CHAPTER 9

Sharks

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I. INTRODUCTION

Despite the fact that sharks constitute an important fishery resource world-wide, there are few well-documented fisheries that specifically target them, or in which sharks constitute an important by-catch. The annual world-wide commercial catch of shark-like fishes (including sharks, rays and chimaeras) rose from 627,245 tonnes (t) in 1981 to 655,700 t in 1987 (FAO, 1989). Of the 1987 total, 129,572 t were named species of shark and 327,501 t were classified as 'elasmobranchs' but presumably consisting mostly of sharks, as skates and rays are generally reported separately. For individual shark fisheries, the north-east Atlantic piked dogfish (*Squalus acanthias*) fishery was by far the largest by weight, accounting for 46,975 t. Species of houndsharks (especially *Mustelus* spp.) accounted for 29,722 t and species of carcharhinid sharks 32,922 t.

Table I (overleaf) indicates the distribution of world catches of sharks for 1984-1987, the four most recent years for which data are available, broken down by FAO statistical areas for fisheries purposes.

However, the time series data available for commercial shark fisheries and shark by-catches are not reliable indications of the total removals from the sea. This is due to the high degree of under-reporting and non-reporting of discards from fisheries that do not specifically target shark but which nevertheless take large numbers for the production of dried shark-fin, in particular tuna longline, purse-seine and drift gillnet fisheries. In particular, catch by species data are very inadequate. The FAO statistics may therefore be considered minimal figures at best, and as such only indicators of trends in world production.

Most commercial shark catches are taken either on or near the edge of continental shelves and around islands, although some species are truly oceanic-pelagic. For the western central and south-west Pacific, the area served by the South Pacific Forum Fisheries Agency (FFA), commercial shark catches totalled 55,479 t in 1987, representing around 12 per cent of the world total reported for that year. The FFA region is therefore currently of relatively minor importance in terms of contribution to world shark production.

Major fishing nations active in shark fishing worldwide are from Asia (India, Thailand, Taiwan, Japan and Korea) and Europe (France, Spain, Norway, CIS,

Table I. Geographical distribution of world shark catches, 1984-1987, ranked by 1987 percentage contribution to total for that year.

Major fishing areas	FAO area no.	1984	1985	1986	1987	%
Western Indian Ocean	51	54,451	66,959	71,494	75,213	16.5
North-west Pacific	61	74,293	79,323	81,283	73,296	16.0
North-east Atlantic	27	54,994	57,150	54,276	60,534	13.2
Eastern Indian Ocean	57	44,499	38,863	42,317	49,655	10.9
Western central Pacific	71	41,892	43,178	44,341	43,902	9.6
South-west Atlantic	41	28,586	36,011	37,151	35,597	7.8
Western central Atlantic	31	26,275	23,305	23,054	22,708	5.0
Eastern central Pacific	77	28,278	25,520	24,379	22,564	4.9
Eastern central Atlantic	34	32,128	26,317	19,509	21,096	4.6
South-east Pacific	87	28,945	11,018	15,255	16,357	3.6
Med. and Black Seas	37	15,968	16,448	15,462	12,426	2.7
South-west Pacific	81	13,587	13,873	12,004	11,774	2.6
North-east Pacific	67	4,492	3,943	5,717	6,707	1.5
North-west Atlantic	21	1,743	5,457	3,725	3,804	0.8
South-east Atlantic	47	1,465	1,230	1,740	1,328	0.3
Total:		451,596	448,595	451,707	456,961	100.0

Source: compiled from FAO Yearbook of Fishery Statistics (FAO, 1989). Data include fish named as 'elasmobranchs' in catch figures, which may therefore include some rays and chimaeras.

UK). There has been a significant increase in sport fisheries for shark and consumption of shark meat in the USA since 1974, largely as a result of popularist films such as *Jaws* and its sequels (Compagno, 1990a). In many cases this has lead to over-fishing and concerns regarding the status of shark stocks. Several species of triakids, carcharhinids and sphyrnids are important in shark fishing for sport in the USA, England, South Africa, Australia and New Zealand (Compagno, 1988). In the USA, game fishing for sharks increased dramatically after the first *Jaws* film, especially off the Atlantic coast, and two species of carcharhinid, the blue shark *Prionace glauca* and the tiger shark *Galeocerdo cuvieri* are recognised as big-game species by the International Game Fish Association (IGFA, 1984). Several other species have been added in recent years.

However, few industrial scale fisheries specifically target sharks in the South Pacific. The largest in terms of annual catch is the south Australian fishery for school shark (*Galeorhinus galeus*) and gummy shark (*Mustelus antarcticus*), which until recently has produced around 5,000 t per year, but which is now considered over-exploited, and a small (around 500 t per year) fishery for carcharhinid sharks operating off northern Australia (Stevens, 1990). There is also a western Australian shark fishery currently worth around A$6 million with annual landings of approximately 1,600 t (1989-90). About 33 per cent of the catch is dusky shark (*Carcharhinus obscurus*), 22 per cent whiskery shark (*Furgaleus macki*) and 22 per cent gummy shark. The remainder includes mainly pencil shark (*Hypogaleus hyugensis*), other whaler sharks, hammerheads and wobbegongs.

New Zealand has a sizeable fishery for 'rig' (*Mustelus lenticulatus*) which lands between 2,500 and 3,800 t per year (Francis and Smith, 1988). Papua New Guinea has a small (probably less than 300 t per year) shark gillnet fishery operating within the Gulf of Papua, carried out by Taiwanese flag vessels operating under license.

Throughout the South Pacific region, sharks are commonly taken as a by-catch by commercial tuna fishing vessels using longline, purse-seine and, to a lesser extent, pole-and-line fishing techniques. In these fisheries, sharks are an incidental catch and only the fins are retained for sale as additional income for the crew, although in the longline fishery, occasionally shark carcasses are retained. In the Polynesian and Micronesian countries, and to a lesser degree in Melanesia, shark fishing is carried out at the subsistence level for domestic consumption of the meat and production of dried shark fin. Although catches are not substantial, and shark meat forms a minor part of the protein component in the diet of rural communities, sharks play an important role in providing income-earning opportunities for rural fishermen in the Pacific islands through the preparation of dried fins. Teeth and jaws are commonly sold as curios to the tourist industry. In many countries, sharks form an important part of island culture and customs.

II. BIOLOGY

Very few species of sharks can be described as biologically well-known. Even for relatively well-studied, commercially important species such as the European piked dogfish (*Squalus acanthias*), and New Zealand rig (*Mustelus lenticulatus*), many aspects of the life history and biology are not known. Shark research tends to be biased towards studying the biological and population parameters of species upon which commercial fisheries are based, and matters concerning shark attack on humans. Such applied research activities tend to be more likely to receive funding support than research into shark ecology and behaviour.

In general, sharks are difficult to age, they have a relatively slow growth rate (except when very young), and females tend to reach greater maximum lengths than males (Holden, 1977). The majority of commercially important shark species in the FFA region are ovoviviparous or viviparous, have a long gestation period and low fecundity. Shark species usually display sex and size segregation and females of some species may move inshore to give birth in selected nursery areas.

The characteristics of low fecundity, long gestation, slow growth, and often very localised movements result in many sharks populations being very prone to recruitment over-fishing (Holden, 1977; Okera *et al.*, 1981). This fact is becoming very apparent in almost all commercial shark fisheries, especially off the Atlantic and Pacific coasts of the USA, and in the Australian and New Zealand shark fisheries.

TAXONOMY

Modern taxonomy of fishes recognises four major divisions, or classes: Osteichthyes (bony fishes), Cephalaspidomorphi (lampreys), Chondrichthyes (cartilaginous fishes *ie.* sharks, rays and chimaeras), and Pteraspidomorphi (hagfishes). By far the greatest number of fish species, around 23,000, are found within the class Osteichthyes, with the Chondrichthyes forming the next most important group.

The class Chondrichthyes is a varied and relatively large group, comprising 51 living families, 165 living genera, and around 900 described species and possibly 1,100 known living species including undescribed taxa and species of uncertain validity (Compagno, 1990a).

Until recent years shark taxonomy was confused and in urgent need of comprehensive review, a state of affairs that has not helped fisheries workers in the field to identify sharks accurately. This has resulted in unreliable or misleading statistics relating to shark fisheries in the literature. Since the early 1980s there has been a marked increase in the knowledge of shark systematics; groups that were previously difficult to identify and those that were poorly known have been revised. Garrick (1982) reviewed, for the first time, the taxonomy of carcharhinid sharks on a circum-global level; Fourmanoir (1975, 1976) provided taxonomic descriptions and ecological notes on species of the genus *Carcharhinus*. A definitive work on sharks of the order Carcharhiniformes is given in Compagno (1988); a definitive review of all shark species is given in Compagno (1984a, 1984b).

The phylogenetic relationships of the shark orders both to each other and to the rays is currently in dispute, but the work of Compagno (1973) which describes the linear arrangement of orders and families is widely accepted by shark biologists. According to Compagno (1990a), the class Chondrichthyes is subdivided into two, unequally sized subclasses. The smaller of the two is the subclass Holocephalii (which contains the order Chimaeriformes, comprising 3 families, 6 genera and between 31 and 50 species of chimaeras, ratfishes, and elephantfishes). The second, much larger subclass Elasmobranchii contains the living sharks and rays, therefore the majority of cartilaginous fish species. For this reason, cartilaginous fishes are often referred to as 'elasmobranchs'.

The subclass Elasmobranchii is divisible into two morphologically distinct types: the Squalimorphea (sharks) and the Batoidea (rays, skates, guitarfishes and sawfishes). For sharks, currently 8 orders, 30 families, 100 genera and somewhere between 375 and 478 species have been described. By comparison, the Batoidea are a diverse and highly specialised group comprising 5 orders, 18 families, 59 genera and between 494 and 572 species.

The number of new species of squalimorphs and batoids being described each year is growing steadily (Compagno, 1990a). Of the described species of shark, the majority (around 55 per cent) are ground sharks of the order Carcharhiniformes, although the reasons for the dominance of this group amongst living sharks is not clear (Compagno, 1988).

The orders, constituent families and common English (or vernacular) names generally given to the type of shark found within each family are given in Table II (overleaf).

STRUCTURAL BIOLOGY

It is generally accepted that the sharks and their relatives diverged from the bony fishes as a distinct evolutionary line around 400 million years ago. All possess a skeleton consisting of cellular, partially calcified porous cartilage, a unique feature of the group, instead of true acellular bone of which the skeletons of all other classes of bony fishes are composed (Holden, 1977).

In general, sharks are relatively large compared to bony fishes, with an average maximum length of 1.5 m (Compagno, 1981). Few truly dwarf species occur. They are diverse in terms of morphology, ecological habitat and behaviour, being surpassed only by the bony fishes. They are specialist feeders, ranging from the small, ectoparasitic 'cookie-cutter' shark *Isistius* spp. which cuts round chunks of meat out of bony fishes (a common sight in tropical tuna fisheries where tuna often have round, bleeding wounds on their sides inflicted by 'cookie-cutters') and marine mammals, to giant filter-feeders, such as the whale shark *Rhincodon typus*. Sharks have between five and seven gill slits and a spiral valve intestine; they lack an internal gas-bladder (or swim bladder). Many species have nictating membranes, which are eyelids attached to the skin below the eyes, and cover the eyes to protect them during feeding.

