THE SPINY DOGFISH - A REVIEW

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INTRODUCTION

The spiny dogfish (Squalus acanthias L.) has been one of the most intensively studied fishes, but one in which extensive knowledge is lacking. The species is studied by college students in zoology, ichthyology, comparative anatomy, and vertebrate taxonomy, and is a favorite experimental animal for physiological studies including pharmacological toxicity tests.

Unfortunately there have been few comprehensive life studies of this fish. These include Ford's (1921) study at Plymouth, England; Templeman's (1944) study for Newfoundland, and the studies made by Bonham, et al (1949) for the State of Wahington. In general, most of the published reports present isolated observations or extremely specific studies. As a result, we know something of the function of the rectal gland of the spiny dogfish, but we do not know the over-wintering grounds. We know the mechanism controlling movements of the spiral intestine, but we do not know the relation of separate groups of dogfish in any one area.

All papers quoted, or listed in the bibliography, have been read by the senior author. Some selection of papers was carried out and reports not included are mostly those dealing with esoteric biochemical or physiological studies. In addition to information gained from the literature, some original data from our own studies have been included here. As a convenient method of handling the information, the various phases of the life history of the fish are taken up in turn. Because the distribution of the species is world-wide through the Northern Hemisphere (Bigelow and Schroeder 1948), we have reviewed reports from both the Atlantic and Pacific Oceans. Some consideration has been given, as well, to the role of the spiny dogfish in the commercial fishery - industrial and human food.

Much of the information reported here is of interest solely because it adds to man's fund of knowledge about the species, but the information has more concrete implications for our commercial fishermen. This latter consideration has been aptly summed up by Bigelow and Schroeder (1948), who state:

"From a practical aspect the spiny dog in the Western Atlantic is chiefly important because it is undoubtedly more destructive to gear and interferes more with fishing operations than does any other fish - shark or teleost."

PRESENT KNOWLEDGE OF THE SPINY DOGFISH

DESCRIPTION

The spiny dogfish is typically shark-like in appearance (fig. 1).

Figure 1.--The spiny dogfish (Squalus acanthias).

In the western Atlantic waters it grows to about 2 to 3-1/2 feet long (50 to 90 cm.) and weighs 7 to 10 pounds, with a maximum of about 4 feet (100 cm) and 15 to 20 pounds. The females are slightly larger than the males (Bigelow and Schroeder 1953). In the Pacific Ocean, off the west coast of the United States, the males reach a maximum of about 4 feet (100 cm.) and 8 pounds, while the females reach a maximum of about 5 feet (124 cm.) and 20 pounds (Bonham et al. 1949).

The upper part of the fish is slate colored, sometimes tinged with brown, with irregular rows of small white spots on each side. The white spots are generally typical of younger fish and may be lacking on older individuals. A distinguishing feature of this shark is the presence of two sharp spines, one anterior to each dorsal fin, the rear spine longer than the front spine. It has been suggested that the spines may be poisonous, although there is not direct evidence to support this (Bigelow and Schroeder 1953). The spines are presumably used in defense and are capable of inflicting a nasty and painful wound.

DISTRIBUTION AND MIGRATIONS

Distribution of the spiny dogfish has been, until recently, somewhat obscured by the identity of the species. Many ichthyologists held that there were two distinct species, S. acanthias in the North Atlantic Ocean, and S. suckleyi in the North Pacific Ocean. Bigelow and Schroeder (1948) noted that although it was not entirely clear how the two species were related, they had not obviously differentiated themselves specifically during the period since their ranges had become discontinuous. The prevailing opinion today is that the two populations represent but a single species, S. acanthias, that occurs in both the Atlantic and Pacific Oceans (American Fisheries Society 1960). Briefly, the distribution may be expressed as, both sides of the North Atlantic, chiefly in temperate and sub-arctic latitudes, and also on both sides of the North Pacific, in similar latitudes, (fig. 2) with close allies in corresponding latitudes in

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Figure 2.--Distribution of the spiny dogfish in the northern hemisphere.

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the Southern Hemisphere. It occurs chiefly in continental, as contrasted with oceanic, waters, anywhere between the surface and the bottom down to 90 or 100 fathoms (Bigelow and Schroeder 1945).

The distribution in the Northeast Atlantic is described in detail by Bigelow and Schroeder (1948). It is found in waters off France, north to Ireland, Scotland, southern Scandinavia, the English Channel, and the North Sea, from there eastward to the Kattegat. The spiny dogfish rarely enters the Baltic Sea. It is plentiful around the Orkney Islands, the Faroes, and the south and east of Iceland (but less to the north and west), and is found off Norway to the Murman coast. It is also found in the Mediterranean Sea and the Black Sea.

In the Northwest Atlantic (Bigelow and Schroeder 1948) the spiny dogfish is found in coastal waters from Cape Lookout, North Carolina, northward around Nova Scotia, along both the northern and southern shores of the Gulf of St. Lawrence, past the Strait of Belle Isle to southeast Labrador. There is no record of it occurring along the coast north of Hamilton Inlet. Offshore it occurs in season on Nantucket Shoals, Georges Bank, Browns Bank, the Nova Scotian banks, and on the Grand Bank. It is also recorded on the west coast of Greenland to Sukkertoppen and Holsteinborg. Hansen (1949) reports dogfish were formerly a rarity around Greenland, but in the 1930's some were caught in several places on the southwest coast, and, in the autumn of 1947, around Sukkertoppen.

Local observations of spiny dogfish, and their seasonal occurrence, are reported by Perley (1852), Stafford (1912), Cox (1921), and Jeffers (1932). In each case these early reports noted that the appearance of dogfish usually indicated an end of commercial food fishing.

In the Pacific Ocean, Bigelow and Schroeder (1948) report that the spiny dogfish is found on ". . . both sides of the Northern Pacific south to California, Japan, Northern China and the Hawaiian Islands."

Migrations. The spiny dogfish is one of the more gregarious kinds of fishes and occurs in schools or packs containing large numbers of individuals. Usually the schools are composed of either, (1) very large, mature females, (2) medium size individuals, all mature males or all immature females, or, (3) small immature individuals of both sexes in about equal numbers (Bigelow and Schroeder, 1953). Hickling (1930) in his studies of spiny dogfish collected off the southwest part of Ireland, noted a relationship between the size of the individuals in the schools and the depth of water. Fish of both sexes, from 30 to 45 cm. long, were caught in 30 fathoms, while larger fish of both sexes, from 50 to 89 cm. long, were caught in 90 to 100 fathoms. In general, male dogfish were found in shallower water than females of the same size. The exception to this, however, was for the large pregnant females that were migrating into shallower water to bear their young.

The appearance of dogfish in our eastern coastal waters is a rather sudden event. One day, in a given area, there will be fine cod and haddock fishing, the next day there will be nothing but dogfish. They appear as early on Georges Bank (March-April) as they do along New Jersey (March) (Bigelow and Schroeder, 1953). Dogfish are spring and autumn transients only in the southern part of their range, from New York to North Carolina, and in the Cape Cod area they are mostly transients, moving to the north in the spring and to the south in the autumn.

In Newfoundland waters they first begin to appear in June, off the southern end of the island (Templeman, 1944). The largest fish--mature and probably pregnant females--appear first. The mature males appear in the late autumn. As the season progresses, dogfish appear further northward along the coast and are off Labrador by September. In general, dogfish are plentiful around Newfoundland from June through November or December.

The nature of the dogfish's seasonal migration - coastal north-south, offshore-onshore, or a combination of the two - is not clearly understood. Part of the problem is the mystery of where the dogfish spends its winters. Bigelow and Welsh (1925) stated, "The winter home of the Gulf of Maine dogfish is still to be learned". They considered the presence of the adults in deep water in Long Island Sound in midsummer, the almost simultaneous appearance of the fish all along the coast north of North Carolina in the spring, and the capture of dogfish by the Albatross, February 1920, in 90 to 199 fathoms along the continental edge off Chincoteague, Virginia, and off Delaware Bay, and concluded that this ". . . argues for an on-and-off rather than a long-shore migration, with the deep water off the continental slope as their winter home".

More recent evidence of their presence in deep water during the winter has been accumulated from observations of dogfish off the Middle Atlantic and New England states (Bigelow and Schroeder, 1940, 1948, 1953) and some that summer in the general region of Newfoundland may survive the winter in the deep trough of the Gulf of St. Lawrence (Bigelow and Schroeder, 1953). In January, 1961, spiny dogfish were taken in an otter trawl by the research vessel Delaware in 87 to 100 fathoms along the edge of the continental shelf 80 miles south of Martha's Vineyard (Fish and Wildlife Service unpublished records).

At times, however, dogfish may come into shallow water in the winter. Collins (1883) quotes an item in the newspaper "Cape Ann Advertiser" dated February 10, 1882: "Immense schools of dogfish, extending as far as the eye can reach, have appeared off Portsmouth, an unusual sight in winter."

The accumulated wealth of evidence suggests that there is a temperature relationship governing the seasonal movements of the spiny dogfish. Bigelow and Schroeder (1948) note that dogfish do not appear along the east coast until the water warms to 6° C. (42.5° F.) and disappear when the water temperature rises to about 15° C. (about 59° F.). The preferred range of temperature on the offshore wintering grounds seems to be 6° to 11° C. (42.5° to 52° F.).

