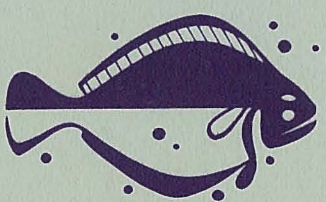
Bulletin No. 153

POPULATION DYNAMICS of the PETRALE SOLE,

Eopsetta jordani, in waters off western Canada



by K.S. Ketchen and C.R. Forrester

Fisheries Research Board of Canada • Ottawa • 1966

POPULATION DYNAMICS OF THE PETRALE SOLE, *EOPSETTA JORDANI*, IN WATERS OFF WESTERN CANADA

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Fisheries Research Board of Canada
Biological Station, Nanaimo, B. C.

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ABSTRACT

The petrale sole is an important contributor to the trawl fishery along the west coast of North America. Results of tagging suggest that there are two main units of stock in British Columbia waters, one off southern Vancouver Island and the other to the northward, mainly in Queen Charlotte Sound and Hecate Strait. Sharp reduction in abundance occurred in both stocks after the inception of fishing. Paralleling classical examples, average size and age decreased in catches from the southern stock until 1947, but this trend was reversed between 1948 and 1955 and accompanied a continued decline in abundance. Timing of the rising trend in size and age composition was the same in both the southern and northern stocks, though the histories of exploitation were different, thus indicating trends in recruitment. Year-classes of 1940–1943 contributed strongly to the fishery, but succeeding year-classes to 1949 were progressively weaker. Thereafter, there was some recovery, and early performance of the 1958 year-class suggests that it is of about the same size as those of the early 1940s.

Growth of petrale sole, for practical purposes, conforms with the von Bertalanffy growth equation, the growth coefficient, K, being 0.160 for males and 0.167 for females, with corresponding asymptotic lengths, L_∞, being 49.0 cm and 58.6 cm. Fifty percent of male fish mature at a length of 38 cm or age VII, while corresponding figures for females are 44 cm and VIII years.

Average instantaneous total mortality rate Z of the strong year-classes 1940–43 is estimated as 0.70 for males and 0.45 for females. Best estimate of instantaneous natural mortality rate (M) is 0.25 and 0.20 for the two sexes respectively, whence average instantaneous rate of fishing (F) is 0.45 for males and 0.25 for females. Alternatively, consideration is also given to the possibility that the indicated sex difference in Z is due largely to a difference in M, namely, M is 0.45 for males and 0.20 for females, whence F is 0.25 for both sexes. These two possibilities, when incorporated in models of yield per recruitment, lead to essentially the same conclusion, viz. a modest increase in yield (2–12%) theoretically could be achieved by reduction in the minimum size of fish retained for market, and/or by more intensive fishing. However, the models are of restricted usefulness because of the observed trends in recruitment, possible trends in effective fishing effort (lack of equilibrium conditions), and because they do not permit prediction of effects of fishing on highly vulnerable spawning concentrations.

Variations in year-class strength appear to be correlated with variations in the environment at the time of the pelagic egg and larval stages, as indicated by seawater temperatures and geostrophic wind patterns.

Discussion is provided on the consequences of unrestricted fishing of spawning concentrations and on prospects for future regulation of the fishery.

Chapter I

INTRODUCTION

During World War II, exploitation of demersal fishes by means of otter-trawling underwent rapid development in the northeastern Pacific Ocean, particularly in waters adjacent to Canada and the northwestern United States. Stimulation for expansion of this industry, which for nearly three decades had been confined largely to sheltered inshore waters, was gained from the sharp increase in demand for foodfish to offset war-time meat shortages and for supplies of vitamin A (principally from dogfish liver). Among the numerous species which contributed heavily

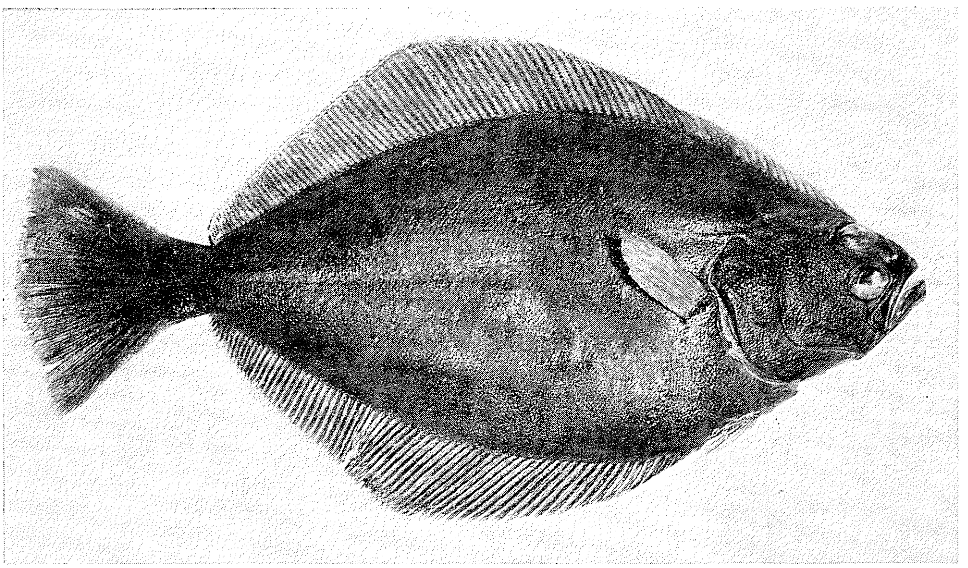

FIG. 1. The petrale sole, *Eopsetta jordani* (Lockington).

to the offshore fishery in its initial stages was the petrale sole, or brill, *Eopsetta jordani* (Lockington).[1] This is a relatively large member of the family Pleuronectidae (Fig. 1), closely related to the genus *Hippoglossoides* and restricted in its distribution to the northeastern Pacific between the Gulf of Alaska and lower California. One other member of the genus (*E. grigorjewi*) occurs in the western Pacific between Japan and Formosa (Norman, 1934, p. 309).

