447

THE SPINY DOGFISH (*Squalus acanthias*) IN THE NORTHEASTERN PACIFIC

SPECIAL SCIENTIFIC REPORT–FISHERIES No. 447

UNITED STATES DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE

UNITED STATES DEPARTMENT OF THE INTERIOR, Stewart L. Udall, *Secretary*
FISH AND WILDLIFE SERVICE, Clarence F. Pautzke, *Commissioner*
BUREAU OF COMMERCIAL FISHERIES, Donald L. McKernan, *Director*

THE SPINY DOGFISH (Squalus acanthias) IN THE NORTHEASTERN PACIFIC

by

Dayton L. Alverson and Maurice E. Stansby

United States Fish and Wildlife Service
Special Scientific Report--Fisheries No. 447

Washington, D. C.
July 1963

CONTENTS

DOGFISH (Squalus acanthias)

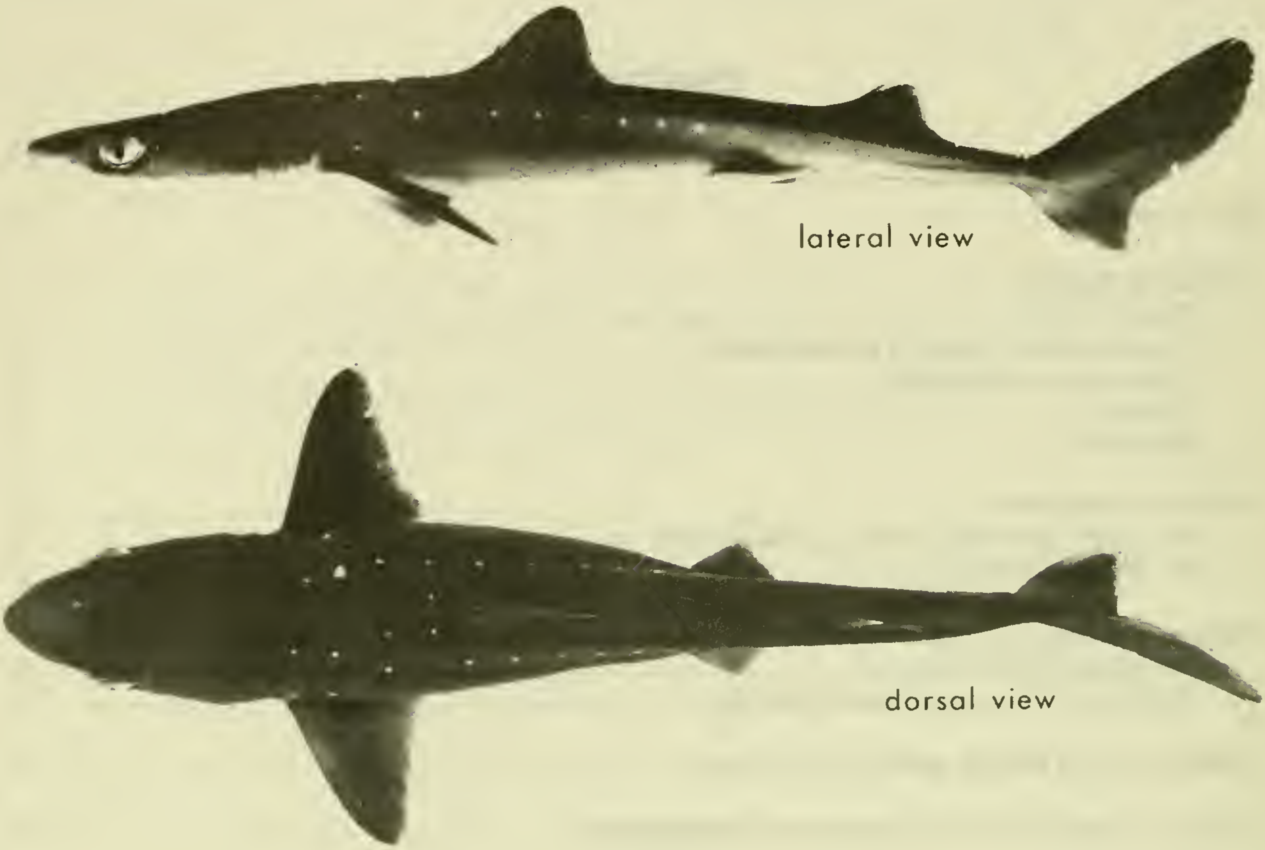

Figure 1.--Dogfish *(Squalus acanthias)*

THE SPINY DOGFISH (Squalus acanthias)
IN THE NORTHEASTERN PACIFIC

by

Dayton L. Alverson and Maurice E. Stansby

ABSTRACT

Recent depredations attributed to dogfish have been of serious concern to commercial and sport fishermen in the Pacific Northwest. Three possible ways of controlling the dogfish, all of them dependent upon a knowledge of dogfish biology, are discussed. Of these, development of a commercial dogfish fishery appears to be the most practical. Development of such a fishery, however, is dependent upon research leading to a high market demand for dogfish products. To assure the success of the fishery, all parts of the dogfish should have uses. Moreover, at least some of the products derived from dogfish should serve unique uses and be obtainable from no other source. Finally, a careful examination of import relationships must be made to assure that a domestic dogfish fishery would be able to compete with foreign fisheries.

INTRODUCTION

Recent increases in the size of dogfish populations on the Pacific coast have been of growing concern to commercial and sport fishermen. This report has been compiled to provide technical background material on the dogfish. It consists primarily of a survey of the available knowledge of the abundance and distribution of dogfish in waters of the Pacific Northwest, the effects of dogfish on the fisheries, and ways to use dogfish in commercial products. The report also discusses the roles of Government and the commercial fishing industry in controlling dogfish populations.

Note.--Dayton L. Alverson, Base Director, Exploratory Fishing and Gear Research, and Maurice E. Stansby, Laboratory Director, Technological Laboratory, Bureau of Commercial Fisheries, U. S. Fish and Wildlife Service, Seattle, Washington.

BIOLOGY OF DOGFISH

Classification

Dogfishes, in common with other sharks, are distinguished from bony fishes by cartilaginous endoskeletons and internal fertilization. The dogfishes are placed by taxonomists in Class Chondrichthyes, Subclass Elasmobranchii, Order Selachii, and Suborder Squaloidea. At one time the Pacific dogfish was distinguished from the Atlantic dogfish as a separate species, *Squalus suckleyi*. Bigelow and Schroeder (1948), however, could find no morphological differences between the two. Following normal systematic procedure, they gave precedence to the name under which the species was first described. *S. suckleyi* is, therefore, considered a junior synonym of *S. acanthias*.

Distribution and Centers of Abundance

The Pacific dogfish ranges from Baja California, to Alaska in the eastern Pacific, and it has been recorded from off northern China and Japan in the western Pacific. The same fish is found throughout the temperate and subarctic waters of the North Atlantic where it is called the Atlantic spiny dogfish.

Centers of abundance for dogfish along the Pacific coast of North America have not been studied, although results of the intense commercial fishery that was carried on in the midforties did shed some light on the subject. If productive fishing grounds are used as an index, Puget Sound, Strait of Georgia, and waters over the Continental Shelf from northern Washington to Hecate Strait would appear to be the centers of large concentrations. Within Puget Sound, dogfish apparently are common in most of the bays and inlets (figs. 2 and 3).

Development and Growth

The mating period of the Pacific dogfish is not known with certainty, but Bonham, Sanford, Clegg, and Bucher (1949) have described the beginnings of embryonic development in females captured in December. Mating, therefore, probably takes place in fall and early winter.

The reproductive organs of the female dogfish are relatively complex. The mature dogfish eggs pass from the ovary to the shell gland where they receive the sperm and are fertilized before they receive a protective, transparent membrane or shell. The fertilized, shelled eggs then pass to the uterus where they undergo the period of gestation. During gestation, the uterine walls of the shark are thrown into oblique rows of folds or villi through which gaseous materials are exchanged between the mother and the embryos (Daniel, 1934). Growth and maturation of the embryos are slow, with gestation lasting approximately 20 months. Eggs fertilized in December develop into embryos about 8.5 mm. (0.33 inches) long by the following March (Bonham, Sanford, Clegg, and Bucher, 1949) and 25 to 50 mm. (1.08-1.97 inches) by July. Just prior to birth, the membrane or shell is shed and the young emerge alive at lengths of 220 to 280 mm. (8.66-11.02 inches).

Owing to the long gestation period, females can give birth to a set of pups no oftener than every second year. Females from Puget Sound have been observed with from 2 to 20 pups, and the average is about 8. Birth of the young takes place in the late fall and early winter of the second year of gestation, generally in November or December.

Growth after birth continues to be slow. Data from Bonham, Sanford, Clegg, and Bucher, (1949) and Kaganovskaia (1933, 1937) indicate that a 61-cm. (24 inches) dogfish is about 8 years old. Maturity is probably not reached until after the 10th year of life, for females reach maturity at a minimum observed length of about 92 cm. (36 inches) and males at about 72 cm. (28 inches). A 92-cm. (3 feet) male dogfish may be 15 years old. Dogfish live longer than 30 years.

Feeding

A great variety of vertebrate and invertebrate marine organisms have been noted in dogfish stomachs. Bonham, Sanford, Clegg, and Bucher (1949) analyzed stomachs of 1,122 dogfish, mostly from Puget Sound[1], and found that fish constituted two-thirds of the diet. Food fish accounted for nearly one-half of the volume of identified items. Ratfish *(Hydrolagus colliei)*, herring *(Clupea harengus pallasi)*, and krill *(Euphausia* sp.) were the items most commonly reported by these authors.

Chatwin and Forrester (1953) studied the feeding habits of dogfish in the Fraser River estuary, British Columbia, during the springs of 1950 and 1953. They found that dogfish were feeding on eulachon *(Thaleichthys pacificus)* that were entering the river. A positive relation was noted between availability of dogfish to trawlers in the area and the relative abundance of eulachon at the Fraser River mouth. Of the

[1] The collection area is not mentioned in the text, but in a telephone conversation with the senior author, Bonham stated that most of the specimens examined were collected in Puget Sound.