Survey data tends to support Bigelow and Schroeder's statement that this species winters in relatively deep water, moving into shoaler water in summer and fall. The average depth at which 100+ dogfish per haul were obtained during the period January - June (1948 - 1960) is found to be significantly different from the corresponding depth for the period July - December (75 and 47 fathoms, respectively).

Dogfish Catches (_ 100)

Date	Area	Depth (Fthms)	Temp. (F)	No. of Fish
8/4/48	I	302	44	123
8/5/48	II	19	56	131
8/5/48	II	22	53	210
10/16/48	IV	13	54	374
10/17/48	I	20	47	101
10/30/48	I	40	60	248
10/30/48	I	42	56	100
10/30/48	I	33	58	283
10/30/48	I	30	60	115
10/31/48	I	34	59	1561
11/5/48	I	34	58	187
12/3/48	I	46	--	190
7/29/49	II	36	51	3637
4/22/50	II	67	49	560
4/23/50	III	61	45	100
4/26/50	V	120	46	103
4/26/50	V	120	45	224
5/1/50	V	104	48	372
5/1/50	V	100	--	1200
5/1/50	V	96	48	475
5/1/50	V	110	48	269
5/2/50	V	60	40	420
5/13/50	I	50	52	1476
5/13/50	I	50	52	152
5/13/50	I	45	52	150
5/13/50	I	44	41	610
5/14/50	I	46	45	258
5/15/50	II	78	52	110
5/16/50	III	62	46	120
5/16/50	II	46	44	140
5/17/50	II	42	42	156
8/1/50	III	46	46	224
8/1/50	III	46	47	455
8/2/50	III	52	48	146
8/5/50	V	160	43	234
6/14/55	V	56	43	110
11/17/56	I	32	56	160
11/17/56	I	32	62	211
10/8/58	V	111	46	900
10/9/58	V	122	46	122
2/3/59	I	99	49	428
2/3/59	I	83	53	367
10/20/59	IV	30	52	1050
Mean			50	

The temperature preferance of dogfish appears to fall in the 45° - 55° F. range. Calculation of fish-degrees from survey data (100+ fish per haul) during the period 1948 - 1960 gave a figure of 50.6° F. The average temperature at which 100+ fish per haul were obtained during the period January - June was 47° F; for the period July - December, 52° F.

In Alaskan waters incidental catches of spiny dogfish are reported by Hanavan and Mitchell (1959) during experimental gill netting for salmon. The dogfish were caught in the Bering Sea and in the Gulf of Alaska during July and August when the surface water temperatures ranged from 7° to 13.3° C. (44.4° to 55.5° F.).

In waters off Japan Sato (1935) reports an interesting diurnal migration of spiny dogfish. He recorded the body temperatures of dogfish caught in the daytime and at night, on a fishing ground in 60 to 70 fathoms. Thirty dogfish caught at night in a surface drift gill net had body temperatures of from 9.5° to 11.2° C. (49° to 52° F.). The surface water temperature at the time was quite similar, from 9° to 12.2° C. (48° to 54° F.). In contrast, 28 dogfish caught during the day on a long-line on the bottom, had body temperatures of from 3.5° to 5.8° C. (38° to 42.5° F.). Unfortunately he does not report the water temperature on the bottom. It seems reasonable to assume, however, that the bottom water temperature was within the range of the body temperature of the fish caught on the bottom and that the dogfish were rising to, or near, the surface at night and descending to the bottom during the day.

In early August, 1961, dogfish were frequently observed at or near the surface on many of the inshore fishing grounds. The water temperatures at the surface were normal (around 60° F.) but at the bottom they were abnormally cold (37° to 39° F. at 250 feet). Few dogfish were taken by otter trawl at this time.

The dogfish appeared at the surface itself late at night and early in the morning. On one morning in Ipswich Bay they were observed to be harrying small schools of euphausiids--as many as 6 to 8 fish circling each school. The numbers of fish that could be seen at this time were in the thousands. During the day the dogfish retreated to depths of 3 to 5 fathoms. Several hundred were handlined from this depth. In the late afternoon occasional fish were again frequently observed at the surface. Further south of Cape Cod, the dogfish were to be taken again a few fathoms below the surface. There they appeared at the surface whenever the otter trawl was hauled back and unwanted fish were discarded.

Little is known of the salinity preferences of the spiny dogfish. Bigelow and Schroeder (1948), however, note a record of a spiny dogfish that entered a river in Denmark. In their opinion the water was undoubtedly brackish, at least near the bottom, rather than fresh, since both cod and Merluccius were also present in the river at the same time. Spiny dogfish captured off British Columbia and studied in the laboratory,

were able to live for more than one hour in distilled water and for nearly two hours in tap water (Quigley, 1928a). The author concludes, "Since the dogfish continued to breathe for an average of 113 minutes in tap water and remained active during most of this time, they probably could escape from a freshwater stream even if they were to swim into it above tide water level."

Tagging studies.--Spiny dogfish have been tagged by biologists interested in making more precise determinations of the migration routes of this fish, and also to learn something of the nature of the dogfish populations. Tag returns from most of the experiments have been at a lower rate than for tagging experiments with commercially valuable fishes; in most fisheries the dogfish is either a nuisance to be avoided or, at best, retained as a very minor part of the catch. Thus, although many tagged dogfish are undoubtedly recaptured, few of them are reported to the taggers. Tags that have been returned suggest that the dogfish is long-lived since several fish were at liberty for up to 10 years. Some individual fish made long distance migrations.

In a British experiment that took place in November and December, 1957, 75 spiny dogfish were tagged with a yellow plastic tab attached with a braided nylon loop (Beverton, Gulland, and Margetts, 1959). The fish were tagged incidentally during a whiting tagging experiment conducted in the northwest part of the Irish Sea. At the time of the report, after 7 months at liberty, only two tagged dogfish were returned despite the fact that originally the dogfish appeared particularly robust and little affected by capture or tagging. No information was given as to the place of recapture of the tagged fish.

One thousand spiny dogfish were tagged near the Shetland Islands, north of Scotland in November 1958 (Aasen, 1960). The mark used was a yellow slip of polyethylene film with printed text rolled up as a cylinder and attached to the fish with a stainless steel bridle in front of the first dorsal fin. After 2-1/2 months at liberty, 12 tagged fish (1.2%) were recaptured, most of them near the west coast of Norway.

On the Pacific Coast of North America a great deal of attention was directed to dogfish tagging in the 1940's because of the intensive fishery then conducted for the species in which the livers were taken for the extraction of vitamin A. Nearly 10,000 dogfish were tagged in the waters off British Columbia and Washington and 655 (6.7%) were recovered (Holland, 1957). In general, the tag returns demonstrated a southward, coastal migration in the autumn and winter, and a northward migration in the spring and summer. Several long-distance recaptures were reported from the coastal migrations but the one outstanding off-shore, long distance migration was reported when a dogfish that had been tagged off Willapa Bay in 1944 was recaptured near the northern end of Honshu Island, Japan, in 1952. This represents a straight line distance of 4,700 miles, but the author concluded that the fish probably followed a great circle route at accustomed depths along the coastal shelf. The longevity of the spiny dogfish is suggested by the above example, at liberty 7 years, and two other fish, tagged in the same experiment that were at liberty 8 years and 10 years respectively.

Dogfish tagging experiments in the Northwest Atlantic have been reported by Templeman (1954, 1958) for the Newfoundland-Grand Bank area, and by Jensen (1961) for the Gulf of Maine-Georges Bank, and Browns Bank areas (fig. 3). In the Newfoundland experiment, 279

Figure 3.--Results of dogfish tagging in Northwest Atlantic.

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females were tagged near St. John's in July 1942 and as of September, 1949, 14 fish (5%) were recaptured. Many of the tagged fish were caught in the local area and in the offing of the Maritimes, but two were caught off Gloucester, Massachusetts (one in 1942 and one in 1943) a distance of 900 miles, and one was caught off Cape Henry, Virginia, in 1947, a distance of 1,300 miles. The last return was from the Strait of Canso, Nova Scotia, in 1949. Templeman noted (1954), " . . . most of the tagged fish were mature females carrying young and the recaptures show a southward late fall movement of some at least of these large pregnant females, with presumably a compensating northward movement in the spring and early summer." In an earlier report (1944) he suggested that the dogfish migrate rapidly and for long distances in the upper layers of the water.

While the tag returns Templeman reported indicated a coastwise migration, he did report an astonishing offshore migration from a later tagging experiment (Templeman, 1958). This involved a fish that had been tagged on the southwestern slope of the Grand Bank in June 1947 and was recaptured in Faxa Bay, Iceland, in August 1957. The straight line distance between the tagging area and the point of recapture is over 1,300 nautical miles.