For most pelagic sharks, positive buoyancy is achieved through the possession of a large, oil-rich liver, large, broad-based fleshy fins set at relatively fixed angles to provide lift while swimming, and continuous swimming behaviour. The large, low density liver emulates (though not entirely) the gas-bladder found in the bony fishes. Relying on a large oil-filled liver to provide positive buoyancy and relatively massive, set fins for swimming stability, the possible range of efficient body shape available to sharks conducive with a predominantly top predator life-style is limited. Hence the characteristic and immediately recognisable shark body shape has evolved as the most efficient form for hydrody-

Table II. The number of species in each order along with the percentage contribution of the order to the total of all known shark species, in parentheses (after Compagno, 1984a,b; 1988).

Order	Families	English name(s)
Carcharhiniformes (56%)	Scyliorhinidae	Cat sharks
(210+ species)	Proscyllidae	Finback cat sharks
	Pseudotriakidae	False cat sharks
	Leptochariidae	Barbeled hound sharks
	Triakidae	Hound sharks
	Hemigaleidae	Weasel sharks
	Carcharhinidae	Requiem sharks
	Sphyrnidae	Hammerhead sharks
Squaliformes (23%)	Echinorhinidae	Bramble sharks
(87+ species)	Squalidae	Dogfish sharks
	Oxynotidae	Rough sharks
Orectolobiformes (9%)	Parascyllidae	Collared carpet sharks
(32+ species)	Brachaeluridae	Blind sharks
	Orectolobidae	Wobbegongs
	Hemiscylliidae	Bamboo sharks
	Stegostomatidae	Zebra sharks
	Ginglymostomatidae	Nurse sharks
	Rhiniodontidae	Whale sharks
Lamniformes (4%)	Odontaspididae	Sand tiger sharks
(15+ species)	Mitsukurinidae	Goblin sharks
	Pseudocarchariidae	Crocodile sharks
	Megachasmidae	Megamouth sharks
	Alopiidae	Thresher sharks
	Cetorhinidae	Basking sharks
	Lamnidae	Mackerel sharks
		Porbeagles, White sharks
Squatiniformes (4%) (13+ species)	Squatinidae	Angel sharks, Sand devils
Heterodontiformes (2%)	Heterodontidae	Bullhead sharks
(8 species)		Horn sharks
		Port Jackson sharks
Pristiophoriformes (1%) (5+ species)	Pristiphoridae	Saw sharks
Hexanchiformes (1%)	Chlamydoselachidae	Frilled sharks
(5 species)	Hexanchidae	Cowsharks, Six-gill sharks, Seven-gill sharks

namic efficiency. Thompson and Simanek (1977) recognise four basic body patterns in sharks, based on swimming behaviour and caudal fin morphology:

a. generalised species, typified by members of the family Carcharhinidae;
b. high-speed pelagic species, with fusiform bodies and crescentic caudal fins, such as members of the family Lamnidae;
c. demersal sharks with low caudal fins, such as members of the family Scyliorhinidae; and
d. squalimorph sharks, with enlarged epichordal caudal lobes and no anal fin.

Strong jaws are a feature of the group, with transverse replicating rows of teeth. The teeth are modified dermal denticles that are not fixed in sockets but attached to a band of tissue which grows forward, the teeth at the rear thus becoming erect and functional as they move forward to replace the older, worn teeth at the front, which are then shed, in a perennial system of replacement. Shark teeth display a great variety of size and shape. In general, triangular, serrated, blade-like teeth occur in species that feed by cutting pieces away from large prey; multicuspid teeth occur in species that catch and masticate 'bite-sized' prey; and flat, nodular teeth are found in multiple rows in species that feed upon hard-shelled crustaceans and molluscs. In the plankton feeders, *e.g.* the whale shark (*Rhincodon typus*) the teeth are minute and functionless; filter feeding on plankton being achieved by straining water through highly modified gill arches.

The pectoral fins of sharks are not attached to the head as in bony fishes, and the gill slits are located on the sides behind the jaws, usually anterior to the pectoral fins. Chondrichthyian scales consist of small tubercles, or dermal denticles, called placoid scales, rather than the large, overlapping discs found in the bony fishes. The denticles are structurally very similar to mammalian teeth and give a rough texture to the skin when stroked towards the head.

SENSORY PERCEPTION

All Chondrichthyians possess acute senses. Sharks in particular have well-developed eyes, but excel in their non-visual senses, particularly auditory capabilities, olfaction, electroreception, taste, and hydrostatic receptors for depth determination. The development of the various senses varies greatly between species, but generally speaking olfaction probably operates over the greatest range, then the acoustico-lateralis system, then vision and finally electrical detection.

The acoustico-lateralis system consists of lateral-line pores on the lateral flanks and head, pit organs on the back and an inner ear, which facilitate the detection of low-frequency sound and low-pressure vibrations in the water over great distance and in low light conditions. A sense of taste is provided through the possession of sensorial pits inside the mouth, which allow the shark to reject distasteful items of food. Research into feeding behaviour of sharks and rays has demonstrated an ability to detect the very weak electrical fields generated through muscular activity in living organisms. This ability is of particular importance in foraging in bottom feeding sharks and rays. Hodgson (1987) describes the highly developed chondrichthyian senses as providing a multidimensional and integrated synergistic 'picture' of the underwater world in which they live, which is particularly appropriate to a predatory life-style.

HABITAT AND ECOLOGY

Sharks are primarily marine organisms, the vast majority of species being truly marine with only superficial or peripheral affinity to fresh water. However, a number of species readily enter brackish to almost fresh estuaries, lagoons and bays; a few species of the family Carcharhinidae (*e.g. Carcharhinus leucas* and *Glyphis gangeticus*) occur far up rivers and in fresh water lakes with connections to the sea. Sharks are common in most of the habitats in which they occur and are predators at all levels. Their highly developed senses, swimming capabilities and feeding mechanisms make them highly competitive with other marine animals occupying similar predatory niches.

The distribution of a number of species of far-ranging shark are not known with any great certainty. This is especially the case in the western Pacific and Indian Oceans. Sharks inhabiting the continental slopes are generally poorly known for much of the world, and deep-dwelling species may well be more widespread than is currently known (Compagno, 1984a). As mentioned previously, past misidentification of shark species has compounded the problems of accurately determining the range of individual species.

Although they are restricted to some extent in their ecological roles by morphological, reproductive and other factors, the living cartilaginous fishes show a great array of alternative life-history styles. Compagno (1990a) describes at least eighteen different Chondrichthyian ecomorphotypes. The vast majority of chondrichthyian species are truly marine; only around 5 per cent, all of which are batoids (freshwater stingrays) exclusively inhabit freshwater, and occur in African and Asian rivers and lakes (Compagno and Roberts, 1982). Some large species of carcharhinid sharks occasionally move far up freshwater river systems in tropical and warm-temperate areas, but do not remain there for extended periods (Compagno, 1990a).

On a global basis, 55 per cent of chondrichthyians inhabit the continental shelf area from the inter-tidal zone to a depth of 200 m. Species diversity for these neritic species is greatest in the tropics and sub-tropical areas. Around 35 per cent of species inhabit the continental slope areas between 200-2,000 m, and a very small number of species (2 per cent of the total) inhabit epipelagic and mesopelagic oceanic waters (Compagno 1990a). Eight per cent of chondrichthyian species have a 'mixed' range of habitats covering shelf-slopes and shelf-oceanic waters.

Within the South Pacific region, the most commonly encountered sharks on reefs and lagoons, hence those which are most important in subsistence and artisanal catches, are members of the family Carcharhinidae, the requiem sharks. Common species of shallow water reefs throughout the South Pacific include the blacktip reef shark *Carcharhinus melanopterus*, the lemon shark *Negaprion acutidens*, and the whitetip reef shark *Triaenodon obesus*. In the near-shore waters of the high islands of Melanesia, species of *Rhizoprionodon* sharks are common, whereas more open lagoonal or neritic waters adjacent to areas with wide continental shelves have a shark fauna including *C. limbatus, C. tilstoni* and *C. sorrah*. In deeper waters off coral reefs, the grey reef shark *C. amblyrhynchos* and silvertip whaler *C. albimarginatus* are found. Larger species, including the tiger shark *Galeocerdo cuvieri*, bull shark *C. leucas*, and Java shark *C. amboinensis*, as well as several species of hammerhead shark (*e.g. Sphyrna lewini* and *S. mokarran*) also inhabit these waters.

More oceanic, offshore waters are the preferred habitat of the silky shark *C. falciformis* and mako shark *Isurus oxyrinchus* (McPherson, 1988). The oceanic whitetip *C. longimanus* and silky shark *C. falciformis* are distributed between 20° latitudes North and South. In the Pacific, these species form an important element in the by-catch of commercial longline, purse-seine and troll fisheries. The high quality of the Mako sharks, especially the short-fin mako *Isurus oxyrinchus* makes them an important by-catch in tropical tuna longline and gillnet fisheries. Mako sharks are also important to sport fishing in Vanuatu, Papua New Guinea and Fiji due to the highly energetic performances given once the fish is hooked. The thresher sharks *Alopias vulpinus, A. superciliosus* and *A. pelagicus* are widely distributed species in temperate and tropical waters and form an important part of Japanese and CIS longline fisheries in the North Indian Ocean and the Central Pacific. Other species of significance in the longline by-catch include the crocodile shark *Pseudocarcharias kamoharai*, and the tiger shark *Galeocerdo cuvier*, especially near continental shelves.

Another shark of commercial importance is the blue shark *Prionace glauca*. This species has a circumglobal oceanic distribution in temperate and tropical waters and is considered the most abundant shark in open ocean habitats, in the eastern Pacific and the Atlantic (Litvinov, 1989). It is caught in the North Pacific as a by-catch in the drift-net fishery for giant flying squid, where it becomes entangled in the nets while preying on the enmeshed squid (Garcia and Majkowski, *in press*). It is also widely caught throughout the Pacific by hook and line, and in pelagic and bottom trawls. This species represented the bulk of the 7,000 t per year shark landings in Japan in the early 1970s, a significant proportion of which was taken in the South Pacific (Gulland, 1971).

Also of interest in the South Pacific is the whale shark *Rhincodon typus* which attains a length of 18 m, thus is the world's largest fish. This highly migratory species is distributed between 30° North and South latitudes and feeds exclusively on plankton and small pelagic fishes. This shark is never taken by longlines, although it is actively fished with pelagic gillnets and harpoons in Senegal, Pakistan, India and Taiwan. Another filter-feeding giant, the basking shark *Cetorhinus maximus* is heavily fished in the Pacific around the coasts of China and Japan. It has been reported that fisheries based on this coastal-pelagic species are never sustainable (Garcia and Majkowski, *in press*).

REPRODUCTION

Unlike bony fishes, all chondrichthyians exhibit internal fertilisation of the egg. Sperm is transferred through the insertion of one of a pair of ventrally positioned claspers of the male into the genital atrium (or cloaca) of the female.

