor catch documentation and the lack of international regulation of catches, can easily lead to over-exploitation of oceanic pelagic sharks (Clarke *et al.*, 2007). One such signal may be found in a comparison between annual chondrichthyan (sharks, skates, rays and chimaeras) catches reported to FAO and shark fin imports reported by Hong Kong (Figure 3). The rate of increase in the amount of fins traded was higher than the rate of increase of reported catches until 2000. These data suggest that year-by-year fisheries began more fully utilizing the fins on the sharks they caught, as was documented in the Hawaiian longline fishery (Ito and Machado, 1999). However, in the six years following 2000, the trends in the shark fin trade very closely parallel trends in catches suggesting that all sharks' fins were being utilized already and the only way traders could obtain more fins would be if catches increased. The reasons for the observed decline in global catches since 2000, e.g. over-exploitation of sharks, a reduction in fishing effort, or simply a delay in reporting catches to FAO, are unknown. Nevertheless, the downturn in catches in combination with similar trends in the fin trade, despite indications that demand for fins is growing (Clarke *et al.*, 2007), calls for urgent consideration of effective fisheries management measures.

## MANAGEMENT ISSUES AND POSSIBLE SOLUTIONS

Oceanic pelagic elasmobranch assessment and management is hindered by a dearth of species-specific catch data from high seas fisheries, and a complete lack of information on stock status in major parts of the species' ranges (including the entire Indo-Pacific Ocean). Both fishery and biological data are needed to assess the status of pelagic and other shark populations (Table 4). Basic catch and effort data of fleets catching sharks are often of poor quality because of non- or misreporting, particularly when sharks are taken as bycatch. A huge unreported catch (fleets not reporting catch and illegal unreported unregulated [IUU] fishing) of pelagic sharks is evident from shark trade analysis (ICCAT, 2005; Clarke *et al.*, 2006a, b). In addition, many countries do not make their data available for the assessment process.

The development of fisheries and threat assessments and the provision of management advice are hampered by considerable uncertainty, even where data are available. There are statistical frameworks that allow the incorporation of different sources of uncertainty and provide probabilistic statements about the consequences of alternative management actions (Cortés, 2002; Peterman, 2004; Kell *et al.*, 2007). However, data quantity and quality are still the main impediments to assessment of pelagic shark stocks, and hence the development of management advice (Pilling *et al.*, 2008). Where a large body of information



DOI: 10.1002/aqc

Table 4. Proposed management actions that would contribute to rebuilding threatened populations of oceanic pelagic elasmobranchs and sustaining associated fisheries

| We recommend fishing nations and Regional Fisheries Management Organizations: |
|---|
| I. implement, as a matter of priority, existing scientific advice for preventing overfishing, or to recover, pelagic shark populations (e.g. ICCAT Scientific Committee recommendation to reduce fishing mortality on North Atlantic shortfin mako sharks); |
| II. draft and implement Plans of Action pursuant to the IPOA-Sharks which include, wherever possible, binding, science-based management measures for pelagic sharks; |
| III. significantly improve observer coverage, monitoring, and enforcement in fisheries taking pelagic sharks; |
| IV. require the collection and accessibility of species-specific shark fisheries data; |
| V. conduct stock assessments for pelagic elasmobranchs; |
| VI. implement pelagic shark catch limits, ensuring these are precautionary where sustainable catches are scientifically uncertain; |
| VII. strengthen finning bans by requiring sharks to be landed with fins attached. Until then, ensure fin-to-carcass ratios do not exceed 5% of dressed weight (or 2% of whole weight) and standardize Regional Fisheries Management Organizations finning bans to specify ratios apply to dressed rather than whole weight; |
| VIII. promote research and gear modifications aimed at mitigating elasmobranch bycatch and discard mortality; and |
| IX. commence programmes to reduce and eventually eliminate overcapacity and associated subsidies in pelagic fisheries. |

| We recommend country governments: |
|---|
| I. ensure active membership in CITES, CMS, Regional Fisheries Management Organizations and other relevant international agreements; |
| II. adopt bilateral fishery management agreements for shared, pelagic elasmobranch stocks; |
| III. propose and work to secure pelagic shark management at Regional Fisheries Management Organizations; |
| IV. ensure full implementation and enforcement of CITES shark listings based on solid non-detriment findings, if trade in listed species is allowed; |
| V. collaborate on regional agreements for CMS-listed shark species; |
| VI. promote and support the advice of the CMS Scientific Council and the CITES Animals Committee with respect to sharks; |
| VII. propose and support the listing of additional threatened pelagic shark species under CMS and CITES; and |
| VIII. develop and promote options for new international and global conservation agreements for migratory sharks. |

is available, for example for the blue shark, there are considerable difficulties reconciling the different spatial scales and relevance of the wide range of ecological and fisheries information to produce a coherent picture of fisheries or threat status. In particular, standardisation of catch rates for species, like the blue shark, is a major problem.

The boundaries of pelagic shark populations are difficult to define and are likely to span across more than one region. The available data from all regions were used to produce a global assessment of extinction risk for each species. However, in some cases it was considered necessary to produce regional assessments where fisheries are well-monitored, and population data are available, in order to highlight documented population trends. So, while regional assessments are available for some species considered here, little ecological or fisheries information were available for the Indian Ocean, and to a lesser degree, the South Atlantic Ocean. As better data become available for these data-poor regions, higher global threat categorizations for some species may be warranted.

Oceanic pelagic shark and ray populations remain a very low priority for fisheries management and are therefore at risk of further depletion, despite increased awareness of and concern for their conservation status. The 1999 FAO International Plan of Action for the Conservation and Management of Sharks (IPOA–Sharks) called on all fishing nations and Regional Fishery Management Organizations (RFMOs) to assess shark populations and prepare National and Regional Shark Plans by 2001 (FAO, 2000). The IPOA is, however, wholly voluntary and progress toward its implementation has been slow: insufficient political



DOI: 10.1002/aqc

will among these entities and their members is believed to be the largest obstacle to improving the status of pelagic sharks. No RFMOs have implemented Plans of Actions for Sharks — the only regional Action Plan published (for the Mediterranean) was developed under a UN Regional Seas Environment Programme (Anonymous, 2003; Camhi *et al*., 2008).