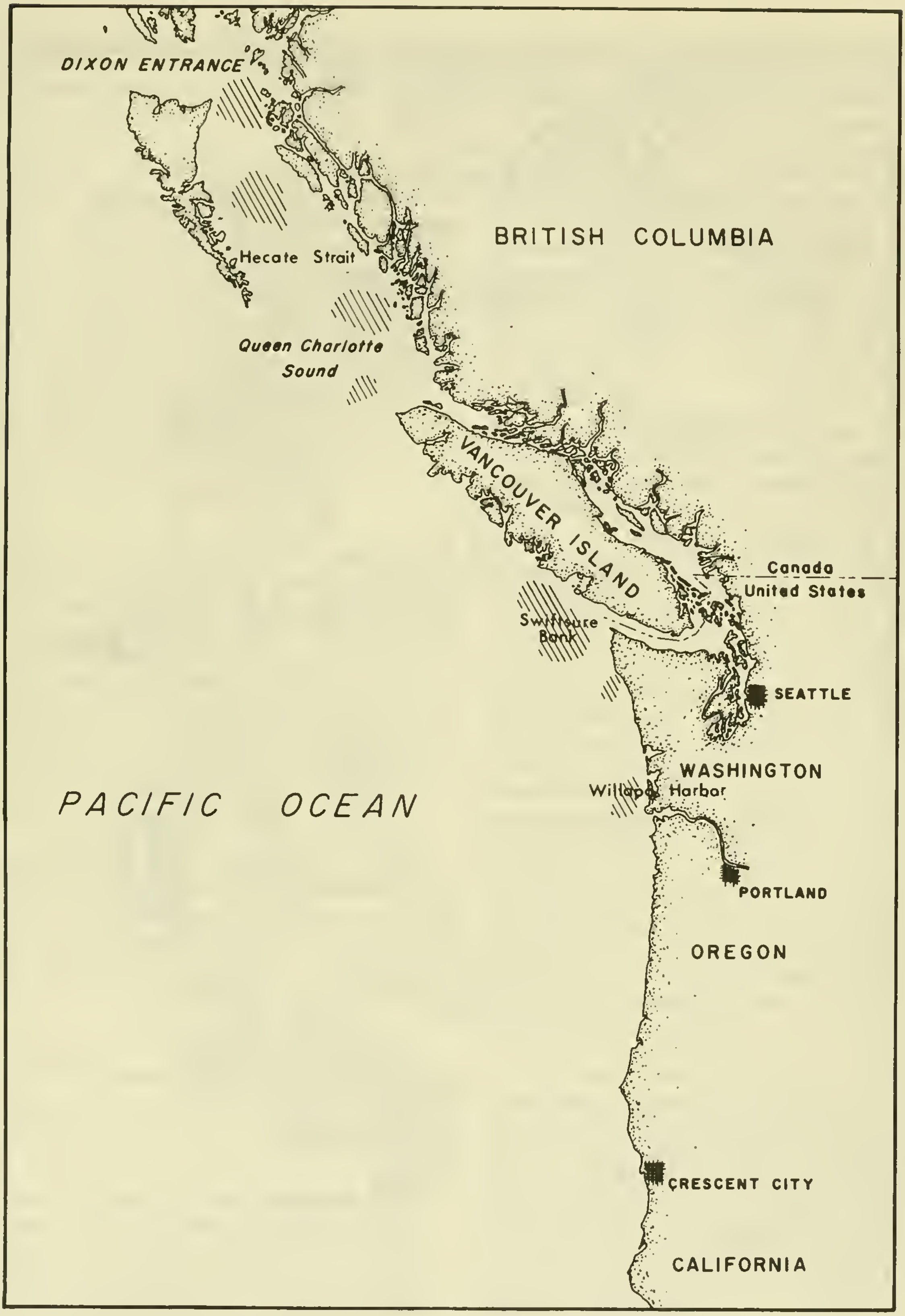

Figure 2.--Offshore areas of the Pacific Northwest where dogfish are found in large concentrations.

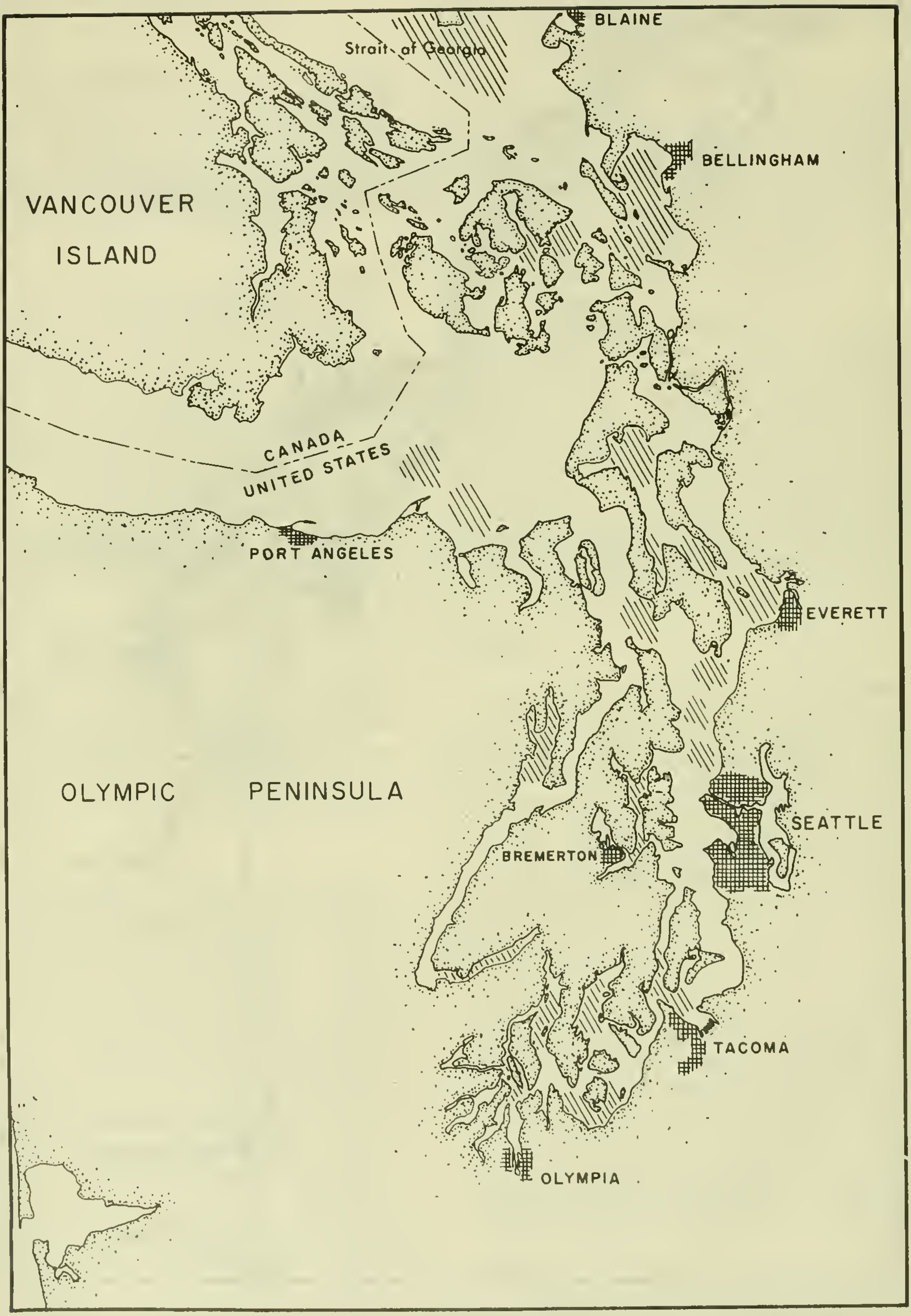

Figure 3.--Areas of Puget Sound where dogfish are heavily concentrated.

249 dogfish stomachs examined, 188 contained food, and all of the stomachs having food contained some eulachon. Salmonoids were found in two stomachs.

Dominant food items in stomachs of dogfish taken from the west coast of Vancouver Island, British Columbia, included shrimp, herring, flatfish, and sand lance *(Ammodytes tobianus)*; whereas dogfish collected from Hecate Strait contained large amounts of flatfish, herring, squid, octopus, and shrimp. The investigators (Chatwin and Forrester, 1953) concluded that dogfish are "opportunists, rather than discriminating predators." There is no evidence to suggest that dogfish materially affect salmon stocks by predation.

Migrations

Movements of dogfish have been studied and reported by Holland (1957), Kauffman (1955), and Bonham, Sanford, Clegg, and Bucher (1949). Tagging studies have indicated that the offshore dogfish population or populations may be highly migratory. Some rather long migrations have been noted. One fish, tagged in Willapa Harbor, Wash., was recovered off the northeast corner of Honshu Island, Japan. Migrations between California and British Columbia have also been noted.

Dogfish within Puget Sound show less tendency to migrate, and Puget Sound stocks are apparently somewhat independent from coastal and offshore stocks. Nevertheless, some movement of dogfish may occur between ocean areas and Puget Sound.

HISTORY OF THE FISHERY

The North American Fishery in the Pacific

Along the shores of the eastern Pacific, dogfish were first exploited by Indians who extracted clear oils from dogfish livers by heat and pressure (Lord, 1866). Oils so obtained were used primarily for dressing animal skins, flavoring food, finishing wood, and preparing paint. Early white settlers in the Pacific Northwest used the oil also in lamps and as a machine lubricant and grease for skidways on logging roads. Before cheap petroleum products became available, dogfish oils brought as much as 40 cents a gallon in the Puget Sound area. Barraclough (1953) reports that large quantities of dogfish oil were used for lubrication and lighting in sawmills at Burrard Inlet and in coal mines at Nanaimo and Departure Bay, British Columbia. Lighthouses in British Columbia also burned dogfish oil. Clemens and Wilby (1946) state that a reduction plant in Skidegate Inlet, British Columbia, was producing dogfish oil in 1880.

Attempts to use dogfish as human or chicken food have been largely unsuccessful in North America. A program designed to encourage human consumption of dogfish in the United States was approved as a wartime measure on June 21, 1916. Congress appropriated $25,000 for the purpose, and 4 million pounds of dogfish were landed in 1917. But the market, which disappeared as the more traditional food fish became available again after World War I, has never been revived. Experimental attempts to can dogfish have not met with success owing, in part, to the in-the-can breakdown of dogfish urea into ammonia and carbon dioxide. Reduction of dogfish carcasses to provide meal for chicken feeds has also been attempted, intermittently, without much success, although limited quantities of carcasses are still reduced for chicken feeds and fertilizer. Properties of meals, and the suitability of meals as chicken feeds, are described in a bulletin published by the State College of Washington (Rhian, Carver, Harrison, and Hamm, 1942).