In sharks, the claspers (or mixopterygia) are paired, grooved extensions of the posterior bases of the pelvic fins, which are designed to remain anchored within the female during copulation (Compago, 1988). They receive sperm from the urino-genital papilla and act like hypodermic syringes, injecting sperm into the female's genital apertures during mating. During courtship in some species, the male clasps the female behind the head with his jaws and pectoral fins and twists his body around the female in order to bring the claspers into position. This leads to mating scars or 'love-bites' seen around the head and body of mature specimens. Courtship in sharks, where known, is complex and may contribute to the extreme rarity of inter-specific hybridisation (Compago, 1990a).

Female sharks produce large, densely yolked eggs which undergo direct development. New born sharks are like miniature adults, and thus are highly precocial and ready to fend for themselves. Three distinct forms of reproductive strategy are seen in the sharks and rays, differing primarily in the mode by which nutrients are derived by the developing embryo; these are oviparity, ovoviviparity and viviparity. In the latter two forms, the young are born alive and are highly precocial.

Egg-laying sharks and rays are termed oviparous. These include the skates (Rajiidae), bullhead sharks (Heterodontidae), cat sharks (Scyliorhinidae) and some species of carpet and nurse sharks (Orectolobidae). In oviparous species, the embryos develop inside a leathery cased egg which is laid on the sea bed and is usually attached to seaweed or some other benthic material.

In most sharks, however, the developing eggs are retained within the body of the female, where they develop into embryos which are released as free swimming juveniles. The two forms of live-bearing in sharks, ovoviviparity and viviparity, differ in the mode of nutrition of the developing embryo: in ovoviviparous sharks, the embryo is initially nourished by the egg yolk, enclosed within a thin egg capsule. When the yolk is exhausted, the embryo ruptures the thin capsule and then gains sustenance from the nutritive secretions of the surrounding uterus. Unfertilised eggs within the uterus may form a food source for the developing embryo in some species of shark. The majority of shark species are ovoviviparous and include species of the families Hexanchidae, Carcharhinidae (one species), Isuridae, Alopiidae, some species of the Triakidae and Squalidae and most of the families found in deep water habitats.

In the viviparous sharks, the early development of the embryo follows closely that of ovoviviparous species. After the egg capsule is ruptured, the yolk sac is retained after all the yolk has been absorbed from it. The yolk sac has a well-developed blood system. This becomes closely associated with the highly vascularised walls of the uterus, to form a structure which is similar to the mammalian placenta. Viviparous shark species are found in the families Sphyrnidae, most of the Carcharhinidae and some species of the Triakidae. The large, well-developed juveniles (commonly called pups) to which most species of shark give birth are capable of swimming and feeding almost immediately when they are born.

Compagno (1990a) proposes six distinct types of chondrichthyian reproduction. These range from primitive forms of extended oviparity (where large eggs are fertilised within the oviducts, enclosed within a keratinous egg case which is then laid on the substrate), through retained oviparity (where the eggs are retained and only laid when development of the embryo is advanced) and yolk-sac viviparity (analogous to ovoviviparity), to three forms of 'derived viviparity', where live, precocious young are born. He notes that reproductive modes are not strongly correlated with ecomorphotypes or phylogeny in living elasmobranchs.

What little research that has been carried out on the reproductive biology of sharks within the FFA member countries is limited to Australia and New Zealand. An example is the comprehensive study carried out by Stevens and McLoughlin (1991), who describe the distribution, reproduction and diet of 17 species of shark from northern Australian waters. From this work, four reproductive strategies were apparent.

First, in most species reproduction is strongly seasonal, with females reproducing each Austral summer after 9-12 months gestation (*e.g.* many species of *Carcharhinus*). A second group is similar but reproduces every second year on a biennial cycle, *e.g. Hemipristis elongatus, Carcharhinus macloti, C. plumbeus, Sphyrna mokarran*. A third group reproduces annually but throughout the year; these are small (maximum total length 100 cm) bottom dwelling sharks, *e.g. C. dussumieri, C. falciformis, Loxodon macrorhinus* and *Rhizoprionodon acutus*. A fourth group (comprising a single species, *Hemigaleus microstoma*) reproduces twice each year after 6 months gestation (biannual cycle). Size at birth varies from 27-75 cm and litter size from 2-34 pups. Average size at maturity was calculated at around 70 per cent of maximum size. These authors found a positive correlation between size at which females mature and total litter size, possibly due to the increased carrying capacity of larger sharks and age of sexual maturity.

FECUNDITY

Sharks produce relatively few offspring at a time, after a lengthy gestation period. The relatively low fecundity results in shark populations being particularly susceptible to recruitment over-fishing, where spawning stock biomass is reduced to such a low level that recruitment is significantly reduced. Some species do not breed each year. The number of eggs or pups produced per year ranges from 1 or 2 to a maximum of 135 pups in the blue shark (*Prionace glauca*). Most chondrichthyians probably produce fewer than 50 eggs or young per year, and many produce fewer than 20 per year. Gestation periods of live-bearing sharks may range from 6 months to 2 years or more; young from egg cases may hatch in under 2 months to over a year (Compagno, 1990a).

Francis and Mace (1980) report that the number of eggs produced per litter in *Mustelus lenticulatus* in New Zealand increases with length of the female. The most eggs found in one female was 24, with an average of around 11. The gestation period for this species is 11 months.

Stevens and Lyle (1989) working on the biology of three species of hammerhead sharks in North Australia, found sexual dimorphism in size at first maturity. The usual size at maturity of male *Eusphyra blochii, Sphyrna mokarran* and *S. lewini* was calculated at 108, 150 and 225 cm total length, and for females 120, 200 and 210 cm, respectively. Breeding is strongly seasonal in these commercially important North Australian sharks. *Sphyrna mokarran* and *E. blochii* give birth between January and March, after a 10-11 month gestation period. *S. lewini* has a more extended breeding season, and a gestation period of 9-10 months. Mean litter size ranges from 12 in *E. blochii*, 15 in *S. mokarran* and 17 in *S. lewini*. These authors indicate that *E. blochii* females breed every year, but *S. mokarran* females breed every other year.

There is a trend in sharks for larger species and large individuals within a species to produce more young than smaller sharks of the same species or smaller species. Compagno (1988) shows that a survey of litter sizes in 52 species of viviparous hemigaleids, carcharhinids and sphyrnids showed a strong general trend, roughly linear, of increasing litter sizes with increasing size of female shark.

GROWTH

Sharks are generally slow-growing, long-lived and may take from 3 or 4 years to over 20 years to mature (Compagno, 1990a), although *Rhizoprionodon* *taylori* probably matures in its first year in Australian waters (J. Stevens, *pers. comm.*). The temperate and deeper water shark species are characterised by slow adult growth and late sexual maturity.

Methodologies used in shark growth studies include tagging experiments. Internal tags have been used in experiments to determine the growth and movements of the commercially important school shark, *Galeorhinus galeus*, in Australian waters. Recently two school sharks were recaptured after extended lengths of time at liberty after tagging: one shark, tagged internally and released by CSIRO in March 1953, was recaptured in October 1989, 75 km from the point of release south of Kangaroo Island, after a period of 36.6 years (SPC, 1990a). During this time, this male shark had grown 9 cm, from 144 to 153 cm and had been an estimated 13 years old at time of release. Australian Fisheries magazine (May 1991) reports that a fisherman in Victoria, Australia, netted a male school shark off north-west Tasmania after 42 years at liberty. The shark was tagged in 1949 by CSIRO and released at Otway Bank, Victoria. Its point of recapture was 194 km away. The shark was estimated to be around 55 years of age and had grown 4 mm per year since it was tagged. These cases emphasise the typically slow adult growth rate which is a characteristic of most shark species.

Growth has also been determined by plotting age (determined by reading growth rings on vertebral centra) against total length, and fitting the data to the von Bertalanffy growth formula. Using this approach, Chen *et al.* (1990) report fast growth in the early life stage of the scalloped hammerhead, *Sphyrna lewini*, in north-east Taiwan. Growth rates for females was faster than that calculated for males. Female growth rates were estimated at 63 cm in the first year, 23-50 $cm.yr^{-1}$ for years 2-5, and 3-19 $cm.yr^{-1}$ for years 6-13. Equivalent values for males were 54 cm in the first year, 22-42 $cm.yr^{-1}$ for years 2-5 and 11-18 $cm.yr^{-1}$ for years 6-8.

Growth strategies and maximum size reached appear to vary significantly between species. Davenport and Stevens (1988) found relatively rapid growth in the early stages of life for *Carcharhinus tilstoni* and *C. sorrah* from Australian waters. Olsen (1984) demonstrates strongly decreasing growth rates after maturity in *Galeorhinus galeus* and *Carcharhinus plumbeus*, suggesting that in some species of sharks, growth is indeterminate.

Compagno (1984b) reports that 80 per cent of carcharhinoid species fall within a maximum adult total length range between 25 and 175 cm, and that only 8 per cent of species in this order attain a size in excess of 3 m, 2 per cent exceed 4 m and 1 per cent (two species, *Galeocerdo cuvieri* and *Sphyrna mokarran*) reach sizes between 5 and 7.5 m. Springer (1960) suggests that the observed narrow size range of mature species of *Carcharhinus* indicates determinate growth, with growth ending after maturation. He found that most mature fish of *Galeocerdo cuvieri* and *Sphyrna mokarran* fall in a narrow size range, 2.0-

2.9 m for *G. cuvieri* females and 3.1-3.7 m for *S. mokarran* females. However, some individual females of both species grow well in excess of 4.5 m. It is not known whether such abnormally large fish have higher than normal growth rates while following a normal growth curve or if they continue growing at a high rate beyond maturity.

AGE AND SIZE AT FIRST MATURITY AND RECRUITMENT

Sharks generally reach sexual maturity at a greater age than is the case for most other fish species. Francis and Mace (1980) report a size at first maturity of 85 cm for female *Mustelus lenticulatus* in New Zealand waters, with males generally maturing at an earlier age than females. Earlier sexual maturation in males has also been described for *M. manazo* (Teshima *et al.*, 1971; Tanaka and Mizue, 1979). Chen *et al.* (1990) estimate age at maturity for *Sphyrna lewini* at 4.1 years (210 cm total length) for females and 3.8 years (198 cm total length) for males.

Unlike bony fish stocks, there is a clear relationship between stock and recruitment in sharks. Chondrichthyians produce relatively few young and the level of recruitment is largely determined by the time they are born. The regulation of fecundity in adult female sharks determines the relationship between stock and recruitment. Holden (1977) notes that this close relationship between adult spawning stock and recruitment is one of the reasons that make shark populations very susceptible to over-fishing.

NUTRITION

Fish forms an important component of the diet of the vast majority of sharks. Stevens and Lyle (1989) report that fish is the major component of the diet of hammerhead sharks (Sphyrnidae) in northern Australian waters. Cephalopods are important to a lesser extent in the diet of *Sphyrna lewini* and crustaceans in the diets of *S. mokarran* and *Eusphyra blochii*. *S. mokarran* is reported especially to favour stingrays and other batoids, groupers and sea catfishes (Compagno, 1984b). Clarke (1971) found large amounts of squid in the stomachs of adult *S. lewini* in Hawaii.