Finning bans, which prohibit the retention of shark fins on board vessels without the corresponding carcasses, are the most widely implemented shark management measure. At present, finning bans have been implemented by 19 countries and the European Union (EU), as well as by nine RFMOs, including the tuna commissions in the Atlantic (ICCAT), Eastern Pacific (IATTC), and Indian (IOTC) Ocean (Camhi *et al*., 2008). Most countries and RFMOs use a fin-to-carcass weight ratio as a means to ensure compliance with finning bans, although such ratios are difficult and costly to enforce (Hareide *et al*., 2007). Moreover, ratios vary between fleets depending upon cutting practices. Whereas the upper limit ratio for mixed US Atlantic shark fisheries is approximately 2% live weight, ratios of up to 5% fin to live carcass weight can be obtained when whole caudal fins are retained and crude cuts leave flesh attached to fins (Hareide *et al*., 2007). Such high ratios (e.g. 5%), like that adopted in the EU, and replicated at the tuna commissions, create loopholes that potentially enable fishermen to fin sharks without exceeding the ratio limit (IUCN, 2004b). A requirement that sharks be landed with their fins attached to their bodies, as used in parts of Central America and Australia and proposed for the US Atlantic, would allow for better effectiveness, enforcement and data collection (IUCN, 2004b; Hareide *et al*., 2007).

Finning bans should curb mortality and reduce waste, but these alone are insufficient to secure effective conservation: enforced catch limits are also required (Table 4). As of 2007, only about 22 nations and the EU have imposed any catch limits for oceanic elasmobranchs within their waters. In most cases, including the EU, such action involves protection for just one or two species listed on biodiversity conservation legislation (primarily whale, white and/or basking sharks). Australia, Canada, New Zealand, Papua New Guinea, South Africa and the USA have implemented domestic fishing limits (primarily quotas) for pelagic sharks, while Republic of the Congo, Ecuador, Egypt, Israel and Palau prohibit targeted shark fishing (Camhi *et al*., 2008). Enforcement of these prohibitions can be challenging, for example, shark fishing and finning continues illegally within the Galapagos Marine Reserve (Camhi, 1995; Anonymous, 2007). On the high seas, no catch limits for shark have been established to date by any RFMOs. For the most part, RFMOs remain focused on more commercially-valued species such as billfish or tuna. However, those organizations with a mandate to manage tuna and billfish are most relevant to pelagic sharks, based on catch composition and obligations to address bycatch issues. When RFMOs have considered their remit for shark management, they have focused on calls for more data rather than implementation of catch limits (e.g. ICCAT, 2007).

Regional and global wildlife conservation agreements may offer alternative routes to RFMOs for pelagic shark and ray conservation. These include regional treaties such as the Barcelona and Bern Conventions and International treaties such as the Convention on International Trade in Endangered Species (CITES) and the Convention on Migratory Species (CMS) (Table 4). Ideally, measures under these instruments, which seek to promote sustainable management for listed species, should be applied in conjunction with effective fisheries management measures. The giant devilray, white shark and basking shark are listed on Annex II 'List of endangered or threatened species' of the Barcelona Convention and Appendix II 'Strictly protected fauna species' of the Bern Convention. The Barcelona Convention requires Parties to ensure maximum protection and aid the recovery of listed species; however these listings are implemented in Malta and Croatia only (Cavanagh and Gibson, 2007). Three oceanic pelagic species (shortfin mako, porbeagle and blue shark) are listed under Annex III of both Conventions, which permit a certain level of exploitation if population levels allow (Bern) or require exploitation to be regulated (Barcelona); however these regulations have yet to be implemented (Serena, 2005).

Three oceanic pelagic sharks are listed on CITES Appendix II (whale and basking shark in 2002, white shark in 2004) with an aim to limit international trade to sustainable levels through a permitting system. A



DOI: 10.1002/aqc

Shark Working Group of the CITES Animals Committee provides advice to Parties regarding proposed listings, species status, and fishery management priorities. An EU proposal to list the Vulnerable porbeagle shark on CITES Appendix II was unsuccessful in June 2007.

The same three sharks are listed on the CMS Appendices (whale shark on Appendix II in 1999, white shark on Appendices I and II in 2002, and basking shark on Appendices I and II in 2005). These listings led to complete protected status for basking and white shark in the EU (with the establishment of zero quotas), and for white shark in New Zealand, but not yet to regional conservation agreements, as intended (Camhi *et al*., 2008). In 2005, a CMS Recommendation called for stronger protection of migratory sharks and the development of a global conservation agreement to mitigate shark bycatch and identify alternatives to consumptive use (CMS, 2007). The CMS convened a workshop in December 2007 to examine related options and its Scientific Council has concluded that 35 species of migratory elasmobranchs, including most of the species discussed in this paper, could benefit from listing on appendices of the CMS.

Overall, despite widespread acknowledgment and understanding of their intrinsic vulnerability to over-exploitation and numerous commitments to conserve them, oceanic pelagic sharks and rays remain a low priority for resource managers and continue to be over-exploited. To improve the conservation status of these species and ensure they are exploited sustainably, fishery managers and other government officials have the ability to take immediate, decisive action at national, regional and international levels. These actions include: implementing and enforcing finning bans (requiring sharks to be landed with fins attached) and scientifically-based (or precautionary) catch limits. Effective conservation of pelagic sharks and rays will also require developing new management tools for their conservation (Table 4). Oceanic pelagic sharks and rays may face greater threats than are currently portrayed in the IUCN Red Listing categories, given current data and management limitations. Regular reviews of threatened status, as additional data become available, are necessary to continually refine our understanding of the degree of threat faced by oceanic pelagic sharks and rays.

## ACKNOWLEDGEMENTS

Assessing species for the IUCN Red List of Threatened Species™ relies on the willingness of dedicated experts to contribute and pool their collective knowledge thus allowing the most reliable judgments of a species' status to be made. Without their enthusiastic commitment to species conservation, this work would not be possible. We therefore thank all of the IUCN Shark Specialist Group (SSG) members and invited regional and international experts who have attended Regional, Generic and Expert Review SSG Red List workshops. Many thanks are also due to all experts who have contributed data to Red List assessments by email.