Returns of dogfish tagged in the Gulf of Maine area have done little to confirm either a north-south or inshore-offshore migration pattern (Jensen, 1961). In these experiments 155 dogfish were tagged near Cape Ann, Massachusetts, in July 1956 and 50 were tagged on Browns Bank in October 1957. To date, 8 tags have been returned (3.9%), 7 from the 1956 experiment and 1 from the 1957 experiment. The tagged fish were recaptured relatively close to the areas in which they had been released; 6 were caught less than 50 miles from the tagging area, 1 was caught 73 miles away and another was caught 140 miles away. In general, the recaptures suggest that spiny dogfish return to the same general area at about the same time of year and the same fish probably school together for long periods of time.

FOOD HABITS

Several studies of the stomach contents of spiny dogfish from many parts of the Northern Hemisphere have shown that it is primarily a fish eater but will also feed on invertebrates, both swimming and bottom-dwelling forms. In many areas, Clupeoids are important in the diet of the dogfish, but it undoubtedly feeds on whatever species are abundant and not too difficult to capture.

In the Pacific Ocean three important studies of dogfish feeding habits have been made. One such study was conducted to determine the amount of predation, if any, by dogfish on salmon smolts as they descended the Fraser River, British Columbia (Chatwin and Forrester, 1953). In the river mouth, 249 dogfish were examined and 20 (8%) had empty stomachs. Of those that contained food, 100% contained eulachon (a smelt, Thaleichthys pacificus), or traces of it, 5% contained sand lance (Ammodytes), and 19% contained invertebrates, including shrimp, crabs, small crustaceans, squid, and octopus. A large number (21%) contained sticks and leaves, no doubt ingested accidentally with the food items. Outside the river mouth, the dogfish diet was much the same; 91% contained eulachon, 29% contained invertebrates, and 5% contained sticks and leaves. Miscellaneous food items included a honeybee and polychaete worms. On the basis of their findings the authors concluded the spiny dogfish was an opportunistic feeder.

Another study in the same general area was made by Bonham (1954) who examined more than 1,100 spiny dogfish stomachs, of which nearly 60% contained food. He found more than 77 different food items but fish constituted two-thirds of the diet. The three most common food items were ratfish (Hydrolagus colliei) (20%), herring (Clupea pallasii) (18%), and krill (Euphausiidae) (9%). The only evidence of cannibalism was the finding of a 230 mm. (newborn?) dogfish pup in the stomach of a large pregnant female. Bonham (1954) concluded, "Large and small dogfish eat much the same kind of food, with exception of very small dogfish in whose diet worms and other mud-inhabiting organisms appear prominently."

Sato's (1935) studies of the spiny dogfish in the water around Japan indicate that Clupeoids are important in the diet in this area as they are in other parts of the world. He examined the stomach contents of 128 dogfish collected in gill and set nets in June and July. Sixty stomachs contained fish; 48 contained sardines (Sardinia melanosticta), and 12 contained other fishes, including herring (Clupea pallasii), salmon (Salmo keta), cod (Gadus macrocephalus). Invertebrates were found in 21 stomachs.

In waters north of Japan, around Sakhalin, food items found in the stomachs of spiny dogfish were noted by Kaganoskaia (1937). The items were simply listed as herring, iwashi (sardine), cod, octopus, crab, squid, and sea cucumbers.

Food habits of the dogfish in the North Atlantic are quite similar to those of the dogfish in the Pacific. From waters around the British Isles, Ford (1921) reported food items from 143 spiny dogfish with recognizable stomach contents. Fishes were found in 137 stomachs and included herring and pilchard (67%), mackerel (19%), and gadids (4%). Six stomachs contained crustacea and three contained molluscs. The author notes that the stomachs were collected at a time when the clupeoids and mackerel were abundant and thus readily available to the dogfish.

In the Northwest Atlantic, around Newfoundland, herring and gadids are important in the diet of the spiny dogfish (Templeman, 1944). He made a casual examination of 24 dogfish stomachs collected in July 1942 and found all of them contained caplin (Mallotus). During this month the caplin were plentiful on the inshore grounds and the dogfish appeared to be feeding almost exclusively on them. He notes, "Some of the stomachs were full of caplin, one containing 13 caplin, one of 7 cm. and 12 from 14 to 19 cm. long."

From August to November, Templeman (1944) made a detailed analysis of 1,171 dogfish stomachs of which 665 were empty, 367 contained only the bait used to capture them, and 139 contained food. In the stomachs that contained food, about 60% contained fishes, about 45% contained Crustacea, about 8% contained Coelenterates, and a few odd percentage contained molluscs, polychaetes, algae, and miscellaneous items. The recognizable fishes were herring (14%), caplin (5%), and cod (5%).

In the Gulf of Maine, the spiny dogfish feed on a wide variety of species and at one time or another prey on practically all species smaller than themselves. They are regarded as the chief enemy of the cod, and also feed on mackerel, haddock, herring, squid, worms, shrimps, crabs. They are one of the few fishes that eat Ctenophores (Bigelow and Schroeder, 1953).

Our own observations of spiny dogfish stomach contents have revealed a curious condition in which the stomachs were distended with a clear watery fluid. Casual observation of 50 dogfish stomachs collected during a cruise of the U.S.F.W.S. research vessel Delaware in June 1961 on Stellwagen Bank found fish remains in only three stomachs. Five stomachs contained about 4 ounces of a light-gray, custard-like material, evidently food well advanced in digestion. The majority of the stomachs, however, were filled with clear fluid; only a very few stomachs were empty and flaccid.

In July 1961, John M. Hoberman found silver hake (Merluccius bilinearis) in the stomachs of dogfish collected in Ipswich Bay during a cruise of the Delaware. Silver hake were abundant in the area at the time.

Fifty stomachs examined at Pt. Judith, Rhode Island, in July 1959, contained mostly amphipods (Leptocheirus) and occasional fish remains.

AGE AND GROWTH

The traditional techniques used in fishery biology for age determination are not, unfortunately, applicable to the spiny dogfish. The dogfish does not have scales suitable for examination and being a cartilaginous fish it has no hard bones in which visible growth zones are formed. Dogfish otoliths are simply aggregations of sand particles loosely joined in a gelatinous substance, unlike the calcareous otoliths of the teleosts, thus offer no opportunity for detection of growth zones.

A possible solution to the problem of determining the age of the dogfish is presented in an obscure Russian paper (Kaganovskaia, 1933) read in English translation. Briefly, the paper notes that the dorsal spines of the dogfish are marked with annulations apparently related to growth periodicity (fig. 4). The Russian biologist had collected the

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Figure 4.--Photograph of a dogfish spine showing the annulations.

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dogfish from the waters around Sakhalin, near northern Japan. At first he examined the vertebrae, but the barely noticable rings in these bones became even less visible after treatment. Cross-sections of the teeth and of the dorsal spines were examined, but without success. The teeth showed no zones and the spines were found to have an internal cavity along their entire length. The enamel coating of the spines, however, had markings ". . . which doubtless represent annual deposits."

The makeup of the spine is quite similar to the makeup of a mammalian tooth. Daniels (1934) describes the structure of the spine as follows:

"For almost half its length the spine is buried in the integument. The buried part is designated as the root or base and the exposed portion the crown or spine proper . . .

" . . . The spine contains a large central cavity which when in place fits over a cartilage of the fin skeleton. The walls of the spine are made of dentine which in the crown consists of a double layer. The more superficial layer is bounded anteriorly and laterally by a layer of enamel, but enamel does not extend over the posterior groove which fits up against the basal cartilage of the fin skeleton. A more or less compact layer of pigment . . . separates the enamel . . . in front from the layer of dentine."

Kaganoskaia (1933) did not try to validate the spine markings as year marks although he noted that the spines of fish less than one year old were light gray in color and had no markings. He examined a sample of rear dorsal spines (the posterior spines are more clearly marked than the anterior spines) from 210 dogfish, 380 to 1180 millimeters in length, and reported their ages as from 2 to 25 years. His data were presented in a table which we have incorporated into a growth curve (fig. 5). We believe

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Figure 5.--Two growth rates for the spiny dogfish, based on interpretation of spine markings.

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it not unreasonable to consider the spiny dogfish as a long-lived species in view of the evidence of tagged dogfish at liberty for up to 10 years.

Following the Russian example, Bonham et al., (1949) examined the spines from 215 dogfish collected in State of Washington waters. The fish ranged in length from 34 to 127 centimeters and from 1 to 29 years of age, and although there is more spread in the Washington data, the trend is almost similar to that in the Russian paper (fig. 5). To prepare the spines for reading, Bonham (personal communication) removed them by slicing down along the bases of the spines into the back of the dogfish and freed the spines from adhering skin or muscle. The spines were not treated in any way and low magnification (5X) or none at all was used in the actual examination.

Only about 20% of the spines (215 out of 1100) had markings that were sufficiently distinct as to be readable without appreciable disagreement by different observers (Bonham, personal communication). In his report (Bonham, et al., 1949) the authors cautioned, "It must be understood that rejection of unclear or doubtful spines would probably eliminate from consideration most of the old dogfish, whose spines usually are broken, badly eroded, and have the annulations closely crowded near the bases of the spines."

