Management of Sharks and Their Relatives (Elasmobranchii)

By J. A. Musick, G. Burgess, G. Cailliet, M. Camhi, and S. Fordham

POLICY

The American Fisheries Society (AFS) recommends that regulatory agencies give shark and ray management high priority because of the naturally slow population growth inherent to most sharks and rays, and their resulting vulnerability to overfishing and stock collapse. Fisheries managers should be particularly sensitive to the vulnerability of less productive species of sharks and rays taken as a bycatch in mixed-species fisheries. The Society encourages the development and implementation of management plans for sharks and rays in North America. Management practices including regulations, international agreements and treaties should err on the side of the health of the resource rather than short-term economic gain. The Society encourages the release of sharks and rays taken as bycatch in a survivable condition. Regulatory agencies should mandate full utilization of shark carcasses and prohibit the wasteful practice of finning. Multilateral agreements among fishing nations, or management through regional fisheries management organizations are sorely needed for effective management of wide ranging shark stocks. The Society encourages its members to become involved by providing technical information needed for protection of sharks and rays to international, federal, and state policy makers so decisions are made on a scientific, rather than emotional or political, basis.

A. Issue statement

Sharks and their relatives, the rays (subclass Elasmobranchii), are a group of about 1,000 species of mostly marine fishes. Most sharks and rays that have been studied have slow growth and late maturity, and very low egg production or fecundity compared to bony fishes (Camhi et al. 1998). These attributes result in very low intrinsic rates of increase (Smith et al. 1998) and very low resilience to fishing mortality (Hoenig and Gruber 1990). Because of their low population resilience, most shark and ray populations can only withstand modest levels of fishing without depletion and stock collapse (Camhi et al. 1998; Musick 1999a). Most sharks and ray populations decline more rapidly and are not able to respond or compensate as strongly or as quickly as other fishes to population reduction by fisheries (Sminkey and Musick 1995, 1996). Thus management must be implemented at the inception of shark fisheries (Musick 1999a). This has not been the case for the vast majority of shark fisheries that have developed around the world. Rather, the overwhelming pattern has been one of no management, rapid stock decline and collapse, with decades to recovery if recovery occurs at all (Anderson 1990; Hoff and Musick 1990).

Although many sharks and rays have been of lower economic value in fisheries, the economic impact of stock collapse may be similar to more productive species because the population recovery time and economic loss lasts much longer (Musick 1999a). The greatest threats to sharks and rays may be from mixed-species fisheries where the sharks and rays with lower intrinsic rates of increase may be fished to collapse or extirpation while the more productive fishes continue to drive the fisheries. Because most sharks and rays (particularly the larger, most vulnerable species) are migratory, effective management will require integrated U.S. management plans involving both state and federal waters, as well as bilateral or multilateral international agreements.

B. Background

Well-documented cases of collapsed shark fisheries are the porbeagle (*Lamna nasus*) fishery in the North Atlantic (Anderson 1990), the tope or soupfin shark (*Galeorhinus galeus*) fisheries off California and Australia (Ripley 1946; Olsen 1959), various basking shark (*Cetorhinus maximus*) fisheries (Parker and Stott 1965), the spiny dogfish (*Squalus acanthias*) fisheries both in the North Sea and off British Columbia (Holden 1968; Ketchen 1969; Hoff and Musick 1990), and most recently the large coastal shark fishery off the East Coast of the U.S. (Musick et al. 1993; NMFS 1999).

Mixed species fisheries. Although directed fisheries have been the cause of stock collapse in many species of elasmobranchs, the greatest threat to long-lived sharks and rays appears to be mortality in mixed species fisheries. In those fisheries, species with higher production rates continue to support the fishery while species with lower rebound potential are driven to stock collapse or extirpation (Musick 1999a). Thus, the sand tiger (*Odontaspis taurus*) and dusky shark (*Carcharhinus obscurus*) populations, which have very low intrinsic rates of increase, collapsed because of the western North Atlantic shark fisheries and show little sign of recovery, while the more productive sandbar shark (*Carcharhinus plumbeus*), although depleted, continues to drive

