106231

The Dogfish Scourge: Protecting Fishing Gear From Shark Attack

G.V. Hurley*, H.H. Stone* and David Lemon

Fisheries Development Branch
Scotia-Fundy Region
Halifax, Nova Scotia B3J 2S7

* Hurley Fisheries Consulting Ltd.

July 1987

Canadian Industry Report of Fisheries and Aquatic Sciences No. 180

Fisheries and Oceans / Pêches et Océans

Canada

Canadian Industry Report of Fisheries and Aquatic Sciences

Industry reports contain the results of research and development useful to industry for either immediate or future application. They are directed primarily toward individuals in the primary and secondary sectors of the fishing and marine industries. No restriction is placed on subject matter and the series reflects the broad interests and policies of the Department of Fisheries and Oceans, namely, fisheries and aquatic sciences.

Industry reports may be cited as full publications. The correct citation appears above the abstract of each report. Each report is abstracted in *Aquatic Sciences and Fisheries Abstracts* and indexed in the Department's annual index to scientific and technical publications.

Numbers 1–91 in this series were issued as Project Reports of the Industrial Development Branch, Technical Reports of the Industrial Development Branch, and Technical Reports of the Fisherman's Service Branch. Numbers 92–110 were issued as Department of Fisheries and the Environment, Fisheries and Marine Service Industry Reports. The current series name was changed with report number 111.

Industry reports are produced regionally but are numbered nationally. Requests for individual reports will be filled by the issuing establishment listed on the front cover and title page. Out-of-stock reports will be supplied for a fee by commercial agents.

Rapport canadien à l'industrie sur les sciences halieutiques et aquatiques

Les rapports à l'industrie contiennent les résultats des activités de recherche et de développement qui peuvent être utiles à l'industrie pour des applications immédiates ou futures. Ils sont surtout destinés aux membres des secteurs primaire et secondaire de l'industrie des pêches et de la mer. Il n'y a aucune restriction quant au sujet; de fait, la série reflète la vaste gamme des intérêts et des politiques du ministère des Pêches et des Océans, c'est-à-dire les sciences halieutiques et aquatiques.

Les rapports à l'industrie peuvent être cités comme des publications complètes. Le titre exact paraît au-dessus du résumé de chaque rapport. Les rapports à l'industrie sont résumés dans la revue *Résumés des sciences aquatiques et halieutiques*, et ils sont classés dans l'index annuel des publications scientifiques et techniques du Ministère.

Les numéros 1 à 91 de cette série ont été publiés à titre de rapports sur les travaux de la Direction du développement industriel, de rapports techniques de la Direction du développement industriel, et de rapports techniques de la Direction des services aux pêcheurs. Les numéros 92 à 110 sont parus à titre de rapports à l'industrie du Service des pêches et de la mer, ministère des Pêches et de l'Environnement. Le nom actuel de la série a été établi lors de la parution du numéro 111.

Les rapports à l'industrie sont produits à l'échelon régional, mais numérotés à l'échelon national. Les demandes de rapports seront satisfaites par l'établissement auteur dont le nom figure sur la couverture et la page du titre. Les rapports épuisés seront fournis contre rétribution par des agents commerciaux.

Canadian Industry Report of

Fisheries and Aquatic Sciences No. 180

July 1987

THE DOGFISH SCOURGE: PROTECTING FISHING GEAR FROM SHARK ATTACK

by

Geoffrey V. Hurley
Heath H. Stone
Hurley Fisheries Consulting Ltd.
P. O. Box 3049
Dartmouth, Nova Scotia
B2W 4Y2

and

David W. Lemon

Department of Fisheries and Oceans

Scotia-Fundy Region
P.O. Box 550
Halifax, Nova Scotia
B3J 2S7

Minister of Supply and Services Canada

Cat. No. FS 97-14/180 ISSN 0704-3694

Correct citation for this publication:

Hurley, Geoffrey V., Heath H. Stone and David W. Lemon. 1987. The Dogfish Scourge: Protecting Fishing Gear from Shark Attack. Cdn. Ind. Rep. Fish. Aquat. Sci. 180:viii + 34 p.

ABSTRACT

Hurley, Geoffrey V., Heath H. Stone and David W. Lemon. 1987. The Dogfish Scourge: Protecting Fishing Gear from Shark Attack. Cdn. Ind. Rep. Fish. Aquat. Sci. 180:viii + 34 p.

In recent years, the spiny dogfish, Squalis acanthias, has become a destructive predator of fixed gear fisheries of Nova Scotia. This highly migratory species consume bait and hooked or netted fish as well as damage longlines and gill nets. To detect and locate prey, S. acanthias possess complex sensory systems which operate in concert to identify chemical, mechanical, visual and electrmagnetic cues of bait, fish and gear. Effective shark repellents, on or near gear, must overcome these attractive stimuli and, at the same time, not discourage commercially desirable species, not be toxic to fish or humans, and be affordable. A number of shark repellents have addressed the senses of smell, taste and vision, however, commercial fishing operations need to employ tactics to mask attractive stimuli of shiny metallic hooks, weak pulsed electrical fields of fish, and low frequency vibrations of vessels and gear.

RESUME

Hurley, Geoffrey V., Heath H. Stone and David W. Lemon. 1987. The Dogfish Scourge: Protecting Fishing Gear from Shark Attack. Cdn. Ind. Rep. Fish. Aquat. Sci. 180:viii + 34 p.

Depuis quelques annees, l'aiguillat commun, Squalus acanthias, est devenu un predateur qui detruit le poisson peche aux engins fixes en Nouvelle-Ecosse. Cette aspece fortement migratrice devore les appats et le poisson pris a l'hamecon ou au filet, et endommage les palangres et les filets maillants. Pour detecter et reperer sa proie, S. acanthias possede des systemes sensoriels complexes qui, en fonctionant de concert, lui permettent de reconnaitre, par des stimulus chimiques, mecaniques, visuels et electromagnetiques, les appats, le poisson et les engins. Pour neutraliser ces stimulus, il faut appliquer, sur ou pres des engins, des produits anti-requins puissants qui doivent cependant ne pas repousser les especes commercials recherchees, ne pas etre toxiques pour le poisson ou l'homme et se vendre a un prix abordable. Certains produits anti-requins attaquent les sens de l'odorat, du gouter et de la vue, mais pour la peche commerciale, il faudrait adopter des moyens de masquer des stimulus tels que les hamecons metalliques luisants, les faibles champs electriques pulses produits par certains poissons et les vibrations de basse frequence des navires et des engins.

ACKNOWLEDGEMENTS

We wish to thank P. Yeisley and M. Ortiz of A.T.& T./Bell Labs. for their hospitality and permission to report on the results of their work. Useful discussions were held with E. Clark (U. of Maryland) and B. Zahuranec (U.S. Navy), who also provided us with a copy of his recent book. We are indebted to P. Jangaard (DFO, Halifax) for permitting access to his reprint file and C. Annand (DFO, Dartmouth) for recent information on dogfish abundance and feeding habits. D. Peeling (DFO, Halifax) provided information on "scent saver" and longline gear while P. Underwood (NSDOF), L. Fisher and R. Acker (fishermen) gave us some insight into dogfish behaviour. The authors take full responsibility for any errors or omissions in this report.

EXECUTIVE SUMMARY

Over the past four years, the spiny dogfish, _Squalus acanthias_, has become an increasing menace to inshore fishermen of Southwestern Nova Scotia and more recently the Eastern Shore and Cape Breton. This small, pelagic shark is an aggressive and destructive predator of fixed gear fisheries, consuming bait and hooked or netted fish and causing damage to longlines and gill nets. Although dogfish are only seasonal residents on the Scotian Shelf, inshore fishermen are faced with restricting their operations during periods of peak abundance.

Dogfish are a slow growing, long lived, gregarious and highly migratory species. Essentially an opportunistic feeder, the diet consists mainly of fishes, crustaceans, molluscs and coelenterates. Specializations in skeletal, muscular, dental and integumentary systems have produced a feeding apparatus well suited for severing and consuming prey too large to be swallowed whole.

While the best control measure is a directed fishery, limited markets for dogfish food products, both domestically and abroad, greatly restrict fishery development. An alternative control measure is the development and use of repellents or deterrents to protect gear and catches.

Shark sensory systems are responsive to chemical, mechanical, visual and electromagnetic cues and act in concert to help them locate prey. Understanding their function and operation has been a key factor in the development of approaches to shark repellent/attractant research.

The first sensory cues sharks pick up in their search for prey are mechanical (low frequency sounds) and are detectable at a great distance from the source (over 1000 meters). Pulsed low frequencies in the 50-100 Hertz range are most attractive because they are similar to the vibrations set up by injured or struggling fish or possibly noise from fishing vessel engines. The principal mechanoreceptors are the neuromast cells of the lateral line system and the otolithic organs of the inner ear.

Chemoreception involves smell, taste and common chemical sensory systems. Of these, the olfactory organs (nasal sacs) are most sensitive and can detect weak concentrations of amino or fatty acid solutions at relatively great distances from the source (100 metres). Considerable research on shark olfaction has been directed towards finding chemical compounds that they avoid.

Sharks possess duplex retinas containing photoreceptive rods which function in determining the object's shape and movement, and cones which are important for visual acuity. Vision comes into play at close range (20 metres) and plays an important role in the diurnal habits of dogfish when feeding on pelagic prey.

Potential prey items, such as fish or invertebrates give off electric field vectors. At close range (20-30 cm), these electric fields provide sharks with instantaneous information on prey direction and quantitative information on prey distance. The main electroreceptive structures in sharks are the ampullae of Lorenzini located in the head region.

Shark repellents are categorized as chemical, acoustical, visual and electrical. To be effective, it must be more powerful than attractive stimuli given off from bait and struggling fish caught in the gear. While repellent/attractant research has focused mainly on protecting humans from shark attack, certain aspects of this research may be of use to commercial fishermen.

The effects of chemical repellents are mediated by external sensors of the chemoreceptor systems, gills, central nervous system or general body tissues. Ideally the chemical substance must be stable, inexpensive, harmless to man, effective at low concentrations and when dissolved in water, cause the approaching shark to turn away.

One of the first chemical repellents, Shark Chaser, consisted of 20% copper acetate (an olfactory deterrent) and 80% black nigrosine dye (a visual screen) compressed into a 170 gram cake. While relatively effective for protecting baited hooks from shark attacks, the dye material may be too expensive for protecting commercial fishing gear. Copper acetate could be deployed on its own but its effectiveness specifically on dogfish, remains to be tested.