Comparisons between dogfish growth calculated from spine readings or length frequencies, and growth observed in tagged dogfish indicate that the growth of the tagged individuals is often half, or less, of the calculated values. Bonham et al. (1949) reports that on the basis of a study of eggs and embryos, the suggested rate of growth is 7 centimeters in two years or about 3.5 centimeters per year. The rate calculated from spine readings is 3.1 centimeters per year, and from length frequencies 3.3 centimeters per year, but from tagging studies the rate is only 1.4 centimeters per year.

In the above example, the spine readings were from fish between 40 and 100 centimeters long (2.5 to 21 years, indicated age). An examination of Kaganoskaia's (1933) data for fish of similar lengths and indicated ages suggests a growth of 3.5 centimeters per year. Templeman (1944) calculated ". . . approximately 1-1/2 cm. as the average growth per year for all mature females and 1.6 cm. for the first mature year . . ." However, a tagged dogfish at liberty for 10 years grew only about 8.1 centimeters in that time (Templeman, 1958) but he concludes the fish was in worse condition when recaptured than when tagged, hence the poor growth rate. Kauffman (1955) reports the growth of two tagged spiny dogfish from the Pacific Coast as 14 centimeters after 8-1/2 years at liberty (1.6 centimeters/year), and 23 centimeters after 10 years at liberty (2.3 centimeters/year). A dogfish tagged in British Columbia waters and at liberty almost 8 years grew 5-5/8 inches (Anonymous, 1952), or approximately 14.1 centimeters (1.8 centimeters/year). Our own experience with the growth of tagged dogfish is limited to one specimen at liberty nearly one year during which time it grew only 0.7 centimeters.

At the present time there is no way to resolve the differences reported for the annual growth of the spiny dogfish. There seems no reason to doubt that it is a long-lived species, attaining a maximum age on the order of 25 to 30 years. The lengthy time interval between tagging and recapture, up to 10 years for certain individuals, is perhaps the strongest evidence we have supporting the two reported age determination studies.

POPULATION STATUS

The total population of the spiny dogfish is not known, although there is no doubt that it is relatively abundant and is subject to large fluctuations in abundance. In the spring of 1846 they were so numerous around Gay Head, Massachusetts, that 600 were caught on hooks in one day by the crew of a single boat (Storer, 1867).

Collins (1884) relates an eyewitness report from a fisherman who observed a school of mackerel at the surface off Wood Island, Maine, that were being harried by an immense school of dogfish in August 1880. The fisherman estimated there were about "100 barrels of dogfish" in the school. The dogfish surrounded the mackerel "...in such a manner as to inclose the mackerel on all sides and underneath, completely preventing their escape." Many of the mackerel were seen with their tails bitten off and with wounds in their flanks.

Cod as well as mackerel suffered from the attacks of the dogfish. Earll (1880) considered the dogfish to be the principal enemy of the cod and reported that adult cod in the market were seen to have teeth marks and spine wounds in their flesh, a result of attacks by dogfish. "The arrival of a school of dogfish in any locality," Earll noted, "is the signal for all other species to leave; and in this way the work of the fisherman is often suddenly terminated."

Bowers (1906) reported good groundfishing in Boston Bay in July and August 1903, but in 1904 "...horned dogfish /were/ present in such great numbers that it was impossible to catch anything else."

They were much more numerous in Massachusetts Bay during the last quarter of the 19th Century and during the early 1900's than they had been previously, although in the Woods Hole region they were more plentiful before 1887 than they have been at any time since (Bigelow and Schroeder, 1953). These authors felt that perhaps the period 1904-1905 marked a peak in the cycle of dogfish abundance.

It may be, however, that the population of dogfish does not fluctuate greatly but that in their seasonal migrations the main body of fish may visit one area this year and another area next year. Our lack of knowledge about the nature of the population(s) makes it difficult to come to any firm conclusion regarding the absolute and/or relative numbers of fish involved.

As a result of his early studies of the dogfish around Newfoundland, Templeman (1944) said, "It is obvious ... that dogfish migrate rapidly and for long distances, and since they swim chiefly in the upper layers of water there are no hinderances to migration such as the contours of the bottom offer to haddock and cod. Thus, it is quite possible that the dogfish stocks on the whole eastern coast of North America mingle sufficiently to constitute a single population."

He modified this somewhat later (1954) after analyzing his tag return data. "The distant recaptures are also numerous enough, considering the small number tagged, and occur in enough different years, to show that even if there is not indeed a single population there is at least a widespread intermingling of the populations of adult female Squalus acanthias on the Atlantic Coast of North America."

A review of commercial landings and USFWS survey data obtained the past twelve years fails to indicate an appreciable increase in abundance of this species in New England waters since 1948.

Exploratory cruise data indicate that, rather than being distributed relatively homogeneously over large areas, dogfish congregate in dense, localized schools. Thus, high concentrations of dogfish at a given time and locality provides no accurate indication of their over-all abundance, as they may be exceedingly scarce a few miles distant. Large hauls of dogfish tend to be grouped within a period of a few days, as the vessel fishes the same general area during the interval. Similarly, consecutive tows at different depths may produce no dogfish at one depth but numerous dogfish at only slightly greater depths (see Table 1 - Martha's Vineyard transect).

There is evidence that dogfish may vary in availability and/or abundance from year to year in addition to locality (see annual survey data, Table 2). Dogfish comprised a greater percentage of the trash fishery landings in 1958 than in 1956, 1957 and 1959 (Table 3), in good agreement with other statistics based on survey cruise data.

Table 1.--Dogfish catches (Albatross cruise 126, January-February 1959) by depth, temperature and sex along Middle Atlantic Coast in winter.

Transect	Date	Depth	Temp.	No. of males	No. of females	Total fish
Martha's Vineyard	Feb. 3	46.5	42	48	11	59
		64	54	--	--	--
		82.5	51	14	353	367
		99	49	423	5	428
		146	48	--	--	--
		210	--	2	--	2
Hudson Canyon	Feb. 2	32	45	10	--	10
		46	48	40	2	42
		67	52	5	5	10
		92	50	--	--	--
		103	49	--	--	--
		178	44	--	--	--
		228	--	--	--	--
Barnegat	Jan. 23	25	45	--	--	--
		45	51	--	--	--
		62	52	--	--	--
		80	52	--	--	--
		159	--	--	--	--
Cape May	Feb. 1	32	50	53	4	57
		43	53	144	138	282
		62	53	251	466	717
		86	52	--	--	--
		117	50	--	--	--
		153	--	--	--	--
		180	--	--	--	--
Delaware Bay	Jan. 24	30	50	14	--	14
		42	54	53	66	119
		65	54	2	1	3
		80	52	1	1	2
		100	52	--	--	--
		125	49	--	--	--
		150	--	--	--	--
		220	--	--	--	--
V. interquarter	Jan. 25	18	50	58	1	59
		37	54	4	1	5
		48	56	1	--	1
		72	52	17	8	25
		130	--	--	--	--
		238	--	--	--	--
Cape Charles	Jan. 25	17	48	--	--	--
		24	54	25	56	81
		42	55	--	--	--
		77	54	--	--	--
		107	50	--	--	--
		173	--	--	--	--

Table 2.--Spiny dogfish catches on USFWS annual survey cruises, all seasons, all grounds

Year	Total tows	Number of tows with dogfish	Total number caught	Catch per tow
1948	233	57	4551	19
1949	115	21	3755	33
1950	339	173	10333	31
1955	279	64	672	2+
1956	93	40	727	8
1958	159	63	1923	12
1959	212	38	1106	5+
1960	45	2	25	--

Table 3.--Percent dogfish in landings of industrial fishery from various grounds

Area	1956	1957	1958	1959	1960
Pt. Judith (inshore)	3.0	7.1	7.8	2.0	6.4
Pt. Judith (offshore)	2.7	6.5	6.9	3.6	6.4
No Mans	0.3	1.3	2.7	1.7	0.2
Ipswich	0.1	2.2	1.1	4.9	--
Nauset	0.9	1.6	1.6	4.9	--
Stellwagen	1.5	0.8	3.2	4.6	--
Mean	1.7	3.3	3.9	3.6	--

POPULATION DYNAMICS

At the present writing, a study of the dynamics of the spiny dogfish population would be difficult to carry out to any fine degree because much of the necessary information is lacking or is imperfectly known. Perhaps the greatest gap in our understanding of the species is a knowledge of the nature of the population itself.

The basic plus and minus factors of natality and mortality lack adequate quantitative investigation. There have been some studies, however, of certain phases in the reproductive cycle and these are discussed below.

Reproduction

Spiny dogfish are ovoviviparous, with the eggs being fertilized internally by means of the male's claspers. The period of development is lengthy, up to two years, and the number of young produced is small.

Sex ratio.--During development in the females, and presumably at birth, the sex ratio of the pups is very nearly 1:1. Ford (1921) collected a total of 2720 embryos at the fish market in Plymouth, England, and found 1377 were males and 1343 were females. Templeman (1944) counted 933 male and 931 female in the uteri of 492 females collected in the period July-November 1942, in the offing of St. John's, Newfoundland. For dogfish in the Pacific, Bonham et al (1949) reports, "Males and females occur in equal numbers among the embryos." Our observations for dogfish in the Gulf of Maine are in agreement with those from other waters. During a cruise of the Bureau of Commercial Fisheries research vessel Delaware in Ipswich Bay (near Gloucester) during July-August, 1961, a total of 234 female dogfish were examined. Fifty-three contained pups, of which 155 were males and 140 were females.