J. A. Musick

The Portuguese shark (*Centroscymnus coelolepis*) and other deep-sea sharks may have metabolic and growth rates as low as one-tenth those of coastal sharks, and thus are able to sustain only modest levels of harvest. Recent developments of deepwater industrial fisheries may threaten some populations of deep-sea sharks with extirpation.

the fisheries (Musick et al. 1993; Musick 1999b). Similarly, the depleted barndoor skate (*Raja laevis*, skates are rays in the family Rajidae) is taken as bycatch in the New England and Canadian Atlantic groundfisheries and its decline would have been unnoticed were it not for the fishery-independent data sets (where individual species are recorded) that were analyzed by Casey and Myers (1998). Imprecise reporting of fishery statistics where several species are lumped together as one category, i.e., "sharks" or "skates," can mask basic changes in community structure and profound reduction in populations of the larger, slower growing species (Dulvy et al. 2000). Thus the traditional paradigm that fisheries will become commercially extinct before the targets of those fisheries become biologically extirpated may be false.

Some of the larger species of sharks and rays have population dynamics that are more similar to whales or sea turtles than to bony fishes (Musick 1999a). Obviously, whales and sea turtles have been widely recognized by both international (Baillie and Groombridge 1996) and national agencies (U.S. National Marine Fisheries Service, Office of Protected Resources, Silver Spring, Maryland) to be endangered with extinction, and the same may be true of some sharks and rays. The barndoor skate was reported extirpated from large parts of its range in Canadian Atlantic and New England coastal waters (Casey and Meyers 1998). Several other large species of skates may potentially be threatened with extinction (Dulvy and Reynolds, unpublished information). The barndoor skate, two species of sawfishes (*Pristis pristis, P. perotteti*) and the sand tiger, dusky, and night (*Carcharhinus signatus*) sharks have been recently added to the National Marine Fisheries Service (NMFS) Candidate List for Threatened and Endangered Species because of large documented declines caused by overfishing (Diaz-Soltera 1999).

Shark fisheries. The sand tiger shark is currently protected under the NMFS Fishery Management Plan (FMP) for Sharks of the Atlantic Ocean (NMFS 1999), and also by regulations in South Africa and Australia (Camhi et al. 1998). This species is particularly vulnerable to overfishing and stock collapse because it produces only two young, probably every other year (Branstetter and Musick 1994). The dusky shark is among the slowest growing marine chordates and among the latest to mature (20 years) (Natanson et al. 1995). The dusky and some other species of sharks were to be protected by the most recent NMFS FMP for tunas, swordfishes, and sharks (NMFS 1999). However, these and other new regulations have not yet been implemented because of a court injunction. Although the dusky shark has undergone more than an 80% decline in the western North Atlantic (Musick et al. 1993) and is still showing no definitive sign of recovery six years after FMP implementation (NMFS 1998; Musick 1999b), it is still being taken in the shark fishery.

Recently the United Nations Food and Agriculture Organization (FAO) reviewed the status of knowledge of shark stocks globally and made recommendations for their management needs (FAO 1998). This effort was initiated as a result of a request from the parties to the Convention on International Trade in Endangered Species (CITES) (Resolution Conf. 9.14). The CITES Animals Committee became concerned about the conservation status of some sharks because of their inherent vulnerability, and rapidly expanding shark fisheries around the world (Anonymous 1997). Much of the shark fishery expansion was driven by the Asian shark fin markets (Rose 1996). Shark fins, mostly used for soup in more expensive Asian restaurants, increased in demand with the Asian economic boom of the mid-1980s and early 1990s, thus increasing in exvessel value from less than $1.00/lb (wet weight) to more than $30.00/lb and higher. This incentive led to the widespread practice of finning where only the fins are landed from captured sharks, and the less valuable carcasses are dumped at sea (Rose 1996; Sant and Hayes 1996). This practice is clearly wasteful and unethical in the eyes of many people, and in direct contradiction to FAO recommendations (FAO 1991). Indeed, several states and the NMFS FMP for Atlantic sharks have made finning illegal along the Atlantic and some of the Pacific coast of the U.S. (Camhi 1998, 1999; NMFS 1993). Hawaii is an obvious exception, where sharks (primarily blue sharks, *Prionace glauca*) are taken as bycatch in the tuna and swordfish fisheries, and the percentage of the shark bycatch that is finned has increased dramatically over the last several years (Camhi 1999).