Pardaxin, a proteinaceous secretion from the Moses sole (Pardachirus marmoratus), is extremely effective in preventing shark attack. However, the natural supply is limited and chemically unstable except in the less-effective freeze-dried form.

Industrial surfactants, such as sodium lauryl sulphate, are qualitatively similar to pardaxin and appear to be even more effective as shark repellents. Because of their ability to inhibit shark feeding behaviour, surfactants could be used to deter dogfish from attacking fishing gear. While they show considerable promise with regard to availability, low cost and inoffensiveness to humans, they are toxic to fish and require further investigation.

Sound can elicit either attraction or withdrawal responses from sharks depending on frequency, bandwidth, amplitude and type of signal. Low frequency, pulsed sounds in the range of 50-100 Hertz are attractive for considerable distances because of their similarity to physical movements of prey, or predators actively feeding. While S. acanthias is likely attracted to low frequency sounds generated by fish caught on hooks or in nets, vibrations given off by fishing vessel engines may also produce attractive stimuli. Shutting off the engine and drifting for a few minutes before deploying gear could be a solution to this problem.

Sounds having frequencies above 1000 Hertz are unattractive to sharks and may have repellent qualities. More research is required to determine if it is feasible to develop a practical acoustic repellent device suitable for use by commercial fishermen.

Highly reflective surfaces are more attractive to sharks then are dull, dark colours. Flashes from hooks or metal gangions on longline gear may be attractive visual stimuli to spiny dogfish. Painting hooks dull colours could help reduce their susceptibility to dogfish attack.

Sharks will execute typical feeding attacks on prey-simulating electrodes that emit weak pulsed electric fields. Spiny dogfish may be attracted to weak galvanic currents from hooks or other metal components of longline gear as well as electric fields generated by captive fish.

Recent studies suggest that some sharks are repelled by continuous direct currents. Electrical fields produced by electrodes attached to commercial fishing gear may be useful for repelling spiny dogfish.

Dogfish appear to strike baited hooks as the gear is sinking, shortly after deployment. Hooks carrying chemical repellents or ice-glazed baits with reduced olfactory properties, may help to reduce initial attack rates on sinking gear.

Development of an effective program to repel or deter *S. acanthias* is dependent on a thorough understanding of their behaviour in the presence of repellent substances or devices. For any potential repellent there needs to be a two phase testing program consisting of: a) laboratory tests on captive dogfish under controlled conditions and b) field tests on wild dogfish in their natural environment.

INTRODUCTION

BACKGROUND

The spiny dogfish, Squalis acanthias Linnaeus, is a small pelagic shark with a bad reputation among Maritime inshore fishermen. Even the name dogfish was adopted because schools of this shark, called "packs" by fishermen, are often seen relentlessly persuing schools of smaller fish. Often referred to as the "locust of the sea", the dogfish is an aggressive and at times highly destructive predator of fixed gear fisheries. By consuming bait, damaging longlines and gillnets and devouring hooked or netted fish, they interfere with fishing operations more than any other species. Sharp teeth and dorsal spines make them difficult to remove from fixed gear and bottom trawls, however, the increasing use of colour sounders allows trawler fishermen to identify dogfish schools and reduce their capture rate to a certain extent. Although dogfish are generally seasonal residents on the Scotian Shelf (Leim & Scott 1966), inshore fishermen are faced with restricting their operations or stopping fishing altogether during periods of peak abundance.

Over the past four years, S. acanthias has become an increasing menace to inshore fishermen of Southwestern Nova Scotia and more recently the Eastern Shore and Cape Breton (Salsbury 1987). Catch per tow indices from Canadian summer groundfish surveys indicate a trend of increasing dogfish biomass in the southwestern Shelf region (NAFO Division 4X) from 1980-84 (Annand 1985). Survey results for 1985 and 1986 indicate that biomass levels have not changed from 1984 (Annand pers. com.). Similarly, U.S. bottom trawl surveys conducted off the southeast coast of the United States from 1980-83 show an increase in abundance of large females and juveniles (Waring 1984).

Various factors have been cited as possible causes for the apparent increase in abundance: decreased fishing mortality on dogfish by distant water fleets, reduced groundfish stocks which are competitors of dogfish and increased prey abundance (Waring 1984). Environmentally induced changes in dogfish migration patterns along the Scotian Shelf may also be responsible for greater occurrences inshore where conflict with the longline fishery has occurred. Whatever the cause, increased dogfish abundance is hurting the inshore commercial groundfish fishery. Although difficult to quantify, a recent report by Salsbury (1987) indicates that the current "dogfish problem" costs the Scotia-Fundy fishery about 10 million dollars a year.

While dogfish have long been a nuisance to commercial fishermen, methods of controlling them have not been very successful. As far back as 1904, a scheme was devised to attach coloured streamers or dangle chains onto dogfish and then release them to frighten the schools away (World Fishing, January 1968). Other methods such as bounties and dynamite were often rather naive.

The best control measure is ultimately a directed fishery, which would assist in minimizing dogfish damage by reducing their numbers. Demonstration projects have been carried out in Newfoundland (Anon. 1979) and Nova Scotia (Peeling 1982) and indicate that dogfish stocks present in summer are large enough to support limited longline fisheries. However, Canadian east coast fishermen are reluctant to fish dogfish because of damage to gear, extra work involved in processing the catch and the low landed value (Peeling 1985). Moreover, limited markets for North American dogfish food products, both domestically and abroad, greatly restrict development of the fishery(Salsbury 1986). Another alternative is to try and exterminate the sharks. Their population may be vulnerable to intense fishing pressure because they travel in dense schools. This could mean subsidizing large factory trawlers to carry out a directed fishery which is unappealing for many reasons. Maritime fishermen would clearly prefer the flexibility of being able to fish selectively for haddock and cod while avoiding spiny dogfish.

With no market for dogfish, fishermen need a way to keep these predators from taking their catch and ruining nets and lines. An alternative control measure is the development and use of repellents or deterrents to protect gear and catches. This report reviews various aspects of shark repellent research and examines their potential for use by commercial fishermen. While much of this research has focused on protecting humans from shark attack, it has considerable application to the dogfish problem. A review of dogfish biology, feeding habits and sensory systems is included to give perspective on shark repellents and attractants.

METHODS OF COLLECTING INFORMATION

Much of the information used in this review was obtained from a keyword computer search of the "Biological Abstracts" and "Fisheries and Aquatic Sciences Abstracts" database systems, as well as from various government libraries. Personal interview with fishermen and shark researchers also provided up-to-date information on dogfish/fishing gear interactions and current shark repellent research activities. The report has been structured to include the following sections: 1) General Biology, 2) Sensory Systems, 3) Shark Attractants and Repellents, 4) Dogfish/Gear Interactions and

5) General Conclusions and Options for Future Research.

GENERAL BIOLOGY

Squalis acanthias is a member of the Subclass Elasmobranchii (Class Chondrichthyes) which includes approximately 550 species of sharks, skates and rays (Leim & Scott 1966). Members of this group are nearly always marine and tend to be predacious in habit. They have high concentrations of urea in the blood, no bone in the skeleton, no swim bladder and no operculum over the gills. Placiod scales (denticles) cover the body and are specialized in the mouth region to form rows of teeth that are continuously replaced. The upper jaw is often separate from the rest of the skull - a condition that is an important feature in feeding. Other prominent characteristics include a heteroceral tail and modification of the inner edges of the male pelvic fins to form claspers, which play a major role during internal fertilization.

LIFE HISTORY

In the western North Atlantic, S. acanthias ranges from southern Labrador to North Carolina, straying to Florida and Cuba (Leim & Scott 1966). They are migratory and gregarious, travelling in schools which are generally segregated by size when immature and by size and sex after maturing (Templeman 1944). In winter they concentrate in the Mid-Atlantic region, where pupping and mating is presumed to occur, and moving north in summer to coastal waters off Newfoundland and Labrador (Templeman 1944, Bigelow & Schroeder 1953). It is during summer and late fall that they migrate across the Scotian Shelf. Results of tagging studies conducted off Newfoundland (Templeman 1954) and the northeastern coast of the United States (Jensen 1966) indicate that dogfish in the N.W. Atlantic probably comprise one population which makes extensive seasonal migrations. However, groups of immature individuals appear to overwinter in pockets of deeper water on the Scotian Shelf (Annand 1985) and Grand Banks (Templeman 1944).

Dogfish are a long-lived (max.=40 yrs), slow growing species, with females reaching maturity at 79.9 cm (12.1 yrs) and males at 59.5 cm (6.0 yrs) (Nammak et al. 1984). Maximum theoretical lengths of 92.5 cm and 100.5 cm have been obtained for males and females, respectively, from Von Beralanffy growth equations (Nammak et al. 1984). Development is ovoviparous (i. e. females bear live young internally) and the gestation period is the longest of any vertebrate. Females can produce from 1-15 embryos but generally average 6 every two years (Nammak et al. 1984).

DIET AND FEEDING ADAPTATIONS

Specializations of the skeletal, muscular, dental and integumentary apparatus have produced mechanical systems for eating which are unparalleled by other fishes and which have placed sharks at the top of the marine food web (Moss 1977). The feeding dynamics of S. acanthias are fairly well understood and are based on morphological and dietary characteristics. In dogfish, the jaws are very short with relatively small, sharp teeth, tightly overlapped to form a continuous knife edge from one side of the mouth to the other. This "cutting" feeding apparatus is well suited for attacking prey too large to be swallowed whole and allows the predator to sever its prey into several bite-sized pieces (Moss 1977). Their relatively small mouths with kinetic upper jaws enable them to suck up small benthic prey items with little difficulty.

Studies by several researchers indicate that S. acanthias is an opportunistic feeder, with a diet consisting mainly of fishes, crustaceans, molluscs and coelenterates (Templeman 1944, Jones & Geen 1977, Nammak 1982, Bowman et al. 1984). Teleosts such as sand lance, mackerel and herring generally comprise most of the diet by weight (60-70%) in dogfish greater the 60 cm. but vary according to their availability and abundance (Bowman et al. 1984). Ontogenetic shifts in diet composition are reflected by a switch from pelagic squid to benthic bivalves at or near the size of dogfish at maturity (60 cm) and suggests that mature dogfish may be more demersal than younger individuals (Nammak 1982). Dogfish consume approximately twice as much food in summer as in winter and annual consumption for small individuals (less than 46 cm) is estimated at about 5 times their body weight, while larger animals (60-111 cm) consume 2 times their body weight (Jones & Geen 1977).