[1]The name petrale sole is used throughout because of its more general acceptance by industry and international scientific circles. "Brill" is in common usage among Canadian fishermen and is the name accepted by Clemens and Wilby (1961). The latter name presumably can be traced to fishermen from Great Britain where "brill" refers to *Scophthalmus rhombus* which resembles the petrale sole only vaguely and belongs to a different family (Bothidae).

Because of its large size and excellent quality as a fresh or frozen fillet product, the petrale sole has commanded the highest price among the various species of flatfish landed for market, with the exception of halibut which is landed exclusively by the long-established and well-known setline fishery.

Until about 1949, production of petrale sole kept pace with the general expansion of the trawl fishery off the Canadian coast, but thereafter declined steadily in spite of continued high demand and improvement in fishing techniques. Total yield from the region between Juan de Fuca Strait and Dixon Entrance, British Columbia reached a peak of 13.7 million lb in 1948, but by 1960–62 it had declined to a relatively low level of 2–3 million lb annually. In less than a decade the petrale sole had become reduced to a position of secondary importance in the British Columbia and Washington trawl fisheries—displaced on the market by species of poorer quality and lower unit value. It now accounts for less than 10% of the trawl landings of flatfish in British Columbia, a situation markedly in contrast to the peak year of 1948 when it exceeded all other trawl-caught flatfishes combined.

It is the purpose of this paper to examine critically the decline in importance of the petrale sole, particularly in the region adjacent to Canada, and to obtain some measure of the extent to which the fishery and the environment has been responsible. To achieve this goal it is necessary to draw together the results of various types of investigations, none of which has been more than partially reported in the past. Indeed, much of the information vital to the study has remained unpublished until now. This presents certain obstacles to a straightforward development of the results of numerous lines of investigation. Where possible, however, the text has been organized in such a way that the reader may if he wishes, bypass certain of the more lengthy digressions which are essential to the historical documentation of the fishery and of the scientific evidence.

The report can be divided into three more or less separate parts. Chapters III–V are concerned with the quantitative evaluation of the changes in abundance which have occurred since the inception of the fishery. This is based on records of catch and catch per unit of effort, which in turn are dependent on an understanding not only of the historical development of the fishery but also of the basis for interpreting catch statistics in terms of population or stock units. In Chapters VI–XI the information on changes in stock size is examined in light of various biological statistics (age, growth, maturity, mortality, recruitment, etc.) which are basic to determining whether the downward trend in catch should be ascribed entirely to the effects of fishing, entirely to the effects of environment, or to a combination of these factors. Finally, Chapters XII–XV deal with theoretical effects of more intensive fishing and the problem of making practical predictions of these and other effects in designing a policy for rational exploitation of the petrale sole resource, as an integral part of a large and complex ecological community.

ACKNOWLEDGMENTS

A considerable number of people have been involved at one time or another in the research which led to preparation of this document. The original program was instigated by Dr J. L. Hart, now Director of the Board's Biological Station at St. Andrews, N.B. Early field sampling and tagging were conducted by him aboard the chartered trawler *Phyllis Carlyle*, skippered by Mr J. Wingate. Substantial contributions were later made by Messrs J. I. Manzer, W. E. Barraclough, B. M. Chatwin, and J. A. Thomson in respect to tagging and laboratory analysis. Throughout almost the entire period of study, Mr R. M. Wilson played a vital role in the interviewing of trawler skippers and in the execution of the sampling program at the port of Vancouver. We gratefully acknowledge the contributions of all these men, also the long-standing, earnest cooperation of fishermen.

At various times United States investigators through their interest have provided advice as well as manuscript data which have been of inestimable value in the analyses. Among these people Messrs D. L. Alverson, A. T. Pruter, E. K. Holmberg, E. A. Best, and the late A. R. Morgan deserve special mention. Former executive directors of the Pacific Marine Fisheries Commission, Messrs M. C. James and A. Kemmerich played important roles in the informal coordination of research projects and compilation of fishery statistics for the Pacific coast. Special thanks are also extended to the Washington State Department of Fisheries for the release of manuscript records pertaining to the United States trawl fishery off the coast of Canada.

Many helpful suggestions were received from a number of individuals who undertook to read and criticize the first draft of this report: D. L. Alverson, E. A. Best, F. C. Cleaver, E. K. Holmberg, P. A. Larkin, A. R. Magill, A. T. Pruter, W. E. Ricker, and S. J. Westrheim.

Chapter II

HISTORY OF THE PETRALE SOLE FISHERY

1. The United States Fishery

Trawling in waters along the west coast of North America began in 1876 with introduction of the paranzella (two-boat) trawl in California. This type of gear predominated through 1940, though otter trawls first made their appearance as early as 1918 (Scofield, 1948). In Oregon first attempts to fish for groundfish with trawls were made in 1884. The otter trawl was introduced in 1905 but the fishery did not become established on a regular basis until about 1937 (Harry and Morgan, 1963). In Washington the ottertrawl fishery began around 1925 in the sheltered waters of Puget Sound (Alverson et al., 1964).