International management. Most sharks and many rays are highly migratory and routinely cross political boundaries (Camhi et al. 1998). Off New England and in the Canadian Atlantic, several species of skates and the spiny dogfish make coastal seasonal migrations (McEachran and Musick 1974; Nammack et al. 1985). Coastal, subtropical shark populations may make long migrations from the Mid-Atlantic Bight in summer, south into the South Atlantic Bight, or even as far as Mexico in winter (Kohler et al. 1998). Pelagic (open water), oceanic species, like the shortfin mako (*Isurus oxyrinchus*) and the blue shark may make migrations that encompass entire ocean basins (Nakano 1994; Kohler et al. 1998). Many sharks and rays migrate between state waters, where pupping and nursery areas may be managed by the states or regional Marine Fisheries Commissions (with jurisdiction over state waters, 0–3 miles from shore), to offshore feeding areas where the Fishery Management Councils and NMFS have jurisdiction over the Exclusive Economic Zone, (3–200 miles) (Camhi 1998). Management for species that travel across the U.S./Canadian boundary, like porbeagle sharks, may require bilateral fisheries management agreements between the U.S. and Canada. Similarly, effective management of the dusky shark and some other highly migratory, coastal sharks may require bilateral agreements between the U.S. and Mexico (Weber and Fordham 1997).

Management of oceanic sharks will require multilateral action through organizations such as the International Commission for the Conservation of Atlantic Tunas (ICCAT) (although ICCAT's management effectiveness is questionable (Weber and Fordham 1997; Berkeley 1999). However, unilateral management of shark fisheries by any government should be strongly encouraged for transboundary stocks, until multilateral management can be established.

C. Recommended actions

Management. Population models used in fishery management appropriate for more highly productive species may be inappropriate for sharks and rays (Hoff 1990). Shark and ray management should be predicated on the long-term sustainability of healthy populations, and on the precautionary principle (FAO 1995) that management should be conservative in the face of sparse data, erring in favor of maintaining the health of the resource rather than fostering short-term economic gains. Management should be focused on the lowest possible taxon down to the unit stock. Where resources are not available to collect data at the stock or even species level, then species groups should be identified wherein the group members share similar life-history characteristics.

Because of the conservative demographic parameters inherent to most sharks and rays, and their resulting vulnerability to overfishing and stock collapse, shark management should be given high priority with timely implementation before or as fisheries develop, rather than after the fact. Fisheries managers should be particularly sensitive to the vulnerability of less productive species of sharks and rays taken as bycatch in mixed-species fisheries. These less productive species may be rapidly driven to stock collapse or even extirpation, while more productive species continue to support profitable fisheries. Precautionary quotas should be established for these vulnerable bycatch species.

Management should aim to maintain the biomass of shark populations well above levels generally accepted to provide maximum sustainable yields. Traditional fisheries models such as basic surplus production or biomass dynamic models, may be inappropriate for many long-lived, late-maturing sharks and rays because of the long lag time in population responses. In addition, density-dependent compensation in growth or fecundity may be very limited, or even absent. Other models, such as stage- or age-based demographic matrix models, or Bayesian stock production techniques may be more useful for management.

Regulation. Management should take special care to avoid recruitment overfishing by establishing precautionary quotas and size limits that guarantee recruitment. In many sharks and rays, females mature at a relatively large size and advanced age beyond which growth slows considerably. It is possible for some species that yield per recruit modeling may suggest an age and size at entry that is below the minimum size for maturity. In such cases the optimal yield per recruit solution may lead to insufficient pup production and progressive stock decline (Rago and Sosebee 1997). In addition, Punt (in press) noted that in sharks with very low productivity, the biomass and fisheries mortality rate at which recruitment failure occurs may be quite close to the rates where population depensation and ultimate extirpation occur.