Although to date there is no scientific evidence that dogfish deplete groundfish stocks, substantial drops in cod and haddock longline catch rates have been blamed on the high incidence of dogfish on the Scotian Shelf. Recent examination of 665 dogfish stomachs obtained over a two year period (1985-86) from bottom trawl collections on the Shelf, indicated that few commercial species were present in the diet (Annand pers. comm.). However, many of the stomachs were from immature animals that may not feed on demersal fish and were collected during winter surveys, a time when feeding rates generally tend to be low. A feeding study, conducted during the summer influx of dogfish in areas where commercial longlining conflicts occur, may be helpful in determining if demersal fish constitute part of the diet.

SENSORY SYSTEMS

Understanding the function and operation of shark sensory systems has been a key factor in the development of approaches to shark repellent/attractant research. Elasmobranchs have a number of well developed sensory systems (Fig. 1a) responsive to chemical, mechanical, visual and electromagnetic cues which act in concert to help them locate prey.

Probably the first sensory cues sharks pick up in their search for prey are mechanical (low frequency sounds) or chemical (odour) (Fig. 1b). Low frequency vibrations or turbulence created by struggling fish or fish swimming in schools can be detected by the inner ear or lateral line system while odours given off by injured fish can be detected at low concentrations by the olfactory system. At closer range, vision comes into play and when sharks are about to seize their prey, the electroreception system (ampullae of Lorenzini) takes over, which can detect tiny electrical fields created by muscular movement. Important features of each of these specialized sensory systems, described in the following section, were largely obtained from the works of Gilbert (1963) and Moss (1984).

MECHANORECEPTION

Sound is normally thought of as a progressive wave comprised of both pressure variations and particle motions existing in an elastic medium. In seawater, sound is conducted more rapidly and with less attenuation than in air. Sensitive hearing could therefore provide a predator with an excellent means of detecting, recognizing and localizing its prey over considerable distance (Myberg *et al.* 1969). Behavioral evidence from laboratory and field studies indicates that sharks are very sensitive to underwater sounds, especially pulsed low frequencies in the 50-100 Hertz range and can be attracted from distances of 250 m or more (Myberg *et al.* 1969, 1972; Popper & Fay 1977). It is believed that these sounds are similar to the vibrations set up by injured or struggling fish.

The principal mechanoreceptors of elasmobranchs, like other fishes, are the neuromast cells of the lateral line system and the various otolitic organs of the inner ear. The lateral line system (Figs. 2a, 5b), extending from head to tail, contains sensory neuromast cells sunken into the skin, which communicate with each other and the environment through a series of tubes that comprise the lateral line canals. Movement of water, created by turbulence, currents and vibrations, displaces water in these canals and stimulates the neuromast cells to initiate nerve impulses. Patches of cilia, projecting from the free end of the cell into the lateral line cavity, can detect water current differences of about 1 cm/sec. or less. Therefore, the lateral line system plays an important role in the rheotactic behaviour of sharks as well as in the muscular coordination of swimming (proprioreception).

The inner ear or labrynth system of elasmobranchs (Fig. 2b) is developmentally and anatomically related to the lateral line system. Located within cartilaginous capsules, the only indication of their position from external anatomy is the presence of tiny pores (leading to the inner ear) located laterally on each side of the chondrocranium. The labyrinth consists of three fluid-filled semi-circular canals connected to a system of chambers containing sensitive hair cells overlain by a gelatinous cupula. Fluid movements in the canals cause movements in the cupula which in turn stimulate the sensory hair cells. By having canals in three planes, it is possible for sharks to detect angular acceleration in all directions. In addition to acceleration and gravity detection, this system is also modified to receive sound in the form of vibrations that excite the neuromasts of the inner ear.

While both the inner ear and lateral line systems can detect various components of underwater sound, it is not known exactly how these two sensory systems differ in terms of sensitivity, frequency range and amplitude of signals to which they respond (Popper & Fay 1977). Sharks can and do respond to water movements caused by other animals and inanimate objects in the near field (i.e. where there are large displacements of the medium), but also orient towards sound sources in the far field (i.e. where only pressure waves exist) (Boord & Campbell 1977). However, of the two mechanoreceptor systems, it is not clear which is more important in the detection of sounds from each of these fields. Interestingly, Myrberg et al. (1969) demonstrated that sharks can perceive acoustic signals from the far field, and can also orient directionally to a given sound source from this same area.

CHEMORECEPTION

Chemoreception involves at least three separate sensory systems: smell (olfaction), taste (gustation) and the common chemical sense. Of these, olfaction is the most sensitive; capable of detecting very dilute solutions of certain chemicals (i.e. amino acids, amines, short chain fatty acids) at relatively great distances from the source. Positive responses to concentrations as low as 1 ppb of amino acids (glycine, glutamic acid) and amines (betaine, trimethylamine, trimethylamine oxide) have been demonstrated (Moss 1984).

The olfactory

organs consist of paired nasal sacs found on the ventral surface of the head in front of the mouth. As the shark swims, water is forced into the nasal sacs and perfuses numerous receptor cells located on plate-like lamellae lining the sacs. To locate the source of attractive odours, olfactory corridors are negotiated by the shark turning into the current (rheotaxis) and following it to the chemical source (Fig. 3). In cases where current direction cannot be detected, sharks may use gradient searching behaviour (klinotaxis) and determine the chemical source by orienting directly towards increasing concentrations of the chemical stimulus (Mathewson & Hodgson 1972). Considerable research on shark olfaction has been directed towards finding chemical compounds that they avoid. Some of the more effective chemical agents will be discussed in the section on repellents.

Gustation is less sensitive than olfaction, but nontheless important. Taste allows the shark to make a final discrimination about the palatability of a prey item before it is swallowed. The receptors are specialized epidermal cells clumped into taste papillae (buds) scattered over the mucosal lining of the mouth and pharynx (Fig. 4). Gustation is the most likely chemical sensor involved in food rejection.

The common chemical sense is separate and distinct from the sense of smell and taste, and is presumed to detect various irritating chemicals (i.e. acids) when they come into contact with the surface of the skin. The receptors are free nerve endings which occur all over the outside body surface, but most are concentrated in the mucous membranes of the oral and nasal cavities and around the eyes. In addition, pit organs or sensory crypts resembling taste buds and receptors of the lateral line system are located over the head and back and are assumed to have a chemoreceptive function. Repellents of the noxious irritant type are believed to act on the free nerve endings of the common chemical sense.

VISION

In the past, researchers have had a tendency to overlook the visual system of sharks, assuming its importance to be minimal. Recent evidence suggests otherwise and indicates that elasmobranchs possess several ocular characteristics which are unique and well-adapted to their needs (Gruber 1977). Some of the more important specializations which assist in their predatory role are discussed below.

To make use of all available light, sharks possess a specialized structure known as the tapetum lucidum, located in the choroid layer of the retina (Fig 5a). The mirror-like plates of the lucidum reflect light back along the same optical path so that it can strike photoreceptors a second time and increase the sensitivity of the eye (Cohen 1981). This adaptation allows sharks to see in dim light conditions. In some species, a moveable membrane covers the reflective plates to the tapetum in bright light conditions to prevent damaging sensitive retinal photoreceptors by light overdoses.

The eyes of sharks are set with a fair degree of overlap; up to 45 degrees in S. acanthias. The combination of head movements during swimming and coordinated eye movements eliminates the 60 degree blind spot below and behind the head and provides Squalus with stable and nearly panoramic vision (Harris 1965).

Most sharks possess duplex retinas containing photoreceptive rods and cones indicating that they are capable of both nocturnal and daylight activity. Cone cells are considered to represent the anatomical basis for colour vision, allowing greater visual acuity under bright light conditions. Rod cells function primarily in determining shapes of objects but are also important in discerning movement. In S. acanthias the ratio of rods to cones is about 50:1 (Stell 1972) which is a low number of cones by human and teleost standards. However, vision plays an important role in the diurnal habits of Squalus, when feeding on pelagic prey. Visual association is a possible mechanism that could work in the absence ofgradient or water current cues, particularly within close range of a potential prey item.

ELECTRORECEPTION

Olfactory and acoustic cues play an important role in the initial perception of prey over longer distances. At close range, electric field vectors, like vision, provide instantaneous information on prey direction and quantitative information on prey distance based on the strength of the electric field (Tricas 1982). Only direct mechanical contact dominates over electrical stimuli. Elasmobranchs can also detect their own electric fields when swimming through the earth's magnetic field, enabling them to sense their compass heading (Kalmijn 1977).

The sensitivity of elasmobranchs to weak electric fields is mediated by small, electroreceptive structures known as the ampullae of Lorenzini (Fig. 5b). These sensory vesicles contact the surrounding water via jelly-filled canals leading to a group of pores around the head and mouth and enable the animal to detect voltage gradients as low as 0.01 micro-volts/cm (Kalmijn 1966). Each ampulla consists of a cluster of sac-like alveoli containing numerous sensory cells innervated by nerves which pass to the brain. Potential prey items, such as invertebrates or teleost fish, produce electric fields around themselves for a distance of about 25 cm. In fish, it is the mucous membranes lining the mouth and gill epithelia which give rise to steady D.C. fields, modulated (pulsed) by ventilatory movements (Kalmijn 1977). Because these voltage gradients fall off rapidly with distance, elasmobranchs can perceive potential prey only at short range (25-30 cm).

Initially motivated by odour or low frequency vibrations, sharks and rays directly zero in on their prey, deriving its location from the spatial configuration of the animal's bioelectric field. Because odour fields are easily distorted by water currents, they may be too vague for an exact location of the prey without the assistance of the ampullary system. In this way both the electric sense and olfactory sense compliment each other very well. Artificially induced electromagnetic signals have been used to attract and repel sharks in laboratory and field situations and will be discussed in the following section.

When considering each of these sensory systems in association, it is easily understood why spiny dogfish are such a serious nuisance to longline and gillnet fishermen. Low frequency vibrations created by struggling fish combined with substances secreted or excreted from hooked or netted fish likely serve as long range attractants making the gear a prime target for dogfish attack. Therefore, any potential repellent will have to be much more powerful than these attractive stimuli.

SHARK ATTRACTANTS AND REPELLENTS

Nelson (1983) defines a shark repellent as any chemical, acoustical, visual or electrical stimulus that stops a shark from approaching and/or biting potential prey, and refers to repellency as the behavioral act of turning away or withdrawing. While repellent/attractant research has focused mainly on protecting humans from shark attacks, certain aspects of this research may be of use for protecting commercial fishing gear. In this section, we discuss various repellents and attractants, their effects and possible uses relative to the current dogfish problem in the Maritimes.