Washington trawlers were the first to engage in active exploitation of the petrale sole resource off the Washington and British Columbia coasts. Fishing began in a small way in 1933 when trawlers extended their operations beyond the territorial waters of Puget Sound and Strait of Georgia to the more exposed grounds between Cape Flattery and Destruction Island on the Washington coast (Smith, 1936, p. 3). This region is here designated as Statistical Area 3B (see Fig. 2).[2] Thus began the shallow-water phase of the fishery.

(a) shallow-water phase

Subsequent development of the fishery on open-coast grounds by vessels based in Washington has been well documented by Cleaver (1949). By 1938 the fishery had expanded northward across the Juan de Fuca trench to grounds adjacent to the Vancouver Island shore, namely Swiftsure Bank at the entrance to Juan de Fuca Strait, and the Forty-Mile Bank (Big Bank), the southern part of a larger expanse of continental shelf known as La Perouse Bank. These grounds, predominantly at depths of 45–70 fath, lie within the bounds of a region now designated as Statistical Area 3C.

[2]In 1956, informal agreement was reached among various research agencies along the Pacific coast to establish a uniform description of fishing areas as a means of coordinating the collection and compilation of ottertrawl catch statistics. This work was undertaken by the Pacific Marine Fisheries Commission (representing the States of Washington, Oregon, and California) with the informal cooperation of the Fisheries Research Board of Canada. Areas 1A, 1B, and 1C encompass waters off the California coast, while Areas 2A–2D involve waters adjacent to Oregon and a small part of southern Washington. The remainder of the Washington coast and the waters off the west coast of Vancouver Island comprise Areas 3A–3D, while United States and Canadian inshore waters (Juan de Fuca Strait, Strait of Georgia, and Puget Sound) are represented by Areas 4A and 4B, respectively. Fishing grounds between the northern end of Vancouver Island and the British Columbia–Alaska boundary are represented by Areas 5A–5E. The entire Alaskan coast is designated as Area 6, but except for a small amount of fishing in inshore channels, this area has not come within the trawling range of North American nationals.

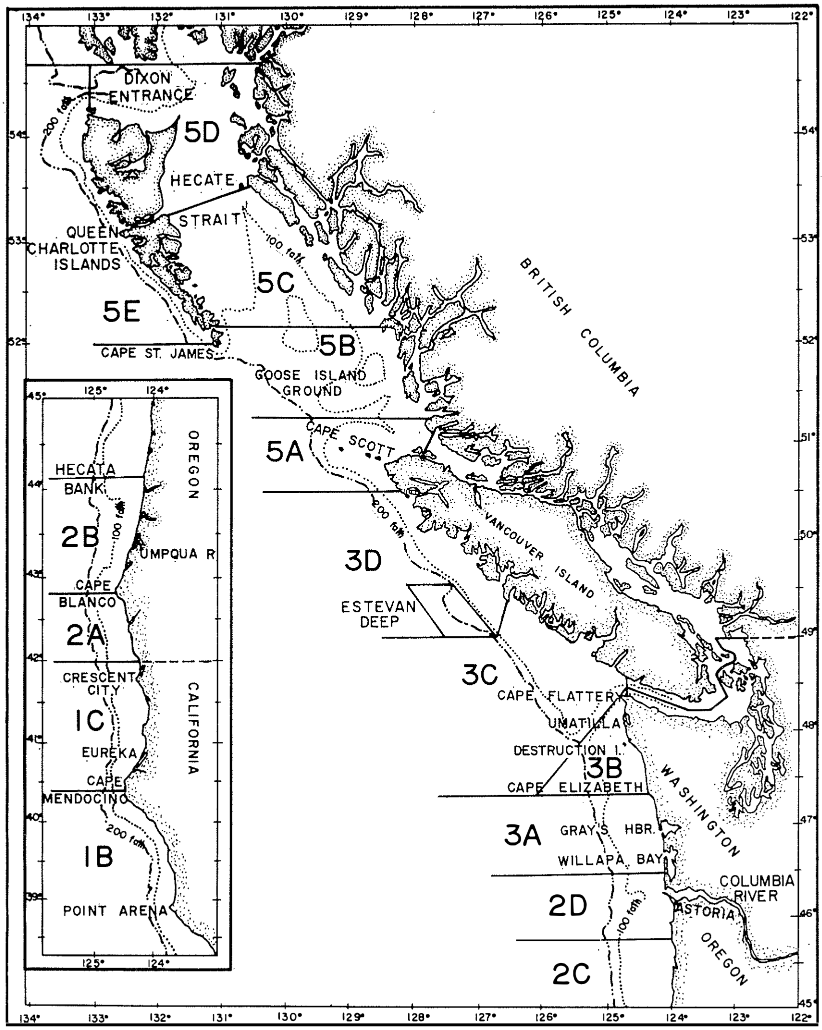

FIG. 2. Pacific coast of North America from Dixon Entrance to central California, showing statistical areas pertaining to the ottertrawl fishery. The area known as Estevan Deep is referred to as $3D_{\Delta}$.