Early tests (based on total nitrogen) indicated that dogfish flesh might have a high protein content, but later tests (based on protein nitrogen) proved that the protein content (and therefore the nutritive value) of the edible portions of the dogfish is less than that of teleost (bony) fishes. Dogfish tissues contain a high percentage of nonprotein nitrogen, much of which is in the form of urea plus trimethylamine.

The use of shark livers as a source of vitamin A was responsible for the large-scale dogfish fishery of the 1940's. Harrison and Samson (1942) report that in the United States shark livers were first used as a source of vitamin A in 1936-37. California processors of sardine oils became interested in fortifying biologically tested sardine oils with low cost vitamin A. Dogfish livers were found satisfactory, but soupfin shark livers, yielding a very high-potency vitamin A, and cheap vitamin-rich oils from Europe were preferred. Unable to compete, the dogfish fishery developed slowly until European sources of liver oil were cut off with the outbreak of World War II.

Demand for domestic oil sources during the war led to technological advances in extraction of vitamin A from oils. A process was developed that made it economical to concentrate vitamin A from oils of relatively low vitamin potency (such as dogfish liver oil). With European competition cut off and with a means of competing with the higher potency soupfin liver sources, the dogfish fishery was given impetus necessary to develop into a large-scale industry. Vitamin oils from dogfish and soupfin sharks became the major sources of vitamin A in the United States and Canada. The processed oils were used by pharmaceutical houses, food processors, and stock and poultry feed manufacturers (Holland, 1957).

The dogfish fishery of the Pacific Northwest built up rapidly to a peak in 1944, when almost 133 million pounds of whole fish were caught between California and Alaska. In the 9 years, 1941-49 (table 1), annual catches exceeded 40 million pounds, and the cumulative catch exceeded one-half billion pounds.

The fishermen were paid for the livers at a price dependent on vitamin potency. Average prices paid are shown in table 2. Excellent prices, obtained by fishermen between 1944 and 1949, reached a high of 56.6 cents a pound in 1948.

During the early phases of the fishery, the largest portion of the catch was taken on longline gear in coastal waters, but otter trawling and diver (sink) gill nets soon dominated the fishing. Holland (1957) reports that "following 1941, the ocean fisheries became the dominant source of dogfish caught by Washington fishermen, producing between 64 and 79 percent of the total state's landings." Otter trawl catches comprised from 63 to 89 percent of the catches from the offshore grounds.

Major grounds fished by Washington fishermen in the 1940's were in Puget Sound, in the Gulf of Georgia, between Destruction Island and Cape Flattery, on Swiftsure Bank, on 40-Mile Bank, and in Hecate Strait. Canadian fishermen operated off lower Vancouver Island, in inside waters east of Vancouver Island, and in Hecate Strait. Most of the fish were gutted at sea (except in California), and only the livers were landed. The livers, stored in 5-gallon tins, were sometimes salted for preservation.

Since 1949 imports of dogfish oils (fig. 4) and the production of synthetic vitamin oils have sharply reduced the demand for dogfish livers and virtually eliminated the west coast fishery. In recent years total landings on the Pacific coast have amounted to only a few million pounds annually.

The Atlantic Fishery

Dogfish have been used for human food in Asiatic and European countries for many years. A German trawl fishery, supplying dogfish for human foods, existed in the North Sea as early as 1906. In 1903 the English government seriously considered a method of eradicating or removing dogfish, which at that time were considered a "scourge" to other lucrative fisheries (Ford, 1921). The government's solution was to encourage capture through creation of a market for dogfish as a human food. Toward this end, the government subsidized transportation costs of dogfish, and a number of cookery experiments were undertaken. Partial success was achieved, and landings of dogfish increased rapidly.

On the east coast of the United States and Canada similar attempts have been made to encourage capture and develop markets for dogfish.

TABLE 1.--Catch of dogfish in thousands of pounds[1]

Year	California	Oregon[2]	Washington[2]	British[3] Columbia	Alaska[4]	Total
1937	913	--	1,620	11,322	--	13,855
1938	--	--	578	15,969	--	16,547
1939	--	--	2,365	11,482	--	13,847
1940	--	1,244	3,347	14,488	13	19,092
1941	--	5,084	23,980	25,513	531	55,108
1942	--	1,313	17,374	31,103	40	49,830
1943	--	2,299	23,546	37,555	221	63,621
1944	47[5]	4,374	41,018	56,977	31,115	133,531
1945	20	2,220	23,414	42,694	911	69,259
1946	6	3,109	22,132	20,858	1,001	47,106
1947	--	2,824	15,282	28,160	689	47,955
1948	--	4,659	12,504	22,249	446	39,858
1949	--	3,423	10,645	29,253	918	44,239
1950	--	703	1,928	4,041	15	6,687
1951	--	152	2,452	7,311	10	9,925
1952	--	47	3,065	5,573[6]	--	8,685
1953	--	37	2,405	5,698	--	8,140
1954	--	39	2,012	4,635	--	6,686
1955	--	--	1,935	4,789	--	6,724
1956	--	57	1,526	2,053	--	3,636
1957	--	24	1,861	4,517	--	6,402
1958	--	65	4,233	2,933	--	7,231
1959	--	64	3,092	10,362	--	13,518

[1] The livers only were landed from a large portion of the catch. Because of the varied methods which have been used in computing whole weights and reporting landings, the values shown are estimates only.

[2] Fishery Statistics of the United States, U. S. Fish and Wildlife Service Statistical Digest Nos. 1, 4, 7, 11, 14, 16, 18, 19, 21, 22, 25, 27, 30, 34, 36, 39, 41, 43, 44, and 49.

[3] Fishery Statistics of Canada, 1937-51. Total pounds of dogfish caught = pounds of livers landed x 8.33.

[4] Alaska Fishery and Fur Seal Industries, 1937-54.

[5] Holland (1957).

[6] Fishery Statistics of British Columbia (Preliminary), 1952-59. Total pounds of dogfish caught = pounds of livers landed x 8.33.

During the early phases of the English fishery, difficulty was encountered in overcoming public prejudice against using sharks as human food. The obstacle was partially overcome by introducing the market name "flake", a name later adopted in the United States and Canada along with "grayfish".

Regardless of the somewhat low protein content of dogfish meat, use of dogfish for human food in Europe has increased rapidly. Since the end of World War II, the growing interest in dogfish has skyrocketed landings in Great Britain and Norway. Approximately 88 million pounds of dogfish were marketed in Europe in 1955.

Dogfish landed in Europe for human food are gutted and skinned at sea. In Great Britain, the catch is auctioned at the docks along with other food fish and is marketed extensively in the fish-and-chip trade. Smoked dogfish are used, to some extent.

EFFECTS OF FISHING ON DOGFISH

The actual changes occurring in stock abundance during the period of intense fishing

TABLE 2.--Prices and landings of dogfish livers in the Pacific Northwest

Year	Value per pound[1]	Landings[2]	Year	Value per pound[1]	Landings[2]
	Cents	*Pounds*		*Cents*	*Pounds*
1940	5.5	2,320,742	1950	21.2	849,843
1941	16.4	7,107,846	1951	26.7	1,229,041
1942	21.3	6,488,620	1952	20.9	1,018,179
1943	33.8	8,275,655	1953	16.9	906,498
1944	38.1	13,646,630	1954	16.0	715,815
1945	34.3	9,020,239	1955	14.4	740,986
1946	43.3	6,010,480	1956	11.5	326,014
1947	36.5	6,025,622	1957	11.5	820,547
1948	44.8	5,154,256	1958	10.3	439,168
1949	33.7	5,802,304	1959	15.5	1,440,554

[1] Prices per pound based on total value of livers landed divided by total value for California, Oregon, Washington, British Columbia, and Alaska.
[2] Sources -

a. Holland (1957).

b. Fishery Statistics of the United States. U. S. Fish and Wildlife Service Statistical Digest Nos. 4, 7, 11, 14, 16, 18, 19, 21, 22, 25, 27, 30, 34, 36, 39, 41, 43, 44, and 49.

c. Fishery Statistics of Canada, 1937-51.

d. Fishery Statistics of British Columbia (Preliminary), 1952-59.

e. Alaska Fishery and Fur Seal Industries, 1937-54.

[3] Based on British Columbia statistics. Includes Government subsidy of 10 cents per pound amounting to $129,985.

in the 1940's are masked by changes in economics, gear efficiency, and fishing intensities. The biological changes in Pacific coast dogfish populations were not intensively investigated, but all information available suggests that a marked reduction occurred in the availability of dogfish as a result of the fishery.

The dogfish fishery developed rapidly in 1940-43, with the upward trend in landings closely following the increasing prices paid to fishermen (fig. 5). Annual landings fell rapidly after 1944, the peak year in the fishery, but the price per pound did not peak until 1948. The catch in 1948 represented only 39 percent of the record 1944 landings in spite of a price increase from 38.1 cents to a peak price of 44.8 cents per pound. The reduction in catch occurred during a period when fishing grounds were being expanded by American trawlers. That annual yields of dogfish should decline as prices paid for livers increased and the grounds expanded suggests strongly that the relative availability of the species had been reduced.

The Soupfin Shark Fishery

Some indications of the effects of intense fisheries on the abundance of shark populations may be obtained by reviewing the history of the soupfin shark fishery. The soupfin, because of its high vitamin potency, was intensely exploited from 1941-49. Ripley (1946) and Westrheim (1950) have described the development of the soupfin shark fisheries off California and Oregon. The California fishery for soupfin sharks somewhat preceded the Oregon fishery. California landings rose sharply between 1937-38. Intense fishing and

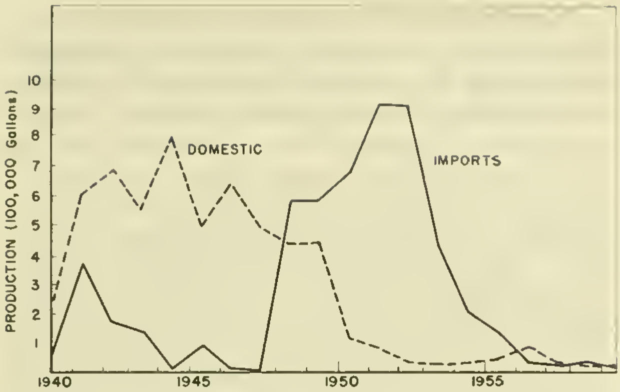

Figure 4.--Production of domestic dogfish and other shark oils as related to imports.

excellent prices continued through 1949, although catches had fallen to less than 30 percent of the record 1937-38 period.