The pelagic shark workshop and the work presented in this report were supported by the Pew Charitable Trust/Lenfest Ocean Programme. Conservation International is funding the completion of the SSG's global chondrichthyan assessment. We also acknowledge the numerous other funders of the SSG's various Red List workshops over the past four years. Full details are provided on the Funding Acknowledgements page of the SSG's website (www.flmnh.ufl.edu/fish/organizations/ssg/ssgfunds.htm). We thank Fabrizio Serena, Colin Simpfendorfer and John Baxter for their constructive comments.

The views expressed herein by E. Cortés are solely those of this co-author and do not necessarily reflect the opinions of NOAA Fisheries Service.

## REFERENCES

Aasen O. 1961. Some observations on the biology of the porbeagle shark (*Lamna nasus* L.). *ICES C.M. Near Northern Sea Committee* **109**: 7.

Aires-Da-Silva AM, Gallucci VF. 2007. Demographic and risk analyses applied to management and conservation of the blue shark (*Prionace glauca*) in the North Atlantic Ocean. *Marine and Freshwater Research* **58**: 570–580.

Amorim AF, Arfelli CA, Fagundes L. 2005. Bigeye sand tiger *Odontaspis noronhai* (Maul, 1955). In *Sharks*, *Rays and Chimaeras*: *The Status of the Chondrichthyan Fishes*, Fowler SL, Cavanagh RD, Camhi MA, Burgess GH, Caillet GM, Fordham SV, Simpfendorfer CA, Musick JA (eds). IUCN, World Conservation Union, Gland, Switzerland and Cambridge, UK.

Anonymous. 2003. *Action Plan for the Conservation of Cartilaginous Fishes* (*Chondrichthyans*) *in the Mediterranean Sea*. United Nations Environment Programme, Regional Activity Centre for Specially Protected Areas, Tunis.

Anonymous. 2007. The end of the line? Global threats to sharks. Oceana and WildAid report.

Baillie JEM, Hilton-Taylor C, Stuart S. 2004. *2004 IUCN Red List of Threatened Species*: *A Global Species Assessment*. World Conservation Union (IUCN), Gland, Switzerland and Cambridge, UK.

Barker MJ, Schluessel V. 2005. Managing global shark fisheries: suggestions for prioritizing management strategies. *Aquatic Conservation*: *Marine and Freshwater Ecosystems* **15**: 325–347.

Bass AJ, D'Aubrey JD, Kistnasamy N. 1975. Sharks of the east coast of southern Africa. IV. The families *Odontaspididae*, *Scapanorhynchidae*, *Isuridae*, *Cetorhinidae*, *Alopiidae*, *Orectolobidae* and *Rhiniodontidae*, Report No. 39. Oceanographic Research Institute Investigational Report.

Baum JK, Myers RA, Kehler DG, Worm B, Harley SJ, Doherty PA. 2003. Collapse and conservation of shark populations in the northwest Atlantic. *Science* **299**: 389–392.

Baum JK, Kehler D, Myers RA. 2005. Robust estimates of decline for pelagic shark populations in the northwest Atlantic and Gulf of Mexico. *Fisheries* **30**: 27–30.

Beerkircher LR, Brown CJ, Abercrombie DL, Lee DW. 2004. SEFSC Pelagic observer program data summary for 1992–2002. Report No. 522. NOAA NMFS SEFSC.

Bishop SDH, Francis MP, Duffy C, Montgomery JC. 2006. Age, growth, maturity, longevity and natural mortality of the shortfin mako (*Isurus oxyrinchus*) in New Zealand waters. *Marine and Freshwater Research* **57**: 143–154.

Blagoderov AI. 1994. Seasonal distribution and some notes on the biology of salmon shark (*Lamna ditropis*) in the northwestern Pacific Ocean. *Journal of Ichthyology* **34**: 115–121.

Bonfil R. 1990. Contribution to the fisheries biology of the silky shark *Carcharhinus falciformis* (Bibron, 1839) from Yucatan, Mexico. MSc, University of Wales.

Bonfil R, Mena R, de Anda D. 1993. Biological parameters of commercially exploited silky sharks, *Carcharhinus falciformis*, from the Campeche bank, Mexico. Report No. 115. NOAA NMFS.

Bonfil R. 1994. Overview of world elasmobranch fisheries. Report No. 341. Food and Agriculture Organisation of the United Nations, Rome.

Bonfil R, Meyer M, Scholl MC, Johnson R, O'Brien S, Oosthuizen H, Swanson S, Kotze D, Paterson M. 2005. Transoceanic migration, spatial dynamics, and population linkages of white sharks. *Science* **310**: 100–103.

Branstetter S. 1987. Age, growth and reproductive biology of the silky shark, *Carcharhinus falciformis*, and the scalloped hammerhead, *Sphyrna lewini*, from the northwestern Gulf of Mexico. *Environmental Biology of Fishes* **19**: 161–173.

Branstetter S. 1990. Early life-history implications of selected carcharhinid and lamnoid sharks of the northwest Atlantic. In *Elasmobranchs as Living Resources*: *Advances in the Biology*, *Ecology*, *Systematics*, *and the Status of the Fisheries*, Pratt HL, Gruber SH, Taniuchi T (eds). NOAA Technical Report NMFS 90; 17–28.

Butchart SHM, Akçakaya HR, Kennedy E, Hilton-Taylor C. 2006. Biodiversity indicators based on trends in conservation status: strengths of the IUCN red list index. *Conservation Biology* **20**: 579–581.

Cailliet GM, Bedford DW. 1983. The biology of three pelagic sharks from California waters, and their emerging fisheries: a review. Report No. 24. CALCOFI.

Camhi M. 1995. Industrial fisheries threaten ecological integrity of the Galapagos Islands. *Conservation Biology* **9**: 715–724.

Camhi M, Pikitch EK, Babcock EA. 2008. *Sharks of the Open Ocean*: *Biology*, *Fisheries and Conservation* Blackwell Publishing: Oxford.