In these early years the fishery was devoted to exploitation of foodfish, with attention being directed almost exclusively to petrale sole. However, by the early 1940s a strong interest had developed in the fishery for Pacific dogfish (*Squalus suckleyi*),[3] following discovery that the liver of this small shark contained a high concentration of vitamin A. The war-time demand for vitamin A and for foodfish resulted in a rapid expansion of the Washington trawler fleet, and new areas and

[3]A list of common and scientific names of species mentioned in this paper is contained in Appendix I.

species were brought under exploitation. Between 1938 and 1943 the fishery was intensified on the Swiftsure and Forty-Mile Banks and spread northward along the Vancouver Island shore, reaching Lennard Island in the spring of 1943 (Cleaver, 1949, p. 26), still within the bounds of Statistical Area 3C. Some of the boats may have extended farther north in that year, but the first heavy exploitation in Area 3D took place adjacent to Esperanza Inlet in the following year, 1944. The years 1944 and 1945 marked the first significant United States (Washington) fishery on banks to the north of Vancouver Island, in Queen Charlotte Sound (Areas 5A and 5B). According to Cleaver a large part of the fishery in 1945 took place in these areas, on the Cape Scott and Goose Island Banks (see Fig. 14). He also points out that the vanguard of the advancing United States fleet had worked these localities many years before, and that the dates mentioned above refer to the time when the bulk of the fleet began to operate there. Whether or not the catches made in the course of explorations were of any significance in terms of the later removals is unknown. Certainly, the main interest in earlier years was stimulated by the fishery for dogfish. In any event, 1944 marked the first year in which activity north of Vancouver Island was recorded in log books (Cleaver, 1949, p. 30).

Cleaver's study covered the years up to and including 1945. For the succeeding 3–5 years the further northward expansion of the United States fishery is poorly documented. It is presumed that by 1948 the main fleet of Washington vessels had encompassed all important trawlable banks within the limits of the continental shelf as far north as Dixon Entrance (the northern part of Area 5D). As shown in Fig. 3 (details of which will be discussed later), Washington landings of petrale sole increased rapidly between 1938 and 1943, fluctuated between 5 and 6 million lb from 1943 to 1948 and then entered a decline. It was during the 1943–48 period of relative stability in catch that the fishery made its rapid advance along the coast of British Columbia.

As noted by Cleaver, the fishery for petrale sole in the area between Cape Flattery and Umatilla Reef (Area 3B) began prior to 1939. To judge from his records of fishing effort for subsequent years, it appears that neither the summer nor the winter fisheries extended much farther south than Cape Elizabeth (the southern boundary of Area 3B). Some Washington vessels did operate in the area between Grays Harbor and the Columbia River (3A and 2D), but the main fishing effort was directed northward to the British Columbia coast. This pattern, evident in the period 1939–45, has applied throughout the history of the Washington fishery. To this day only a small fraction of the fishing effort has been directed to waters south of Area 3B.

The Oregon trawl fishery was small and desultory during the first few decades of this century. Harry (1956, p. 11) considers that 1937 marks the beginning of the recent or permanent phase of the fishery. During 1940 the base of operations in Oregon shifted northward from Newport to Astoria and then expanded greatly with United States entry into World War II (Harry, 1956, p. 14). Between 1942 and 1947 the Astoria fleet fished mainly in the areas now designated as Areas

2D and 3A. Records of the fishery suggest that during this period there was little expansion to distant grounds, for there appeared to be little change in the lengths of individual trips (Harry, 1956, p. 153). However, it is known that in 1945 and 1946 five boats, in the course of fishing for dogfish, did land petrale sole from grounds as far north as Sydney Inlet in Area 3C, off the Vancouver Island coast (Harry, 1956, p. 29). The size of these landings is not known, but it is presumed that they were of minor significance, in contrast to those made by the Washington and British Columbia fleets in that area. In any event, by far the greater part of the Oregon fishery for petrale sole took place in areas south of Area 3B (mainly in 3A and 2D). Historically, there has been little overlap between the petrale sole fisheries of Washington and Oregon. The former seldom fish south of Area 3B and the latter seldom fish north of Area 3A.

Throughout the early years of the Washington and Oregon fishery and until as recently as the winter of 1952–53, exploitation of petrale sole occurred mainly in the spring, summer, and early autumn months. In general, fishing was confined to depths considerably less than 100 fath and involved fish which were not in spawning condition. In winter months petrale sole appeared to be absent from regular trawling grounds, or at least in much lower apparent abundance than in the summer months. Thus, in the case of Washington, fishing pressure was attracted to more available species such as the English sole or lemon sole (*Parophrys vetulus*) on grounds in the vicinity of Cape Flattery (Cleaver, 1949, p. 30–31). Similarly, in Oregon the bulk of annual landings of petrale sole occurred in the period April–September, and although unfavourable weather was an important factor in limiting fishing during the winter, petrale sole were nevertheless not as available on the inshore banks at that time of year (Harry, 1956, p. 154–156). Until the winter of 1952–53 the whereabouts of petrale sole during the winter (spawning) months were not known.

Between 1948 and 1959 the so-called shallow water fishery conducted by Washington vessels remained essentially unchanged in pattern, being confined to the several fishing grounds already noted. However, in the summer of 1960 as a result of explorations conducted by the U. S. Bureau of Commercial Fisheries vessel *John N. Cobb*, trawlable grounds were found on the Cape Flattery Spit south of the Forty-Mile Bank at depths between 60 and 80 fath (Hitz et al., 1961). Some of these supported concentrations of petrale sole which immediately attracted the attention of the Washington trawler fleet. Addition of the Flattery Spit grounds to the traditionally fished grounds in Area 3C resulted in a resurgence in the production of petrale sole by United States vessels in the "shallow grounds."

(b) DEEP-WATER PHASE

Early in the 1950s United States trawlers began to develop a fishery for "Pacific ocean perch" (*Sebastodes alutus*). This is a species of rockfish which inhabits relatively deep water (mainly between 100 and 250 fath) along the continental slope from the latitude of Oregon northward (Alverson, 1960; Alverson et al., 1964). In the course of exploration for this species, dense concentrations of spawning petrale sole were encountered in March 1953 in a small area off the coast of Vancouver Island. This ground, now known as Estevan Deep (situated in Area $3D_{\Delta}$ in Fig. 2), was only about 6 miles in length and $\frac{1}{2}$ mile in width and lay between depths of 170 and 250 fath (Alverson and Chatwin, 1957, p. 958). In subsequent years, until international agreement in 1957 resulted in cessation of winter fishing specifically for petrale sole,[4] the spawning concentrations in Estevan Deep were heavily fished by United States vessels, particularly in January–February 1957.