Landings in Oregon rose quickly in 1941-42 and reached a peak in 1943. The market demand was good, and prices for shark livers continued to rise until 1949 when $18 a pound was paid for high-test (vitamin A) livers. The catches did not follow the upward trend in prices, but declined rapidly from 1942 on. By 1946, total landings of soupfin shark livers in Oregon had fallen to about 30 percent of peak year landings.

The trend in soupfin liver landings in Oregon closely parallels the history of the dogfish shark fishery. Together, the histories of the dogfish and soupfin shark fisheries demonstrate that intense exploitation can quickly reduce the cumulative stock levels of these sharks.

Concern for the dwindling number of dogfish and soupfin sharks was expressed as early as 1943, and in October 1944 a meeting was called in Victoria, British Columbia, to consider the necessity of regulations and to recommend methods of avoiding wasteful practices in exploiting soupfin and dogfish sharks.

Biological Evidence of Stock Reduction

Fishermen have indicated that during tne latter years of the fishery the availability of dogfish was much reduced on known fishing grounds. Statements by zoologists have also pointed to a considerable reduction in cumulative stock levels following development of the fisheries in the 1940's. According to K. S. Ketchen of the Fisheries Research Board of Canada (personal conversation with the senior author), dogfish became extremely scarce on traditional British Columbia grounds by 1949. Holland (1957) noted that although the average total landings of trawlers remained fairly constant from 1941-46, fishing time increased. He also observed a decrease in the average catch per effort of longline.

The Fisheries Research Board of Canada studied changes in availability and abundance of dogfish in Hecate Strait from 1943-46 by examining tally slips or the fish receipts of those fishermen that used sunken gill nets during the May-October period (Barraclough, 1948). Catches in sink gill nets for boats fishing in 1944, 1945, and 1946 were compared monthly with catches from boats fishing in 1943. Link relations were thus obtained. Barraclough's data indicate a decline in availability of dogfish for each month compared, except October, from 1943 through 1946.

When the total yearly landings of dogfish livers from the same boats were compared (fig. 6), a reduction of 50 percent in relative availability of dogfish was indicated. The decrease, which occurred in 4 years, indicates that a considerable reduction in cumulative stock level, at least in a localized

Figure 5.--Total landings of dogfish livers in Washington, Oregon, California, British Columbia, and Alaska--1940-59.

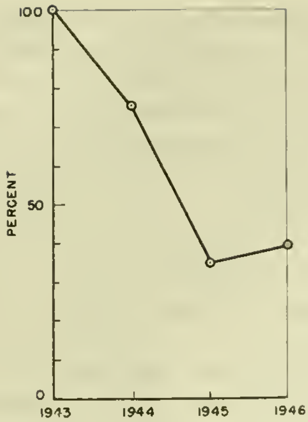

Figure 6.--Index of the total catch of dogfish livers landed by the same boats fishing sink gill nets in the periods 1943-44, 1944-45, and 1945-46 in Hecate Strait. Determined by the method of link relatives.

area, probably resulted from the intense fishery. Barraclough (1948) has said that the decline in availability of dogfish in Hecate Strait was closely related to removal of the older age classes from the population. Barraclough summarized his findings by pointing out that "the decline in availability and vitamin A potency of dogfish was not sufficient evidence to indicate biological depletion; however, the economic consideration of reduced yield per boat accompanied by reduced value per unit was a matter of real concern." The Canadian studies were on a rather small scale and lack the confirmation of supporting statistical data, and the conclusions or trends indicated in the Hecate Strait fishery are not necessarily indicative of the overall coastal fishery.

Shepard and Stevenson (1956) give an indication of the size of dogfish stocks and possible effects of the fishery off British Columbia. Using reduction of stock of about 50 percent (from Barraclough's 1948 work) for the 1940's, and neglecting natural mortality and recruitment, they estimate that the 500 million pounds of dogfish removed in approximately 5 years represents about one-half the original stock. If recruitment and natural mortality were approximately equivalent, then a fishing mortality in the vicinity of 13 percent per year could be considered sufficient to materially reduce the dogfish.

What happened to the populations after fishing ceased is purely speculative. The life history of the dogfish is not conducive to a rapid buildup of the stocks to their former abundance. Contemporary estimates as to the status of the stocks after the fishery, as compared with their status prior to the fishery, are subjective. Reports from fishermen suggest that dogfish have become increasingly abundant in recent years. Whether they are as numerous as during the period prior to the fishery is an academic question. That dogfish are again very abundant seems evident from reports of fishermen, biologists, and sportsmen. Shepard and Stevenson (1956) report that: "In consequence of the cessation of fishing for dogfish, the stock now appears to be in the process of a strong recovery. Already the dogfish has become a plague on many of the British Columbia fishing grounds--disrupting trawling and seine fisheries for other species."

EFFECTS OF LARGE DOGFISH POPULATIONS ON MAN

The presence of increasing numbers of dogfish in offshore waters and within Puget Sound has stimulated industry requests for assistance. Destruction of gear, excess wear on fishing nets, loss of fishing time, practical loss of fishing areas, and reduction in food and shellfish stocks through predation are attributed to dogfish.

Gear losses and damage are most common in the net fisheries (trawl, seine, and gill net) and often result when nets are set or dragged in areas heavily infested by dogfish. If the catch of dogfish is large enough, the entire net may be lost. Because of the relatively high specific gravity of dogfish, when extremely large catches are made, the weight may be sufficient to break the entire net or portions of it. Net damage is probably most prevalent in the trawl fisheries, although it also has been reported in the salmon seine and gill net fisheries.

Gear losses are also experienced in commercial and sport line fisheries, where the damage usually results from shearing of leaders or gangings by the sharp teeth of dogfish. Even wire leaders are sometimes bent or twisted so that they are unusable.

Continued "gilling" or working of dogfish in a net and the efforts needed to remove them cause rapid abrasion of twines and often result in destruction of nets. When catches of dogfish are large, time in clearing the nets may range from several hours to 2 days of fishing time. Salmon trollers may lose fishing time and efficiency while removing dogfish from their hooks and replacing lost gear.

Loss of historic fishing areas owing to dogfish infestation is one of the important claims of fishermen. The claim is substantiated for the trawl fisheries by records of the Washington State Department of Fisheries and the Fisheries Research Board of Canada. Reduced yields and reduced fishing effort on the dogfish-infested grounds off southwest Vancouver Island are clearly shown. K. S. Ketchen of the Fisheries Research Board of Canada has mentioned to the senior author that it has been increasingly difficult to follow abundance trends of groundfish off southern Vancouver Island, because trawl fishermen have been forced from these areas. This situation has also been noted for the Washington trawl fleet, where fishermen report having been plagued with dogfish on 40-Mile and Swiftsure Banks during the summer and having been repeatedly forced from these areas.

Representatives of the local commercial and sports fishing industries estimate that in the Pacific Northwest dogfish cause losses of about $2.2 million due to gear destruction and loss of fishing time, and being forced from historical fishing grounds.

EFFECTS OF LARGE DOGFISH POPULATIONS ON OTHER SPECIES

The effects of increased dogfish populations on species of food fish through predation and spatial competition are entirely unknown. That "populations of organisms inhabiting a common habitat are in constant flux and react upon each other" (Walford, 1958), is a known ecological principle. The predator-prey relationship has received little study in marine fisheries. Walford, however, points out that: (1) members of a population compete with one another for food and space; (2) changes in the combination of environmental conditions in an ecological system--such as fluctuation of climate, a shift in ocean currents, the invasion of a new predator, or the sudden infestation of an area by a new species that becomes dominant--all cause changes in the species composition; and (3) a population tends to fill all the space in its sector that meets its peculiar physiological and behavior requirements up to limits set by the abundance of food, predators, competitors, and other controlling factors.

General ecological principles dictate that the increase in dogfish stocks has caused greater competition with and predation upon other species. That dogfish are the dominant groundfish, and are probably exceeded only by herring, in basic stock size off British Columbia has been estimated by Shepard and Stevenson (1956). Their estimate that the basic weight of dogfish stocks exceeds that of all other groundfish combined demonstrates how dominant this species has become.

Walford (1958) states: "The abundance of a stock of a species is greatly influenced by the abundance of species of prey, competitors, and predators." The dynamics of ecological shifts are complex, and which species would be most likely to benefit from reduction in dogfish population levels is unknown. Predation of dogfish on food fishes, especially in offshore areas, suggests that food fishes might benefit from a reduction in dogfish numbers. Barraclough (1953) states: "The removal of large numbers of predators, such as dogfish, must of necessity dislocate the economy of the coastwise waters. The exact change in the whole or main populations resulting from vigorous pursuit of this fishery cannot be stated with certainty but the first effects might be expected to include an increase in the forage species, such as herring, and increased opportunity for growth in competing predators, such as salmon, lingcod, and halibut."

Elimination or reduction in numbers of predators or competitors from an area has been described by Rounsefell and Everhart (1953) as being desirable when "because of their abundance and predacious habits they are limiting the abundance of more desirable species." These authors further state that "when a fish population becomes unbalanced or becomes undesirable in the ecology of an area, it may be necessary in the interest of good wildlife management to control it." We cannot, however, at this time state that these principles are necessarily applicable to dogfish, for the limiting effect of dogfish on more desirable fishes is unknown.

METHODS OF CONTROL

Eliminating or decreasing dogfish damage can be achieved through (1) reducing the numbers of dogfishes or (2) developing and using chemicals (repellents or deterrents) to protect gear and catches.

Reducing Dogfish Numbers

Most control measures proposed are aimed at minimizing dogfish damage through reducing their numbers. Presumably decreased gear loss and damage would follow stock reduction, but whether or not such decreases would be directly proportional to the reduction in stock is unknown.