For a general review of shark nutrition, see Compagno, Ebert and Smale (1989), Springer and Gold (1989) or Moss (1984).

III. PACIFIC REGION FISHERY INFORMATION

SHARKS IN TRADITIONAL BELIEFS AND FOLKLORE

Sharks form an important role in the culture and folklore of many South Pacific island states, and amongst the Aborigines of Australia, where they appear in carved form. Shark worship is common in the Melanesian islands, especially Solomon Islands and Papua New Guinea, where a number of cultures believe sharks to be the living embodiment of the souls of deceased ancestors. Although the cultural importance of sharks in the island countries may out-weigh their value as a food source, there is a paucity of documentation on such matters.

In Fiji, a legend is told of Dakuwaqa, a mythical, 40 feet long shark which could lift boats out of the water. The peoples of Polynesia have built up a mythology in which sharks, shark-gods and beings in whom the features of sharks and men are combined (Whitley, 1940). Shark worship has traditionally been a common feature in Solomon Islands and continues to this day in some islands. Whitley (1940) states that shark worship was formerly prevalent on the islands of Malaita, Ulawa and Makira and continues to this day. Shark worship on these islands may be divided into 2 classes: sharks associated with ancestors, where sharks are worshipped and considered harmless by the worshippers, and 'wild' sharks, wherein the shark is not 'owned' by anybody, not being incarnations of ancestors, and will attack anyone. Altars dedicated to the worship of sharks were common in coastal villages in these islands of the Solomons in pre-christian times. These altars were uniformly composed of a ring of coral stones gathered from the shore and placed beneath a large tree on the shore. In the sea nearby would be an underwater cave in which the sharks were believed to live, and victims would be first strangled then thrown into the sea near the cave by those who wished to employ the sharks' services.

Traditional shark worship in the Solomons is based on the belief that at death the souls of certain men inhabit the bodies of sharks, or rather, after death certain men actually become sharks. Two shark altars at Manu Au are described by Whitley (1940): one at the waters edge and the other a short way up a hill. The shark ghosts worshipped at the first altar were ghosts of men belonging to the village; the ghosts worshipped at the second altar were those of women members of the family who had died, and were believed more potent for magical purposes than male ghosts. According to local belief, shark worshippers are able to bring about the death of people through black magic. For example, a piece of flint is charmed by an appeal to the sharks, then is inserted in a coconut and left to drift at sea. Any person attempting to pick the floating nut up from a canoe would supposedly suffer from having his hand or arm torn off by a shark.

In Vanuatu in past times, the 'festival of the shark' was held once every year, lasting for about a week. The body of a shark was placed in a shallow grave which was adorned as an altar. An artist painted the figure of a shark on the grave with white pigment, and this would be constantly guarded for a time.

The much sought-after *pounamu* or greenstone of New Zealand was believed by the old Polynesians to have been generated inside a shark and at that time was quite soft, only hardening upon exposure to air. A similar legend concerning the origin of jade from fish occurs in China.

In the Line Islands of Kiribati, the shark plays a leading role in mythology, where it is believed that of all the fish spirits, *Noronikantan te antin te bakoa* (the Shark-Spirit) is most important. The people of Kiribati have in some parts traditionaly credited the shark with intelligence equalling man's.

TRADITIONAL FISHERIES

Although subsistence and small-scale commercial fisheries for sharks exist throughout the South Pacific region, they are poorly documented. Gudger (1927) provides a general description of shark fishing in the Pacific islands using traditional, carved wooden hooks and vine lines, before the advent of modern steel hooks and monofilament. The commonest gear employed in recent times includes shark hook and line and pelagic gill nets. In the Melanesian islands, traditional methods such as a noose and rattle are employed, especially in Papua New Guinea and Solomon Islands. The shark is attracted to the canoe or other fishing platform by rhythmically shaking the rattle underwater, and is lassoed around the tail or head once it comes close enough to the fisherman (Rubel and Rosman, 1981). Bataille-Benguigui (1981; 1986) describes a similar method of traditional shark fishing in Tonga, using a lasso to catch sharks by the tail once attracted to the canoe.

In Tokelau, shark fishing is generally carried out by older men who use nylon lines with wooden floats and shark hooks, fished from canoes anchored on the reef and made to drift over deeper water. Eels are considered excellent bait. The last quarter of full moon is considered the best shark fishing time, and fishing is carried out after dusk. Catches of up to 50 sharks a night are taken by some fishermen (Hooper and Huntsman, eds., 1991).

In many South Pacific island countries, the development and emplacement of Fish Aggregating Devices (FADs) have developed rapidly over the past ten years, both for commercial purse-seine and pole-and-line operations and for enhancing the catches of artisanal fishermen operating within a few miles of shore. As efficient fish aggregators, FADs also tend to attract large populations of sharks, especially oceanic whalers, makos and whitetips. This increases the opportunities for artisanal fishermen to exploit these shark concentrations, primarily for shark meat and fins (Lewis, 1985). Vertical droplines, often buoyed as single lines with a single baited hook, short gillnets and slow trolling with artificial lures or rigged deadbaits are the most common fishing techniques used in association with FADs.

For a number of years, the South Pacific Commission has been assisting Pacific island countries to develop deep water (generally greater than 150 m depth) fisheries for snappers and groupers using vertical longlines. Through such activities, the exploitation potential of deep-water sharks for squalene oil production has become known. Among these, species of spiny dogfish of the genera *Squalus, Centrophorus, Centroscymnus* and *Deania,* and the six and seven gilled sharks (*Hexanchus* spp., *Heptranchias* spp.) present considerable potential. A small commercial fishery in Solomon Islands currently exploits deep-water sharks for the production of shark liver oil.

COMMERCIAL SHARK FISHERIES

The largest industrial shark fisheries that have operated adjacent to the FFA region are those active in the waters of the two metropolitan member countries of FFA: Australia and New Zealand. Taiwanese shark gillnetters operated in the northern waters of the Australian Fishery Zone (AFZ) up until 1986, and Australian vessels are now active in the fishery. In addition, there is a sizeable shark fishery currently active in the southern waters of the AFZ, and in the waters of western Australia, although this latter fishery is not considered here. A commercial shark fishery also exists in New Zealand.

The largest commercial shark fishery operating within the waters of a FFA island nation is the Taiwanese gillnet fishery of the Gulf of Papua, Papua New Guinea (Chapau and Opnai, 1986).

AUSTRALIAN COMMERCIAL SHARK FISHERIES

The commercial shark fisheries operating in the AFZ are the largest for any of the FFA member countries and, along with the New Zealand commercial shark fisheries, one of the best documented.

Currently, approximately 90 per cent of all shark landed from East and northern Australian waters is consigned to the Victoria market, with small consumption in the home states. Most sought after species include gummy shark *Mustelus antarcticus* and school shark *Galeorhinus galeus*, primarily for the 'fish and chips' trade (Welsford *et al.*, 1984).

The southern shark fishery: At its height, the southern Australian shark fishery landed around 5,000 t of shark per year, worth around A$20 million, but in recent years catches have fallen dramatically to around 1,000 t per year. Principal species are the gummy shark *Mustelus antarcticus* and school shark *Galeorhinus galeus*, which are marketed primarily for the 'fish and chips' trade (Walker, 1988; Anon. 1989; Stevens, 1990).

The south-east shark fishery dates back to the late 1800s, when school shark were exploited for liver oil. During the 1920s demand for shark meat for human consumption increased, especially in Melbourne, with prices reaching a peak in 1949. The fishery, based mostly on school shark, expanded rapidly using 10 km longlines fishing several hundred hooks (Stevens, 1990). A decline in near-shore catch rates during the 1940s resulted in fishermen moving to offshore grounds. Monofilament nets were introduced in the mid-1960s, which rapidly became the major gear used. As a result, gummy sharks increased in proportion in the catch. Strict mercury regulations were introduced which decreased the acceptability of large school sharks for human consumption. The fishery peaked in 1969 with landings of around 3,800 t. Mercury regulations resulted in a drop in catches to around 1,800 t in 1978. Current landings are around the 1969 levels.

The northern shark fishery: Australia's other major commercial fishery for sharks lies in the tropical waters off northern and north-western Australia, and due to its closer proximity is perhaps of more direct interest to the FFA region.

Commercial fishing for sharks began in northern Australian waters in 1974, when Taiwanese gillnetters began operations. Between 1975 and 1978, average catches were over 17,000 t, with sharks representing 70 per cent of total weight (Walter, 1981), although tuna (*e.g. Thunnus tonggol*) and Spanish mackerel (*Scomberomorus* spp.) were also target species, the catch being landed in Taiwan. Two carcharhinid sharks, *C. tilstoni* and *C. sorrah* accounted for 55 per cent of catch by weight (Stevens, 1990). Taiwanese gillnet catches reportedly peaked at over 20,000 t in 1978, although some of this may have come from waters now within the Indonesian 200 mile fishing zone (Lyle and Timms, 1984).

The Australian Fishing Zone was declared in November 1979, and the Australian Government imposed management measures on the northern shark fishery, including restriction of Taiwanese gillnetting to specific offshore areas within the AFZ, closure of the area within 15 miles of the coast and a catch quota of 7,000 t processed weight of shark (Branford, 1984). This was further reduced to 6,000 t annually in 1985, due to concern over dropping catch per unit of effort (CPUE) for sharks in the fishery, and increasing involvement of Australian vessels in the fishery (Lyle, 1987).

Interest in developing shark fisheries for Australian interests in the early 1980s prompted a number of fishing research surveys using pelagic gillnets and longline gear. Lyle and Timms (1984) describe exploratory fishing results using commercial size gillnets of 1,200 m length and longline gear in Northern Territory waters. Gillnet trials were designed to test for selection between mesh sizes. Sharks accounted for 86 per cent by numbers and 96 per cent by weight of total catches. Of 15 species of shark taken, the black-finned school shark *Carcharhinus limbatus* and *C. sorrah* accounted for 65 per cent of the shark catch. The main blacktip shark in the fishery was initially identified as *C. limbatus* but was subsequently found to be *C. tilstoni*. *C. limbatus* occurs in the area but in much smaller proportions (J. Stevens, *pers. comm.*). Gillnet catches at night were 2.3 times greater than those taken in the day, around 258 kg per net hour. The 150 mm stretched mesh net produced most sharks of market acceptability. Shark catch rates using longlines were poor, at around 8 sharks per 100 hooks.

This and other studies into the potential of developing shark fishing in Northern Territory waters all concluded that sharks existed in commercial quantities and that development prospects for a commercial shark fishery were promising (Puffet 1969, Church 1981, Lyle 1984a; Lyle 1984b; Stevens and Wiley, 1986; Davenport and Stevens, 1988). Commercial catch rate data, biological factors such as species composition, length-weight relations and size distribution of the populations, as well as market trials and mercury levels were determined. Subsequently, a small inshore gillnet fishery developed off the Northern Territory, which has spread to north-western Australia and northern Queensland. Landings fluctuate between 50 and 400 t annually, mostly of *Carcharhinus* spp. (Stevens, 1990). The fish from this fishery are marketed almost entirely in Victoria.