Farther to the south, near the boundary between Areas 3A and 3B, Oregon fishermen discovered the Willapa Deep late in February 1954, but the main attraction there was a spawning concentration of Dover sole, *Microstomus pacificus* (Westrheim and Morgan, 1963). However, some spawning of petrale sole has been reported from this ground. Alverson and Chatwin (1957, p. 970) state that several small spawning grounds of petrale sole were discovered (prior to 1957) off Cape Flattery, Destruction Island, and Grays Harbor. The Cape Flattery ground was in the deep water near the tip of the "Flattery Spit," close to the southern boundary of Area 3C (for location see Fig. 16a). The other two (and one subsequently reported adjacent to Umatilla Reef) lie in Area 3B, off the Washington coast, but apparently none supported such large concentrations of fish as were observed on Estevan Deep.

Deep water spawning concentrations of petrale sole occur in several localities off the California coast (Best, 1963) adjacent to Cape Mendocino (Area 1C), Point Montara (Area 1B) and Point Sal (Area 1A). These grounds were discovered in 1948, 1953, and 1957, respectively. Recently one was encountered off the southern Oregon coast between Coos Bay and the Umpqua River (Area 2B) (Anon., 1960).

Although the California trawl fishery for various species of flatfish has had a long history dating from the 1870s, it did not undergo major expansion until the close of World War II. The fishery for petrale sole rose to a peak in 1948 with emphasis at first on grounds well within the 100 fath contour (as was the case in the northern states). Beginning in that year, however, it progressed rapidly to deeper water subsequent to the discovery and exploitation of spawning concentrations at depths greater than 200 fath.

The general history of the United States fishery for petrale sole may be summarized as follows. It began as a summer-time operation in rather shallow water and close to major ports of landing. For the first decade of its existence production was maintained or increased by further development of these inshore grounds,

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[4]This agreement arose from a conference on Co-ordination of Fisheries Regulations between Canada and the United States, held in Seattle, Washington, in February 1957 (Anon. 1957a). At that time it was believed that exploitation of spawning petrale sole would serve only to hasten the decline in abundance already apparent on the inshore (summer) fishing grounds. Accordingly, as a conservation measure, a uniform closed season on landings of petrale sole for the period December 20 to April 15 of the following year was established. This regulation, applying to British Columbia, Washington, and Oregon, came into effect in the winter of 1957–58. A tolerance of 3000 lb per trip on incidental catches of petrale sole (to a maximum of two trips per month during the closed period) was permitted. Further discussion of this regulation and of subsequent modifications is given in Appendix II.

or, as in the case of Washington vessels, by expansion to more distant grounds—but still generally within the limits of the continental shelf. Subsequent to 1948 despite various improvements in fishing technique landings of petrale sole by the Washington fleet began to decrease. However, after 1953 the exploitation of winter concentrations of these fish in deep water tended to offset the declining production from the traditional inshore (summer) fishing grounds. Introduction of restrictions on the fishery for spawning fish came into effect in the winter of 1957–58 and forced the fishery once again to depend mainly on the inshore grounds for its production of petrale sole.

2. The Canadian Fishery

The historical development of the Canadian trawl fishery for petrale sole followed a course somewhat different from that in the United States (Fig. 3). Throughout the 1930s, the fleet operating out of ports in southern British Columbia

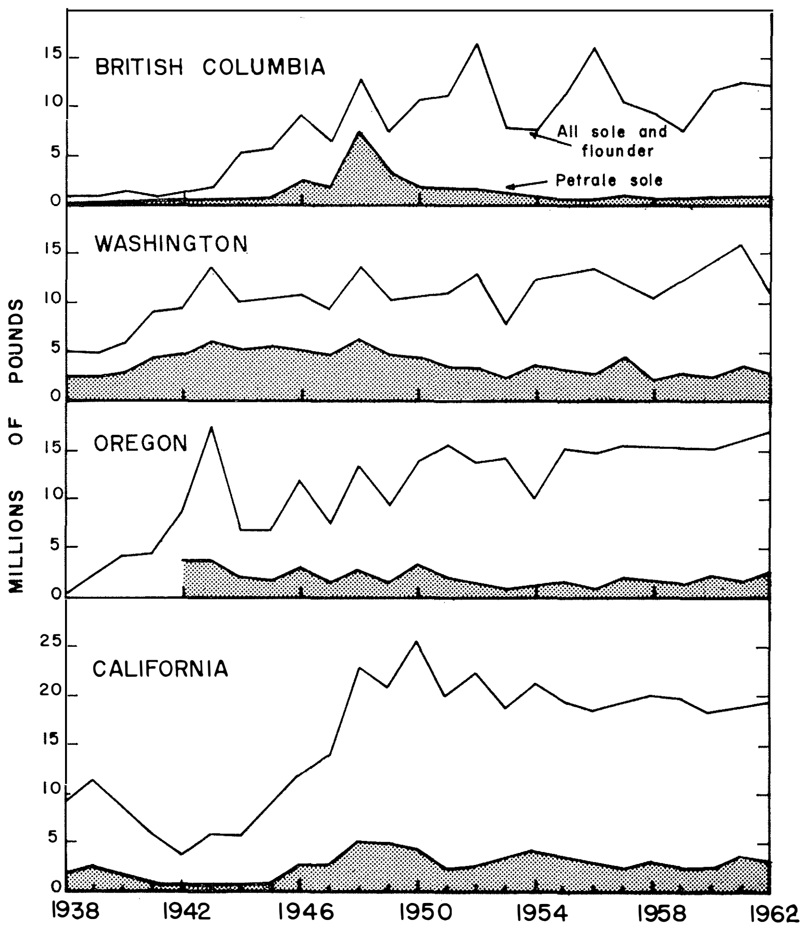

Fig. 3. Landings of petrale sole compared with those of all flounder species (excluding halibut) along the west coast of North America.