Campana SE, Joyce W, Marks L, Natanson LJ, Kohler NE, Jensen CF, Mello JJ, Pratt HL, Myklevoll S. 2002. Population dynamics of the porbeagle in the northwest Atlantic Ocean. *North American Journal of Fisheries Management* **22**: 106–121.

Campana SE, Marks L, Joyce W. 2005. The biology and fishery of shortfin mako sharks (*Isurus oxyrinchus*) in Atlantic Canadian waters. *Fisheries Research* **73**: 341–352.

Campana SE, Marks L, Joyce W, Kohler NE. 2006. Effects of recreational and commercial fishing on blue sharks (*Prionace glauca*) in Atlantic Canada, with inferences on the North Atlantic population. *Canadian Journal of Fisheries and Aquatic Sciences* **63**: 670–682.

Carlton JT, Geller JB, Reaka-Kudla ML, Norse EA. 1999. Historical extinctions in the sea. *Annual Review of Ecology and Systematics* **30**: 525–538.

Castro JA, Mejuto J. 1995. Reproductive parameters of blue shark, *Prionace glauca*, and other sharks in the Gulf of Guinea. *Marine and Freshwater Research* **46**: 967–973.

 
DOI: 10.1002/aqc

Cavanagh R, Gibson C. 2007. *Overview of the Conservation Status of Cartilaginous Fishes (Chondrichthyans) in the Mediterranean Sea*. IUCN, Gland, Switzerland and Malaga, Spain.
Cavanagh RD, Kyne PM, Fowler SL, Musick JA, Bennett MB. 2003. The conservation status of Australasian chondrichthyans: Report of the IUCN Shark Specialist Group Australia and Oceania Regional Red List Workshop. The University of Queensland, School of Biomedical Sciences, Brisbane, Australia.
Cheeseman TF. 1981. Notice of the occurrence of the basking shark (*Selache maxima*, L.) in New Zealand. *Transactions and Proceedings of the New Zealand Institute* **23**: 126–127.
Chen CT, Liu KM, Joung SJ, Phipps MJ. 1996. *Shark Fisheries and Trade in Taiwan*. TRAFFIC East Asia-Taipei, Taipei, Taiwan.
Chen CT, Liu KM, Chang YC. 1997. Reproductive biology of the bigeye thresher shark, *Alopias superciliosus* (Lowe, 1839) (Chondrichthyes: Alopiidae), in the northwestern Pacific. *Ichthyological Research* **44**: 227–235.
Clarke S, Milner-Gulland EJ, Bjørndal T. 2007. Social, economic and regulatory drivers of the shark fin trade. *Marine Resource Economics* **22**: 305–327.
Clarke SC. 2004. Understanding pressures on fishery resources through trade statistics: a pilot study of four products in the Chinese dried seafood market. *Fish & Fisheries* **5**: 53–74.
Clarke SC, Magnussen JE, Abercrombie DL, McAllister MK, Shivji MS. 2006a. Identification of shark species composition and proportion in the Hong Kong shark fin market based on molecular genetics and trade records. *Conservation Biology* **20**: 201–211.
Clarke SC, McAllister MK, Milner-Gulland EJ, Kirkwood GP, Michielsens CGJ, Agnew DJ, Pikitch EK, Nakano H, Shivji MS. 2006b. Global estimates of shark catches using trade records from commercial markets. *Ecology Letters* **9**: 1115–1126.
CMS. 2007. *UNEP/CMS/Recommendation 8.16 Migratory sharks*, Vol. 2005. United Nations Environment Programme, Convention on Migratory Species.
Compagno LJV. 1984. Sharks of the world. An annotated & illustrated catalogue of shark species known to date. *Part 1. Hexanchiformes* to *Lamniformes* Food and Agriculture Organisation of the United Nations, Rome.
Compagno LJV, Last PR. 1999. Mobulidae: devil rays. In *FAO Species Identification Guide for Fishery Purposes. The Living Marine Resources of the Western Central Pacific. Volume* 3. *Batoid Fishes, Chimaeras and Bony Fishes part I* (*Elopidae to Linophrynidae*), Carpenter KS, Niem VH (eds). Food and Agriculture Organisation: Rome; 1397–2068.
Compagno LJV. 2000. *Megachasma pelagios*, Vol. 2007. IUCN Red List of Threatened Species.
Compagno LJV. 2001. Sharks of the world. An annotated and illustrated catalogue of shark species known to date. Vol. 2. Bullhead, mackerel and carpet sharks (*Heterodontiformes, Lamniformes and Orectolobiformes*). Report No. 1, vol. 2. Food and Agriculture Organisation of United Nations, Rome.
Compagno LJV, Dando M, Fowler S. 2005. *Sharks of the World*. HarperCollins: London.
Compagno LJV. 2008. Checklist of oceanic sharks and rays. In *Sharks of the Open Ocean: Biology, Fisheries and Conservation*, Camhi MA, Pikitch EK (eds). Blackwell Publishing: Oxford.
Cortés E. 2000. Life history patterns and correlations in sharks. *Reviews in Fisheries Science* **8**: 299–344.
Cortés E. 2002. Incorporating uncertainty into demographic modelling: application to shark populations and their conservation. *Conservation Biology* **18**: 1048–1062.
Domeier ML, Nasby-Lucas N. 2007. Annual re-sightings of photographically identified white sharks (*Carcharodon carcharias*) at an eastern Pacific aggregation site (Guadalupe Island, Mexico). *Marine Biology* **150**: 977–984.
Domingo A, Menni R, Forselledo R. 2005. Bycatch of the pelagic ray *Dasyatis violacea* in Uruguayan longline fisheries and aspects of distribution in the southwestern Atlantic. *Scientia Marina* **69**: 161–166.
Dulvy NK, Metcalfe JD, Glanville J, Pawson MG, Reynolds JD. 2000. Fishery stability, local extinctions and shifts in community structure in skates. *Conservation Biology* **14**: 283–293.
Dulvy NK, Sadovy Y, Reynolds JD. 2003. Extinction vulnerability in marine populations. *Fish and Fisheries* **4**: 25–64.
Dulvy NK, Jennings S, Rogers SI, Maxwell DL. 2006. Threat and decline in fishes: an indicator of marine biodiversity. *Canadian Journal of Fisheries and Aquatic Sciences* **63**: 1267–1275.
FAO. 2000. Fisheries management. 1. Conservation and management of sharks, Report No. 4, Suppl. 1. Food and Agriculture Organisation of the United Nations, Rome.
FAO. 2007. *FishSTAT Capture Production (1950–2005) Database*, Vol. 2007. Food and Agriculture Organisation of the United Nations: Rome.
Forselledo R, Pons M, Miller P, Domingo A. In press. Distribution and population structure of the black ray (*Pteroplatytrygon violacea*) in the South Atlantic (1998–2006). Report No. ICCAT SCRS/2007/125. International Commission for the Conservation of Atlantic Tunas, Madrid, Spain. Latest infor required.
Fowler S. 1996. Red list assessments for sharks and rays. *Shark News* **8**: 4–5.
Francis MP. 1996. Observations of a pregnant white shark from New Zealand. In *The biology of the White Shark*, Carcharodon carcharias, Klimley AP, Ainley DG (eds). Academic Press: New York.