Reducing the size of dogfish concentrations (mass) can be accomplished only by removing dogfish at a rate exceeding the increase of population through recruitment and growth. A study of the history of the dogfish fishery in Hecate Strait indicates that an annual fishing mortality of 10 to 15 percent may be adequate to initially effect a material reduction in stock sizes. Assuming that the Shepard and Stevenson (1956) estimate of 600 million pounds of dogfish off British Columbia is reliable and assuming further that an additional 200 million pounds may exist off Oregon and Washington, we estimate that from 80 to 120 million pounds of dogfish may have to be removed during the first several years to decrease substantially the cumulative population level. Such quantities could be removed, conceivably, by: (1) selective poisoning or (2) intense fishing effort.

Prospects for selectively poisoning dogfish:--From what we know about the selective toxicity of a number of chemicals, we could, possibly, develop a selective poisoning technique.

Selective poisoning is based upon behavioral or biochemical differences among animals. Poisons, to be effective, must be absorbed by the animal tissues and must produce an effect on a particular biochemical system in the animal. Thus, we could conceivably poison sharks without harming other more valuable fishes by finding and using (1) as bait some substance that would be eaten by sharks but not by other fishes and (2) as a poison dissolved in the water some substance that would interfere with a biochemical system present in sharks but absent in other marine organisms.

Since behavioral (feeding) and biochemical differences do exist between sharks and bony fishes, development of a selective poison seems chemically feasible. But, even assuming that the price of such a poison, in commercial lots, were reasonable, spreading the poison and seeing that the dogfish ingested or otherwise absorbed it in lethal amounts would be extremely difficult. A better prospect seems to be development of an intensive fishery.

Prospects for developing a fishery:--To rejuvenate a fishery for dogfish that would be sufficiently intensive to bring about the required 10- to 15-percent initial mortality would require (1) a bounty system with an attractive reward, (2) a large vessel-charter system, or (3) development of a high market demand for dogfish or dogfish products. In the first two instances, nearly continuous

Government financial supports would be necessary; in the third instance, Government support of research leading to market demand would be followed by a self-supporting commercial enterprise.

In either a bounty or a vessel-charter system, Governmental payment to the fishermen would be necessary. To attract sufficient fishermen to effect the desired mortality, these payments would have to be, roughly, 2 to 3 cents a pound for whole fish or 17 to 25 cents a pound for liver, or between $1. and $3. million in the first year.

The same amounts of money, applied to a developmental research program, would go far toward developing uses for dogfish or dogfish products that would lead to a market demand for the dogfish. This, in turn, would make possible a self-sustaining fishery that would serve to keep the stocks at the desired low levels without further necessity for Governmental supports. Development of market demands, therefore, seems a logical and promising first step in dogfish control.

REPELLING AND DETERRING DOGFISH

Considerable time and effort have been spent on attempts to develop effective chemical substances that would repel or deter sharks. But little information of use to commercial fishermen has resulted. Repellent dye material (including nigrosin), used to some extent by the Armed Forces, is too expensive for use with large nets, and too much of the material is required for it to be economically used even if the price could be lowered appreciably. Then, too, other factors associated with fishing--such as the commotion created by fish in the net, substances secreted or excreted by the fish, and possibly other factors--may negate the effects of repellents by serving as more powerful attractants. Recent studies reported through the shark research panel of the American Institute of Biological Sciences have indicated that, for limited application, it may be possible to develop a chemical repellent or deterrent, but at present there is no substance known that will provide practical protection against shark damage under all conditions.

Mechanical deterrents, including protective poultry-wire covers on trawl cod ends, double-twine nets, and other devices, have been used with some success. Another lead that might result in some decrease in shark damage involves the ultimate use of repellent electrical fields about the net. Electricity is selective in its action. As experiments with electrical fishing gear have demonstrated, the voltage used can be regulated so that larger fish can be dealt stunning doses whereas smaller fish can swim unharmed and even be attracted to the electrode. Perhaps, at some future date, a series of electrodes can be set up to protect both moving and stationary nets against sharks. Unfortunately, dogfish are relatively small sharks, and the differences between their size and the sizes of the fish being sought might not be sufficient to allow the selective action of the electrical fields to be effective.

This is the proper place to stress that development of an effective control program--one seeking to reduce numbers of sharks or one seeking merely to repel or deter sharks--is dependent on a much more thorough knowledge of basic shark biology than we now possess.[2]

POSSIBILITIES FOR DOGFISH UTILIZATION: CHARACTERISTICS AND PROPERTIES OF DOGFISH OILS AND PROTEINS

Oil and protein are the two principal components of dogfish that might be used commercially. Only if processing plants and markets for both oil and protein were available would a commercial dogfish fishery be profitable--and, therefore, self-sustaining.

Moreover, in view of the competition that would be faced by the usual dogfish oil and protein products on the market, uses unique to dogfish products are extremely important. If uses found for dogfish products could be

[2] Much of the material in this paper has been taken from a manuscript by Springer and Gilbert.

filled equally well by products from other fishes or synthetic processes, there would be no assurance that the dogfish products would be used; rather, some other generally available product might be used and the dogfish product might be ignored.

Characteristics and Properties of Dogfish Oils

Oils occur in the dogfish in both body tissues and liver. The chemical nature of the oils from these two sources differs. Those in the tissues are chemically different from those in the liver. The possibility exists that oils from each source might have entirely different applications.

Dogfish body oils:--Dogfish body oils are similar to most other fish oils (table 3). They consist predominantly of glycerides of fatty acids, which may be looked upon as combinations of glycerin with fatty acids that, in fish oils, have long-chain carbon molecules--usually containing 16, 18, 20, or 22 carbon atoms. Further, fish oil fatty acids are often highly unsaturated, i.e., double bonds exist between many of the carbons in the molecules. The remaining small proportion of the body oils consists of "unsaponifiables"--substances that are not affected by alkalies and that are insoluble in water. The unsaponifiable material in fish oils (including dogfish body oils) usually constitutes less than 1 percent of the total.

It is the variation in the proportions of fatty acids of different chain lengths and in degrees of saturation that makes each specific fish oil a little different from all others. Not much is known, specifically, about dogfish body oils. Their compositions indicate that they are probably fairly similar to other fish oils in chemical properties. But, if a technological project on dogfish should be started, an important project phase should be devoted to determining the exact characteristics of the body oils. Relatively simple research would suffice to show whether or not dogfish oils behave chemically as most other fish oils do.

Dogfish liver oils:--The oils taken from dogfish livers seem to hold more promise in the development of unique uses for dogfish products than do body oils. Unsaponifiables are present in the liver oil in far greater proportion (about 15 percent compared with about 1 percent in body oils) than they are in body oils. The definite possibility exists that something is present in the unsaponifiables that is unique and that has a high potential for some industrial application. Just what this something might be cannot be surmised at present.

Glyceryl ethers occur in fish oils in the form of an alkoxydiglyceride. This type of compound differs from the ordinary fish oil (triglyceride) by having one of the fatty acid esters replaced by an ether-linked fatty alcohol. These ethers, representing about one-half of the unsaponifiables, represent one promising point of attack in the search for dogfish products with unique industrial uses. One firm in Vancouver, British Columbia, is already extracting and marketing the glyceryl ethers from dogfish liver oil. Moreover, a search of patents indicates that the glyceryl ethers are valuable intermediates of compounds that include ingredients of textile treatment media, perfume fixatives, dye additives, emulsifiers, insecticides, disinfectants, and foaming agents.

Use of glyceryl ethers as vehicles for food antioxidants is another promising lead. Some work has been done toward development of this use at the Hormel Institute of the University of Minnesota, but the work was discontinued before completion. The dogfish glyceryl ethers are particularly promising in this regard because (1) they can be used to provide substances that mix well with both oil and aqueous phases of foodstuffs and (2) they are natural substances that have been accepted in medicines, so that the U.S. Food and Drug Administration would be able to pass on their suitability in much shorter time than would be the case with most synthetic substances.

In addition to the oil, dogfish livers also contain vitamin A. Extraction of vitamin A from dogfish livers is, at best, a marginally economic operation at the present time. If, however, several other substances could be used for products of high value, such extraction might become profitable.

TABLE 3.--Characteristics of dogfish liver and body oils

	Pacific		Atlantic
	Liver oil	Body oil	Liver oil
Specific gravity at 25° C. (77° F.).......	0.9055-0.9066	--	0.905
at 15° C. (59° F.)......	0.9094	--	--
Coefficient of expansion (per °F.)........			
Refined:			
Apparently solid, 21° - 27° F........	0.000584	--	--
Apparently solid, 27° - 34° F........	0.000922	--	--
Melting stearine, 34° - 48° F........	0.000615	--	--
Unrefined:			
Cloudy stearine, 48° - 59° F.........	0.000518	--	--
No stearine, 34° - 75° F.........	0.000413	--	--
Color (lovibond units, 1-inch cell):			
Yellow..............................	2.5-20.0	6.2	--
Red.................................	--	0.5	--
Viscosity (centipoises):			
At 25° C. (77° F.)..................	48.4-49.2	--	--
At 40° C. (104° F.).................	32.4	--	--
Refractive index at 25° C. (77° F.).......	1.4702-1.4760	1.4733	1.4755
Iodine value..............................	99.6-128.0	172.0	110.7
Saponification value......................	152.1-164.9	167.5	151.7
Acetyl value..............................	5.5	--	--
Unsaponified matter (%)...................	7.5-35 (av. about 22)	--	14.84
(Glyceryl ethers).....................	15		
Free fatty acid (%).......................	--	--	--
Vitamin A (U.S.P. units per gram).........	1,500-65,000	40-600	200-150,000
Vitamin D (U.S.P. units per gram).........	5-25	--	3-25

Source: Fisheries Research Board of Canada, Bulletin 89 (1952).

Characteristics and Uses of Dogfish Proteins

As long as the entire cost of production of dogfish products falls on oil products alone, or on oil products and vitamin A extraction, dogfish fisheries will probably be marginal enterprises. Despite almost negligible chances of developing unique uses for dogfish carcasses, therefore, development of any uses for the carcasses should be pushed so that a portion of the production cost could fall on carcass utilization. Otherwise, oil users would probably find it cheaper to import the oil from Japan or other foreign countries.