was of small size and to a large extent confined its fishing to waters of the Strait of Georgia (Area 4B). There, attention was focussed on species other than petrale sole, namely, English sole (*Parophrys vetulus*), Pacific cod (*Gadus macrocephalus*), and starry flounder (*Platichthys stellatus*). At the same time a small fleet based in Prince Rupert was engaged in fishing on banks at the northern end of Hecate Strait (Area 5D), but there also the petrale sole was an insignificant contributor to production.

Not until 1937 or 1938 did a few boats of the southern fleet extend their operations to the lower west coast of Vancouver Island (Area 3C) near the entrance to Juan de Fuca Strait. The much smaller annual landings of petrale sole by Canadian trawlers in the years leading up to and including World War II, as compared with those in the State of Washington, were due in part to the small size of the fleet and small size of the vessels involved, but possibly also to weaker market conditions in Canada. According to *Pacific Fisherman* (August 1944, p. 68) trawl licences were issued to only 62 British Columbia vessels in 1944, whereas in Washington State the number issued to inshore draggers alone was 170. The latter total was probably an underestimate, since no licence was required for vessels fishing exclusively in international waters. Of course, not all of the vessels of either nation which had licences were actively engaged in trawling throughout the year nor were they involved specifically in the fishery for petrale sole. However, the difference between the two figures mentioned above is roughly indicative of the difference in size of the two fleets engaged in the offshore fishery around 1944.

In the absence of a strong Canadian market for sole fillets in the early 1940s, British Columbia trawlers may have devoted proportionately greater effort to the exploitation of dogfish. British Columbia landings of dogfish liver (obtained by trawl, sunken nets, and longlines) were substantially greater than those in the State of Washington throughout the history of that fishery (Holland, 1957, Table 1). This greater interest in dogfish accounted in part for the low level of activity in the Canadian fishery for petrale sole to the end of World War II.

In the closing years and immediately following the war, declining abundance of dogfish coupled with adoption of a more stringent method of marketing dogfish liver had the effect of diverting more attention to the fishery strictly for foodfish. As a consequence, fishing by Canadian (south coast) trawlers expanded on grounds along the west coast of Vancouver Island (Areas 3C and 3D). They extended their operations to the Cape Scott and Goose Island Banks (Areas 5A and 5D) in 1945, close on the heels of the United States fleet. At the same time the Prince Rupert (north coast) fleet expanded in size, developed further the fishing grounds of northern Hecate Strait (Area 5D), and extended southward into lower central Hecate Strait (Area 5C).

As shown in Fig. 3, Canadian landings of petrale sole rose sharply between 1945 and 1948 (aside from the set-back in 1947 caused by a strike in the industry). The heavy landings in 1948 marked the peak of the Canadian fishery and resulted mainly from the discovery of very productive fishing grounds in the southern part of Area 5D (the Oval Hill and White Rocks grounds in Hecate Strait—see Fig. 14). United States vessels also took advantage of the discovery and this was reflected in the increased Washington landings in that year.

Following 1948 there was a sharp drop in Canadian production of petrale sole. Between 1949 and 1953 the decline paralleled (at a lower level) that observed in the Washington fishery. After 1953, however, Canadian trawlers, unlike those from Washington, continued to operate on the relatively shallow banks within the limits of the continental shelf. Lack of vessels suitably equipped for fishing in deep water during the winter months prevented Canadian participation in the fishery on the newly discovered spawning ground in the Estevan Deep.[5] Consequently, Canadian production continued to decline after 1953, and by 1955 and 1956 it had fallen to less than 10% of that in the peak year of 1948.

Since that time the Canadian fishery for petrale sole has remained a spring to autumn operation confined to the continental shelf. Thus, the conduct of the fishery was entirely unaffected by the 1957 international agreement to restrict winter fishing on spawning concentrations of petrale sole. Furthermore, few if any vessels operating in Area 3C benefitted from the 1960 discovery of petrale sole on the Cape Flattery Spit.

Throughout the history of the Canadian trawl fishery for petrale sole and other demersal fishes, no active interest emerged in the development of grounds to the north and west of Area 5D, that is, off the open coast of Alaska. To the present the only North American vessels which fish these grounds are those involved in the line fisheries for halibut (*Hippoglossus stenolepis*), sablefish (*Anoplopoma fimbria*), the United States trap fishery for king crabs (*Paralithodes camtschatica*), and trawl fishery for shrimps (pandalids), species of high market value relative to other groundfish. Since 1960 distant-water trawlers from the Soviet Union, and more recently from Japan, have conducted extensive fishing for groundfish in the Gulf of Alaska and Alaska Peninsula regions. Although petrale sole have been reported in small numbers or as isolated records by various scientific expeditions (Alverson et al., 1964) as far north and west as Kodiak Island, commercial possibilities have not yet been tested; for high cost of fishing and shore processing have discouraged northward expansion of the North American trawl fishery. It seems likely however, that Hecate Strait is about the northern limit of significant commercial concentrations of petrale sole.