Francis MP, Stevens JD. 2000. Reproduction, embryonic development and growth of the porbeagle shark, *Lamna nasus*, in the south-west Pacific Ocean. *Fishery Bulletin* **98**: 41–63.
Francis MP, Duffy C. 2002. Distribution, seasonal abundance and bycatch of basking sharks (*Cetorhinus maximus*) in New Zealand, with observations on their winter habitat. *Marine Biology* **140**: 831–842.
Francis MP, Duffy C. 2005. Length at maturity in three pelagic sharks (*Lamna nasus*, *Isurus oxyrinchus*, and *Prionace glauca*) from New Zealand. *Fishery Bulletin* **103**: 489–500.
Francis MP. 2007. Unpublished data.
Francis MP, Campana SE, Jones CM. 2007. Age under-estimation in New Zealand porbeagle sharks (*Lamna nasus*): is there an upper limit to ages that can be determined from shark vertebrae? *Marine and Freshwater Research* **58**: 10–23.
Francis MP, Natanson LJ, Campana SE. 2008. The biology and ecology of the porbeagle shark, *Lamna nasus*. In *Sharks of the Open Ocean*: *Biology*, *Fisheries and Conservation*, Camhi MD, Pikitch EK, Babcock EA (eds). Blackwell Publishing: Oxford.
Frisk MG, Millar TJ, Dulvy NK. 2005. Life histories and vulnerability to exploitation of elasmobranchs: Inferences from elasticity, perturbation and phylogenetic analyses. *Journal of the North Atlantic Fisheries Organisation* **35**: 27–45.
Gibson AJF, Campana SE. 2005. Status and recovery potential of porbeagle shark in the Northwest Atlantic. Report No. 2005/53. Canadian Science Advisory Secretariat, Ottawa.
Gilmore RG. 1983. Observations on the embryos of the longfin mako, *Isurus paucus*, and the bigeye thresher, *Alopias superciliosus*. *Copeia* **1983**: 375–382.
Goldman KJ, Anderson SD. 1999. Space utilization and swimming depth of white sharks, *Carcharodon carcharias*, at the South Farallon Islands, central California. *Environmental Biology of Fishes* **56**: 351–364.
Goldman KJ, Musick JA. 2006. Growth and maturity of salmon sharks (*Lamna ditropis*) in the eastern and western North Pacific, and comments on back-calculation methods. *Fishery Bulletin* **104**: 278–292.
Goldman KJ. 2007. Personal communication.
Goldman KJ, Musick JA. 2008. Biology of the salmon shark, *Lamna ditropis*. In *Sharks of the Open Ocean*: *Biology*, *Fisheries and Conservation*, Camhi M, Pikitch EK, Babcock EA (eds). Blackwell Publishing: Oxford.
Guitart-Manday D. 1966. Nuevo nombre para una especie de tiburón del género *Isurus* (Elasmobranchii: Isuridae) de aguas Cubanas. *Poeyana Ser*. *A* **15**: 1–9.
Hareide NR, Carlson J, Clarke M, Clarke S, Ellis J, Fordham S, Fowler S, Pinho M, Raymakers C, Serena F *et al*. 2007. European Shark Fisheries: a preliminary investigation into fisheries, conversion factors, trade products, markets and management measures. European Elasmobranch Association.
Hemida F, Seridji R, Ennajar S, Bradai MN, Collier E, Guélorget O, Capapé C. 2003. New observations on the reproductive biology of the pelagic stingray, *Dasaytis violacea* Bonaparte, 1832 (Chondrichthyes: Dasyatidae) from the Mediterranean Sea. *Acta Adriatica* **44**: 183–192.
Hilborn R, Branch TA, Ernst B, Magnussson A, Minte-Vera CV, Scheuerell MD, Valero JL. 2003. State of the world's fisheries. *Annual Review of Environment and Resources* **28**: 359–399.
Hixon MA. 1979. Term fetuses from a large common thresher shark, *Alopias vulpinus*. *California Fish and Game* **65**: 191–192.
HKSARG. 2007. Census and Statistics Department, Vol. 2007. Hong Kong Special Administrative Region Government.
Hoenig JM, Gruber SH. 1990. Life-history patterns in the elasmobranchs: implications for fisheries management. Report No. 90. NOAA NMFS.
ICCAT. 2005. Report of the 2004 inter-sessional meeting of the ICCAT subcommittee on by-catches: shark stock assessment. *Collective Volume of Scientific Papers of the International Commission for the Conservation of Atlantic Tunas* (*ICCAT*) **58**: 799–890.
ICCAT. 2007. Report of the standing committee on research and statistics (SCRS). International Commission for the Conservation of Atlantic Tunas (ICCAT), Madrid, Spain.
Ito RY, Machado WA. 1999. Annual report of the Hawaii-based longline fishery for 1998. Southwest Fish. Sci. Cent. Admin. Rep. H-99-06.
IUCN. 2001. *IUCN Red List Categories and Criteria*: *Version* 3.1. IUCN Species Survival Commission, Gland Switzerland and Cambridge, UK.
IUCN. 2004a. *Guidelines for using the IUCN Red List Categories and Criteria*. IUCN Species Survival Commission, Gland, Switzerland.
IUCN. 2004b. *REC* 3.116 *Shark Finning*, Vol. 2007. World Conservation Congress 2004.
IUCN. 2006. *2006 IUCN Red List of threatened species*, www.iucnredlist.org/
Joung S-J, Chen C-S, Clark E, Uchida S, Huang YP. 1996. The whale shark, *Rhincodon typus*, is a livebearer: 300 embryos found one 'megamamma' supreme. *Environmental Biology of Fishes* **46**: 219–223.
Kell LT, Mosqueira I, Grosjean P, Fromentin J-M, Garcia D, Hillary R, Jardim E, Mardle S, Pastoors MA, Poos JJ *et al*. 2007. FLR: an open-source framework for the evaluation and development of management strategies. *ICES Journal of Marine Science* **64**: 640–646.