CHEMICAL REPELLENTS

In general, chemical effects are mediated either by external sensors of the three chemoreceptor systems (olfaction, gustation, common chemical sense) or by actions at other sites, such as the gills, central nervous system, internal organs or general body tissues (Nelson 1983). Ideally, the chemical repellent substance, dissolved or dispersed in the water, causes the approaching shark to turn away or withdraw and would be effective at low concentrations at a significant distance from the source of the material. For practicality, the repellent should be quite stable for a long shelf life, relatively inexpensive, and harmless to humans and fish. It must also be effective in the presence of various stimuli that attracted the shark in the first place. Besides repellency, other possible behavioral responses include rejection, regurgitation, feeding inhibition, irritation or ultimately death. A repellent that is fast-acting, especially at low concentrations is the preferred type for protecting individuals (i.e. response time less that 1 min.), while a slow acting repellent (response time = min., hrs., days) would be useful for deterring sharks from fishing grounds or commercial fishing gear.

A wide variety of chemical agents such as fish poisons (rotenone), irritants (chlorine), systemic poisons (cyanide), immobilizers (tricane) and chemical warfare agents have been tried as shark repellents, although most of these have not proved effective in terms of rapid shark withdrawal even though they were noxious to other animals (Nelson 1983).

"Shark Chaser"

One of the best known and most widely used chemical repellent was "Shark Chaser". Developed by the U.S. Navy in the 1940's to protect surviviors of air and sea disasters from shark attacks, "Shark Chaser" originated in part from field observations on shark behaviour. Reports by fishermen indicated that decomposing sharks on a line usually kept other sharks away from longlines used in commercial fishing operations. Ammonium acetate was found to be the principal chemical exuding from decomposing shark flesh and was combined with the copper ion, also known for exerting a repellent action, to form copper acetate. As detailed by Tuve (1963) and Gilbert & Springer (1963), copper acetate was chosen largely as a result of tests on captive smooth dogfish (<u>Mustelus canis</u>) conducted at Woods Hole Oceanographic Institution in 1944. Black nigrosine dye was included as a visual screen but also had the physiological effect of reassurance to the user, who could now see the extent of the material spreading out around them (Gilbert & Springer 1963). In its final formulation, "Shark Chaser" consisted of a mixture of 20% copper acetate and 80% nigrosine dye compressed in a 170 gram cake. It was deployed by unwrapping the cake and swirling it about to create an enveloping cloud of chemical around the user.

Because of its inability to perform in all situations, "Shark Chaser" is no longer available for human use. However, it may have some application in the protection of commercial fishing gear, as indicated by the methods and results from original field tests.

Open water trials were conducted in 1943 and 1944 to determine the effectiveness of nigrosine dye and copper acetate for protecting baits (Gilbert & Springer 1963). Paired surface longlines (Fig. 6) baited with shrimp were fished simultaneously for 100 min. and were identical except for the presence of repellent on one line while the other acted as a control. The effectiveness of a substance for protecting baits was calculated as follows:

$$\frac{A - B}{C} \times 100 = \% \text{ Effectiveness}$$

A = Number of Sharks on Control
B = Number on Repellent Line
C = Number on Control

The numerator represents the best estimate of the number of sharks repelled and the denominator the number that would have been caught had there been no repellent (Gilbert & Springer 1963).

The results of those studies, which involved several different shark species (i.e. lemon, tiger, sharpnose, black tip, hammerhead), indicated that most of the repellency was due to the dye rather than the copper acetate; the latter decreasing in effectiveness with increasing shark activity (such as during a feeding frenzy). Differences in the effects of these two substances were assumed to reflect differences in detection rates of visual versus olfactory stimuli. Copper acetate requires contact with olfactory senses whereas contact with the dye is not necessary to produce a visual response.

When "Shark Chaser" (both dye + Cu acetate) was used to protect baited hooks, it proved to be relatively effective and suggested that stimulation of more than one of the senses increased the efficiency of the repellent (Gilbert & Springer 1963). Furthermore, its use did not appear to deter fish of commercial importance from being attracted to the bait. While it does show some potential as a dogfish repellent for commercial fishermen, the dye material may be too expensive for use with large nets or longline gear, because large quantities would likely be required. This material also diffuses rapidly into the water column and may lose its effectiveness rather quickly. Possibly, copper acetate could be deployed on its own, however its effectiveness as a dogfish repellent remains to be tested.

Natural and Synthetic Repellents

Numerous marine species, both vertebrate and invertebrate, achieve significant protection against predation by producing chemical repellents, toxins and venoms (Halstead 1978). In the 1970's, research on chemical shark repellents shifted to the search for biologically effective natural marine products or synthetic imitations with similar actions. Clark (1983), carried out a series of experiments in 1972 and 1973 which established that the Moses sole (*Pardachirus marmoratus*), a small Red Sea flatfish, produces a proteinaceous toxic secretion which protects it from shark attack. This secretion, known as pardaxin, disrupts the shark's osmoregulatory and salt balance systems in the gill membranes by interfering with the production of the enzyme adenosine triphosphate (ATP) (Primor *et al.* 1983). Primor and his co-workers determined that pardaxin was toxic and lethal to both teleosts and elasmobranchs, with 1-hr LD50 concentrations of 5.1 ug/ml/g body weight when administered externally to *S. acanthias*. Although clearly aversive to sharks and fast acting at low concentrations, the natural supply of pardaxin is limited and once extracted, tends to be relatively unstable except in the less effective freeze-dried form. Also, the complicated sequence of 162 amino acids, which comprise the toxin, can only be synthesized by costly genetic engineering techniques.

Zlotkin & Barenholtz (1983) recognized that pardaxin has surfactant and detergent-like qualities and theorized that strong industrial detergents might act much like pardaxin in repelling sharks. To test that hypothesis, Gruber *et al.* (1984) investigated the effects of strong industrial surfactants on lemon sharks (*Negaprion brevirostris*) and found that sodium lauryl sulphate (SLS) was a more effective repellent than pardaxin. Field studies with blue sharks (*Prionace glauca*) also indicated that SLS has a dramatic repellent effect if delivered into their mouths when feeding on bait (Gruber *et al.* 1984). Surfactants have long been known to be toxic to fishes by attaching to and destroying the phospholipid component of gill membranes much like pardaxin (Nelson 1983).

For testing the hypothesis that surfactants repel sharks, Gruber and his co-workers (1984) developed some relatively unique and simple laboratory bioassay techniques. The response measure used in feeding bioassays was whether a lemon shark, briefly exposed to a test substance, continued to feed. In this bioassay, a dose which was effective in inhibiting 50% of the tested sharks from feeding (ED50) was established by offering the animals bait containing 4 ml of a test substance of known concentration. A behavioral bioassay was based upon termination of a trans-like state known as "tonic immobility". If a shark is disoriented by being held in an inverted position, it will fall into a relaxed state for up to 30 minutes during which the animal is quite insensitive to stimulation. An ED50 for substances' terminating tonic immobility (i.e. flipping over) was then established.

Because of their ability to inhibit shark feeding behaviour, surfactants could be used to deter dogfish from attacking fishing gear. While they show considerable promise as repellents, especially with regard to their availability, low cost and inoffensiveness to humans, much more research remains to be done before they become available for commercial use. The fact remains that they are also toxic to fish and therefore could have adverse effects on commercial species if used to protect fishing gear.

ACOUSTICAL ATTRACTANTS AND REPELLENTS

Both the lateral line and labyrinth systems of elasmobranchs contain numerous receptors that are responsive to mechanical forms of energy such as touch, vibration, water currents, sound and hydrostatic pressure. Sound can elicit either attraction or withdrawal responses from sharks depending on specific acoustical properties such as: frequency, bandwidth, amplitude and type of signal (i.e. continuous versus pulsed) (Klimley & Myrberg 1979).

Acoustical attraction

Experiments by Myrberg _et al._ (1969, 1972) and Nelson & Johnston (1972) demonstrated that low frequency, pulsed sounds in the range of 25-100 Hertz were attractive to sharks for a considerable distance. Generally, these studies involved observation of shark behavioral responses to acoustic stimuli generated from audio equipment (i.e. broad band sound projectors, random noise generators) or pre-recorded test sounds played into the water from a transducer. An important observation made during these studies was that sharks rapidly learned about the value of a sound played repetitively and would soon ignore otherwise attractive sounds if no reward (i.e. food) was forthcoming.

Pulsed, low frequency sounds are believed to simulate the noise bursts generated either by physical movements of prey or by predators actively feeding. Demersal predatory fishes may also be attracted to these sounds for the same reason (Richard 1968). Low frequency sounds travel greater distances than those of higher frequencies produced at the same time, and therefore, are useful to sharks because they extend beyond the effective ranges of vision and olfaction.

While S. acanthias is probably attracted to low frequency sounds generated by fish caught on hooks or in nets, vibrations given off by fishing vessel engines may also produce attractive stimuli, drawing dogfish into the area. Shutting off the engine and drifting a few minutes before deploying fishing gear could be a solution to this problem.

Acoustical Repellents

During experiments on acoustic attraction, it was observed that sounds having frequencies above 1000 Hertz were unattractive to sharks (Myrberg et al. 1969). Banner (1972) noted that juvenile lemon sharks fled at the onset of a sound if they were located in a position where the intensity was well above their hearing thresholds. It was reasoned that such sounds resemble those generated by adult sharks, the major predators of juveniles.

Klimley & Myrberg (1979) investigated the acoustical factors responsible for eliciting withdrawal behaviour (180 degree turn and departure) in lemon sharks and demonstrated that under certain conditions a degree of repellency can be achieved by acoustical means. Sharks that were initially attracted by pulsed sounds would subsequently withdraw if the playback was suddenly changed to another sound at a higher level or with a faster rise in time (i.e. 500-4000 Hertz).

Insofar as the practical application of this knowledge is concerned, the ability to repel sharks acoustically by means of some mechanical device would be advantageous for protecting commercial fishing gear from being attacked by spiny dogfish. However, more research is needed to determine if it is feasible to develop an acoustical repellent device which would be of a size practical for use by commercial fishermen. Furthermore, high frequency sounds which repel sharks may also have the same effect on commercial species which would ultimately defeat the effectiveness of this method.