From the time of birth to the time of attaining sexual maturity, the young dogfish tend to school together, but the mature adults tend to school by sex. Ford (1921) classified the schools, or shoals, as follows: (a) Shoals of large fish consisting exclusively of females, the majority in the pregnant condition; (b) Shoals of medium-sized fish exclusively males in the mature condition; (c) shoals of medium-sized fish of which the majority were immature females; and (d) Shoals of immature fish in which the males and females were equal in number.

Sex/size segregated schools are also reported by Hickling (1930) off Ireland, Templeman (1944) off Newfoundland, and Bigelow and Schroeder (1953) off the Gulf of Maine. In the eastern Pacific, however, Quigley (1928b) observed that the schools contained both sexes, and the data listed by Bonham (1954), for the same general area, supports this statement, although in individual catches the percentage of males varied as much as from 35% to 76%. In the western Pacific, however, Kaganovskaia (1933) observed the schools of dogfish to be segregated by sex, size, age, and depth. He notes, "...the shore-set nets caught mainly immature sharks from 4 to 8 years of age; the bottom-set nets older fish, from 10 to 18 years, mainly males

(July-October); the drift pelagic nets--chiefly mature females." Thus, his observations agree in general with those reported from other parts of the world. We suspect that the dogfish in the eastern Pacific also school by sex despite the reports to the contrary by Quigley (1928) and the data presented by Bonham(1954).

On the basis of the reports from areas that include the known range of the spiny dogfish, it is difficult, therefore, to determine the sex ratio of the adults because of the manner in which they school.

Size at sexual maturity.--Sexual maturity in male dogfish is attained at a smaller size than in females, and, the larger the maximum size the larger the size at maturity. In Table 4 are listed the data extracted from reports that specifically mention average size at first maturity for the spiny dogfish.

Table 4.--Maximum size and size at first maturity of spiny dogfish from several areas

Author	Locality	Size of males (cm.)		Size of females (cm.)	
		Maturity	Maximum	Maturity	Maximum
Ford (1921)	Plymouth, England	59-60	83	70-80	110
Hickling (1930)	Irish Sea	62	--	70-80	--
Kaganovskaia (1937)	Sakhalin	--	--	100	124*
Templeman (1944)	Newfoundland	60	86	74	101
Bonham et al (1949)	Washington	72	100	92	124

* Sex not specified but we suspect it is a female.

Because of the age determination problem discussed earlier, it is difficult to assign an age value to the time of first maturity. Templeman (1944), however, suggests that, "... it takes the average female dogfish 9 or 10 years from the fertilized egg or 7 or 8 years after birth to reach sexual maturity." Based on the spine readings of Bonham et al (1949) the data indicate 11 years for males and 19 to 20 years for females as the age of first maturity for spiny dogfish in waters off Washington. Kaganovskaia (1937) did not discover mature females less than 19 years old or less than 1000 millimeters long. It seems incredible that dogfish mature at such a late age but a critical examination of the data offers some evidence to support Bonham's data and Kaganovskaia's statement.

The reported sizes of spiny dogfish at time of first maturity are about 72% (range 68%-80%) of the reported maximum sizes for the species. This is in general agreement with similar data reported by Bigelow and Schroeder (1953) for nine species of sharks from the Gulf of Maine where the sizes at first maturity are about 65%(range 52%-75% of the maximum sizes. If we assume (1) that the maximum age (sexes combined) of the spiny dogfish is 25 to 30 years, and (2) that we can equate length with age, then the age at first maturity is about 72% of the maximum or about 18 to 21 years.

Mating.--Although there are no recorded observations of the actual mating of spiny dogfish, and no conclusive data to confirm the season of year when it takes place, the evidence presented by most authorities suggest that mating takes place during the cold months of the year. Ford (1921) found newly formed embryos at Plymouth during November to May. Templeman (1944) concludes that the eggs are fertilized and pass into the uteri in February and March, but generally more in the latter month. He cautions, however, that his lack of information about the spring temperatures when the eggs are developing may vary the dates a month in either direction. An examination of dogfish captured in the Woods Hole area suggests that ovulation probably occurs in February or March (Hisaw and Albert, 1947) and perhaps we can infer that mating and fertilization of the eggs takes place soon after. Bigelow and Schroeder (1948) are of the opinion that pairing probably takes place shortly after the young are born, although no definite information is available.

Reports concerning mating of the spiny dogfish in the Pacific Ocean tend to be contradictory, but in general support the hypothesis that mating takes place in the cold months, as in the Atlantic Ocean. Quigley (1928b) examined slightly over 200 dogfish collected in June, July, and August and found embryos that ranged in sizes from the smallest to those with the umbilical scar completely healed and apparently ready for birth. These observations, "... suggests that in the vicinity of Nanaimo, Squalus sucklii breeds at all times of the year." We know now, of course, that what she had seen was the two broods of young that are typical of the species. Hart (1942) on the other hand, reporting the work of Lucus, concluded that breeding takes place during the winter months and that, "... fertilization by the males takes place soon after the birth of the young..." Bonham et al (1949) admitted that the season at which mature dogfish mate and copulate is not known but regards it as a popular misconception that dogfish breed and bear young at all times of the year. Sato (1935) concluded, without much firm basis for the statement, that dogfish breed throughout the year around Hokkaido.

Fecundity.--As might be expected for a live-bearer, the number of young produced per female spiny dogfish is small and the period of development within the mother is long--nearly two years. Spiny dogfish eggs are large and contain a great deal of yolk. They have been well described by

Templeman (1944). Following fertilization, and during early development of the fetus, the eggs are contained in a horny capsule ("candle") that later breaks down leaving the embryos free in the enlarged part of the oviduct (termed the "uterus"). There is no placental attachment (Bigelow and Schroeder, 1953) as with some other species of sharks, but additional material (at least water) is obtained from the uterine wall (Templeman, 1944). We should caution here that the reported number of pups per female probably should be considered a minimal figure. The observations were made of fish caught by otter trawls or other fishing gear and examined on board the vessel or in the market. We have seen pups that were apparently near term, spontaneously aborted when the females were landed on the deck of our research vessel. It seems reasonable to assume that this also happened in the studies reported in the literature. Fortunately, the number of aborted pups was never very great so that the reported data may be accepted with a fair degree of confidence.

The greatest number of pups per female was reported by Kaganovskaia (1937) who recorded 5 to 19, with an average of 11, for the spiny dogfish near Sakhalin. The least number of pups per female was reported by Templeman (1944) who recorded 1 to 7, with an average of 4, for the dogfish near Newfoundland. Ford (1921) reported 1 to 11, mostly 2 to 4, from England, while from the West Coast of North America, Quigley (1928b) reported 3 - 11 (average 7), Clemens and Wilby (1946) reported 3 to 14, and Bonham et al (1949) reported 2 to 17, mostly 7 to 8.

In the Gulf of Maine, Bigelow and Schroeder (1953) state that the number of pups per female may be as many as 8 to 11, or as few as 2, but mostly 4 to 6. Our own data for the inner Gulf of Maine (Ipswich Bay), collected in July-August 1961, show the females may contain from 1 to 11 pups, mostly 4 to 7.

To examine the relationship between the size of pregnant female and the size and number of pups per female, we grouped the data by length of females, by three-centimeter groups. In addition to the pups (fetuses), we also included measurements and numbers of embryos and presented the data in Table 5.

Our data suggest that the larger females tend to have slightly more and slightly larger pups than the smaller females. This is in general agreement with the reports from other parts of the range of the spiny dogfish. A comparison between the average number of embryos per female and the average number of fetuses per female seems to indicate there is very little loss (mortality?) between the two stages of development. The size of the young dogfish at the time of birth lies somewhere between 20 and 30 centimeters, regardless of the part of the world from which the observations are reported (Table 6).

Table 5.--Fecundity of spiny dogfish examined aboard R/V Delaware, 1961

Length of female (cm.)	Fetuses			Embryos		
	Number of females	Avg. no. per female	Avg. length (mm.)	Number of females	Avg. no. per female	Avg. length (mm.)
60	--	--	--	1	5.0	4
63	--	--	--	--	--	--
66	--	--	--	--	--	--
69	--	--	--	--	--	--
72	--	--	--	--	--	--
75	--	--	--	1	5.0	5
78	2	4.5	154	1	3.0	5
81	2	6.0	190	--	--	--
84	6	4.7	186	2	4.5	3
87	6	3.7	194	6	4.5	9
90	14	5.6	197	4	4.2	12
93	9	5.6	194	4	6.2	7
96	5	7.2	197	1	9.0	6
99	8	7.9	205	--	--	--
102	1	8.0	220	1	3.0	20

Table 6.--Size of dogfish at birth

Author	Locality	Reported size of dogfish pups
Ford (1921)	Plymouth, England	25 to 31 cm.
Hickling (1930)	Irish Sea	About 26 cm.
Kaganovskaia (1933, 1937)	Sakhalin	240 mm. average
Templeman (1944)	Newfoundland	24 to 31 cm.
Hisaw and Albert (1947)	Woods Hole	25 to 30 cm.
Bigelow and Schroeder (1948)	Gulf of Maine	220 to 330 cm.
Bonham et al (1949)	State of Washington	27 cm. average

Time of Birth. --The period of development of the young dogfish entails about two years, although the authorities differ in the exact number of months involved, and the season of birth occurs in the cold months of the year. Ford's (1921) extensive studies at Plymouth led him to conclude that gestation occupies 21 to 25 months and the embryos are ready for birth from August to December. Hickling (1930) confirmed Ford's findings. Templeman (1944) considered a gestation period of almost 24 months with the young being liberated between January and May.