Management should be directed at full utilization of shark carcasses once caught. Practices such as finning are wasteful and considered unethical by many people, and should not be allowed. In addition, landing only fins makes it very difficult to identify the landings to species and compounds the problem of recording accurate fisheries statistics, and maintaining effective law enforcement. Landing carcasses (bled and gutted) with the fins intact should be encouraged in all fisheries taking sharks. Live release of unwanted shark and ray bycatch should be mandatory.

Timely status assessments of sharks and rays (including sawfishes, Pristidae) on the NMFS Threatened and Endangered Candidate Species List, or of those species for which Endangered Species Act listing petitions have been filed should be made.

Agreements. Most stocks of sharks and rays are wide ranging so that even coastal species regularly migrate across political boundaries. Effective management of such stocks require multilateral agreements among fishing nations, or management through regional fisheries management organizations. Where the existing mandates of such organizations do not specifically authorize shark and ray management, they should be authorized to do so, provided they apply the precautionary approach and other elements of sound fisheries management (Weber and Fordham 1997). As a matter of priority, countries should sign and ratify the UN agreement on straddling and highly migratory fish stocks and become active members of treaty organizations relevant to sharks and rays. In addition, the U.S. should continue to play a leadership role in implementing the international recommendations and providing technical and financial support to encourage other countries to develop domestic shark management plans as outlined in the FAO International Plan of Action for the Conservation and Management of Sharks (FAO 1998).

Research. Research into fishing practices that reduce shark and ray bycatch and/or increase post-release survivorship is needed.

Priorities. Specific fishery management plan priorities for the U.S. include:

J. A. Musick

American and Mexican scientists collect tissue samples for genetic stock structure analysis. Many shark stocks are migratory and transcend political boundaries. Successful management of these vulnerable fishes will require international cooperation.

Skates in the North Atlantic. Skates represent a large bycatch and also are the targets of fisheries off New England. At least one species, the barndoor skate, has undergone a severe decline.

Sharks in state waters under the Gulf States Marine Fishery Commission. (GSMFC). A comprehensive NMFS FMP for sharks is in place for the Atlantic and Gulf EEZ, and the Atlantic States Marine Fisheries Commission is currently developing complimentary plans for sharks and for spiny dogfish in state waters. So far the GSMFC has not joined this effort which is critical because most of the shark pupping and nursery grounds are in state waters.

Spiny dogfish in the federal waters off California, Oregon, Washington, and Alaska. Spiny dogfish were overfished historically in the northeastern Pacific, and recovered. Renewed fishery pressure, particularly in Puget Sound, is of concern. The U.S. should develop a bilateral management plan with Canada for its shared dogfish stock off Washington and British Columbia.

Skates in the eastern Pacific under the Pacific and North Pacific Fishery Management Councils. Skate landings have increased in recent years in all Pacific states from Alaska to California. At least one species, the big skate (*Raja binoculta*), is similar in its biology to the barndoor skate, and may be at high risk.

Sharks in the eastern Pacific under the Pacific and North Pacific Fisheries Management Councils. Although sharks have been managed by the states along the Pacific coast, there is no comprehensive FMP for such highly migratory species as shortfin mako, salmon (*Lamna ditropis*), and thresher sharks (*Alopias vulpinus*).

Sharks in U.S. waters in the western central Pacific including the U.S. Pacific Island territories. Shark landings in the western central Pacific (Hawaii) have increased significantly in recent years and are comprised mostly of fins. An FMP which includes a ban on finning is sorely needed.

***J. A. Musick** is head of Vertebrate Ecology and Systematics programs at the Virginia Institute of Marine Science in Gloucester Point. **G. Burgess** is vice chair of the IUCN/SSC Shark Specialist Group, Florida Museum of Natural History in Gainesville. **G. Cailliet** is a professor at Moss Landing Marine Laboratories in Moss Landing, California. **M. Camhi** is deputy chair of the IUCN/SSC Shark Specialist Group, National Audubon Society, Living Oceans Program in Islip, New York. **S. Fordham** is fisheries project manager at the Center for Marine Conservation in Washington, DC. This article represents the views of the American Fisheries Society and not necessarily the authors' organizations or agencies.*

References

Anderson, E. D. 1990. Fishery models as applied to elasmobranch fisheries. Pages 473–484 *in* H. L. Pratt, Jr., S. H. Gruber, and T. Taniuchi, eds. Elasmobranchs as living resources: advances in the biology, ecology, systematics, and the status of fisheries. NOAA Tech. Rep. NMFS 90.