The most profitable use for the carcasses would undoubtedly be as food for humans, but development of this would be difficult. Principal objections to such development are: (1) in most parts of the country there is a strong subjective prejudice against eating shark, (2) sharks contain urea, which would have to be removed or fixed in the tissues by special processing methods before the flesh would be acceptable to most people and before canning could be accomplished, and (3) compared with many other low-priced and underutilized species of fishes, the palatability of dogfish is low. These are the same difficulties that have faced previous attempts to market dogfish in the United States and in Europe.

Use of dogfish as canned petfood is open to some of the same objections, and many canners also object to sharks because their tough hides jam the fish grinders at petfood plants. Installation of grinders of different design would overcome the latter objection, but as long as there is a steady supply of the many low-cost and otherwise underutilized fishes currently being used in petfoods, development of a petfood market for dogfish seems unlikely.

A third possibility is that of using dogfish carcasses for fish meal. This possibility seems the best of the three discussed, and some carcasses are being used for meals already. But here, too, there are objections and problems to be met. The meal from dogfish has a relatively low nutritional value. Also, it contains urea, which interferes with traditional tests for protein content; and often the urea nitrogen is not subtracted from the protein nitrogen, leading the user to believe that he is feeding a product superior in protein content to what is actually the case. Research to raise the quality of dogfish meal is badly needed. In addition, tests are needed to determine the suitability of dogfish meals in foods for animals other than poultry (for which most of the meal now being produced is used). Such research could open new and extensive markets. Research already conducted, for instance, has demonstrated that cattle have the ability to use urea nitrogen, whereas this ability is lacking in poultry.

In summary a list has been compiled of the most urgent research needs if uses are to be developed for dogfish products. Among the principal needs are:

1. General research on metabolism of urea in dogfish and location of the urea in the fish. If more were known about this, it might be possible to eliminate the urea before processing the carcasses.

2. Research on the chemical makeup of dogfish oils. This research would include studies of both fatty acid composition of dogfish body and dogfish liver oils, and, especially as a main item of research, the composition of the unsaponifiable matter in dogfish liver oil.

3. Research on utilization of dogfish oil for specific purposes. A project should be started first at Hormel Institute on utilization of glyceryl ethers as an antioxidant vehicle. Later, as results on composition of dogfish oils become known, other potential uses indicated by these results should be looked into.

4. Investigation of the quality for chick feed of currently produced dogfish meal.

5. Study of the possibility of using dogfish meal for cattle feed.

6. Development of the improvements in processing dogfish meal to give better quality meal for poultry or cattle feed.

Unless sufficient funds are available for concurrent technological work on several of these aspects, it probably would not be worthwhile to undertake any of them. Solving of just one aspect of the problem would lead nowhere. As shown above, the various difficulties to utilization of dogfish are interrelated; and unless a balanced approach considering all aspects can be made, little chance of solving the problem exists.

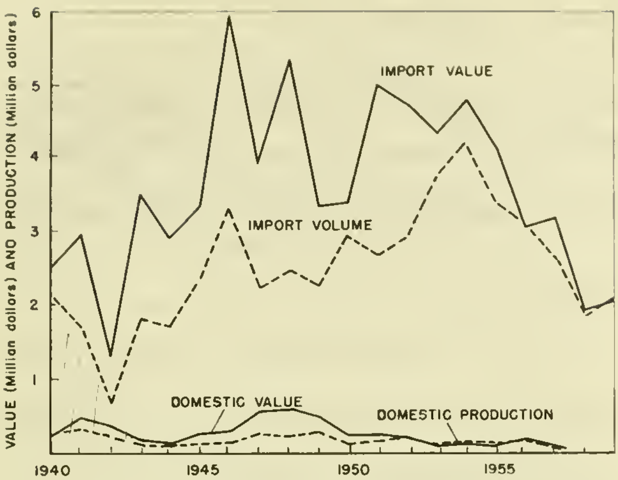

Figure 7.--Domestic and import value and production of cod-liver oil.

IMPORT AND DUTY RATES

Rejuvenating an active fishery for dogfish will also be contingent on the ability of local fishermen to compete with similar or like imported products. Imports of fish-liver oils have historically exceeded domestic production (tables 4 and 5) of like products. Cod-liver oil has dominated fish-oil shipments to the United States. Large quantities were being imported as early as 1940 (fig. 7). Shark-oil imports increased rapidly in 1947, and in 1948 they surpassed domestic production. Since 1953, imports of shark oils have declined to where, in 1956, they were about equal to local production.

The rapid increase in shark-oil imports between 1947 and 1953 demonstrates the ability of foreign competition to participate in any markets we may develop for dogfish. The trend in domestic production of shark oils as related to imports (fig. 4) has been for local production to collapse when imports of shark oil increase. A similar import situation could develop if new products of value are developed for dogfish. The advantages of these developments might, thus, be eliminated.

The possibilities of increased duty rates should be considered if markets are developed for dogfish. Present duty rates (fig. 8) will not suffice.

Figure 8.--Average duty rates for shark oils as percent of product value. The rate shown is total cost of the import as a percent of its value and includes the duty rate plus the Internal Revenue tax.

TABLE 4.--Imports of fish oils, 1940-59

Year	Cod liver[1]		Dogfish and shark liver oil		Other livers and visceral oils[2]		Other fish oils		Dogfish and shark body oil	
	1,000 gallons	*1,000 dollars*	*1,000 gallons*	*1,000 dollars*	*1,000 gallons*	*1,000 dollars*	*1,000 gallons*	*1,000 dollars*	*1,000 gallons*	*1,000 dollars*
1940	2,144	2,521	65	38	--	--	485	268	--	--
1941	1,696	2,946	368	587	101	314	1,537	683	--	--
1942	637	1,300	173	426	1	47	1,567	817	--	--
1943	1,804	3,504	145	502	261	1,470	2,494	1,263	3	8
1944	1,695	2,919	(4)	(4)	61	4,066	2,222	1,180	--	--
1945	2,356	3,293	83	155	521	5,285	1,762	895	--	--
1946	3,296	5,880	16	50	330	5,137	402	155	--	--
1947	2,110	3,893	5	21	143	4,283	403	277	2	7
1948	2,460	5,285	576	6,925	40	2,569	2,501	2,606	2	47
1949	2,160	3,322	576	3,543	74	2,910	2,141	1,368	3	30
1950	2,905	3,395	670	2,101	78	1,987	1,099	567	66	84
1951	2,644	4,990	911	2,952	89	2,282	1,545	1,603	101	146
1952	2,901	4,712	905	2,276	66	2,129	1,453	896	49	135
1953	3,673	4,311	434	1,080	50	1,190	396	276	8	35
1954	4,180	4,780	203	540	50	1,637	542	330	9	14
1955	3,373	4,129	141	323	50	1,667	349	202	11	66
1956	3,056	3,021	28	101	75	1,954	230	133	(4)	7
1957	2,648	3,170	20	68	98	2,624	98	74	6	9
1958	1,834	1,909	33	114	59	1,920	4	32	2	1
1959	2,212	2,052	17	142	52	1,573	99	60	--	--

[1] Includes medical and industrial.
[2] Includes halibut and others.
[3] Includes herring and others.
[4] Less than 1,000 gallons or $1,000.

Source: Fishery Statistics of the United States U.S. Fish and Wildlife Service, Statistical Digest Nos. 1, 4, 7, 11, 14, 16, 18, 19, 21, 22, 25, 27, 30, 34, 36, 39, 41, 43, 44, and 49.

TABLE 5.--Domestic production of fish oils, 1940-59

Year	Cod (liver)		Dogfish and shark (liver)		Other liver and viscera[1]		Other fish oils[2]		Dogfish and shark (body)	
	1,000 gallons	*1,000 dollars*	*1,000 gallons*	*1,000 dollars*	*1,000 gallons*	*1,000 dollars*	*1,000 gallons*	*1,000 dollars*	*1,000 gallons*	*1,000 dollars*
1940	281	253	241	1,133	268	3,702	15,628	4,655	36	16
1941	325	483	608	9,202	300	5,187	21,893	11,829	34	15
1942	241	381	679	7,121	109	2,560	19,446	12,455	56	32
1943	133	189	548	9,932	171	4,720	22,151	14,877	--	--
1944	104	141	797	9,619	97	3,477	27,284	17,745	--	--
1945	123	254	547	6,523	134	4,426	23,657	16,007	--	--
1946	140	282	638	7,600	118	5,597	19,101	21,202	--	--
1947	260	557	491	6,634	81	4,453	15,795	19,986	--	--
1948	214	583	434	6,315	92	5,609	16,176	18,302	--	--
1949	283	484	445	4,707	107	4,654	16,737	7,447	--	--
1950	164	227	119	937	48	2,266	21,391	14,002	--	--
1951	175	242	76	632	48	1,705	17,764	13,958	--	--
1952	195	201	45	334	38	1,540	15,783	7,301	--	--
1953	114	102	27	402	64	932	20,043	10,022	--	--
1954	161	134	26	298	49	960	21,588	11,394	--	--
1955	149	130	47	177	23	282	24,638	12,306	--	--
1956	177	154	87	332	22	139	26,493	16,566	--	--
1957	([3])	([3])	29	192	124	350	19,489	12,188	--	--
1958	([3])	([3])	19	98	31	137	21,499	11,854	--	--
1959	([3])	([3])	22	224	11	76	24,384	12,509	--	--

[1] Includes burbot, halibut, cod, tuna, lingcod, and unclassified liver oil, Atlantic and Gulf coasts; and lingcod, halibut, sablefish, and unclassified liver and viscera oil, Pacific coast and Alaska.

[2] Includes alewife, herring, menhaden, sardine, salmon, tuna, mackerel, groundfish, ocean perch, anchovy, and unclassified fish.

[3] Included in liver and viscera.

Source: Fishery Statistics of the United States, Statistical Digest Nos. 4, 7, 11, 14, 16, 18, 19, 21, 22, 25, 27, 30, 34, 36, 39, 41, 43, 44, and 49.

SUMMARY

The spiny dogfish, *Squalus acanthias,* which ranges through the temperate and subarctic waters of both the North Atlantic and North Pacific Oceans, has increased in numbers until fishermen have become concerned about its depredations.