VISUAL ATTRACTANTS AND REPELLENTS

Recent literature indicates that elasmobranchs are extremely successful marine predators that have been provided with a high degree of visual development and capacity (Gruber 1977, Stell 1972). This is clearly different from the earlier viewpoint, in which sharks were labelled as "swimming noses" with crude sensory organs and a poor visual system. Although colour does play a role in the study of shark repellents, basic data on colour vision and visual acuity in elasmobranchs is either limited or inconclusive (Gruber 1977).

The relative brightness of an object in the water is definitely a factor used in the design of life jackets or other flotation devices. Highly reflective surfaces are more attractive to sharks than are dull, dark colours. This information was incorporated into the design of the "Shark Screen", a patented device in which a person is protected from the shark's visual and olfactory senses. Consisting of a large bag made of thin, strong, lightweight material with inflatible collars at the top, the Shark Screen is a protective flotation device within which a person is visually screened from the shark's view. The electrical fields and olfactory stimuli given off by a person are also contained by this device.

Because bright, shiny objects are known to attract sharks, flashes from hooks or metal gangions on longline gear may be attractive stimuli to spiny dogfish. Hooks with dull, dark colours may be less attractive visually and therefore less susceptable to dogfish attack.

ELECTRICAL ATTRACTANTS AND REPELLENTS

Electrosensitivity in elasmobranchs was first recognized in 1935 when it was observed that spotted dogfish (Scyliorhinus canicula) displayed oriented escape reactions when approached with a steel wire (Kalmijn 1971). There is now abundant evidence to indicate that the ampullae of Lorenzini are biological electroreceptors (Kalmijn 1971, 1977), highly specialized to passively detect very weak DC and low frequency AC electric fields originating from external animate or inanimate (i.e. metallic) sources in the environment. Electrical stimuli can act as attractants or repellents depending on the magnitude of the charge and in some cases, the species of shark involved.

Attracting Sharks Electrically

Behavioral studies have shown that the spotted dogfish (Schliorhinus canicula) responds to electric fields of voltage gradients as low as 0.01 micro-volts/cm. Using controlled laboratory techniques, Kalmijn (1971) established that Schliorhinus could locate small flounder buried beneath the sand by the weak DC and low frequency AC fields given off by the flatfish. Bioelectric fields were then simulated by passing electric current between two closely spaced electrodes and the spotted dogfish executed well-aimed feeding responses to these dipole fields. The validity of this work was later confirmed by studies at sea.

Attacks on real and electrically simulated prey were observed in the smooth dogfish and blue shark in waters off Cape Cod (Kalmijn 1982). When given a choice of biting the source of an olfactory attractant or electrodes emitting an appropriate electric field, both shark species nearly always bit the electrodes.

In the case of the smooth dogfish, tests were conducted at night in depths of 2-3 metres where the animals were foraging for food. Prey fields were simulated by applying direct current to a pair of electrodes to the right or left of an odour source (Fig.7a). Small dogfish detected gradients of less than 0.021 micro-volts/cm. Research on blue sharks was carried out in water 40 metres deep, with the odour source and electrodes attached to a horizontal spreader bar suspended at a depth of 5 metres (Fig. 7b). Two dipoles were mounted 30 cm from the odour source and a direct current of 8 micro-amps was applied to one dipole at a time. The blue shark preferred the prey-simulating field to either the control electrodes or the odour source.

Considering that sharks will execute typical feeding attacks in response to electric fields simulating prey, it is possible that spiny dogfish are attracted to the weak galvanic currents given off by longline hooks or other metal components of the gear. While plastic hooks are currently not available (and possibly too fragile to function as fishing gear), they may help to alleviate this problem. However, stimuli from bait and hooked fish (i.e. smell, vibrations, electric fields) would still be predominate.

Repelling Sharks Electrically

There have been various attempts to develop electrical shark repellent devices. In South Africa, an electric shark barrier has been used to protect bathers from sharks and operates on the principle that in an electric field, a fish swims towards the positive pole. By reversing the field, fish including sharks, can be forced to swim away from the barrier.

A self-contained electrical device known as the "Shark Shield", produced by Electromagnetic Industries (Clearwater, Fla.), has been used successfully by shrimp trawlers to discourage sharks from attacking the cod-end of the trawl (Fig. 8). Powered by rechargeable batteries, the "Shark Shield" delivers a square wave 120 Volt DC electric pulse through a pair of electrodes at a frequency of 1-2 pulses/sec. and duration of 60 millisec. (Gilbert & Gilbert 1973). Various tests using this device have been fairly successful. The "Shark Shield" was able to keep Pacific sharks, attracted to tuna in purse seines, approximately 3 metres from the electrodes (Nelson 1983).

Ongoing research is being conducted at A.T.& T./Bell Labs in New Jersey in an effort to develop an electrical repellent device to deter large deepwater sharks from biting submarine telecommunication cables (P. Yeisly pers. comm.). Sharks may attack a cable because they are attracted to various stimuli such as: a) flourescence around the cable, b) electromagnetic properties of the cable, c) the presence of prey (i.e. octopus) on the cable, or d) "strumming" sounds produced by the cable under tension. Preliminary laboratory experiments conducted by Dr. M. Ortiz (A.T.& T./Bell Labs) were designed to test some of these possibilities and are briefly described below:

1) Chain dogfish (Scyliorhinus retifer) were subjected to various combinations of straight and pulsed direct current; alternating current at varying frequencies; and mechanical "strumming" (oscillation). They were attracted by dipoles with: a) pulsed DC (1.6 amps), and b) AC (8 milliamps, 50 Hertz) combined with strumming (12 Hertz). Strumming by itself was not an attractive stimulus.

2) Coiled copper wire (5-6 loops, 6 mm dia.) with a negative and positive pole was used to test the effects of a changing electromagnetic field on chain dogfish. The sharks were found to be very active when a pulsed direct current of 1.6 amps was passed through the coil. When the polarity in the coil was reversed, the sharks became disoriented.

3) A non-pulsed direct current (1.6 amps) passed through a dipole was found to repel chain dogfish from attractive bait located near the source of the current. Dropping the current from 1.6 to 0.6 amps resulted in the sharks moving in closer and consuming the bait.

4) A T-bar shaped dipole with different amounts of exposed copper on each end was moved around in a tank containing lemon sharks (Negaprion brevirostris). The sharks bit the apparatus when no current was present. However, with a direct current of 1.6 amps, the sharks were repelled in a 2 ft. radius around the T-bar. At 0.5 amps, the radius decreased to 1 ft. and at 0.16 amps, the sharks did not appear to be repelled by the apparatus. When the experiment was repeated with nurse sharks (Ginglymostoma cirratum), they were not repelled at 1.6 amps. Biological differences between species and their feeding habits may account for this variation.

Protective electrical fields produced by a series of electrodes attached to commercial longline gear or gillnets may be useful for repelling spiny dogfish attracted to the bait or catch. If electrical sensitivity is size-related, then currents less than 1.6 amps may be sufficient to repel S. acanthias because lemon sharks are considerably larger than Squalus. In practice, it may be difficult to produce currents of this strength for long periods remotely, particularly on fishing gear. Although several techniques look promising, field and laboratory studies on spiny dogfish have yet to be conducted. Furthermore, commercial fish species may also be affected, either by increased attraction to or avoidance of the gear.

DOGFISH/GEAR INTERACTIONS

Dogfish behaviour in the presence of commercial fishing gear is an important factor to be considered when developing an effective repellent strategy. Therefore, observations made by longline fishermen could provide useful information that can be used for directing laboratory and field studies.

Many fishermen report that spiny dogfish can strike baited hooks as the gear is sinking, shortly after being deployed. Dogfish have been observed occupying the majority of baited hooks when gear was hauled back less than an hour after setting. If dogfish feed predominantly in the upper water column, then the period of efficacy of the repellent need only be as long as the time it takes for the gear to sink to the bottom. This would simplify the solution to the "dogfish problem". For example, the rate of descent of the gear could be increased by adding weights (i.e. bricks) to the groundline.

Hooks with special "scent saver" devices (Fig.9) to carry chemical repellents (i.e. ammonium acetate, industrial surfactants) could possibly reduce initial attack rates on sinking gear. Coating hooks with an inert carrier such as cellulose might also be a means of conveying the repellent substance. While the scent saver and cellulose carriers would likely retain the odour of the repellent when the gear is on bottom, it is not certain how long this effect would be maintained because of dilution with seawater. Use of frozen bait covered with a heavy ice glaze may mask or reduce the olfactory attractiveness of the bait. By the time the gear reaches bottom, the bait will have thawed and its effectiveness restored. Both strategies could help to reduce dogfish attack on baited longlines.

While a device which physically prevents dogfish from biting the bait has yet to be developed, its design should take advantage of differences in the anatomy and feeding behaviour between sharks and other fish species. Due to the shark's long snout and its sub-terminal mouth, it must turn on its side in order to bite the bait, whereas a haddock for example approaches the bait head on. It may be possible to protect the bait by means of a circular, plastic washer attached to the shank of the hook. Such a device could selectively protect bait from dogfish, while allowing commercial species to take the hook.

Some commercial longline fishermen believe that circle hooks retain their shape better and are easier to remove from the mouths of dogfish than standard hooks. Interestingly, an early version of the circle hook proved to be more effective than the standard "J" hook for catching dogfish commercially in the North Sea during the late 1960's (P. Jangaard, DFO, pers. comm.). This may have important ramifications with the recent increase in use of circle hooks by Maritime fishermen. Herring are reported to be the preferred bait of dogfish, more so than mackerel or squid. Although choice of bait may be an important factor in reducing attacks by dogfish, it may also have effects on the commercial catch as well.

While these observations and perceptions are important, they are speculative and require some type of quantitative evaluation, perhaps through carefully planned field studies.

GENERAL CONCLUSIONS AND OPTIONS FOR FUTURE RESEARCH

Sharks possess a battery of senses unparalled by other vertebrates which enables them to be extremely effective predators. Therefore, fixed gear fisheries tend to be prime targets for aggressive attacks by spiny dogfish because they elicit chemical, mechanical, visual and electromagnetic cues which present strong, attractive stimuli. While the preceding sections indicate that there are several methods which may be employed for protecting commercial fishing gear, our knowledge of the capabilities of each of these methods is very limited.

The most promising repellents for use by commercial fishermen are probably those that serve to either lessen attraction in the far field or deter sharks in the near field.