Anonymous. 1997. Biological and trade status of sharks. Report of the CITES Animals Committee (Pursuant to Resolution Conference 9.17).

Baillie, J., and **B. Groombridge.** 1996. IUCN red list of threatened animals. IUCN (International Union for the Conservation of Nature), Gland, Switzerland.

Berkeley, S. 1999. American Fisheries Society, Marine Fisheries Section Newsletter.

Branstetter, S., and **J. A. Musick**. 1994. Age and growth estimates for the sand tiger shark in the Northwestern Atlantic Ocean. Trans. Am. Fish. Soc. 123:242–254.

Camhi, M. 1998. Sharks on the Line: a state-by-state analysis of sharks and their fisheries. National Audubon Society, Living Oceans Program, Islip, NY.

———. 1999. Sharks on the Line II: an analysis of Pacific state shark fisheries. National Audubon Society, Living Oceans Program, Islip, NY.

Camhi, M., S. Fowler, J. Musick, A. Bräutigam, and **S. Fordham.** 1998. Sharks and their relatives: ecology and conservation. Occas. Pap. IUCN Species Surviv. Comm. 20.

Casey, J. M., and **R. A. Myers.** 1998. Near extinction of a large, widely distributed fish. Science 281:690–692.

Diaz-Soltera, H. 1999. Endangered and threatened species; revision of candidate species list under the Endangered Species Act. Federal Register 64(120):33166–33467.

Dulvy, N. K., J. D. Reynolds, J. D. Metcalfe, and **J. Glanville.** 2000. Fisheries stability, local extinctions and shifts in community structure in skates. Conserv. Biol. 14:1–11.

FAO (Food and Agriculture Organization of the United Nations). 1991. Draft code of practice for the full utilization of sharks. FAO Fish. Circ. 844.

———. 1995. Precautionary approach to fisheries. Part 1: Guidelines to the precautionary approach to capture fisheries and species introductions. FAO Fish. Tech. Pap. 350 / 1:52.

———. 1998. International Plan of Action for the conservation and management of sharks. Document FI:CSS / 98 / 3. FAO Fisheries Department Consultation on the management of fishing capacity, shark fisheries and incidental catch of seabirds in long-line fisheries. Food and Agriculture Organization of the United Nations, Rome, October 1998.

Hoenig, J. M., and **S. H. Gruber**. 1990. Life-history patterns in the elasmobranchs: implications or fisheries management. Pages 1–16 *in* H. L. Pratt, Jr., S. H. Gruber, and T. Taniuchi, eds. Elasmobranchs as living resources: advances in the biology, ecology, systematics, and the status of fisheries. NOAA Tech. Rep. NMFS 90.

Hoff, T. B. 1990. Conservation and management of the western North Atlantic shark resource based on the life history strategy limitations of sandbar sharks. Doctoral dissertation. University of Delaware, Newark.

Hoff, T. B., and **J. A. Musick**. 1990. Western North Atlantic shark-fishery management problems and informational requirements. Pages 455–472 *in* H. L. Pratt, Jr., S. H. Gruber and T. Taniuchi, eds. Elasmobranchs as living resources: advances in the biology, ecology, systematics, and the status of fisheries. NOAA Tech. Rep. NMFS 90.

Holden, M. J. 1968. The rational exploitation of the Scottish-Norwegian stocks of spurdogs (*Squalus acanthias L.*). Fish. Investig. Minist. Agric. Fish. Food U.K., Ser. 2, 25(8).

Ketchen, K. S. 1969. A review of the dogfish problem off the western coast of Canada. Fish. Res. Board Can. MS Rep. Ser. 1048.