Catch composition of the domestic fishery is currently similar to Taiwanese catches, but inshore waters produce much higher catch rates. Analysis of the Taiwanese catch and effort data indicated a dramatic increase in effort to maintain catch rates; average net length increased from 8 km in 1979 to around 16 km in 1986, with effort doubling between 1982 and 1983. CPUE has declined from 16 $kg.km^{-1}.hr^{-1}$. in 1976 to about 7 $kg.km^{-1}.hr^{-1}$. Other signs of over-fishing included a steady decline in average length of the dominant shark species over the years.

During the mid-1980s, further management measures for the Taiwanese gillnet fishery included a ban in 1986 on pelagic gillnets over 2.5 km length, a measure which resulted in many Taiwanese vessels operating under foreign access arrangements leaving the northern shark fishery, due to such short nets being considered uneconomic for their operations, and the Taiwanese fishery closed the same year. The domestic Australian inshore fishery was unaffected. The Taiwanese gillnet fishery was followed by a Taiwanese longline fishery which took a very similar species mix. Annual catches of *C. tilstoni* and *C. sorrah* were reputedly nearly as high as in the gillnet fishery (J. Stevens, *pers. comm.*). The longline access agreement terminated in 1991 and that fishery has now also ceased.

With the Taiwanese access fishery gone, 80 per cent of the effort was removed, and it is hoped that stocks are rebuilding. No management measures are considered necessary at this time for the fishery.

In addition to commercial fisheries targeting sharks, sharks have for many years been landed in Northern Territory as by-catch from prawn and barramundi fisheries (Lyle and Timms, 1984). Landings peaked at 221 t in 1980-81, and landings in subsequent years have been around 40 t.

The New Zealand commercial shark fishery: The New Zealand commercial shark fishery is based on a small endemic species, *Mustelus lenticulatus*, commonly called rig, but also known as spotted smoothhound, gummy shark and dogfish (Francis and Smith, 1988). This species is closely related to the commercially important Australian gummy shark, *M. antarcticus*. In order to meet increasing market demand, mainly for consumption as fish and chips or retail as 'lemon fish', landings increased greatly in the 1970s to around 2,500-3,800 $t.year^{-1}$ between 1976 and 1985. This was achieved through the development of monofilament nylon set-netting, a highly efficient method for catching this species. Set-netting accounts for 80 per cent of commercial catches today. Trawling as a fishing method has declined markedly since 1977, having been replaced by set-netting.

The fishery is highly seasonal, with catches peaking during the Austral summer, between October and March. This seasonality is due to the annual inshore migration of rig. The reason for this spring-summer inshore movement is unknown (Francis, 1988), but is possibly to exploit the rich food resources to build up energy prior to breeding (Francis and Mace, 1980; Francis and Smith, 1988).

Analysis of CPUE has indicated that rig stocks are in decline in many parts of New Zealand (Francis and Smith, 1988). Francis (1989) indicates that high exploitation rates for adult rig has led to this decline in stocks; exploitation rates for rig over 90 cm probably exceed 30 per cent per year for females and 20 per cent per year for males. Evidence of stock decline has led to recommendations that commercial rig catches be drastically reduced (Francis, 1989).

Papua New Guinea shark fishery: Prior to 1980, sharks were caught incidentally in Papua New Guinea by coastal fishing groups, and either consumed locally or exchanged for garden products (Chapau and Opnai, 1983).

Commercial gillnetting for sharks in Papua New Guinea began as a result of favourable fishing trials during late 1976 and early 1977 carried out by a 150 grt Taiwanese gillnetter using a 3,440 m long, 14 m deep gillnet with 152 mm stretched mesh (Anon. 1990). Fishing was carried out in the west of the Gulf of Papua, around 30 km offshore.

In 1980, licenses were issued to a Taiwanese fishing company to commence commercial shark fishing using gill nets. Initially, five vessels operated during 1981, but this reduced to two in 1982. These two vessels, each 320 grt, 36 m long gillnetters, fished on average 9 km of 12 m deep gillnet with a stretched mesh of 178 mm.

The gillnet fishery for shark in Papua New Guinea today is carried out by two 320 grt Taiwanese gillnetters fishing with short gillnets of 1.6 km length, 6 m deep and 160 mm stretched mesh (Anon. 1990). The nets are suspended from buoys with the headrope 5-6 m below the surface, presumably to reduce the incidental catch of marine mammals and turtles, and fished around 20 km from shore. Setting starts around 4-5 am each day and the nets are hauled at around 9-10 am the same day, starting from the end of the net which remains attached to the vessel's stern during soak time. The short soak time and shorter nets facilitate quick retrieval of the gear and consequently a higher quality product. Product is intended exclusively for south-east Asian markets. Available catch figures are reproduced in Table III.

Data for this fishery are poor, due to incomplete or non-existent reporting of catches to the Papua New Guinea fisheries authorities. Reliable data are only available for 1981 and 1982 (Chapau and Opnai, 1983; Anon. 1982). The fishery yielded a total of 810 t of sharks in 1981 and 405 t in 1982; average catches rates were 1.01 $t.day^{-1}$ in 1981 and 0.80 $t.day^{-1}$ in 1982. The catch was dominated by the scalloped hammerhead shark *Sphyrna lewini*, which accounted for 40 per cent by weight. Pelagic species of bony fish, taken incidentally, were reported to account for around 8 per cent by weight.

Today, the vessels fish for 3-5 months before calling into Port Moresby for clearance and payment of levies on the catch before departing for Taiwan (Anon. 1990). Catches are dominated by sharks, which are reported to make up 80-90 per cent of the catch by weight. The remainder is made up of mixed pelagics, primarily barred Spanish mackerel *Scomberomorus commerson* and tunas. However, since 1980 inadequate data on the fishery does not allow accurate assessment of the proportion of valuable by-catch species. Due to the lack of catch data, catch rates are not known, but it is estimated that an average catch would be 48 t of shark and 15 t of by-catch, taken over 3 months (A. Richards, Fishery Biologist, Dept. of Fisheries and Marine Resources, Port Moresby, *pers. comm.*).

Table III. Export of shark meat from PNG to Taiwan, 1981-86.

	Production (t)	Value (Kina)
1981	470.9	117,712
1982	472.1	117,523
1983	80.0	20,000
1984	100.0	28,700
1985	110.0	101,750
1986	45.0	40,500

Note: 1986 figures January to May only.
Source: Wright (1986).

Sharks are gutted, finned, headed and blast frozen. By-catch species are blast frozen whole. Tariffs applying to the catch are 1.5 kina per kg for both shark trunks and by-catch.

The Taiwanese fishing interests involved in this fishery are now prohibited from using gillnets near the Torres Strait Protected Zone. The gillnet fishery of Papua New Guinea has recently come under scrutiny in light of recent moves throughout the South Pacific to take action against the practice of drift-net fishing in the region (Stewart, 1990). A number of recommendations for the fishery have been proposed including a moratorium on the issue of new licenses, a cost/benefit analysis be conducted, improved management, reporting and surveillance of vessel activities.

Recent newpaper reports indicate that a deep water fishery for squalene sharks is also being developed in Papua New Guinea (*Post Courier,* November 27, 1991). Two vessels were reported to be operating near the mouth of the Sepik River during 1991, with oil exports to Japan in the region of 15 t.

Commercial shark fishing in Solomon Islands:

Pelagic longlining: During 1984-85, a commercial company operated a single steel-hulled vessel (a converted Japanese longliner) to catch sharks in Solomon Islands, primarily for the production of hides for tanning into shark leather. Fishing occurred throughout the Solomon Islands archipelago; and with the approval of local government and customary reef owners, fishing was also carried out on the seaward side of islands in depths of between 50-150 m, where reef sharks were the target. In areas where provincial approval to fish reef-associated sharks was not given, fishing was carried out beyond 3 nautical miles of land, where water depths were generally in excess of 300 m.

The gear utilised was a pelagic longline, the mainline of which was some 15 km (9 miles) long, supported by around 70 floats. Between 340 and 380 hooks were fished at a time, attached to the mainline on branchlines. Bait comprised tuna heads obtained from a local tuna cannery. The gear was usually set at around 6 pm each day and hauled at 6 am the following day, with a soak time of around 12 hours. Catch rates varied greatly depending on area fished and distance from land, but about 60 sharks per night were usual, with a recorded maximum of 126 sharks. The vessel rested at anchor during soaks. Light floats were attached to the mainline in order to keep track of movements during the night. This method resulted in few by-catch species being taken, only occasional yellowfin tuna, marlin and sailfish being caught on more off-shore locations.

Sharks caught were generally 1-2 m length (15-62 kg weight range), with an average of 1.3 m. Larger species of shark were taken off-shore. The species composition of the catch varied depending on distance from shore. Overall, the commonest species taken in this fishery included grey reef shark *C. amblyrhynchos*, spot-tail shark *C. sorrah*, black-tip reef shark *C. melanopterus* and white-tip reef shark *Triaenodon obesus*. Other species which formed a significant proportion of the catch included silver-tip shark *C. albimarginatus*, hammerhead *Sphyrna lewini*, and tiger shark *Galeocerdo cuvieri*.

Primary utilisation of the catch was for production of hides and fins. Flaying of larger sharks with suitable skins was carried out on-board shortly after hauling. Carcasses were discarded at sea, because the refrigeration capacity of the vessel was only sufficient to keep the tuna head bait preserved. All skins produced were sold to US fish leather producers.

During 1984-85 the company caught a total of 190 t of sharks, and exported around 2,000 skins and 2 t of dried fins. In addition, approximately 10 t of salt dried shark meat were exported to Sri Lanka. An experimental arrangement whereby local fishermen were encouraged to catch sharks on customary owned reef areas then to sell them to the vessel, acting as a mother ship, was unsuccessful.

The company ceased longlining for sharks at the end of 1985, and now concentrates on the collection and marketing of bêche-de-mer, trochus and other invertebrate reef resources.

Bottom set deep-water longlining: An exploratory fishery for deep-water sharks commenced in Solomon Islands in 1987. A locally owned company operates a single 35 t, 19.5 m long fishing vessel, equipped for deep-water droplining and longlining. Fishing occurs over a period of 2 weeks either side of the new moon using approximately 5 bottom-set longlines baited with fresh tuna and fished in 500-1,200 m depth. The vessel currently fishes the waters known as Iron Bottom Sound, to the north of Guadalcanal.

Catch rates are reported to be around 250 sharks per day, principally *Centrophorus* spp. Once caught, the livers are removed and retained in containers on board the vessel. Due to the vessel's limited cold storage capacity, which is only sufficient for preservation of the bait, the shark carcasses are generally dumped at sea. However, some carcasses are frozen towards the end of a trip as space becomes available and marketed locally in Honiara, mostly to the Micronesian community for around SI$1.00 per kg.

Extraction of the liver oil is carried out at the company's shore base. Production to date has been approximately 10 t, (on average 2.5 $t.year^{-1}$), all of which has been exported exclusively to Japan, where it is reported to be of very high squalene content. Although this fishery has yet to reach economic viability, the company plans to expand effort through fishing more longlines and expanding fishing operations to the Western Province of the Solomons.