Chemical repellents are attractive, at least in theory, because they have many potential advantages over other deterrent methods (e.g. simplicity of use, low cost and ease of manufacture and distribution). Their use, in combination with other protective measures (i.e. painting hooks a non-reflective colour, use of ice glazed bait and drifting with the engine off prior to setting gear), may ultimately be the most effective. Both copper acetate and industrial surfactants appear to have the most potential as chemical repellents, however, they must be effective during the commotion of setting and hauling gear, provide effective repellent action in the presence of strong attractive stimuli (e.g. bait) and have no toxic effects on fish or humans.

The use of electrodes attached to longlines or gillnets to provide a protective electrical field may function selectively in deterring dogfish without adverse results on commercial species because of the electroreceptive ampullary system unique to sharks. While recent studies at A.T.& T./Bell Labs suggest that some sharks are repelled by continuous direct currents in the range of 1.6 amps, it is not known whether spiny dogfish would be similarly repelled. Electrical devices must be rugged, dependable and inexpensive if they are to be a viable alternative and will probably need to be designed specifically for use with commercial fishing gear.

Development of an effective control program to repel or deter S. acanthias is dependent on a much more thorough understanding of their behaviour in the presence of potential repellents. For any candidate repellent material (or device), there should be a two phase testing program consisting of: a) laboratory tests on captive dogfish under controlled conditions and b) field tests on wild dogfish in their natural environment. Laboratory tests involving standard assay techniques as described by Gruber et al. (1984) and open water trials using paired longlines (Gilbert & Springer 1963) are possible techniques for evaluating the effectiveness of a particular device or compound. One possible approach is to conduct field tests initially to determine whether the response of dogfish to the strongest attractive stimuli (i.e. olfaction, sound) can be overcome and then proceed to the laboratory to verify these findings and examine dogfish behaviour in the presence of potential repellent substances or devices.

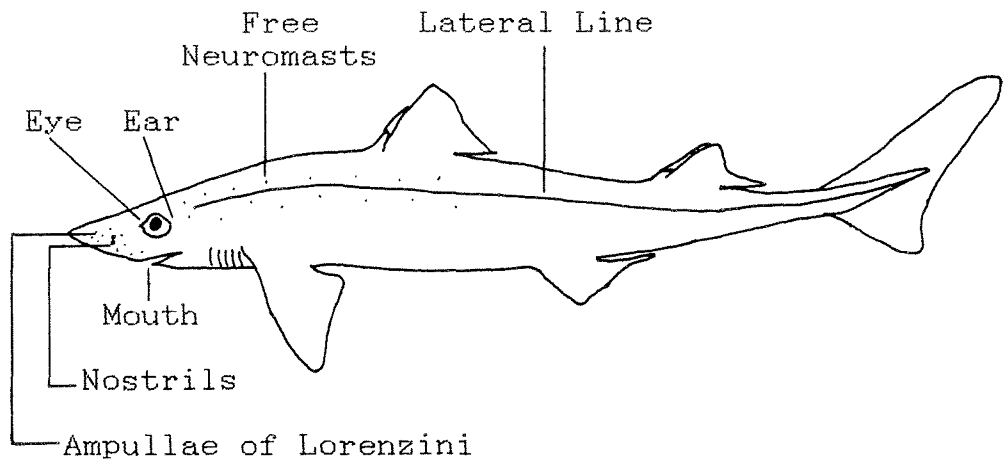
Under controlled environmental conditions, laboratory experiments provide a unique opportunity to observe dogfish behaviour in response to various chemical, acoustical, visual, mechanical or electrical stimuli. Some of the difficulties to be overcome include training/learning problems (i.e. habituation to certain stimuli), determination of adequate rest periods between tests and whether to use animals for tests during the refractory "wild" period or later on after acclimation. Furthermore, dogfish in captivity have certain maintenance requirements which must be met to orient and swim comfortably (i.e. there must be a directed water current in the tank).

Longline experiments for chemical repellents are designed using alternating treated and untreated baits. The repellent substance could be in solid or liquid form either attached to the gear itself or contained on or within the bait. The latter test would be most effective in determining taste aversion or contact repellents which would have to be mouthed before a repellent dose is received. However, these substances may be unpallatable to commercial fish species. In the final analysis, field tests must be conducted under appropriate conditions to determine the true effectiveness of any candidate repellent substance (or device). Observations on dogfish behaviour towards the longline gear may be helpful in this respect and could be obtained using SCUBA diving techniques in shoal areas where dense schools of dogfish are known to occur or by using a fixed underwater camera.

Figure 1. A) Some of the sensory perception systems found in <u>Squalus acanthias</u>.

B) Generalized scheme of the reception of stimuli in sharks.

A.



B.

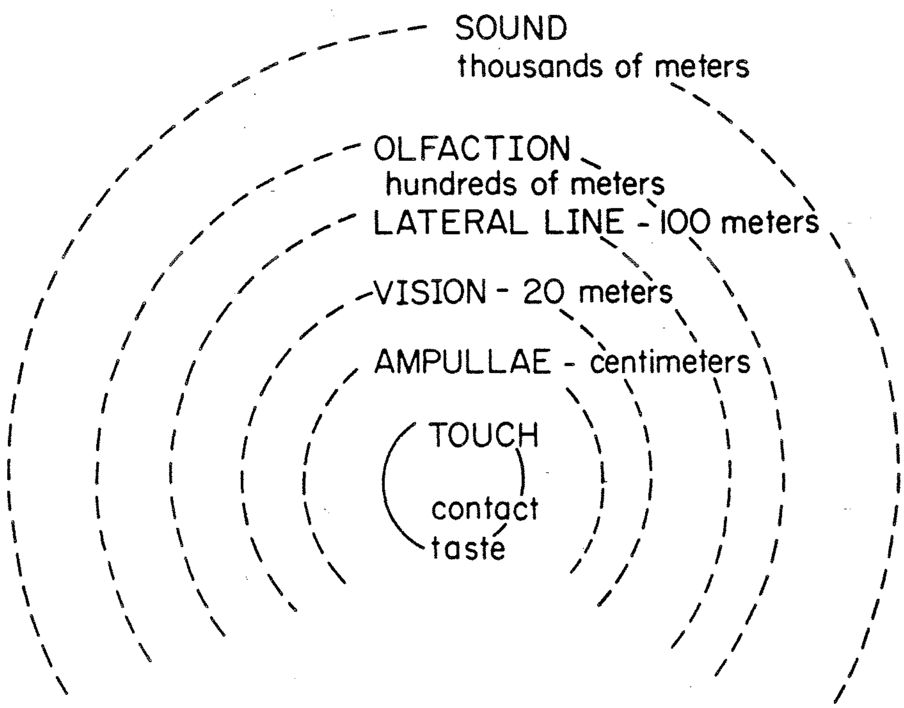
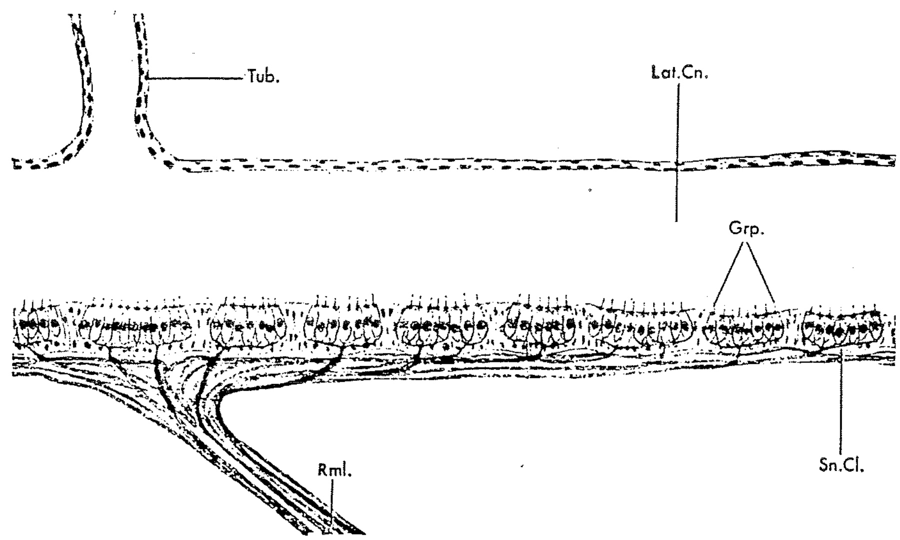


Figure 2. A) Longitudinal section of lateral line canal in the smooth dogfish (Mustelus canis). Grp.=group of sensory hair cells; Lat.Cn.= lateral line canal; Rml.=cranial nerve; Sn.Cl.=sensory hair cell; Tub.= tubule to exterior. (From Gilbert 1963).

B) Left inner ear of the gray reef shark (Carcharhinus menisorrah). The endolymphatic duct (ED) passes from its pore (EP) in the skin through the parietal fossa (PF) to enter the sacculus (S) beneath the chondrocranium (CH). The laguna (L) and posterior vertical canal (PVC) communicate to fenestra (F) in the parietal fossa through the posterior communicating duct (PCD) which houses the macula neglecta (MN), a suspected sound-sensitive receptor. A=ampulla; U=utriculus; AVC=anterior ventral canal; HC=horizontal canal; ANT=anterior. (From Moss 1984).

A.



B.

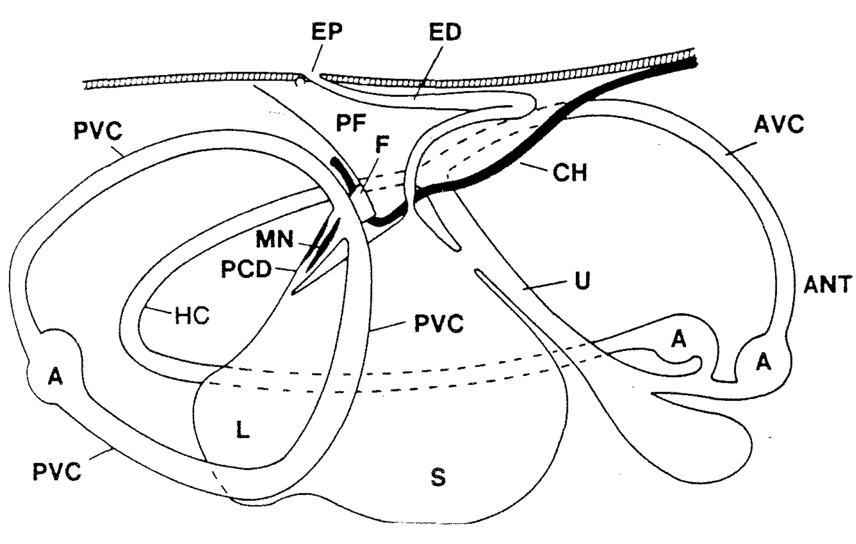


Figure 3 Schematic diagram of a shark locating an odour source by turning into the current whenever an olfactory stimulus is encountered. (From Moss 1984).