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[5]In contrast to the United States fishery, Canadian vessels had little inducement to fish in deep water. Traditionally, markets for deep water species such as "Pacific Ocean perch" (*Sebastodes alutus*), other rockfish and Dover sole (*Microstomus pacificus*) have been much weaker in Canada than in the United States. Thus, gearing up for a fishery specifically for petrale sole presumably was uneconomical.

In summary: the Canadian fishery for petrale sole has had a more spectacular history than that in regions farther to the south. It rose rapidly to a peak in 1948 with the further development of grounds already fished by the United States fleet and also with the discovery of grounds in northern waters of British Columbia. After 1948 production dropped sharply, and by 1955 it had fallen to a position of minor importance in the trawl fishery. Declining abundance of petrale sole on inshore banks did not encourage a shift of Canadian fishing effort to deep water and to participation (with the United States) in the exploitation of spawning concentrations.

Chapter III

DEFINITION OF STOCKS

Before the statistical record of the petrale sole fishery can be examined in detail, it is necessary to review available information on the numbers of stocks involved and their geographical limits. While we are concerned, in this report mainly with identification of stocks in the waters adjacent to British Columbia, the entire Pacific coast must be considered, at least briefly, since the petrale sole contributes (with varying degrees of importance) to the fishery in all areas from northern British Columbia to southern California.

Since 1937, numerous tagging projects involving more than 31,100 petrale sole have been conducted along the Pacific coast of North America (Tables 1 and 14). The majority took place prior to discovery of deep water spawning grounds. Selection of time and place of tagging was governed to a large extent by information gained from the contemporary fishery. Thus, most taggings were conducted in the spring to autumn months on relatively shallow, inshore banks (less than 100 fath) which were known to be productive.

TABLE 1. Petrale sole tagging projects conducted on inshore banks along the west coast of the United States and Canada.

Item	Statistical Area	Locality	Agency	Date	Numbers released	Total release: By locality	Total release: By area
1	1B	Monterey Bay	California	Apr. 1937	32	40	346
2				Mar. 1938	8	...	...
3		San Francisco Area	California	Apr. 1939	4	306	...
4				Aug. 1940	283	...	...
5				Nov. 1959	19	...	...
6	1C	Eureka Area	California	Aug. 1938	218	1315	1315
7				Aug. 1940	68	...	...
8				Oct. 1949	153	...	...
9				Nov.–Dec. 1958	876	...	...
10	2C	Cape Lookout–Cascade Head	Oregon	Apr. 1959	550	550	550
11	2D	(mainly) Tilamook Head to Willapa Bay	Oregon	1948–49 (July–Aug. mainly)	670	670	670
12	3A	Grays Harbour	Washington	June 1942	213	335	335

(*Continued*)

TABLE 1. Petrale sole tagging projects conducted on inshore banks along the west coast of the United States and Canada. — (*Concluded*).

						Total release	
Item	Statistical Area	Locality	Agency	Date	Numbers released	By locality	By area
13				Mar. 1943	122	...	...
14	3B	Umatilla Reef	Washington	Aug. 1942	95	95	360
15		Cape Flattery	Washington	June 1943	200	265	...
16				Sept. 1943	65	...	...
17	3C	Swiftsure Bank	Washington	Aug. 1940	63	1460	7077
18				June–Aug. 1942	265	...	...
19			Washington	May–Sept. 1943	883	...	...
20				May 1944	249	...	...
21		Forty-Mile Bank	Washington	Aug. 1939	92	2980	...
22				May 1944	255	...	...
23				May 1960	224	...	...
24			Canada	June 1945	11	...	...
25				June 1950	25	...	...
26				Sept. 1962	2373	...	...
27		Firing Range	Canada	June 1945	80	1031	...
28				June 1950	951	...	...
29		Lennard Island	Canada	June 1945	38	478	...
30				June 1948	279	...	...
31				June 1950	54	...	...
32				May 1951	107	...	...
33		Sidney Inlet	Canada	July 1947	614	1128	...
34				Sept. 1951	514	...	...
35	3D	Estevan Pt. to Esperanza	Washington	May 1944	385	385	1415
36		Nootka Sound	Canada	June 1944	18	18	...
37		Checleset Bay	Canada	July 1947	1012	1012	...
38	5A	Cape Scott Grounds	Canada	Apr. 1949	549	1294	1314
39				June 1954	14	...	...
40				July 1960	751	...	...
41	5B	Goose Island Ground	Canada	May 1952	402	491	491
42				June 1953	40	...	...
43				May 1954	49	...	...
44	5C	Horseshoe Ground	Canada	Aug. 1946	94	332	332
45				June 1952	238	...	...
46	5D	White Rocks Ground	Canada	Feb. 1947	243	705	888
47				May 1951	224	...	...
48				June 1952	238	...	...
49		Butterworth-Two Peaks	Canada	Mar. 1945	17	51	...
50				Aug. 1948	18	...	...
51				Apr. 1950	16	...	...
52		McIntyre Bay (Dixon Entrance)	Canada	July 1954	132	132	...
Total							15,053

Results of inshore taggings in California waters (Areas 1B and 1C) have been reviewed by Best (1963), those in Oregon and southern Washington waters (mainly areas 2C and 2D) by Harry (1956), Morgan (personal communication), and reports of the international Trawl Fishery Committee.[6] From 1939 to 1944 extensive tagging was conducted by the State of Washington on grounds between the southern Washington coast (Area 3A) and the upper west coast of Vancouver Island (Area 3D). The results have been summarized by Cleaver (1949), while results of more recent taggings (1960 and 1962) have appeared in the reports of the Trawl Fishery Committee. From 1945 to the present the Fisheries Research Board of Canada has carried out taggings on various banks off the British Columbia coast, from the lower west coast of Vancouver Island (Area 3C) to Dixon Entrance (Area 5D). Results of only a small part of this study have been published heretofore Barraclough, 1954).