Kitchell JF, Essington TE, Boggs CH, Schindler DE, Walters CJ. 2002. The role of sharks and longline fisheries in a pelagic ecosystem of the central Pacific. *Ecosystems* **5**: 202–216.

Kukuyev EI. 1996. The new finds in recently born individuals of the Whale shark *Rhincodon typus* (Rhincodontidae) in the Atlantic ocean. *Journal of Ichthyology* **36**: 203–205.

Kunzlik PA. 1988. The basking shark. *Scottish Fisheries Information Pamphlet* **14**: 21.

Lack M, Sant G. 2006. *Confronting Shark Conservation Head On*. TRAFFIC International: Cambridge.

Lessa R, Santana FM, Paglerani R. 1999. Age, growth and stock structure of the oceanic whitetip shark, *Carcharhinus longimanus*, from the southwestern equatorial Atlantic. *Fisheries Research* **42**: 21–30.

Liu K-M, Chiang P-J, Chen C-T. 1998. Age and growth estimates of the bigeye thresher, *Alopias superciliosus*, in northeastern Taiwan waters. *Fishery Bulletin* **96**: 482–491.

Liu K-M, Chen C-T, Liao T-H, Joung S-J. 1999. Age, growth and reproduction of the pelagic thresher shark, *Alopias pelagicus*, in the Northwestern Pacific. *Copeia*: 68–74.

Liu K-M, Changa Y-T, Ni I-H, Jin C-B. 2006. Spawning per recruit analysis of the pelagic thresher shark, *Alopias pelagicus*, in the eastern Taiwan waters. *Fisheries Research* **82**: 52–64.

Mace G, Masundire H, Baillie J, Ricketts T, Brooks T. 2005. Biodiversity. In *Ecosystems and Human Well-being: Current State and Trends: Findings of the Condition and Trends Working Group*. Hassan R, Scholes R, Ash N (eds). Island Press: Washington DC; 77–122.

Mace GM. 1995. Classification of threatened species and its role in conservation planning. In *Extinction Rates*, Lawton JH, May RM (eds). Oxford University Press: Oxford; 197–213.

Malcolm H, Bruce BD, Stevens JD. 2001. *A Review of the Biology and Status of White Sharks in Australian Waters*. CSIRO Marine Research: Hobart, Tasmania.

Marshall A, Ishihara H, Dudley SFJ, Clark TB, Jorgensen S, Smith WD, Bizzarro JJ. 2006. *Manta birostris*, Vol. 2007. IUCN Red List of Threatened Species.

Matsunaga H, Nakano H, Minami H. 2001. Standardised CPUE and catch for the main pelagic sharks species dominated in the SBT fishery. Report No. 011/66. CCSBT-ERS.

Matthews LH. 1950. Reproduction in the basking shark, *Cetorhinus maximus* (Gunner). *Philosophical Transactions of the Royal Society of London*, *B* **234**: 247–316.

Matthews LH, Parker HW. 1950. Notes on the anatomy and biology of the basking shark (*Cetorhinus maximus* (Gunner)). *Proceedings of the Zoological Society of London* **120**: 535–576.

Mejuto J, García-Cortés B, de la Serna JM, Ramos-Cartelle A. 2006a. Scientific estimations of by-catch landed by the Spanish surface longline fleet targeting swordfish (*Xiphias gladius*) in the Atlantic Ocean: 2000–2004 period. *Collective Volume of Scientific Papers of the International Commission for the Conservation of Atlantic Tunas* (*ICCAT*) **59**: 1014–1024.

Mejuto J, García-Cortés B, Ramos-Cartelle A. 2006b. An overview of research activities on swordfish (*Xiphias gladius*) and the by-catch species, caught by the Spanish longline fleet in the Indian Ocean, Report No. IOTC 2006-WPB-11. Indian Ocean Tuna Commission.

Mollet H, Cailliet GM. 1996a. Using allometry to predict body mass from linear measurements of the white shark. In *Great White Sharks: The Biology of* Carcharodon carcharias, Klimley AP, Ainley DG (eds). Academic Press: London; 81–89.

Mollet H, Cailliet GM. 1996b. A review of length validation methods and protocols to measure large white sharks. In *Great White Sharks: The Biology of* Carcharodon carcharias, Klimley AP, Ainley DG (eds). Academic Press: London; 91–108.

Mollet H, Cliff G, Pratt HL, Stevens JD. 2000. Reproductive biology of the female shortfin mako, *Isurus oxyrinchus* Rafinesque, 1810, with comments on the embryonic development of lamnoids. *Fishery Bulletin* **98**: 299–318.

Mollet H, Ezcurra JM, O'Sullivan JB. 2002. Captive biology of the pelagic stingray, *Dasyatis violacea* (Bonaparte, 1832). *Marine and Freshwater Research* **53**: 531–541.

Mollet HF. 2002. Distribution of the pelagic stingray, *Dasyatis violacea* (Bonaparte, 1832), off California, Central America, and worldwide. *Marine Freshwater Review* **53**: 525–530.

Muñoz-Chapuli R, Notarbartolo di Sciara G, Séret B, Stehmann M. 1993. The status of the elasmobranch fisheries in Europe. IUCN Shark Specialist Group.

Musick JA. 1999. Life in the slow lane: ecology and conservation of long-lived marine animals. *American Fisheries Society Symposium* **23**: 1–10.