Oceanic longline fisheries: Sharks are taken as a by-catch in the oceanic longline fishery operating in the region. The longline fleets are composed of Japanese, Korean and Taiwanese vessels targeting deeper-swimming tunas. Sharks caught incidentally provide a substantial proportion of the world supply of shark fins, although actual catch statistics are scant (Garcia and Majkowski, *in press*). The meat is generally discarded once the fins have been removed, although some carcasses may be retained towards the end of a trip depending on freezer hold space.

The proportion to total fishing mortality contributed from incidental catches of sharks by longliners is unknown, but undoubtedly is significant. Wright

(1980) reports total catch for a 60 t Japanese longliner operating in Papua New Guinea waters to comprise around 11 per cent sharks (by number), consisting of mainly 4 species. At least 10 per cent of the tuna catch was discarded due to shark attacks. In some cases, sharks caught had one or even two hooks in their jaws from previous encounters with longline gear, indicating their high succeptibility to this method of fishing.

IV. UTILISATION

Sharks are unique in the fact that, in addition to the flesh providing a source of food for human consumption, all other parts of the body can be used to produce a range of products. In theory, the fins, meat, liver, skin, teeth and jaws all have a commercial value (except in a very few species). Shark meat constitutes a valuable source of protein for domestic consumption, and shark products provide a means for earning cash incomes from domestic tourism and foreign currency exchange. In the South Pacific, this is mostly achieved through the export of dried fins.

It is difficult, however, to achieve a commercial return from all parts of a shark in practice, because not all sharks are suitable for obtaining all products from one animal. High prices are generally paid for the meat of smaller size sharks, whose hides are too small to be used for leather. However, larger sharks produce premium prices for dried fin and skins for leather production, but the meat is of lower acceptability. In addition, larger sharks generally have higher mercury content, resulting in market resistance. Consequently, sharks are often not fully utilised, or processed in a wasteful manner due to poor processing techniques. Traditional, social or religious attitudes to handling and consumption of sharks throughout the South Pacific islands means that some body parts are retained in some communities while being discarded in others (Kreuzer and Ahmed, 1978).

In addition, it is difficult to process sharks commercially for both meat and skins simultaneously (King *et al.*, 1984). Immediate gutting improves the quality of the meat but when the skin is flayed, two 'sides' are produced rather than a whole skin. This is less acceptable to buyers of hides for leather production. Shark meat deteriorates rapidly after death, hence immediate chilling after capture is necessary to preserve meat quality. A time delay due to flaying the skin inevitably results in poorer quality meat.

Despite problems in processing, sharks offer considerable opportunity for small-scale village-based operations to derive a cash income. They constitute a resource that is particularly suited to fisheries development in the rural areas of the Pacific island nations, where shark populations are large but generally underfished.

Meat: Osmoregulation in sharks is dependant on maintaining high tissue levels of urea. This has important consequences in processing of the meat. In order for the meat to be acceptable for human consumption, proper post-harvest handling and preservation is essential. Early bleeding of the meat is important to remove the amount of urea in the flesh (Waller, 1978). Removal of the gills and internal viscera, washing and preservation (chilling, salting, etc.) should, as with any other type of fish, be carried out as soon as possible after capture. Assuming that processing occurs shortly after harvest, it is possible to use the meat of most species of sharks for human consumption. However, King *et al.* (1984) list four species that are considered mildly poisonous, only three of which are present in the general area of the western Pacific (Compagno, 1984a and b): the black-tipped reef shark, *Carcharhinus melanopterus*, a species commonly caught throughout the South Pacific region; the seven-gilled shark, *Heptranchias perlo*, and the six-gilled shark, *Hexanchus griseus*.

Immediate bleeding of the carcass, by cutting the tail and removing the viscera, reduces the amount of ammonia produced from the breakdown of urea in the meat. This ammonia is produced by the action of the enzyme urease, released by bacteria living in the abdominal cavity, on urea in the blood. Although the ammonia smell alone does not render the flesh inedible, it is one of the first signs of spoilage, therefore reduced quality. Greater elimination of urea can be achieved by soaking the carcass in a hypertonic salt solution or dilute organic acid.

Preservation through salting is a common way of preserving the meat in the South Pacific. Commonly used salting techniques include:

(a) dry salting: coarse salt is rubbed into the meat, cut into fillets of 2 cm thickness. This causes dehydration of the meat through osmosis, and the water is allowed to run away, resulting in a moisture content of around 25 per cent. This method, although cheap and easy, leaves the meat susceptible to insect attack and spoilage, as the meat is not covered by brine. Exposure to the air can also lead to oxidation of fats, resulting in rancidity and discolouration; and

(b) pickling: fillets are covered with salt and packed into water-tight containers, with additional salt spread between each layer. Water from the meat, drawn out by osmosis, forms a pickle. Pickling of the meat is usually complete within 4 days at tropical ambient temperatures.

Other drying methods, such as sun, wind and smoke drying, commonly employed to preserve other fish species, work well on shark meat and are practiced especially in the islands of Micronesia and Polynesia.

By far the most effective way of preserving shark meat is through chilling, using ice. Small sharks, once bled, gutted and washed, can be chilled at sea and landed to be sold fresh or frozen for further distribution. Icing tends to mar the quality of shark skin, thus larger sharks are usually skinned before the meat is chilled (King *et al.*, 1984). Freezing of shark, requiring substantial investment in freezing equipment, is usually only carried out in the region's commercial shark fishing operations of Australia and New Zealand, and in the Taiwanese gillnet fishery of Papua New Guinea. Small sharks from these fisheries are generally marketed as dressed frozen carcasses. Larger sharks are dressed and frozen as fillets or steaks. Best results for meat quality in whole dressed carcasses are obtained through blast freezers. Steaks and fillets can be frozen using plate freezers, glazed and stored at -30° C. The final quality of frozen shark meat is, as for other fish species, determined largely by the quality of the fillets or carcass prior to freezing; every effort must therefore be made by fishermen and processors to ensure that the shark is rapidly processed after catching to ensure high quality of the final product on the market (Waller, 1978).

World prices paid for shark meat are low compared with those of most other fish species (Preston, 1984). In addition, imports of shark meat to the industrialized countries often cannot exceed limits for mercury levels in the flesh. Acceptable mercury levels between 0.5 and 1.0 part per million are generally set, depending on the health regulations of the country concerned. Lyle (1984a), working on four species of *Carcharhinus* and three species of *Sphyrna* from northern Australian waters, has shown that mercury concentrations are highly dependent on body size and that males tend to have higher mercury levels than females at any given length.

Preston (1984) notes that testing for mercury levels in shark flesh is generally beyond the means of most Pacific island nations. This calls into question the viability of developing export industries based on shark meat, which gives a poor economic return due to low prices, and may be rejected due to mercury levels above accepable levels in the importing country. The development of home markets for shark meat may be the best option in the context of developing shark fisheries in the Pacific island nations.

Skin: The denticles in shark skin are physically and chemically very resistant and structurally very unlike the scales of bony fishes. They are heavily calcified with an extremely resistant coating of enamel, similar in fact to the structure of the mammalian tooth. In addition, shark skin has an unusual lamellar structure of collagen fibres onto which the muscle blocks are directly attached. These physical properties create particular problems in tanning the skin to form leather.

Shark skins are very susceptible to damage caused by extremes in temperature, microbial activity or acidity/alkalinity (pH value), but if correctly tanned, shark skin produces a leather which is superior in strength and durability to most mammalian leathers. The denticles, once removed, leave an attractive pattern that is unique to shark leather (King *et al.*, 1984). Skins that are for leather production need to be removed as soon as possible after capture; larger sharks tend to be selected for obvious reasons. As a rule of thumb, sharks smaller than 1.5 m are generally considered too small to warrant the costs associated with tanning.

Flaying the skin by a longitudinal cut along the back, prior to cutting the belly open, produces the most useful skins for leather production. The shark is usually supported by the tail at the time of flaying, and the skin cut away carefully from the back and around the body. Sharp knives are essential for a quality product and experience results in fewer cuts in the skin, which reduce its value. Furthermore, if the skin is pulled excessively during flaying, this will result in a stretched, misshapen hide which produces thin therefore weak leather.

Once removed, the skin is carefully scraped to remove excess flesh, washed, then soaked in fresh brine, which may contain a bactericide to arrest microbial spoilage. Curing of the skin, preferably by dry-salting, is carried out as soon as possible after flaying, usually ashore.

Tanning shark skin is similar to the process used for mammalian hides; an initial soak in water removes dirt and induces rehydration. This is followed by immersion in a very mild sodium sulphide solution to remove the thin epidermis. Trimming of the skins is usually carried out at this time.

Tanning is carried out using vegetable tannage, as this produces an attractive feel and shrunken grain appearance in the finished leather. Removal of the denticles (deshagreening) is the most difficult part of the process and is accomplished using acid. The relative ease of the deshagreening process varies between shark species.

Shark skin leather is in demand in the leather market due to its unique appearance, physical strength and resistance to abrasion. However, due to the problems associated with flaying the shark properly, tanners of shark skin are usually undersupplied with raw material. The complexity of the skin tanning process also results in very few successful commercial companies able to produce high quality shark skin leather. Consequently, shark skin forms a very minor part of the novelty leather market. However, there appears to be an increasing demand for fish skin leathers as consumers shy away from mammalian and reptilian leathers, taken from animals that are killed solely for their skins. Factors such as lack of technical information and expertise, the transitory nature of shark catches, species and size of sharks acceptable to tanners, the considerable problems associated with correct post-harvest handling of shark skins needed to produce a useful hide and the geographical isolation from skin buyers all restrict the potential for Pacific islands fishermen to realise an income from the exploitation of shark hides (SPC, 1990b).

Fins: Throughout the South Pacific region, the processing of shark fins provides a relatively easy opportunity for fishermen to supplement their cash income. The fins of the shark constitute the single most valuable asset of the body. Shark fins are thick, solid and relatively inflexible structures, unlike the thin membranous fins of bony fishes. They contain proteinaceous fibres of elastin and collagen, called fin needles, which are highly prized in Asian markets, in particular China, primarily for their use in the production of shark-fin soup. According to King *et al,* (1984), all fins are of some commercial value, with the exception of the upper lobe of the caudal fin in all species of shark, and all fins of the nurse shark (*Ginglymostoma cirratum)* and the pectoral fins of saw sharks (*Pristis* spp.). The fins of catsharks (Scyliorhinidae) are also reported to be of no commercial value, but species of this family of sharks are seldom caught in the Pacific islands (Trachet *et al.*, 1990).

The fins are generally cut from the fish immediately when it is caught, with as little meat as possible attached to the cut end. For this reason, a curved cut is made along the base edges of the fin needles, which are detectable through the skin. Best prices are paid for large fins, preferably kept together to form a set from an individual fish. The fins are carefully washed and scrubbed to remove dirt, slime and blood after removal from the shark. The fin sets are generally kept on ice and sold fresh to shark fin exporters, or sun-dried on board the fishing vessel if an immediate sale to exporters is not possible. Care is taken to keep dried fins from becoming wet again through rain. Sun-dried shark fins keep well in copra sacks, therefore are an ideal way for isolated fishing groups, lacking ice making facilities, to earn additional income from shark exploitation.