A somewhat shorter gestation period is reported by Hisaw and Albert (1947) who state, "The gestation period apparently covers about 20 to 22 months and a female gives birth every other year." The pups, they note, are born in the late fall, somewhere south of Woods Hole. Bigelow and Schroeder (1953) report a gestation period of 18 to 22 months with birth probably taking place on the offshore wintering grounds, although some may be born in the spring and summer. And Latham (1921) confirmed that some may be born in the summer when he reported many young dogfish only a few hours old that were caught in a fish trap in Long Island Sound in August.

In the Pacific, the gestation period is two years with birth taking place during the winter months (Hart, 1942), more specifically, in November and December (Bonham et al, 1949).

Not only is the period of gestation long, and the number of young small, but an individual female produces young only in alternate years (Hart, 1942; Clemens and Wilby, 1946; Hisaw and Albert, 1947; Bonham et al, 1949). The data presented by Ford (1921), Hickling (1930), and Templeman (1944), confirm the broods-in-alternate-years conclusions of the workers cited above.

Mortality

The spiny dogfish has few enemies and is cannibalistic only to a very small degree. Thus, except for disease, there is little to act as a deterrent to the build-up of dogfish populations, and this no doubt is one of the prime reasons for the vast numbers of dogfish reported in one area or another. The predators of the spiny dogfish are mostly the large sharks and large bony fishes. We have tabulated (Table 7) the predators as reported in Bigelow and Schroeder (1953) and noted certain appropriate remarks. We wish to point out that in all but two of the cases the prey is specifically identified as the spiny dogfish. The remaining two cases were simply listed as "dogfish" and possibly may be the smooth dogfish (*Mustelus canis*).

Table 7.--Predators of the spiny dogfish

Predator	Remarks
Mackerel shark (*Lamna nasus*)	Known to prey on spiny dogfish in the eastern Atlantic; probably Gulf of Maine, also.
Maneater (*Carcharodon carcharias*)	One spiny dogfish, evidently torn off a line trawl.
Tiger shark (*Galeocerdo cuvier*)	Dogfish (species?) from one captured in Woods Hole.
Blue shark (*Prionace glauca*)	Preys on spiny dogfish in northern waters.
Barndoor skate (*Raja laevis*)	Spiny dogfish from Woods Hole records.
Lancetfish (*Alepisarus ferox*)	Small spiny dogfish eaten by Black Island specimen.
Tuna (*Thunnus thynnus*)	Swallowed whole dogfish (species?) weighing 8 pounds.
Tilefish (*Lopholatilus chamaeleonticeps*)	One contained two spiny dogfish.
Goosefish (*Lophius americanus*)	One contained a spiny dogfish 1 foot long and the vertebral columns of 6 others.

Marine mammals appear not to pose a threat to the dogfish. In a study of the food habits of seals (Fisher and Mackenzie, 1955), dogfish remains were found in the stomach of a grey seal (*Halchoerus grypus*) but constituted only one percent of the volume of the stomach contents. Killer whales (*Grampus orca*) may feed on dogfish, but probably only when other prey is unavailable. One killer whale was seen, "Scavenging round longlining vessel, eating dogfish." in the Strait of Belle Isle, July 1953 (Sergeant and Fisher, 1957). No doubt the relatively large size, spines, and tough, scabrous skin of the dogfish are effective deterrents to predation.

Many hundreds of thousands of spiny dogfish are killed each year by man (this is discussed in greater detail in the later sections on Utilization) but without much reduction in the size of the populations. It is probable though, that man is by far the greatest predator of the dogfish.

UTILIZATION OF THE SPINY DOGFISH

It should be noted here that the dogfish is not completely valueless or useless. It has some slight value, in limited quantity, in the United States, and it has greater value in some parts of the world where it is sought after as a food fish. The greatest value of the dogfish in North American waters is as an industrial fish, for processing into oil and meal, and at one time it was under intense exploitation for its liver as a source of natural vitamin A.

INDUSTRIAL USES

One of the earliest mentions of industrial uses of dogfish was made by Perley (1852), reporting on the dogfish in the Gulf of St. Lawrence, who noted that the skins were used by cabinet-makers to polish hardwood, the livers were used for oil, and the carcasses were dried and fed as a winter food supplement to cattle. Pigs in particular were said to thrive on this diet.

A fishery for dogfish existed around Provincetown (Mass.) and was prosecuted with handlines in which the hooks were baited with whiting (Merluccius bilinearis) (Storer, 1867). The fishery took place in September through November when the dogfish reappeared in the area, during their seasonal migration. Only the livers were wanted for their oil--one thousand livers yielded one barrel of oil--and the oil was sold to tanners and curriers for preparing and treating leather.

A "pogie factory" existed in East Boothbay, Maine, in which dogfish were processed for oil and guano (Gallup, 1883). The fishermen were paid $1.00 per 100 fish but it was suggested that the Federal Government pay them a subsidy to encourage greater fishing effort.

Spiny dogfish was the principal species used for oil and guano when the guano factory was established at Woods Hole (Smith, 1898), but a scarcity of the species in the season of 1897, and the general irregularity of their supply, caused the factory to turn to menhaden for their raw material.

Field (1907) mentions that dogfish oil (liver oil?) was used for illumination in some areas, while on Cape Cod the carcasses were dried and used for fuel. He later reported (1912) that on Cape Breton Island, dogfish were dried on fences and fed to horses as a diet supplement and the well-yolked eggs were used experimentally as a substitute for hens eggs to tan leather.

Barraclough (1953) cites some rather interesting historical information about the early uses and developments of dogfish oils in and around the coastal areas of British Columbia. The local Indians processed the livers and used the oils obtained for dressing skins and hides. Later, as lumbering operations began in the area, the oils were used to lubricate skidways on logging roads. The oil was used extensively for lubrication and illumination in sawmills, coal mines, and coastal light-houses. Most of the oil was processed in small home-type operations, but in 1877 the first large commercial factory was established for oil production. It is worth noting here that during the time of World War I (1916-1918) almost the entire catch of dogfish from British Columbia was exported as "grayfish" to the United States fresh fish market.

No doubt the greatest industrial exploitation of the dogfish took place during the period from about 1937 to 1947 when an intensive fishery was conducted for the species in Puget Sound and surrounding waters. The dogfish were wanted for their rich, oily livers which were a valuable source of natural vitamin A. The livers contain 50-75% oil and the vitamin A content of the oil is 5,000 to 30,000 International Units per gram (Harrison and Samson, 1942).

The first extraction of vitamin A from shark liver oil was begun on a commercial scale about 1936-1937 and the dogfish fishery was underway in Puget Sound in 1937-1938 (Harrison and Samson, 1942). The fishery was somewhat dormant to about 1940, then, with the entry of the United States in World War II in 1941, and the loss of foreign sources of vitamin A from cod liver oil, the fishery increased in intensity. In 1940, the average price paid to the fishermen for the livers was 5.7 cents per pound but by 1943 the average price was 46 cents per pound and at one point reached a high of 54 cents (Bonham et al., 1949). The intensity of the fishery undoubtedly had a marked affect on the size of the dogfish population. Barraclough (1953) reports a decline in availability of the species in Hecate Strait beginning in 1944.

Dogfish liver oil has great vitamin A potency. Bonham et al. (1949) notes that oil rendered commercially from livers of dogfish taken in the waters in and around Washington varies from 5,000 to 25,000 units (USP ?) of vitamin A per gram. The vitamin values increased several hundred percent when the fish attain sexual maturity and the content is greater in winter than in other seasons. In contrast, Templeman's (1944) laboratory extractions of vitamin A from dogfish liver oil ranged from 300 to 19,700 USP units per gram with an average value for immature females of 1183 units, for mature males of 1662 units and for mature females of 2780 units. (For purposes of comparison, pharmaceutical cod liver oil must contain not less than 850 USP units of vitamin A per gram (Bailey, 1952). Hirao et al. (1959) report vitamin A values of spiny dogfish flesh from 329 to 5,220 international units per 100 grams of flesh. Liver oil from the same fish contained from 2,080 to 38,800 international units of vitamin A per gram.

Following the end of World War II, two major events occurred that had devastating effect on the West Coast fishery for dogfish. Foreign sources of vitamin-rich fish oils again became available, and in 1947 vitamin A was synthesized. Soon after this the dogfish fishery collapsed except for relatively small volumes landed for reduction and an extremely limited food market, Table 8, (fig. 6).