Myers RA, Worm B. 2003. Rapid worldwide depletion of predatory fish communities. *Nature* **423**: 280–283.

Myers RA, Worm B. 2005. Extinction, survival and recovery of large predatory fishes. *Philosophical Transactions of the Royal Society of London*, *Biological Sciences* **360**: 13–20.

Myers RA, Baum JK, Shepherd TD, Powers SP, Peterson CH. 2007. Cascading effects of the loss of apex predatory sharks from a coastal ocean. *Science* **315**: 1846–1850.



DOI: 10.1002/aqc

Nagasawa K. 1998. Predation by salmon sharks (*Lamna ditropis*) on Pacific salmon (*Oncorhynchus* spp.) in the North Pacific Ocean. *NPAFC Bulletin* **1**: 419–433.

Nagasawa K, Azumaya T, Yoshida Y. 2002. Impact of predation by salmon sharks (*Lamna ditropis*) and daggertooth (*Anotopterus nikparini*) on Pacific salmon (*Oncorhynchus spp.*) stocks in the North Pacific Ocean, Report No. 4. North Pacific Anadromous Fish Commission (NPFAC).

Nakano H. 1998. Standardized CPUE for pelagic shark caught by the Japanese longline fishery in the Atlantic Ocean. *Collective Volume of Scientific Papers of the International Commission for the Conservation of Atlantic Tunas* (*ICCAT*) **48**: 72–76.

Natanson LJ, Mello JJ, Campana SE. 2002. Validated age and growth of the porbeagle shark (*Lamna nasus*) in the western North Atlantic Ocean. *Fishery Bulletin* **100**: 266–278.

Natanson LJ, Kohler NE, Ardizzone D, Cailliet GM, Wintner SP, Mollet HF. 2006. Validated age and growth estimates for the shortfin mako, *Isurus oxyrinchus*, in the North Atlantic Ocean. *Environmental Biology of Fishes* **77**: 367–383.

Neer JA. 2008. The biology and ecology of the pelagic stingray, *Pteroplatytrygon violacea* (Bonaparte, 1832). In *Sharks of the Open Ocean*: *Biology*, *Fisheries and Conservation*, Camhi MD, Pikitch EK, Babcock EA (eds). Blackwell Publishing: Oxford.

Notarbartolo di Sciara G. 1987. A revisionary study of the genus *Mobula*, Rafinesque, 1810 (Chondrichthyes: Mobulidae) with the description of a new species. *Zoological Journal of the Linnean Society* **91**: 1–91.

Notarbartolo di Sciara G, Serena F. 1988. Term embryo of *Mobula mobular* (Bonnaterre, 1788) from the northern Tyrrhenian Sea (Chondrichthyes: Mobulidae). *Atti della Societa Italiana di Scienze Naturali e del Museo Civico di Storia Naturale in Milano* **129**: 396–400.

Notarbartolo di Sciara G. 2005. Giant devilray *Mobula mobular*. In *Sharks*, *Rays and Chimaeras*: *The Status of the Chondrichthyan Fishes*, Fowler SL, Cavanagh RD, Camhi MA, Burgess GH, Caillet GM, Fordham SV, Simpfendorfer CA, Musick JA (eds). IUCN, World Conservation Union, Gland, Switzerland and Cambridge, UK; 357–358.

Oshitani S, Nakano H, Tanaka S. 2003. Age and growth of the silky shark *Carcharhinus falciformis* from the Pacific Ocean. *Fisheries Science* **69**: 456–464.

Otake T, Mizue K. 1981. Direct evidence for oophagy in thresher shark, *Alopias pelagicus*. *Japanese Journal of Ichthyology* **28**: 171–172.

Paulin CD, Habib G, Carey CL, Swanson PM, Voss GJ. 1982. New records of *Mobula japanica* and *Masturus lanceolatus*, and further records of *Luvaris imperialis* (Pisces: Mobulidae, Molidae, Louvaridae) from New Zealand. *New Zealand Journal of Marine and Freshwater Research* **16**: 11–17.

Pauly D. 1978. A critique of some literature data on the growth, reproduction and mortality of the lamnid shark *Cetorhinus maximus* (Gunnerus). *International Council for the Exploration of the Sea C. M.* **978/H:17**: 1–10.

Peterman RM. 2004. Possible solutions to some challenges facing fisheries scientists and managers. *ICES Journal of Marine Science* **61**: 1331–1343.

Pilling GM, Apostolaki P, Failler P, Floros C, Large PA, Morales-Nin B, Reglero P, Stergiou KI, Tsikliras AC. 2008. Assessment and management of data-poor fisheries. In *Advances in Fisheries Science*. *50 years on from Beverton and Holt*, Payne AI, Cotter AJ, Potter ECE (eds). Blackwell: Oxford.

Pratt HL. 1979. Reproduction in the blue shark, *Prionace glauca*. *Fishery Bulletin* **77**: 445–470.

Pratt HL, Casey JG. 1983. Age and growth of the shortfin mako, *Isurus oxyrinchus*, using four methods. *Canadian Journal of Fisheries and Aquatic Sciences* **40**: 1944–1957.

Pratt HL, Casey JG. 1990. Shark reproductive strategies as a limiting factor in directed fisheries, with a review of Holden's method of estimating growth parameters. Report No. 90. NOAA NMFS.

Ribeiro-Prado CC, Amorim AF. In press. Fishery biology on pelagic stingray *Pteroplatytrygon violacea* caught off southern Brazil by longliners settled in São Paulo state (2006-7). Report No. ICCAT SCRS/2007/173. International Commission for the Conservation of Atlantic Tuna, Madrid, Spain.

Roberts CM. 2007. *The Unnatural History of the Sea*. Island Press: Washington, DC.

Robinson SMC, Jamieson GS. 1984. Report on a Canadian commercial fishery for flying squid using drifting gillnets off the coast of British Columbia. Canadian Industry Report of Fisheries and Aquatic Sciences.

Rogan E, Mackey M. 2007. Megafauna bycatch in drift nets for albacore tuna (*Thunnus alalunga*) in the NE Atlantic. *Fisheries Research* **86**: 6–14.