The commercial value of the fins is determined by the type and quantity of fin needles they contain, and thus is highly species dependent. Thus, species which are considered valuable include, in roughly decreasing order of value, hammerheads (*Sphyrna* spp.), makos (*Isurus* spp.), blue shark (*Prionace glauca*), white shark (*Carcharodon carcharias*), thresher sharks (*Alopias* spp.), whitetips (*Carcharhinus* spp.), tiger shark (*Galeocerdo cuvieri*), and most species of smaller sharks (King *et al.*, 1984). Fin size is an important determinant of fin value in all species. The larger fins (first dorsal, pectorals and lower lobe of the tail) are generally more valuable than the smaller fins (second dorsal, pelvics and anal fin). It is common for these smaller fins to be kept and processed only from larger specimens.

Shark fin exports by year for four FFA member countries for which data are available are presented in Table IV overleaf. The values given for exported shark fin each year are converted to 1991 US dollar equivalent of the national currency.

National fisheries administrations in the FFA region do not differentiate between fins produced as by-catch from commercial tuna fisheries and fins produced by artisanal and subsistence fishermen. As all four FFA member countries indicated have sizeable domestic commercial tuna fishing concerns, the majority of fins exported most likely come from shark by-catch taken by the commercial tuna fleets.

Shark liver oil: During the course of evolution, sharks have developed massive livers, which store large quantities of low molecular weight oil. The liver thus tends to increase the buoyancy of the shark by decreasing its relative density. In the bony fishes, this function is carried out by the swim bladder.

The liver oil of most shark species is rich in fat soluble vitamins, especially vitamins A and D. In the tropics, the liver oil of the deep-dwelling sharks, especially dogfish sharks (Squalidae), is generally a rich source of a hydrocarbon compound called squalene, which is used in the cosmetics and pharmaceutical industries. These dogfish mostly live at depths in excess of 200 m, and are generally small sharks, averaging 0.5-1.5 m in length. Their livers comprise up to 25 per cent of total body weight. Most species of the group are easily recognisable by the presence of a sharp spine found just anterior to each of the two dorsal fins.

Preston (1984) lists the following twelve species of dogfish sharks (Squalidae), all of which are found throughout the FFA region, which produce high quality oil with a squalene content of over 50 per cent:

Centrophorus atromarginatus	*Centroscymnus crepidater*
C. granulosus	*C. owstoni*
C. squamosus	
C. moluccensis (= C. scalpratus)	*Deania calcea*
C. uyato	*D. profundorum*
C. lusitanicus	*D. quadrispinosum*
Dalatias licha	

If well processed and relatively pure, shark liver oil can provide an additional source of income to rural fishermen in isolated island situations. As in the case of processing shark fins, the equipment required is minimal, and the product can be stored without refrigeration for extended periods.

For the production of high grade oil, the liver should be removed as soon as possible after capture. It is then sliced, chopped or, if possible, minced. There are a number of methods for removing the oil from liver tissue, involving heat, hydraulic pressure or digestion techniques utilising enzymes or alkali.

Probably the simplest method is to boil the liver gently to disrupt the cellular structures which contain the oil. The oil, once it rises to the top of the container, can then be skimmed off. Another method used is to place the chopped or minced liver on a sloping sheet of roofing iron in the sun, with a container at the bottom to collect the oil as it runs out of the liver.

To ensure high quality, the oil is passed through a fine sieve to remove liver particles, stored in an airtight container and kept cool and out of direct sunlight. Storage times can be extended by using anti-oxidants.

Other shark products: Throughout the South Pacific region, the jaws and individual teeth of sharks are sold as curio items to the tourist trade, especially in areas with both an active domestic fishery and thriving tourism, such as Fiji, Vanuatu and the Cook Islands. The teeth of species such as the tiger shark *Galeocerdo cuvieri*, which has attractively shaped teeth, are commonly fashioned into necklace pendants and earrings, in some countries using domestically

Table IV. Shark fin exports by year for four FFA member countries. Values indicated are approximate.

		Fiji	Solomon Islands	Kiribati	Vanuatu
1980	kg	53,700	n.a	1,100	10,700
	US$	272,260	n.a	14,570	59,950
1981	kg	41,600	n.a	900	14,000
	US$	213,300	n.a	11,500	71,520
1982	kg	14,500	n.a	1,600	5,000
	US$	73,540	n.a	23,010	25,910
1983	kg	7,700	n.a	900	9,000
	US$	41,650	n.a	13,800	47,220
1984	kg	8,000	n.a	3,000	22,000
	US$	43,260	n.a	37,580	46,000
1985	kg	10,820	n.a	1,800	11,000
	US$	73,140	n.a	26,840	70,570
1986	kg	8,320	n.a	1,100	5,000
	US$	57,020	n.a	16,870	15,170
1987	kg	6,330	4,456	1,000	n.a
	US$	29,960	53,770	12,270	n.a
1988	kg	n.a	2,073	1,200	n.a
	US$	n.a	40,990	13,800	n.a
1989	kg	n.a	4,931	2,000	n.a
	US$	n.a	n.a	32,210	n.a

Source: Annual reports, relevant national fisheries administrations. 'n.a.' denotes data not available.

produced gold, *e.g.* in Papua New Guinea and Solomon Islands. Production of such novelty items is small and of minor importance to national economies.

In Japan, shark ovaries are used to make a kind of fish paste called *atsuyuki*, and in Bangladesh the sun-dried stomach is considered a delicacy (King *et al.*, 1984). In addition, the pancreas is a potential source of insulin and proteolytic enzymes. Shark products also have important medical properties; shark cartilage is important in anti-cancer research, and the cornea of shark eyes are used for corneal transplants in humans.

V. REVIEW OF RESEARCH METHODOLOGY

To date, relatively limited attention has been given to shark resources by researchers and research funding authorities despite their success in the marine environment as top level predators. Chondrichthyian research has been concentrated on a small number of temperate species and to "elucidate the objectively minuscule phenomenon of shark attack on human beings" (Compagno, 1990a). Areas such as behaviour and ecology are poorly researched and presently have few active workers, despite the fact that shark fisheries in most areas are poorly studied, unregulated and often sub-optimally fished. Consequently, many shark populations are now facing similar overfishing problems that have caused so much popular concern for whales and dolphins in recent years.

Compagno (1990a, 1990b) asserts that public ignorance, hostility and indifference, often hyped by popularist documentaries and films such as *Jaws*, has resulted in the generally negative feelings for sharks held by the public at large. This has allowed the exploitation of shark resources to continue in many cases beyond sustainable levels without raising popular concern about the long-term viability of shark populations.

Biological and fisheries research into sharks in the South Pacific region has been carried out almost exclusively in the Australian and New Zealand commercial fisheries in response to concerns over the status of shark stocks and sustainability of commercial catches. In addition, a limited amount of work has been carried out in the region into shark attacks on humans.

In New Zealand, exploitation rates, seasonal movements in respect to reproductive cycles and stock distribution of rig (*Mustelus lenticulatus*) have been studied using tagging experiments (Francis, 1989; 1988). The high exploitation rates discovered, especially for adult-size classes in the predominantly set-net commercial fisheries, are thought to explain the steady decline in CPUE observed in several areas of New Zealand. Francis and Mace (1980) studied the reproductive biology of rig, King and Clark (1984) examined feeding habits, and King (1984) studied seasonal changes in female rig condition. Smith (1986) unsuccessfully attempted to differentiate rig populations using electrophoretic protein analysis, due to the low genetic variability of the rig stocks. Massey and Francis (1989) examined the length, sex and maturity composition of rig catches in Pegasus Bay, New Zealand, and discuss some aspects of the reproductive biology of this species.

Tagging experiments have also been conducted in northern Australian waters to determine stock structure, movements and growth rates (Lyle, 1987). Longline fishing trials were undertaken in waters off the Northern Territory in Australia to evaluate different fishing strategies and determine indicative catch rates (Lyle and Griffin, 1987). Lyle *et al.* (1984b) describe fishing research carried out in Northern Territory waters to evaluate the development of the shark industry using gillnets and longlines, while Lyle (1984b) analysed mercury concentrations in sixteen species of shark from Northern Territory coastal waters. Lavery and Shaklee (1989) investigated the population genetics of *Carcharhinus tilstoni* and *C. sorrah* in North Australian waters using starch gel electrophoresis on tissue samples and concluded that a single population of each species is present in these waters.

Behavioural studies on sharks have been conducted by a number of researchers in the FFA region, especially in regard to attacks on humans. Nelson *et al.* (1986) investigated agonistic behaviour in reef sharks at Enewetak Atoll in Marshall Islands using a submersible, and found that grey reef sharks (*C. amblyrhynchos*) were most aggressive towards the submarine. Attacks were positively correlated to the degree of 'cornering' the shark on the reef. All attacks appeared to be elicited as a response to the presence of an apparent predator in the form of the submersible, rather than for obtaining food. Nelson and Johnson (1972) investigated the response of five species of shark to low-frequency, pulsed sounds at Enewetak Atoll using an underwater hydrophone. Pulse intermittency contributed more to attracting sharks than pulse rate variability.

The fast growth of the early year classes of tropical Carcharhinid species possibly makes them suitable for length-based stock assessment techniques, but slow growth rates and difficulties associated with obtaining suitable sample sizes for adults would restrain this type of analysis. The generally high vulnerability of most of the shallow water, near-shore shark species in the region to a wide variety of fishing gear and techniques could facilitate abundance surveys through depletion fishing experiments (McPherson, 1988).

Ageing methods in sharks have been summarised by Schwartz (1983). Clarke (1971) studied the growth of scalloped hammerhead shark (*Sphyrna lewini*) in Hawaii by tagging tag-recaptured neonatal juveniles. Other studies on the growth of the scalloped hammerhead include Schwartz (1983) and Branstetter (1987) through analysis of vertebral rings. Holden (1974) used reproductive data including gestation period, maximum length, and length at birth of embryos to estimate growth rates in elasmobranchs, including sharks. Branstetter *et* *al.* (1987) used vertebral ring counts to analyse growth rates in the tiger shark, *Galeocerdo cuvieri*.

The early development of Papua New Guinea's gillnet fishery for sharks was fostered through a survey and research programme carried out by the Fisheries Department in association with Taiwanese commercial fishing interests (Chapau and Opnai, 1983). In addition to establishing the commercial viability of gillnetting for shark in Papua New Guinea, the survey provided useful data on species composition of shark populations in the Gulf of Papua, catch rates and other relevant fishery data. However, apart from determination of the composition of the catch, no biological parameters were described for individual species.

Apart from activities in Solomon Islands described previously, few other investigations into the commercial potential of sharks in the South Pacific island states have been conducted. Information is generally limited to export statistics of shark fins, and some anthropological accounts of the importance of sharks in island cultures. This is hardly surprising given the relatively minor role sharks currently play in the fisheries sector of these states. However, it would be useful for fisheries managers to improve data collection on current patterns of shark exploitation. Present levels of exploitation of shark populations in the South Pacific island states through the activities of subsistence and artisanal fishermen is unknown. Perhaps more important, the degree of mortality due to incidental catches taken by commercial tuna operations have not been assessed. Improving data collection for these activities would be a starting point to the determination of the health of shark populations in the South Pacific island countries and an assessment of their sustainable fishery potential.