Dogfish abundance centers in the eastern Pacific include Puget Sound, Strait of Georgia, and the Continental Shelf from central Washington to Hecate Strait, B. C.--all areas of intensive commercial and sport fishing activity. Offshore dogfish populations appear to be highly mobile, whereas those of inshore areas seem to be relatively stable.

A mature female dogfish may give birth to from 2 to 20 pups every second year; dogfish longevity may exceed 30 years. Most studies indicate that dogfish are opportunists rather than discriminant feeders. Ratfish, krill, shrimp, herring, flatfish, eulachon, and octopus have been noted in stomachs of dogfish caught. There is no evidence that dogfish affect salmon stocks adversely through predation.

Small fisheries for dogfish have been carried out along the coast of the Pacific Northwest since Indian days. Both the Indians and early white settlers used dogfish oil for a variety of lighting and lubricating functions. Spasmodic attempts have been made more recently to use the dogfish as human food, but all such attempts in this country have been relatively unsuccessful. In Europe the dogfish is used to some extent as food--generally as fried fish.

During World War II, a sizable fishery for the Pacific dogfish was brought about by the demand for a source of vitamin A and the development of methods of extracting the vitamin from relatively low potency oils. With the advent of synthetic vitamins, however, the fishery collapsed, not to be renewed.

With the collapse of the fishery, the dogfish populations, which Canadian studies indicated were considerably reduced as a result of fishing efforts, began to increase--leading to the present high stock levels and interference with more valuable fishing endeavors. Practically all segments of commercial and sport fisheries claim losses from dogfish. Estimates by industry members indicate that the annual loss in gear damage alone exceeds $2 million.

Three general methods for controlling dogfish seem to be available: (1) selective poisoning, (2) use of deterrents and repellents, and (3) reduction of dogfish numbers through fishing efforts. Selective poisoning, although theoretically possible, would be difficult to control in practice. There are, at present, no deterrents or repellents that are effective under all conditions, and application of such substances to commercial gear, even if fully effective, would be extremely expensive. Perhaps, in the future, the selective action of a series of electrodes could be used.

The best possibility for controlling dogfish, however, appears to be through fishing effort. This could be achieved through (1) payment to the fishermen of a bounty, (2) initiation of a vessel charter system, or (3) development of high-priced markets for dogfish products, leading to development of a commercial dogfish fishery. The first two schemes would require continual Government support; the third scheme would require support only during the developmental stages, after which it could be expected to be self-sustaining.

Possibilities for dogfish markets exist in development of uses for both oils and protein. Unique uses, if they could be developed, would be more effective in stimulating and supporting a fishery than would uses that could be filled by products from other sources. Dogfish liver oil, containing approximately 15 percent unsaponifiables including glycerol ethers, appears to hold promise for development of unique uses. Nonunique uses for products from the body oil and the carcass (protein) could then be used to distribute production costs over the entire animal.

If a domestic dogfish fishery is to be self-sustaining, some adjustments in import duties on dogfish products and other fish oils from abroad would probably have to be made, or at least the import situation would have to be examined carefully.

ACKNOWLEDGMENTS

Material presented in this report resulted from a staff effort. The authors are indebted to the following persons within the Bureau for assistance in assembling and helping to prepare material for this paper: M. J. Hanavan, F. M. Wood, F. B. Sanford, and S. Springer.

LITERATURE CITED

BARRACLOUGH, W. E.

1948. Measures of abundance in dogfish *(Squalus suckleyi).* Transactions of the Royal Society of Canada, series 3, vol. 42, section 5, May, p. 37-43.

1953. The development of the dogfish fishery in British Columbia. Proceedings of the Seventh Pacific Science Congress (1949), vol. 4, Auckland, New Zealand, p. 513-519.

BIGELOW, HENRY BRYANT, and WILLIAM C. SCHROEDER.

1948. Fishes of the western North Atlantic. Part I - Lancets, cyclostomes, and sharks. Memoirs of Sears Foundation for Marine Research, Yale University, 576 p.

BONHAM, KELSHAW, F. BRUCE SANFORD, WILLIAM CLEGG, and GLENN C. BUCHER.

1949. Biological and vitamin A studies of dogfish landed in the State of Washington *(Squalus suckleyi).* State of Washington, Department of Fisheries, Biological Report No. 49-A, April, p. 83-114.

CHATWIN, B. M., and C. R. FORRESTER.

1953. Feeding-habits of dogfish *(Squalus suckleyi)* (Girard). Fisheries Research Board of Canada, Progress Reports of the Pacific Coast Stations, No. 95, p. 35-38.

CLEMENS, W. A., and G. V. WILBY.

1946. Fishes of the Pacific coast of Canada. Fisheries Research Board of Canada, Bulletin No. 68, 368 p.

DANIEL, FRANK JOHN.

1934. The Elasmobranch fishes. 3rd ed. University of California Press, Berkeley, Calif., 332 p.

FORD, E.

1921. A contribution to our knowledge of the life-histories of the dogfishes landed at Plymouth. Journal of the Marine Biological Association of the United Kingdom, N. S., vol. 12, no. 3, p. 468-505.

HARRISON, R. W., and V. J. SAMSON.

1942. Pacific coast shark and dogfish liver fisheries. Pacific Fisherman, vol. 40, no. 8 (June), p. 29-31.

HOLLAND, GILBERT A.

1957. Migration and growth of the dogfish shark, *Squalus acanthias* (Linnaeus), of the eastern North Pacific. Washington Department of Fisheries, Fisheries Research Paper, vol. 2, no. 1, p. 43-59.

KAGANOVSKAIA, S. M.

1933. Method of ascertaining the age and catch composition of the spiny shark, *Squalus acanthias* L. Bulletin, Far Eastern Branch of the Academy of Sciences, U.S.S.R., nos. 1-3, p. 139-141. (In Russian.)

Translation by N. B. Notkin, 6 p., available on interlibrary loan from the International Halibut Commission, Fisheries Hall No. 2, University of Washington, Seattle, Wash. Another translation by W. E. Ricker, 1960, 3 p., available at the Fisheries Research Board of Canada, Biological Station, Nanaimo, B. C., Translation Series No. 281, and also available on loan from the Bureau of Commercial Fisheries Biological Laboratory, U. S. Fish and Wildlife Service, Seattle, Wash., or the Department of the Interior Library, Washington, D. C.

1937. Contribution to the biology of the spiny shark *(Squalus acanthias* L*).* Russian Pacific Scientific Institution of Fish and Oceanography Bulletin, vol. 10, p. 105-115. (In Russian).

Translation by N. B. Notkin, 8 p., available on interlibrary loan from the International Fisheries Commission, Fisheries Hall No. 2, University of Washington, Seattle 5, Wash.

KAUFFMAN, DONALD E.
1955. Noteworthy recoveries of tagged dogfish. Washington Department of Fisheries, Fisheries Research Papers, vol. 1, no. 3, p. 39-40.

LORD, JOHN KEAST.
1866. The naturalist in Vancouver Island and British Columbia. R. Bently, London, 358 p.

RHIAN, M., J. S. CARVER, R. W. HARRISON, and WM. S. HAMM.
1942. Value of dogfish meal as a protein supplement. Washington (State) Agricultural Experiment Station, Pullman, Wash., Bulletin No. 416, 24 p.

RIPLEY, WM. ELLIS.
1946. The soupfin shark and the fishery. California Division of Fish and Game, Fish Bulletin No. 64, p. 7-37.

ROUNSEFELL, GEORGE A., and W. HARRY EVERHART.
1953. Fishery science. John Wiley and Sons, Inc., New York; Chapman and Hall, Ltd., London; 444 p.

SHEPARD, M. P., and J. C. STEVENSON.
1956. Abundance, distribution and commercial exploitation of the fisheries resources of Canada's west coast. Fisheries Research Board of Canada, Studies from Stations of Fisheries Research Board of Canada, no. 453, p. 1-60.

Reprint from the 9th B. C. Natural Resources Conference Transactions, February 1956.

WALFORD, LIONEL A.
1958. Living resources of the sea. Opportunities for research and expansion. The Ronald Press Co., New York, 321 p.

WESTRHEIM, SIGURD J.
1950. The 1949 soupfin shark fishery of Oregon. Fish Commission Research Briefs of Oregon, vol. 3, no. 1, p. 39-49.

ADDITIONAL REFERENCES

ANONYMOUS
1952. Contrast in dogfish migrations. Fisheries Research Board of Canada, Progress Reports of the Pacific Biological Station and Pacific Fisheries Experimental Station, no. 92, p. 20.

BAILEY, B. E. (Editor).
1952. Marine oils with particular reference to those of Canada. Fisheries Research Board of Canada, Bulletin No. 89, 400 p.

BONHAM, KELSHAW.
1954. Food of dogfish *(Squalus acanthias)*. Washington Department of Fisheries, Fisheries Research Papers, vol. 1, no. 2, p. 25-36.

BUCHER, D. L., and K. L. OSTERHAUG.
1943. Preliminary notes on dogfish as a food. U.S. Department of the Interior, Fish and Wildlife Service, Fishery Market News, vol. 5, no. 10 (October), p. 24-25. [Also as Separate No. 43.]

BUTLER, CHARLES.
1943. The fish liver oil industry. U.S. Fish and Wildlife Service, Fishery Leaflet 233, March, 104 p.

CHAPMAN, A. CHASTON.
1922. The physical and chemical properties of dogfish liver oils (particularly the tope, *Galeus galeus)*. The Analyst, vol. 47, p. 203, London.

CLARK, DONALD H.
1958. Dogfish-Puget Sound villain. Seattle Times Magazine Section, August 17, p. 7.

CLEGG, W., F. BRUCE SANFORD, and M. E. STANSBY.
1945. Effect of fish liver freshness on E value ratios of resulting oil. U.S. Department of the Interior, Fish and Wildlife Service, Fishery Market News, vol. 7, no. 5 (May), p. 7-8. [Also as Separate No. 103.]

CUNNINGHAM, F. H.
1920. Report of chief inspector, Lt. Col. F. H. Cunningham, Western Fisheries Division (British Columbia) for the year 1919. Fifty-third Annual Report of the Fisheries Branch, Department of Naval Service for the year 1919, p. 42-51.

ELLIOTT, R. PAUL.
1952. Reduction of trimethylamine oxide in dogfish flesh. Food Research, vol. 17, no. 3 (May-June), p. 225-234. [Now Journal of Food Science.]