Kohler, N. E., J. G. Casey, and **P. A. Turner.** 1998. NMFS cooperative shark tagging program, 1962–93: An atlas of shark tag and recapture data. Marine Fisheries Review 60(2):87.

McEachran, J. D., and **J. A. Musick**. 1975. Distribution and relative abundance of seven species of skates (Pisces: Rajiidae) which occur between Nova Scotia and Cape Hatteras. Fish. Bull. 73 (1):110–136.

Musick, J. A. 1999a. Ecology and conservation of long-lived marine animals. Pages 1–10 *in* J. A. Musick, ed. Life in the slow lane: ecology and conservation of long-lived marine animals. Am. Fish. Soc. Symp. 23.

———. 1999b. Criteria to define extinction risk in marine fishes. The American Fisheries Society initiative. Fisheries 24(12):6–14.

Musick, J. A., S. Bransletter, and **J. A. Colvocorosses**. 1993. Trends in shark abundance from 1974 to 1991 for the Chesapeake Bight region of the U.S. Mid-Atlantic Coast. Pages 1–18 *in* S. Bransletter, ed. Conservation biology of elasmobranchs. NOAA Tech. Rep. NMFS 115.

Nakano, H. 1994. Age, reproduction and migration of blue shark in the north Pacific ocean. Bull. Nat. Res. Inst. Far Seas Fish. 31:141–256.

Nammack, M. F., J. A. Musick, and **J. A. Colvocoresses**. 1985. Life history of spiny dogfish off the northeastern United States. Trans. Am. Fish Soc. 114:367–376.

Natanson, L. J., J. G. Casey, and **N. E. Kohler**. 1995. Age and growth estimates for the dusky shark, *Carcharhinus obscurus*, in the western North Atlantic Ocean. Fish. Bull. 93:116–126.

NMFS (National Marine Fisheries Service). 1993. Fishery management plan for sharks of the Atlantic Ocean. Silver Spring, MD.

———. 1998. Report of the 1998 Shark Evaluation Workshop. NOAA, National Marine Fisheries Service, Southeast Fisheries Science Center, Miami, FL.

———. 1999. Final fishery management plan for Atlantic tunas, swordfish and sharks. NOAA, National Marine Fisheries Service, Silver Spring, MD.

Olsen, A. M. 1959. The status of the school shark fishery in south-eastern Australia waters. Aust. J. Mar. Freshw. Res. 10:150–176.

Parker, H. W., and **F. C. Stott.** 1965. Age, size and vertebral calcification in the basking shark, *Cetorhinus maximus* (Gunnerus). Zool. Meded. (Leiden) 40:305–319.

Punt, A. B. In press. Extinction of marine renewable resources, a demographic analysis. Popul. Ecol.

Rago, P., and **K. Sosebee.** 1997. Spiny dogfish (*Squalus acanthias*) SAW-26 SARC Working Paper D1. National Marine Fisheries Service, Northeast Fisheries Science Center, Woods Hole, MA.

Ripley, W. E. 1946. The soup-fin shark and the fishery. Fish. Bull., Calif. 64:7–37.

Rose, D. A. 1996. Shark fisheries and trade in the Americas, Volume 1: North America. TRAFFIC, Cambridge, U.K.

Sant, G., and **E. Hayes**, eds. 1996. The Oceania Region's harvest, trade and management of sharks and other cartilaginous fish: an overview. TRAFFIC, Cambridge, U.K.

Sminkey, T. R., and **J. A. Musick**. 1995. Age and growth of the sandbar shark, *Carcharhinus plumbeus*, before and after population depletion. Copeia 1995:871–883.

Sminkey, T. R., and **J. A. Musick.** 1996. Demographic analysis of the sandbar shark, *Carcharhinus plumbeus*, in the western North Atlantic. Fish. Bull. 94:341–347.

Smith, S. E., D. W. Au, and **C. Show.** 1998. Intrinsic rebound potentials of 26 species of Pacific sharks. Mar. Freshw. Res. 41:663–678.

Weber, M. L., and **S. V. Fordham**. 1997. Managing shark fisheries: opportunities for international conservation. TRAFFIC International and Center for Marine Conservation, Washington, DC.