Figure 6.--Dogfish catch from Puget Sound, Washington, 1915-1959.

Table 8. --Catch of grayfish* at principal ports (catch in pounds, value in dollars) (1915-1959).

YEAR	New England States Catch	New England States Value	Middle Atlantic States Catch	Middle Atlantic States Value	Puget Sound, Wash. Catch	Puget Sound, Wash. Value
1915	---	---	---	---	7,093,996	15,959
1919	63,667	184	---	---	---	---
1922	---	---	---	---	6,359	22
1923	---	---	---	---	53,400	70
1924	21,950	367	---	---	97,005	247
1925	---	---	---	---	41,549	86
1926	---	---	6,755	347	290,395	1,452
1927	---	---	---	---	89,707	449
1928	206,309	3,312	---	---	3,203	16
1929	213,306	2,829	38,605	552	286,419	1,060
1930	93,196	3,049	12,690	267	371,180	1,309
1931	44,330	454	4,796	90	778,560	2,335
1932	27,049	374	8,140	81	---	---
1933	13,428	151	6,739	135	---	---
1934	---	---	---	---	---	---
1935	35,300	733	115,500	2,053	277,500	527
1936	---	---	---	---	330,700	764
1937	31,600	578	57,700	545	1,620,100	14,360
1938	46,200	1,111	102,200	1,021	578,100	4,153
1939	85,700	1,124	47,800	478	2,365,200	17,738
1940	575,500	19,426	51,800	1,009	3,341,100	36,504
1941 1/	575,500	19,426	51,800	1,009	23,532,300	751,620
1942	---	---	127,300	3,802	16,932,400	668,863
1943	89,700	1,637	47,300	1,959	22,021,500	1,243,858
1944	53,300	1,446	6,600	200	39,513,700	2,094,217
1945	31,100	565	31,000	1,211	22,149,100	1,063,149
1946	107,600	2,472	54,200	3,327	20,991,800	1,366,513
1947	24,000	455	21,200	1,046	14,984,800	954,535
1948	55,100	775	3,000	150	12,302,700	711,125
1949	625,200	5,718	55,500	2,163	10,587,000	447,828
1950	111,200	1,171	37,200	1,829	1,914,600	33,197
1951	39,600	539	63,700	3,051	2,412,900	58,750
1952	11,200	254	42,700	1,857	2,981,400	47,535
1953	9,000	>500	65,000	3,000	2,225,600	17,669
1954	2,000	"	61,000	3,000	2,008,800	19,931
1955	7,000	"	86,000	3,000	1,935,300	14,029
1956	486,000	4,000	60,000	2,000	1,526,400	12,808
1957	1,287,000	10,000	55,000	2,000	1,860,900	33,390
1958	893,000	8,000	50,000	1,000	4,233,100	26,675
1959	763,000	6,000	71,000	3,000	3,091,900	28,189

1/--No survey on East Coast. Data reported were those collected in 1940.
* --Grayfish is the market name for dogfish.

The fishery for dogfish never developed in the Northwest Atlantic to the extent that it did in the Pacific. The Canadian government became interested in the liver oils and their vitamin content but the prices paid to the fishermen were too low to arouse enough interest in the venture (Templeman, 1944).

Oils obtained from dogfish are of value today chiefly as raw materials for other industrial processes. The liver oil is sulfurized and used as a rubber extender while the body oils are used in the tanning of leather (Bailey, 1952).

The late 1940's saw the beginning of a new kind of fishery in New England--the so-called trash or industrial fishery--in which non-food species including spiny dogfish were landed in great quantities for reduction to meal and oil. Sayles (1951) marks 1948 as the start of the trash fishery at southern New England ports with the processed meal destined for use as supplements in hog and poultry feeds.

The amount of dogfish used was small at the start of the industry. For example, the species composition of a sample from one boat that landed at New Bedford in October 1949, included only one dogfish in the sample of 536 fishes (Snow, 1950) but by 1956, 259,000 pounds of spiny dogfish were landed by the industrial fleet at New Bedford (Edwards and Lux, 1958). The dogfish represented 1.0% of the total industrial landings and were caught off Nomansland, mostly in November and December.

In 1957, the Southern New England industrial landings of spiny dogfish amounted to slightly more than 5 million pounds (3.0% of the total), with most of them landed at Point Judith (Edwards, 1958a). There were two peaks in the landings of dogfish, one in the spring and one in the fall, no doubt representing periods when they were locally abundant during their migration. The industrial fishery fleet at Gloucester caught quantities of dogfish off Cape Ann, on Stellwagen Bank, and off Nauset, although the volume landed represented only from 1.5% to 3.0% of the total pounds landed (Edwards, 1958b).

Reduction plants do not like to process large amounts of spiny dogfish because they yield only meal, with very little oil, and there are serious mechanical problems involved in handling the species. Some of the problems include a tendency to jam conveyor belts, and to pack in bins and chutes due to the rough skin, and a clogging of screens because of the collagen content of the carcasses (Tarr, 1958). Tarr also states that the dogfish result in a poor yield of meal compared to other fishes.

No doubt the mechanical problems are not without solution, as suggested by this item in the "Blue Sheet" for February 17, 1959.

"A Gloucester, Mass., byproducts manufacturer has developed a process that enables it to use dogfish as well as other species in the manufacture of fish meal. Dogfish have long been a nuisance to local fishermen."[1/]

1/ - (United States)Bureau of Commercial Fisheries. 1959. Fishery Products Report B-33, p. 4. (Market News Service, Boston, Mass., processed).

And this item in the Fishing Gazette for August 1961"

WANTED: DOGFISH AND SHARKS

"A leading Gloucester businessman is ready to process dogfish and sharks if the fishermen will catch them. John Ryan said in mid-July that his idle plant, the former Dehydrating Process Co. of Gloucester, Inc., is 'capable and available' of handling a thousand tons of the two sea scourges of the fishermen per week. He said that dogfish and shark contain a lot of urea which if processed correctly is good for dairy feed and fertilizer, especially for cud-chewers. Gloucester fishermen for a century or more have lost hundreds of thousands of dollars because of sharks and dogfish."[2/]

2/ - Fishing Gazette. 1961. Wanted: dogfish and sharks. August, p. 32 (vol. 78, no. 8). New York, New York.

The rapidly expanding pet-food industry has been suggested as a potential user of great quantities of dogfish. Jones (1961) reports that on the Pacific coast the estimated potential annual production of dogfish for dog and cat food is on the order of 60 to 80 million pounds.

FOOD USES

A vast protein food resource is wasted each year because only infinitely small amounts of spiny dogfish are used for human food. Under present economic conditions, however, and because of certain psychological and sociological barriers, it probably would be most unprofitable today to try to fish and market spiny dogfish for human food. The flesh is quite palatable however, and may be prepared in a variety of ways.

The senior author and his family have eaten fried dogfish fillets and enjoyed the meal. The fillets are easily cut and easily skinned from the fish. The meat is bone-free, white, and has a flaky consistency and firmness similar to haddock fillets. The flavor is mild and during the cooking process there were no odors other than would be expected when fish is fried. The repugnance (and perhaps fear) that most people feel toward sharks in particular does not help to make dogfish popular as food fish. The very name "dogfish" also connotes something not suitable for humans. Efforts to disguise the species under a euphemism have included simply not mentioning what it was. Thus, Field (1907) reports it was served as "fish" on two occasions in the Marine Biological Laboratory (Woods Hole) mess hall and enthusiastically accepted by the unsuspecting diners. It has been served experimentally in hotels and listed on the menu as "Japanese halibut". In England dogfish are gutted, skinned, beheaded and marketed as "flake" and is widely used as one of the ingredients in the popular carry-out dish, fish-and-chips.

In the United States, during World War I, a great effort was made to populatize a number of relatively unexploited fishes to increase their acceptance by the consumer and thus relieve the war-induced meat shortage. Spiny dogfish was one such fish and it was dubbed "grayfish" the name by which it is marketed today. A 14-ounce can of grayfish sold retail for 10 cents and a government circular (Moor, 1916) was published in which 17 different recipes for preparing grayfish were listed.

Canned grayfish did not, however, prove to be a practical solution to the problem. Corrosion of the cans, caused by changes in the chemistry of the meat, and the offensive ammonia smell that developed, caused the buying public to reject the product. The flesh of dogfish, as with other Elasmobranchs, contains large amounts of urea that breaks down rapidly under decomposition to form ammonia (Mavor, 1921). Fresh and frozen dogfish tissue both contain about the same amounts of urea (0.9 to 1.5%) and hydrolysis, with the subsequent release of ammonia, occurs in the frozen flesh (Benson, 1924). Moyer et al. (1959) tested several methods of storing fresh dogfish flesh for periods up to 21 days. The storage included in ice and in refrigerated seawater, with and without added antibiotics (chlorotetracycline). They concluded, ". . . dogfish, when stored under nearly ideal conditions, appear to

spoil no more rapidly than most other sea fish." It seems obvious though that dogfish is best eaten when very fresh.