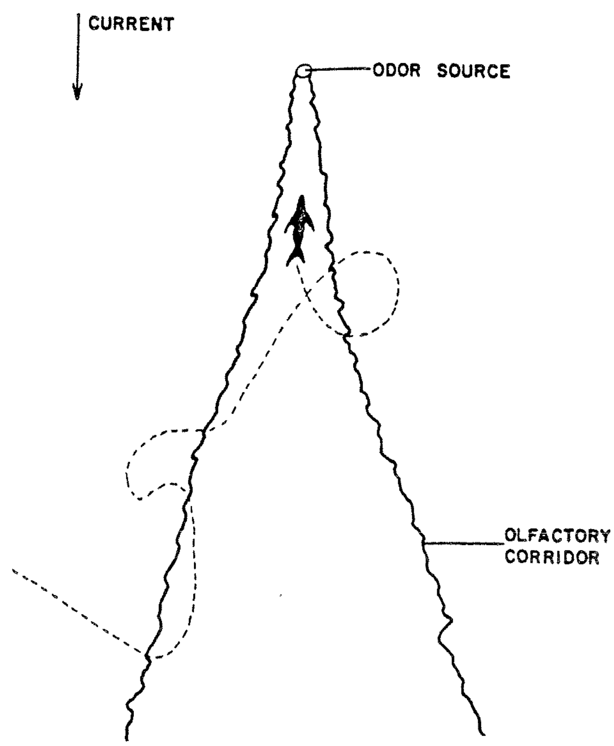


Figure 4. Pharynx of adult spiny dogfish (<u>Squalus acanthias</u>), laid open to show the distribution of taste papillae. (From Gilbert 1963).

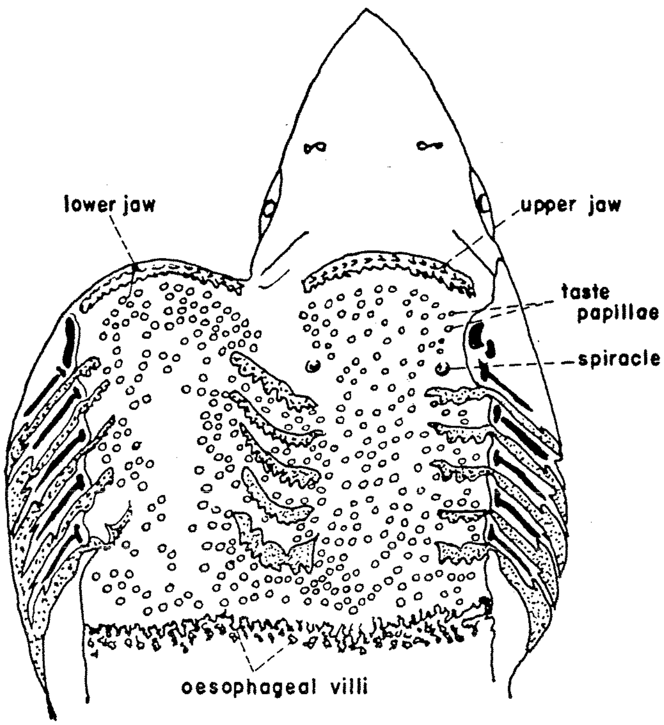
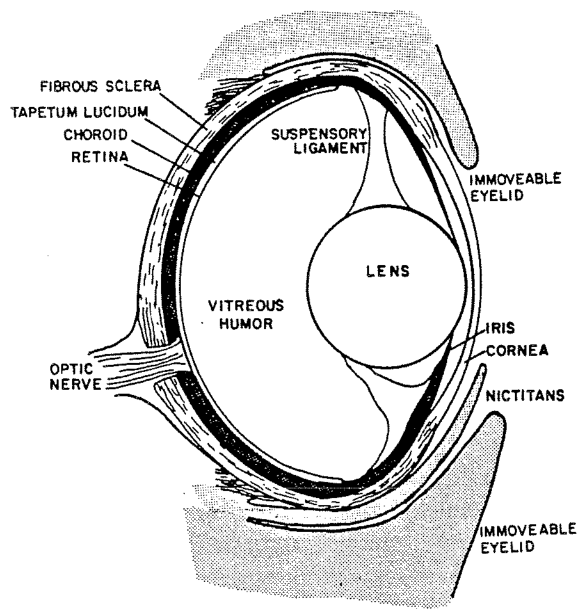


Figure 5. A) General structure of an elasmobranch eye.

B) Ampullae of Lorenzini and mechanical lateral line system in the head region of the shark Schliorhinus canicula. Solid dots: skin pores of electroreceptors. Small circles: openings of lateral lince canals.

A.



B.

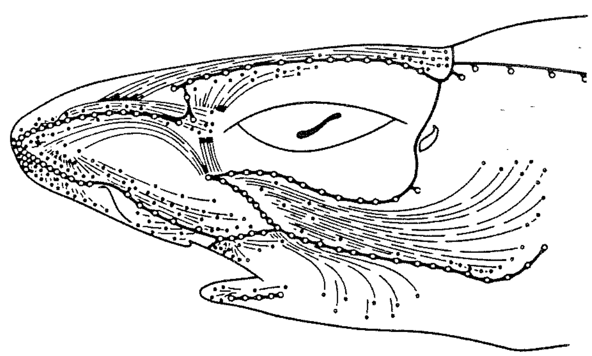


Figure 6. Rig of set line used in shark repellent tests for nigrosine dye and copper acetate. (From Gilbert and Springer 1963).

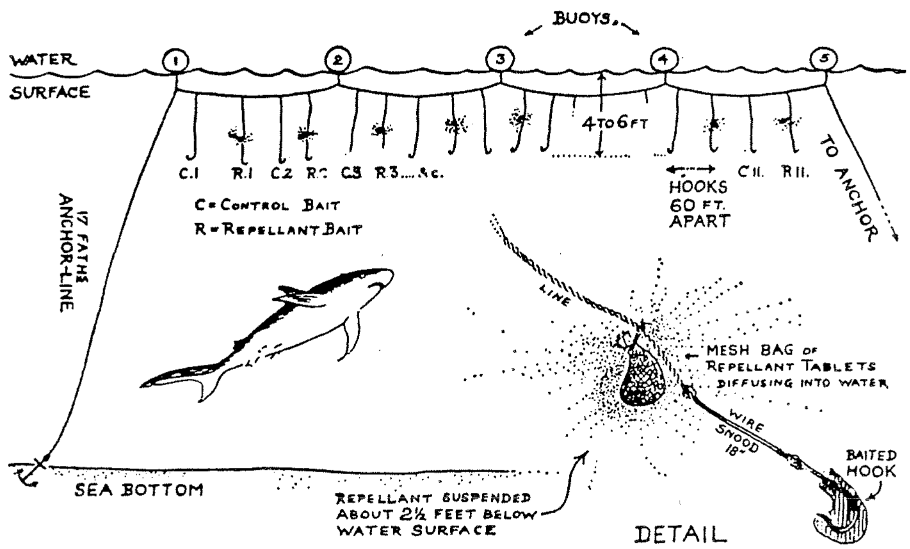
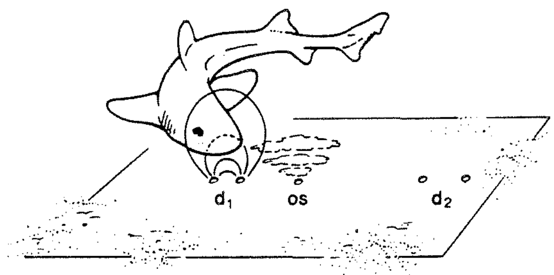


Figure 7. Feeding attacks of (A) smooth dogfish (Mustelus canis) and (B) blue shark (Prionace glauca) on electrically simulated prey. Both sharks will attack electrodes (dl) passing a current of only 8 microamps in preference to a nearby odour source (os) or control electrodes (d2). (From Kalmijn 1982).

A.



B.

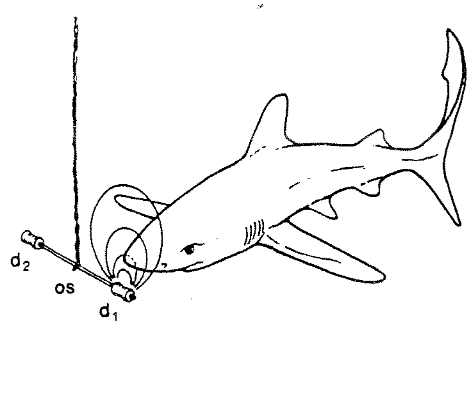


Figure 8. Schematic diagram of Shark Shield unit and electrodes on a prawn trawl net.