FIELD, IRVING A.
1910. Sea mussels and dogfish as food. Bulletin of the Bureau of Fisheries, vol. 28, part 1, 1908, p. 241-257.

FOSTER, FRED J.
1943. Soupfin shark and dogfish investigations. Annual Bulletin, State of Washington, Bulletin No. 43, December, 12 p.

GREENWOOD, MELVIN R.
1957. Bottom trawling exploration in the Strait of Juan de Fuca - February to March 1956. U.S. Fish and Wildlife Service, Commercial Fisheries Review, vol. 19, no. 3 (March), p. 1-10. [Also as Separate No. 472.]

HARRIS, JOHN E.
1952. A note on the breeding season, sex ratio and embryonic development of the dogfish *Scyliorhinus canicula* (L). Journal of the Marine Biological Association of the United Kingdom, vol. 31, no. 2, p. 269-275.

HARRISON, R. W., and WM. S. HAMM.
1944. Extraction of vitamin A from dogfish livers. U.S. Fish and Wildlife Service, Fishery Leaflet 99, October, 2 p.; also in Pacific Fisherman, vol. 39, no. 9, July 1941, p. 37-38.

HART, J. L.
1942. Reproduction in the dogfish. Fisheries Research Board of Canada, Progress Reports of the Pacific Biological Station and Pacific Fisheries Experimental Station, no. 51, p. 16, 17.

HIGASHI, HIDEO, SHUICHI HIRAO, KAZUKO SHIMIZU, HUAMI YAMADA, and HYO KIKUCHI.
1953. Studies on fluctuation of the vitamin A content in fishes. I. Study on vitamin A in the dogfish, *Squalus suckleyi*. Bulletin of the Japanese Society of Scientific Fisheries, vol. 18, no. 7, p. 310-318.

JONES, G. I., F. B. SANFORD, and D. MIYAUCHI.
1947. Studies on deterioration of vitamin A in fish livers and liver oils. Part 3. Loss at 37° C. of vitamin A from liver oil in presence and absence of grayfish liver tissue. U.S. Fish and Wildlife Service, Commercial Fisheries Review, vol. 9, no. 4 (April), p. 5-8. [Also as Separate No. 170.]

MANZER, J. I.
1946. Interesting movements as shown by the recoveries of certain species of tagged fish. Fisheries Research Board of Canada, Progress Reports of the Pacific Coast Stations, no. 67, p. 31.

METTERN, H.
1939. Studies on the reproduction of the dogfish. Philosophical Transactions of the Royal Society of London, Serial B., vol. 230, no. 569, p. 217-238.

MIYAUCHI, D., and F. SANFORD.
1947a. Studies on deterioration of vitamin A in fish livers and liver oils. Part 2. Loss of vitamin A potency and stability in frozen ground grayfish livers. U.S. Fish and Wildlife Service, Commercial Fisheries Review, vol. 9, no. 5 (May), p. 7-9. [Also as Separate No. 173.]

1947b. Studies on methods of extracting vitamin A and oil from fishery products. Part 1. Vitamin A potencies of oils from grayfish livers obtained by extraction with petroleum ether and by cooking with water. U.S. Fish and Wildlife Service, Commercial Fisheries Review, vol. 9, no. 9 (September), p. 19-20. [Also as Separate No. 186.]

NORMAN, JOHN ROXBOROUGH.
1948. A history of fishes. A. A. Wyn, Inc., New York, 463 p.

OYA, TAKEO, TADASI ANDO, and HIROTUNE SIRATORI.
1940. Chemical study of *Squalus sucklii* (Girard). I. Bulletin of the Japanese Society of Scientific Fisheries, vol. 8, no. 6, p. 313-318.

PUGSLEY, L. I.
1937. The vitamin A content of grayfish liver oil *(Squalus sucklii)*. Fisheries Research Board of Canada, Progress Reports of the Pacific Biological Station and Pacific Fisheries Experimental Station, no. 34, p. 3-7.
1940. Factors influencing the vitamin A and D potency of grayfish liver oil *(Squalus sucklii* (Girard). Journal of Fisheries Research Board of Canada, vol. 4, no. 5, p. 312-322.

ROEDEL, PHIL M., and WM. ELLIS RIPLEY.
1950. California sharks and rays. California Division of Fish and Game, Fish Bulletin No. 75, 88 p.

1953. Common ocean fishes of the California coast. California Department of Fish and Game, Fish Bulletin No. 91, 184 p.

SANFORD, F. B[RUCE].
1945a. Grayfish liver trading on a potency basis fosters conservation. U.S. Department of the Interior, Fish and Wildlife Service, Fishery Market News, vol. 7, no. 2 (February), p. 16. [Also as Separate No. 92.]

1945b. Vitamin A potencies of livers of mature female grayfish caught in Hecate Strait. U.S. Department of the Interior, Fish and Wildlife Service, Fishery Market News, vol. 7, no. 11 (November), p. 7-8. [Also as Separate No. 117.]

SANFORD, F. B[RUCE], and K[ELSHAW] BONHAM.
1946a. Grayfish liver color related to finspine length, U.S. Fish and Wildlife Service, Commercial Fisheries Review, vol. 8, no. 6 (June), p. 6-8. [Also as Separate No. 139.]

1946b. Studies on deterioration of vitamin A in fish livers and liver oils. Part 1. Loss of vitamin A and stability in grayfish livers in storage, U.S. Fish and Wildlife Service, Commercial Fisheries Review, vol. 9, no. 2 (February), p. 11-15. [Also as Separate No. 167.]

1947. Relationship between body length of grayfish and vitamin A in liver. U.S. Fish and Wildlife Service, Commercial Fisheries Review, vol. 9, no. 9 (September), p. 1-7. [Also as Separate No. 184.]

SANFORD, F. B., K. BONHAM, W. CLEGG, and G. C. BUCHER.
1945. Fetal livers of the grayfish. U.S. Department of the Interior, Fish and Wildlife Service, Fishery Market News, vol. 7, no. 2 (February), p. 19. [Also as Separate No. 94.]

SANFORD, F. BRUCE, GILBERT A. HOLLAND, and GLENN C. BUCHER.
1950. Vitamin A in 155 grayfish livers. U.S. Fish and Wildlife Service, Commercial Fisheries Review, vol. 12, no. 3 (March), p. 17-21. [Also as Separate No. 248.]

SANFORD, F. B., and IVOR JONES.
1946. Liquid gold--some problems of grayfish liver fishery. International Fisherman and Allied Worker, vol. 6, no. 4 (April), p. 5-15.

SANFORD, F. BRUCE, and ELIZABETH VAUGHAN.
1949. E. value ratios for grayfish, soupfin shark, sable fish, and halibut liver oils produced in the Pacific Northwest. U.S. Fish and Wildlife Service, Commercial Fisheries Review, vol. 11, no. 9 (September), p. 11-12. [Also as Separate No. 237.]

SATO, SHINICHI.
1935. A note on the Pacific dogfish *(Squalus suckleyi)* (Girard) in the coastal waters of Hokkaido, Japan. Journal of Faculty of Science, Hokkaido Imperial University, series VI, vol. 4, no. 3, p. 127-141.

SHEPHERD, D. M., G. B. WEST, and V. ERSPAMER.
1953. Chromaffin bodies of various species of dogfish. Nature, vol. 172, no. 4376, September 12, p. 509.

SOUTHERN FISHERMAN.
1949. Try repellent to defeat sharks. Southern Fisherman, vol. 9, no. 12, October, p. 78.

1952. Shark chaser. Southern Fisherman, vol. 12, no. 4, April, p. 77, 82.

STANSBY, MAURICE E., and JAMES M. LEMON.
1937. Quantitative determination of oil in fish flesh. Industrial and Engineering Chemistry, vol. 9, July, p. 341-343.

SWAIN, LYLE A.
1947. Vitamin A in dogfish livers. Fisheries Research Board of Canada, Progress Reports of the Pacific Coast Stations, no. 73, November, p. 57.

SWAIN, LYLE A., and B. H. MORTON.
1945. Glycerol yield from dogfish liver oil. Journal of the Fisheries Research Board of Canada, vol. 6, no. 4, May, p. 326-333.

TARR, H. L. A.
1958. Dogfish Fisheries Research Board of Canada, Progress Reports of the Pacific Coast Station, no. 110, April, p. 12-16.

TEMPLEMAN, WILFRED.
1944. The life-history of the spiny dogfish *(Squalus acanthias)* and the vitamin A values of dogfish liver oil. Newfoundland Department of Natural Resources, Research Bulletin No. 15 (Fish), 1-102 p.

1954. Migrations of spiny dogfish tagged in Newfoundland waters. Journal of Fisheries Research Board of Canada, vol. 11, no. 4, p. 351-354.

U.S. FISH AND WILDLIFE SERVICE.
1955. Dogfish demand good. U.S. Fish and Wildlife Service, Commercial Fisheries Review, vol. 17, no. 11 (November), p. 71-72.

YAMAMURA, YAROKURO.
1950. The vitamin A in the liver of *Squalus suckleyi*. Bulletin of the Japanese Society of Scientific Fisheries, vol. 15, p. 611-614, 635-637.

1952. Study on vitamin A in the liver of aburazame *Squalus suckleyi*. IV. Seasonal variation of the vitamin A protency. Bulletin of the Japanese Society of Scientific Fisheries, vol. 17, no. 11, p. 337. (In Japanese with English summary and tables.)

ZAMA, KOICHI, MUNEO KATADA, and HISANAO IGARASHI.
1955. Studies on the egg fat of shark *Squalus sucklii* (Girard). Bulletin of the Japanese Society of Scientific Fisheries, vol. 21, no. 4, p. 244-247. (In Japanese with English abstract and tables.)

MS #1232

Created in 1849, the Department of the Interior—America's Department of Natural Resources—is concerned with the management, conservation, and development of the Nation's water, fish, wildlife, mineral, forest, and park and recreational resources. It also has major responsibilities for Indian and Territorial affairs.

As the Nation's principal conservation agency, the Department works to assure that nonrenewable resources are developed and used wisely, that park and recreational resources are conserved for the future, and that renewable resources make their full contribution to the progress, prosperity, and security of the United States—now and in the future.