VI. CONSIDERATIONS FOR FISHERIES

DEVELOPMENT AND MANAGEMENT

Sharks possess particular biological characteristics which render them especially susceptible to high fishing pressure, and as such, qualify them as a special case for management. As apex predators, they have few natural enemies. The biological characteristics of sharks - long-lived, slow growth rates, low fecundity and reproductive rates (some species do not reproduce every year), long gestation period, relatively large size at first spawning, and strongly density dependent recruitment - result in shark fisheries being particularly sensitive to over-fishing.

Holden (1974) outlined data requirements for assessing stocks of sharks, stressing that accurate assessment of growth and reproduction parameters are more critical for efficient stock management than for teleost fisheries. Holden (1977) states that on the basis of available case studies, the long-term sustainability of most commercially exploited shark fisheries is doubtful. Examples of collapsed shark fisheries, including the North Atlantic porbeagle shark fishery, the Californian soupfin shark (*Galeorhinus galeus*) fishery, the Scottish-Norwegian dogfish fishery, the South Australian school shark fishery, and the Pacific coastal shark fisheries in the USA emphasise the susceptibility of shark populations to over-fishing. Gulland (1971) suggested that the world potential for sustainable shark catches may be no more than a few thousand tonnes.

The fact that shark populations display a close relationship between adult stock and recruitment, unlike bony fishes, means that they have a low capacity to recover in the event of recruitment over-fishing. The period between birth and recruitment to the fishery is often even longer than the gestation period, consequently several years may elapse before the effects of recruitment over-fishing are noticed. Reduced spawning stock biomass is reflected in reduced recruitment and the effects of recruitment over-fishing and corrective management action may have a lag time of many years.

The dramatic increase in fishing pressure on shark populations in recent years in the waters of cosmopolitan nations around the Pacific rim is largely attributed to three factors: international trade in shark fins continues to produce high demand and prices; consumer demand for shark meat has increased due to highly successful marketing campaigns (in the USA), and relatively lower prices and greater availability (in Australia); and the growing popularity of shark fishing tournaments among recreational fishermen.

The traditional, rather morbid view of sharks as man-eating killers has been burned into the public consciousness by folk-tales, films, alarmist documentaries, news accounts and popularist literature. This ingrained paranoia may have allowed the seafood industry, particularly in the USA and Australia, to overfish a valuable food resource to the point of oblivion without public outcry; sharks do not invoke sympathetic emotions with the general public in the way other marine animals do. There are no conservation groups dedicated to the plight of sharks, although this situation may be changing.

In recent years, newspapers have carried numerous articles highlighting the plight of shark populations which are clearly being heavily over-exploited, especially in US, Australian and New Zealand waters. The *Los Angeles Times* (August 1990) reports that federal legislation is planned to protect heavily exploited stocks in the USA. *Time* magazine has also recently reported on the fact that many shark species are endangered. In its 4 March 1991 issue, an article entitled 'Are sharks becoming extinct?' states that commercial fishing in the USA is threatening stocks of thresher, mako and hammerhead sharks. US commercial shark catches increased from fewer than 500 t in 1980 to 7,144 t in 1989, largely due to an increased consumer demand for shark meat in restaurants. By 1990 commercial catches had decreased by 20 per cent, presumably reflecting diminishing populations.

During March 1991 a consultation attended by shark biologists, fishery managers and interested parties was held in Sydney, Australia. This was the first ever world conference on shark management and conservation. The main aim of the conference was to combat the long-standing 'image problem' sharks suffer and advocate appropriate management measures. The report of this meeting was published as a special issue of the Australian Journal of Marine and Freshwater Research (Pepperell, 1992).

The recent increase in awareness of the predicament faced by sharks in many industrialised fisheries world-wide has come when conservation issues are becoming increasingly more important in the minds of governments and the general public. The US commercial shark fishery exemplifies a classic case of poorly planned expansion and susequent decline in a commercial fishery. During the 1970s the US government financed promotional campaigns to encourage consumption of obscure but abundant fish species, including shark, hake and mackerel. This led to a remarkable increase in consumption of shark meat. The Pacific coast fishing fleet, recognising an increased demand for shark, developed drift-gillnet techniques, initially concentrating on thresher shark stocks.

By 1979 West Coast fleets were landing 4,900 t of shark, up from 385 t landed in 1976. Fisheries targeting thresher, leopard, mako, blue and Pacific angel sharks increased landings dramatically from 1976 to the mid-1980s, after which all declined sharply in a classic 'boom-and-bust' pattern. The shark fishing fleets off the West Coast moved from one species of shark to the next, as catch rates declined through over-fishing on each species. Increased demand has been matched with increased retail prices; thresher shark which sold for under US$2 per pound in 1976 had increased to US$7-8 per pound in 1991, similar to prices paid for other premium species such as salmon, halibut and swordfish. As a result, shark stocks off the West Coast have become severely over-exploited and are in urgent need of management.

In 1989 the US National Marine Fisheries Service announced that shark populations off the Atlantic (East) Coast were so over-fished that fishing would have to be reduced severely. A new Secretarial Shark Fishery Management Plan aims to bring 39 species of Atlantic and Gulf of Mexico sharks under federal management, divided into large coastal, small coastal and pelagic categories, with quotas and bag limits set for each. Key features of the plan are: a prohibition against removal of fins at sea; commercial quota of 3,050 t annually (a cut of 50 per cent from 1990 landings); a limit of two large coastal and pelagic sharks and five small coastal sharks per boat per trip for anglers; no sale of recreational catch; and a minimum size limit of 66 inches (167 cm) fork length for mako sharks. The plan has, however, been criticised because there is no provision for reducing mortality of sharks taken incidentally in other fisheries such as longlining and trawl fisheries. The plan for the Atlantic and Gulf coasts was scheduled to take effect from 1 October 1991.

However, no such plan exists for the West Coast Pacific shark fisheries; it has been left to the Californian State Government to manage these fisheries. Strong demand for shark continues to keep retail prices high and to maintain the incentive for fishermen to continue catching sharks.

Resource monitoring and assessment: In the New Zealand commercial rig (*Mustelus lenticulatus*) fishery, catches are strongly seasonal, peaking in spring-summer when rig aggregate in shallow coastal waters and drop off to a minimum in winter (Francis, 1988; Francis and Smith, 1988). These regular annual aggregations, which are most likely linked with the reproductive cycle, have led to rapid expansion of commercial catches. Between 1976 and 1984, landings ranged from 2,600-3,800 $t.year^{-1}$, taken by set net vessels and trawlers (Francis, 1988). Since 1984, catch rates have declined steadily in many parts of New Zealand, raising fears that rig stocks may be over-fished (Francis and Smith, 1988). Francis (1989) suggests that moderate exploitation rates before maturity, very high exploitation rates after maturity and low fecundity have probably caused the large declines in CPUE reported by Francis and Smith (1988) for the fishery.

According to Francis (1989), the Australian *Mustelus antarcticus* fishery has declined markedly following exploitation rates of the same order as those applied to the New Zealand rig fishery. Management measures for the New Zealand rig fishery have included individual transferrable quotas, introduced in 1986, which were designed to reduce landings by 69 per cent of average annual landings. Francis indicates that prediction of recovery rates is difficult, but due to an exponential relationship between size of adult females and fecundity, recovery of the New Zealand rig fishery will be slow.

Research into the South Australian shark fishery commenced during the 1940s when tagging and biological studies were initiated to determine the biology and life history of the school shark, *Galeorhinus australis* (= *G. galeus*) (Olsen, 1984). Fisheries authorities of the state of Victoria are continuing similar studies into the gummy shark which began in the 1970s. Stock assessments carried out on both these species during the 1980s were based on the same models applied to fisheries for bony fish. These models are in the main unsuited to stock assessment work for sharks, due to the low reproductive capacity, low fecundity and strong relationship between adult spawning biomass and recruitment in chondrichthyian species (Holden, 1977; Stevens, 1990).

Management issues have been addressed in recent years by a Southern Shark Assessment Group, which has worked towards creating appropriate models and management structures for the gummy and school shark resources of South Australia (Walker, 1988). This group is developing a modified yield-per-recruit model for the long-term rational management of the fishery. This requires information on fecundity, growth, mortality and index of abundance as input parameters. In the meantime, commercial catch and effort data have been analysed and seemingly appropriate management measures introduced. Options considered have included area closures, vessel buy-back systems, mesh-size restrictions, quotas and gear controls.

Stevens (1990) describes the problems associated with these management options. Limited fishing seasons were introduced and later rescinded, as was the fixing of a maximum length for school sharks marketed. Quotas were not satisfactory because there was a sizeable black-market and all the landed catch could not be traced through normal market outlets. Increasing mesh sizes were not necessarily beneficial, as this tended to increase the number of large, more fecund females that were caught (smaller mesh sizes allow many of these females to escape). Licence limitations were introduced in 1988 with limits placed on size and number of gillnets which could be carried by vessels in the fishery. This was done with the intention of reducing effort to the 1982 level, at which CPUE seemed stable. One unforeseen problem was that the longline sector of the industry, in response to warnings of impending restrictions, increased effort significantly before legislation was passed. Hook fishing is not covered in the management plan, with the result that effort is now increasing rapidly for this gear.

Further restrictions and alternative management options are currently under investigation, but controls on fishing effort is difficult to establish in this fishery as several state governments have management responsibility for the fishery and because the shark fishing industry has several sectors which differ in their management objectives and interests (Walker, 1988). A detailed discussion paper on the management issues and possible options for a solution are presented in Anon. (1985).

Potential for development in the island states: The possibility of large-scale commercial fisheries specifically targeting sharks in the South Pacific region is, for the island countries, low. However, localised shark fisheries using low-cost techniques have potential for the production of meat, fins and shark liver oil, but recruitment over-fishing on localised populations of sharks is a real possibility, and this should be considered before capital investment is made in any local enterprise specifically targeting on sharks.

Davenport and Stevens (1988) suggest that the relatively rapid early growth and early maturity of some tropical species of *Carcharhinus* may infer greater resistance to intensive fishing pressure than is the case in other, more temperate groups of shark.

Future prospects for marketing shark products: Demand for shark fins is very keen, especially on Asian markets, and is likely to continue, especially as supplies of large fins become scarcer with the decline in shark populations world-wide. Small-scale industrial shark fishing enterprises aimed at producing high quality meat from small, reef-based sharks and hides from larger ones around off-shore FADs shows promise. Such enterprises are within the financial resources of Pacific island fishermen. Tourism development in the South Pacific could make use of sharks for sport fishing and production of curio items (jaws, teeth necklaces etc.). Deep water sharks are virtually untapped in the region, and provide an excellent opportunity for development of shark oil fishing activities. Only in Solomon Islands and Papua New Guinea are such deep-water sharks being commercially exploited by island fishermen at present.

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