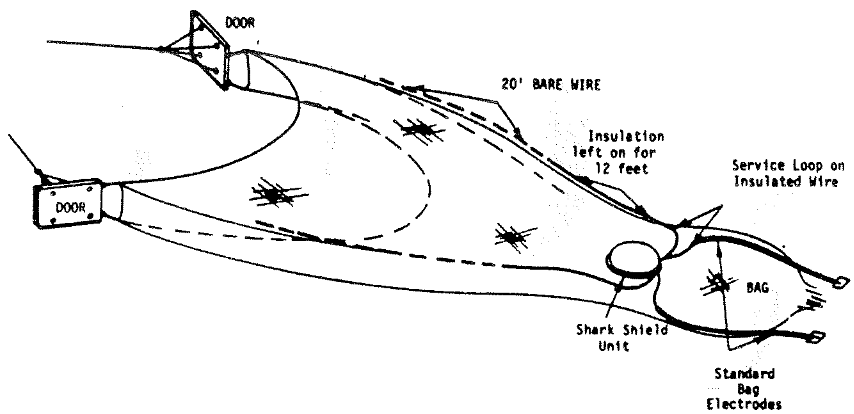
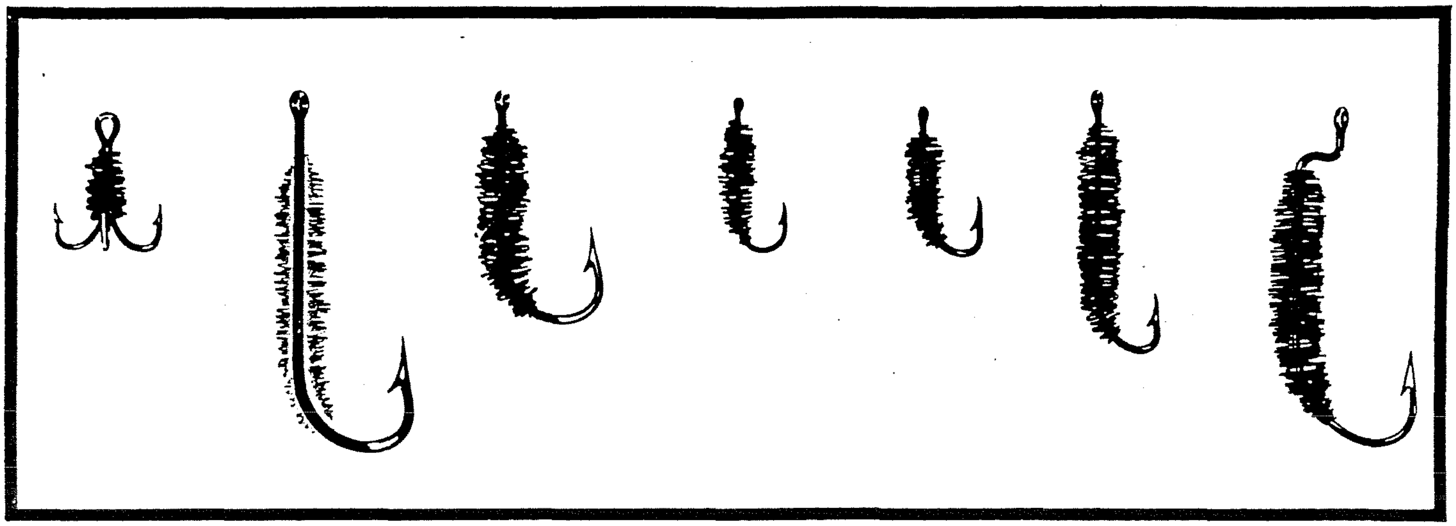


Figure 9. Scent Saver fish hooks. Bristles on shank absorb repellent substance which is subsequently released when hook is immersed in water.



LITERATURE CITED

Anonymous. 1979. Development of the dogfish fishery in Newfoundland during 1978. Newfoundland and Labrador Dept. of Fisheries. Development Branch Report No. 4. 31 p.

Annand, C. 1985. Status report on 4VWX dogfish (Squalus acanthias). CAFSAC Res. Doc. 85/73. 23 p.

Annand, C. 1986. Pers. Comm. Marine Fish Division, Bedford Institute of Oceanography, Department of Fisheries and Oceans, Dartmouth, Nova Scotia.

Banner, A. 1972. Use of sound predation by young lemon sharks, Negaprion brevirostris (Poey). Bull. Mar. Sci. 22: 251-283.

Bigelow, H.B. & W.C. Schroeder. 1953. Fishes of the Gulf of Maine. Fish. Wildl. Serv. Fish. Bull. 53: 47-51.

Boord, R.L. & C.B.G. Campbell. 1977. Structure and functional organization of the lateral line system of sharks. Amer. Zool. 17: 431- 441.

Bowman, R., R. Eppi & M. Grosslein. 1984. Diet and consumption of spiny dogfish in the northwest Atlantic. Int. Counc. Explor. Sea. C.M. 1984/G:27.

Clark, E. 1983. Shark repellent effect of the Red Sea Moses sole. 135-150. In: B.J. Zahuranec (ed). Shark Repellents From the Sea, New Perspectives. Westview Press. Boulder, Colorado. 210 p.

Cohen, J.L. 1981. Vision in sharks. Oceanus. 24(4): 17-22.

Gilbert, P.W. 1963. Sharks and Survival. D.C. Heath and Company. Boston, Mass. 578 p.

Gilbert, P.W. & C. Gilbert. 1973. Sharks and shark deterrents. Underwater J. 5: 69-79.

Gilbert, P.W. & S. Springer. 1963. Anti-shark measures. 465-494. In: P.W. Gilbert (ed.). Sharks and Survival. D.C. Health and Company. Boston, Mass. 578 p.

Gruber, S.H. 1977. The visual system of sharks: adaptations and capability. Amer. Zool. 17: 453-469.

Gruber, S.H., E. Zlotkin & D.R. Nelson. 1984. Shark repellents: behavioral bioassays in laboratory and field. 26-42. In: L. Bolis, J. Zadunaisky & R.Gilles (ed.). Toxins, Drugs and

Pollutants in Marine Animals. Springer-Verlag. Berlin, Heidlberg.

Halstead, B.W. 1978. Dangerous Marine Animals. Cornell Maritime Press. Cambridge, Md.

Harris, A.J. 1965. Eye movements of the dogfish, Squalus acanthias L.J. Exp. Biol. 43: 107-130.

Jangaard, P. 1986. Pers. Comm. Fisheries Development Branch, Department of Fisheries and Oceans, Halifax, Nova Scotia.

Jensen, A.C. 1966. Life history of the spiny dogfish. Fish. Wildl. Serv. Fish. Bull. 65(3): 527-553.

Jones, B.C. & G.H. Geen. 1977. Food and Feeding of spiny dogfish (Squalus acanthias) in British Columbia Waters. J. Fish. Res. Bd. Canada. 34: 2067-2078.

Kalmijn, A.J. 1966. Electro-perception in sharks and rays. Nature, Lond. 212: 1232-1233.

Kalmijn, A.J. 1971. The electric sense of sharks and rays. J. Exp. Biol. 55: 371-383.

Kalmijn, A.J. 1977. The electric and magnetic sense of sharks, skates and rays. Oceanus 20(3): 45-52.

Kalmijn, A.J. 1982. Electric and magnetic field detection in elasmobranch fishes. Science. 218: 916-918.

Klimley, A.P. & A.A. Myrberg. 1979. Acoustic stimuli underlying withdrawal from a sound source by adult lemon sharks, Negaprion brevirostris (Poey). Bull. Mar. Sci. 29(4): 447-458.

Leim, A.H. & W.B. Scott. 1966. Fishes of the Atlantic Coast of Canada. Bull. Fish. Res. Bd. Canada. 155, 485 p.

Mathewson, R.F. & E.S. Hodgson. 1972. Klinotaxis and rheotaxis in orientation of sharks toward chemical stimuli. Comp. Biochem. Physiol. 42: 79-84.

Moss, S.A. 1977. Feeding mechanisms in sharks. Amer. Zool. 17: 355-364.

Moss, S.A. 1984. Sharks - an introduction for the amateur naturalist. Prentice-Hall Inc. Englewood Cliffs. New Jersey. 246 p.

Myrberg, A.A., A. Banner & J.D. Richard. 1969. Shark attraction using a video acoustic system. Marine Biol. 2: 264-276.

Myrberg, A.A., S, J. Ha, S. Walewski & J.C. Banbury. 1972.Effectiveness of acoustic signals in attracting epipelagic sharks to an underwater sound source. Bull. of marine Sci. 22(4): 926-949.

Nammak, M.F. 1982 MS. Life history and management of spiny dogfish off the northeastern United States. MA Thesis. The college of William and Mary, Virginia Institute of Marine Science. Gloucester Point, Virginia. 63 p.

Nammak, M.F., J.A. Music & J.A. Colvocoresses. 1984. Life history of the spiny dogfish off the northeastern United States. Trans. Am. Fish. Soc. 114: 367-376.

Nelson, R.N. 1983. Shark attack and repellency research: an overview. In: B.J. Zahuranec (ed). Shark Repellents From the Sea, New Perspectives. Westview Press. Boulder, Colorado. 210 p.

Nelson, D.R. & R.H. Johnson. 1972. Acoustic attraction of Pacific reef sharks: effect of pulse intermittency and variability. Comp. Biochem. Physiol. 42: 85-95.

Peeling, D. 1982. A Canadian east coast longline fishing demonstration project for the harvesting of spiny dogfish (Squalus acanthias). Fisheries Development Branch Rep. No. 47. 23 p.

Peeling, D. 1985. Harvesting Spiny Dogfish. Fisheries Development Branch, Project Summary No. 5.

Popper, A.N. & R.R. Fay. 1977. Structure and function of the elasmobranch auditory system. Amer. Zool. 17: 443-452.

Primor, N.,C. Bonaventura & J. Bonaventura. 1983. Effect of Moses sole secretion and its active factor, paradaxin, on elasmobranchs. 151-156. In: B.J. Zahuranec (ed.). Shark Repellents From the Sea, New Perspectives. Westview Press. Boulder, Colorado. 210 p.

Richard, J.D. 1968. Fish attraction with pulsed low-frequency sound. J. Fish. Res. Bd. Canada. 25(7):1441-1452.

Salsbury, J. 1986. Spiny dogfish in Canada. Can. Ind. Rep. Fish. Aquat. Sci. 169: xii + 57 p.

Salsbury, J. 1987. An assessment of the dogfish problem in the Scotia-Fundy Region. Fisheries Development Branch Contract No. 09SC.FP111-6-0302. 28 p.

Stell, W.K. 1972. The Structure and morphologic relations of rods and cones in the retina of the spiny dogfish, _Squalus_. Comp. Biochem. Physiol. 42: 141-151.

Templeman, W. 1944. The life history of the spiny dogfish, _Squalus acanthias_, in the Northwest Atlantic. NAFO Sci. Coun. Studies 3: 46-52.

Templeman, W. 1954. Migrations of spiny dogfish tagged in Newfoundland waters. J. Fish. Res. Bd. Can. 11(4): 351-354.

Tricas, T.C. 1982. Bioelectric-mediated predation by swell sharks, _Cephaloscyllium ventriosum_. Copeia. 4: 948-952.

Tuve, R.L. 1963. Development of the U.S. Navy "Shark chaser" chemical shark repellent. 455-464. _In_ P.W. Gilbert (ed.). Sharks and Survival. D.C. Heath and Company. Boston, Mass. 578 p.

Waring, G.T. 1984. Changes in population structure and abundance of spiny dogfish off the northeast coast of the United States. NAFO SCR Doc. 84/IX/105. 14p.

Yeisley, P. 1986. Pers. Comm. A.T.& T./Bell Labs.

Zlotkin, E. & Y. Barenholz. 1983. On the membranal action of paradaxin. 157-171. _In_: B.J. Zahuranec (ed.). Shark Repellents From the Sea, New Perspectives. Westview Press. Boulder, Colorado. 210 p.