Dogfish is popular today as a food fish, not only in England, but also in Continental Europe, especially Norway where, in 1958, 23,000 metric tons, worth 9 million Kroner (one Kroner = about U.S. 14 cents), were landed (FAO, 1959). It is marketed both in steak and fillet form.

A small but steady market for dogfish (grayfish) exists in New York's Fulton Fish Market where it sells, ex-vessel, for 3 to 4 cents per pound and has gone as high as 8 cents per pound. (June 24, 1960). The fish are caught mostly by otter trawlers incidental to their catches of other food fishes. They are gutted, skinned, and cut into small pieces and the retail buyers are mostly of southern European extraction (Italians, Portugese, Greeks), Chinese, and Negroes. Some retailers fry up the pieces for orders of "fish and chips". (Further south on the Atlantic Coast, in the Chesapeake States, the species sold as grayfish is the smooth dogfish, Mustelis canis).

FISHING METHODS AND EQUIPMENT

In the three main areas of commercial exploitation - New England states, Middle Atlantic states, and the Puget Sound district of Washington - most of the dogfish are caught with otter trawls and gill nets. In New England, prior to the collapse of the Southern New England industrial fishery, the otter trawl was the leading type of gear, but in 1958, Maine, the largest producer of dogfish landings in the region, reported 640,500 pounds caught in gill nets and 115,500 pounds caught on long lines (Power, 1960), with less than 7,000 pounds caught in otter trawls in the entire region. In that same year in the Middle Atlantic states, otter trawls accounted for 62,000 pounds and gill nets accounted for 3,300 pounds. The 1958 landings in the Puget Sound district were as follows: nearly 3 million pounds in otter trawls, 200,000 pounds in gill nets, and nearly 11,000 pounds on long lines. In the Puget Sound fishery, many of the dogfish carcasses are discarded at sea and only the livers are landed.

MANAGEMENT OF THE SPECIES

The problem of the spiny dogfish as a pest of the commercial fishermen has led to a search for some method to control the species and at least reduce their numbers to the point where they would no longer constitute a problem. Many ideas have been advanced - some quite fanciful - including the usual solution to such pest problems, the payment of bounties for their capture. Unfortunately, most of the schemes suffer from a lack of, or incomplete, knowledge of the life history and habits of the dogfish.

Some of the earlier control methods proposed were based on methods used to control terrestrial pests. Atkins (1904) recounts a few suggestions offered by the public as to how the dogfish problem might be handled. Among these are the following: a) Attach streamers, bells, chains, etc. to hundreds of dogfish and release them to frighten off the

school (like belling a rat in a pack), b) Innoculate some of the dogfish with a fatal disease organism, such as had been done with the rabbits in Australia. c) Dynamite the dogfish schools when they appear, d) Employ government boats and men to capture the dogfish until the plague is reduced, e) Pay a bounty to fishermen for capturing the dogfish, and f) Use long seines of strong cord, 41,000 yards or more in length and surround the schools, as is done with the schools of sharks in India.

The best control method, however, would be greater utilization of the dogfish, particularly as human food. Or, as Atkins stated it; let the public ". . . apply their teeth and eat the dogfish up".

Increased utilization of the species, particularly industrial utilization, carried out over a period of years, would undoubtedly reduce the numbers and keep it at a relatively low point. There is evidence that short-term programs designed to reduce the dogfish population, particularly if carried out in local areas, are not successful. Templeman (1944) notes, "In Placentia Bay alone during the 1938 attempt to reduce dogfish numbers, about 10,391,000 pounds of dogfish were caught or approximately 2 or 3 million fish without any apparent diminution of the supply."

In contrast, there was a decline in availability of dogfish in Hecate Strait beginning in 1944 (Barraclough, 1953) no doubt due to a real decline in abundance since the species had been under intense exploitation for their liver oil since about 1941.

The most recent attempt to control the dogfish have been made by the Canadian government in the waters off British Columbia. The Canadian government hoped to induce fishermen to wage a concerted attack on the dogfish populations that had increased steadily in Pacific Coast waters during the past 10 years. The increase was attributed to the decline in commercial fishing for the species after the price of the liver oil dropped sharply (when the war-time demand disappeared) and synthetic Vitamin A entered the market.

A government fund was established in 1959 to pay the fishermen a bounty of ten cents per pound for dogfish livers delivered to processing plants. "In addition, the Federal Department of Fisheries will charter five trawlers to help in eliminating the dogfish menace. The fish caught will become the property of the Government of Canada for such disposal as may be directed.

The Fisheries Association of British Columbia has announced that an annual kill of at least 30,000 tons of dogfish must be made in order to reduce the damage caused food fish." 2/

2/ Commercial Fisheries Review. 1959. vol. 21, no. 4 (April) p. 67.

The eradication program proved to be very disappointing. A little less than 3,000 tons of fish were taken, mostly because the fish were not available in sufficient numbers during the season (winter) of the operations, and prolonged spells of bad weather made it difficult to fish for them.

"Cost of the dogfish on a tonnage basis was rather high. The government paid an average of $27.40 a ton, including the cost of the charters and the subsidy of 10¢ a pound on livers. For the charter boats alone, the cost of catching dogfish was $45 a ton." 3/

Continuation of the Canadian program in 1960 and 1961 featured an increase in the subsidy payments to 12 per pound for the livers, and the program was extended to March 31, 1962.

"In the 1959/60 season, which started in mid-August 1959, and ended on March 31, 1960, a total of 1,500,000 pounds of livers were taken under the subsidy plan. The government spent $150,000 at 10 cents a pound." 4/

To make the Canadian effort most effective, it was felt that the United States should also undertake a dogfish eradication program. Thus, on September 2, 1958, Public Law 85-887 was approved, "Authorizing and directing the Secretary of the Interior to investigate and eradicate the predatory dogfish sharks to control the depredations of this species on the fisheries of the Pacific coast, and for other purposes." A later amendment (S. 1264) set the program to continue for 5 years after approval, with bounty payments to the fishermen not to exceed $15 per ton for dogfish carcasses and up to 15 cents per pound for dogfish livers, in addition to whatever payment the fishermen received from commercial buyers.

As of now there has been no documentation of further developments in the United States program for eradication of the dogfish on the Pacific Coast and no plans for such a program on the Atlantic Coast.

3/--Commercial Fisheries Review. 1959. vol. 21, No. 7 (July), p. 59.

4/--(United States) Bureau of Commercial Fisheries. 1961. Fishery Products Report B-62, p. 2. (Market News Service, Boston, Massachusetts) (processed).

If increased exploitation of the dogfish population is not feasible, either for food or industrial uses, some other method of control should be investigated. A rather unique method - the sterile male technique - has been used successfully to control the screw-worm, an insect pest of cattle, and may prove of some value in the case of the spiny dogfish. The method is described by Knipling (1959) and, briefly, involves sterilizing laboratory-reared male screw-worms through the use of gamma irradiation. The treated males are released in the area of infestation in a ratio of 5 to 10 times the number of normal males. Females that mate with the sterile males lay infertile eggs, thus reproduction is greatly reduced. The treatment has been successful in eliminating the pest on the island of Curacao and controlling it in Florida. Knipling states that this control method is based on the following biological principle: "The introduction of sexually sterile but otherwise sexually vigorous males, and to a lesser extent females, into the natural population of an animal species will have greater influence in reducing the biotic potential of the population than elimination of the same number of individuals from the same population by destruction or removal." The sterilization could be done either by irradiation or with chemicals.

It would be difficult at the present time to try to evaluate on a theoretical basis the sterile-male technique applied to the spiny dogfish problem. We lack some very necessary knowledge of the life history of the species. For example: - a) How many dogfish need to be sterilized to effect control (that is, how many dogfish are present in the total population?), b) Screw-worms live only one season, but dogfish may live 25 to 30 years, c) Screw-worms mate once. How many times in its life-span will a dogfish mate?, and d) Does one male dogfish mate with more than one female?

The low fecundity of the spiny dogfish and the long period of gestation are factors very much in the favor of any control method that might be applied. From a conservation standpoint it would be more desirable, of course, to find a use for what is very obviously a rich potential resource. It is possible that in future years, when additional sources of animal protein are needed for human food, we may see development of an active fishery for the species. Such a development would then remove the dogfish from the pest classification.

NEEDED KNOWLEDGE OF THE SPINY DOGFISH

It is obvious from the foregoing discussion that there are many gaps in our knowledge of the life history of the spiny dogfish. The additional knowledge needed to effect any sort of management is categorized in the following outline:

1. Population level and distribution.
   a. Total numbers and seasonal distribution
   b. Sex and age composition. Distribution by sexes and ages in time and space.
   c. Factors affecting distribution and migration; hydrography, breeding, feeding habits.

2. Biology:
   a. A method for age determination, to solve b and c, below.
   b. Recruitment:
      1. Sex ratio, at birth and at succeeding ages.
      2. Segments of the population involved in breeding, and breeding behavior. Geographic location of breeding.
      3. Minimum age when breeding first takes place, by sexes.
      4. Age-specific fecundity and fertility rates.
   c. Mortality:
      1. Mortality rates
      2. Agents

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