Rose DA. 1996. *An Overview of Word Trade in Sharks and other Cartilaginous Fishes*. TRAFFIC International: Cambridge.

Schindler D, Essington TE, Kitchell JF, Boggs C, Hilborn R. 2002. Sharks and tunas: fisheries impacts on predators with contrasting life histories. *Ecological Applications* **12**: 735–748.

Seki T, Taniuchi T, Nakano H, Shimizu M. 1998. Age, growth and reproduction of the oceanic whitetip shark from the Pacific Ocean. *Fisheries Science* **64**: 14–20.

Serena F. 2000. In volo nel blu. *Oasis Anno* **16**: 96–105.

 

Serena F. 2005. *Field Identification Guide to the Sharks and Rays of the Mediterranean and Black Sea*. Food and Agriculture Organisation of the United Nations: Rome.
Sibert J, Hampton J, Kleiber P, Maunder M. 2006. Biomass, size, and trophic status of top predators in the Pacific Ocean. *Science* **314**: 1773–1776.
Simpfendorfer CA, Hueter RE, Bergman U, Connett SMH. 2002. Results of a fishery-independent survey for pelagic sharks in the western North Atlantic, 1977–1994. *Fisheries Research* **55**: 175–192.
Skomal GB. 1990. Age and growth of the blue shark, *Prionace glauca*, in the North Atlantic. MSc, University of Rhode Island, USA.
Skomal GB, Natanson LJ. 2003. Age and growth of the blue shark (*Prionace glauca*) in the North Atlantic Ocean. *Fishery Bulletin* **101**: 627–639.
Smith SE, Au DW, Show C. 1999. Intrinsic rebound potentials of 26 species of Pacific sharks. *Marine and Freshwater Research* **49**: 663–678.
Springer S. 1963. Field observation on large sharks of the Florida-Caribbean region. In *Sharks and Survival*, Gilbert PW (ed.). DC Heath & Co.: Boston, USA; 95–113.
Stevens JD. 1975. Vertebral rings as a means of age determination in the blue shark (*Prionace glauca* L.). *Journal of the Marine Biological Association UK* **55**: 657–665.
Stevens JD. 1984. Biological observations on sharks caught by sport fishermen off New South Wales. *Australian Journal of Marine and Freshwater Research* **35**: 573–590.
Stevens JD. 1999. Variable resilience to fishing pressure in two sharks: the significance of different ecological and life history parameters. In *Life in the Slow Lane*: *Ecology and Conservation of Long- lived Marine Animals*, Musick JA (ed.). American Fisheries Society: Bethesda; 11–16.
Stevens JD, Bonfil R, Dulvy NK, Walker P. 2000. The effects of fishing on sharks, rays and chimaeras (chondrichthyans), and the implications for marine ecosystems. *ICES Journal of Marine Science* **57**: 476–494.
Tanaka S. 1980. Biological survey of salmon shark, *Lamna ditropis*, in the western North Pacific Ocean. Report of new shark resource exploitation survey in the fiscal year 1979 (North Pacific Ocean). Japan Marine Fisheries Resource Research Centre, Tokyo; 59–84.
Taylor VB, Bedford DW. 2001. Shortfin Mako Shark. In *California's Living Marine Resources*: *A Status Report*, Leet WS, Dewees CM, Klingbeil R, Larson EJ (eds). The Resources Agency, California Department of Fish and Game; 336–337.
Verity PG, Smetacek V, Smayda TJ. 2002. Status, trends and the future of the marine pelagic ecosystem. *Environmental Conservation* **29**: 207–237.
Wang JY, Yang S-C. 2005. *Megamouth Shark #31*, http://www.flmnh.ufl.edu/fish/sharks/megamouth/mega31.html.
Ward P, Myers RA. 2005. Shifts in open-ocean fish communities coinciding with the commencement of commercial fishing. *Ecology* **86**: 835–847.
West G, Stevens JD, Basson M. 2004. Assessment of blue shark population status in the western South Pacific. Report No. R01/1157. Research report prepared for the Australian Fisheries Management Authority. (Unpublished report available from CMAR library Hobart, Tasmania).
White WT, Giles J, Dharmadi, Potter IC. 2006. Data on the bycatch fishery and reproductive biology of mobulid rays (Myliobatiformes) in Indonesia. *Fisheries Research* **82**: 65–73.
Wintner SP. 2000. Preliminary study of vertebral growth rings in the whale shark, *Rhincodon typus*, from the east coast of South Africa. *Environmental Biology of Fishes* **59**: 441–451.
Wolfson FH. 1983. Records of seven juveniles of the whale shark, *Rhincodon typus*. *Journal of Fish Biology* **22**: 647–655.
Zeeberg J, Corten A, de Graaf E. 2006. Bycatch and release of pelagic megafauna in industrial trawler fisheries off Northwest Africa. *Fisheries Research* **76**: 186–195.

## APPENDIX 1. LIST OF ACRONYMS USED IN THIS PAPER

| Acronym | Full name | Web reference |
|---|---|---|
| Barcelona | The Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean | www.unep.ch/regionalseas/main/hconlist.html |
| Bern | Convention on the Conservation of European Wildlife and Natural Habitats | http://www.coe.int/t/e/cultural_co-operation/environment/nature_and_biological_diversity/Nature_protection/ |



DOI: 10.1002/aqc

| | | |
|---|---|---|
| CITES | Convention on International Trade in Endangered Wild Species of Fauna and Flora | www.cites.org |
| CMS | Convention of Migratory Species | www.cms.int |
| EEZ | Exclusive Economic Zone | |
| FAO | Food and Agriculture Organization of the United Nations | www.fao.org |
| IATTC | Inter-American Tropical Tuna Commission | www.iattc.org |
| ICCAT | International Commission for the Conservation of Atlantic Tunas | www.iccat.es |
| IUCN | World Conservation Union | www.iucn.org |
| IUU | Illegal, unreported and unregulated | |
| RFMO | Regional Fisheries Management Organisation | |
| SSG | IUCN Shark Specialist Group | http://www.flmnh.ufl.edu/fish/organizations/ssg/ssg.htm |
| UNCLOS | United Nations Convention on the Law of the Sea | www.unclos.com |