In 1954 and 1955, following discovery of a winter spawning concentration of petrale sole off British Columbia, the Washington State Fisheries Department and the Fisheries Research Board of Canada engaged in joint tagging projects on the Estevan Deep (Area $3D_{\Delta}$, at depths of 180–205 fath). A smaller tagging was conducted in the latter year on another spawning ground in Area 3C (Cape Flattery Spit, at depths of 140–150 fath). Results of the Estevan tagging have been reviewed in detail by Alverson and Chatwin (1957).

More recently (February–March 1960), heavy tagging was conducted by the Oregon Fish Commission on deep water concentrations of petrale sole near Hecata Bank (Area 2B at depths of 90–200 fath), and in February 1962, by the Washington State Department of Fisheries in the Willapa Deep (Area 3A). Preliminary results of these taggings are contained in the reports of the Trawl Fishery Committee.

In the sections which follow, results of the above-mentioned taggings are examined from the standpoint of definition of stocks—particularly with reference to waters adjacent to the Canadian coast. Two more or less separate groups or stocks of fish have been distinguished: (a) the *southern stock*, a group of populations inhabiting waters south of Estevan Point to the Juan de Fuca trench, i.e. the region defined by Statistical Area 3C and (b) the *northern stock*, a group of populations inhabiting Estevan Deep (Area $3D_{\Delta}$) and waters north of Estevan Point to northern Hecate Strait (Areas 3D and 5A to 5D, inclusive).

The term stock, as used here, is based on the observation that there is relatively little intermingling of adult fish between the two regions described. It does not imply that within each region the fish are necessarily homogeneous and freely

[6]Pursuant to recommendations of the Second (1959) Conference on Coordination of Fisheries Regulations between Canada and the United States, an international Trawl Fishery Committee was formed to consider problems of joint interest. This Committee in turn established a technical subcommittee consisting of scientists from the Pacific coast States fishery agencies and the Fisheries Research Board of Canada. Reports of this subcommittee containing summaries of research results are submitted annually to the parent committee. These reports do not receive general circulation.

mixing. On the contrary, tagging results suggest that, even within the relatively narrow confines of the *southern stock*, there are numerous populations or substocks identified with specific banks and which maintain a relatively high degree of separation throughout most of the year. The *northern stock* similarly consists of several units each one of which probably deserves distinction as a "stock." While it may be possible at some future time to subdivide the *northern stock* into smaller units, it is impractical to do so at present. Throughout most of the period of study, statistics on the United States fishery in northern British Columbia waters lacked sufficient detail to permit examination of smaller units of stock. Furthermore, difficult problems are posed by what appear to be more lengthy seasonal migrations in the northern waters. A so-called substock may be identified with a particular bank for most of the year, but during its spawning and post-spawning migrations it may be exposed to fishing in other areas en route. Thus, the basis for separating catch statistics by particular substocks will remain uncertain until more detailed knowledge can be acquired. In the meantime, we shall limit our considerations largely to two units of stock in the British Columbia area.

Results which led to the definition of a *northern* and *southern stock* follow below.

1. Results of Inshore Tagging

(a) United States inshore taggings

First to be reviewed are the taggings conducted off the Washington and British Columbia coasts (items 12–23 and 35 in Table 1) and off the southern Washington and Oregon coasts (item 11 in Table 1).[7] Results of these studies have been reported by Cleaver (1949) and Harry (1956), respectively. Neither of these authors provide information on the amount of migration or exchange in terms of particular localities. However, Cleaver noted (p. 24) that over 90% of the recoveries were made within 20 miles of the point of release, whether grouped by recoveries within the first season (within 6 months of the time of tagging) or by recoveries from subsequent seasons. Thus, he concluded that there is apparently little exchange of fish (in the marketable size range) between banks which are more than 20 miles apart. This conclusion seemed to be "... substantiated by the observation that fishing on one ground does not remove the fish from a neighbouring ground to a like degree. ..."

Cleaver's tagging (1939–1944) was conducted mainly on Swiftsure Bank and Forty-Mile Bank in Area 3C and on the nearby Cape Flattery and Umatilla grounds in Area 3B. He observed no definite indications of seasonal migrations, but noted some tendency for recoveries to be made farther to the south in the winter months.

[7]In all but three of the taggings listed in Tables 1 and 14 tags were the Petersen-type (plastic discs affixed with a metal pin through the musculature near the base of the dorsal fin). Exceptions were item 9 in Table 1 and item 1 in Table 14 (vinyl "spaghetti" tubing) and item 23 in Table 1 (plastic darts).

However, he cautioned that this might be accounted for solely by a southward shift in fishing effort. Nevertheless, he did not discount the possibility of extensive seasonal migrations along the coast. A marked seasonal periodicity in recoveries seemed to be explained partly by seasonal variations in fishing effort but also partly by reduced availability of petrale sole during winter months. These taggings were of course conducted many years before the deep water spawning grounds were discovered—when the fishery was still confined to the shallower coastal banks.

Farther to the south, in Area 2D (Willapa Bay, Washington to Tillamook Head, Oregon), results of petrale sole tagging reported by Harry (1956) were essentially similar to those of Cleaver. Most of the recoveries from taggings in 1948 and 1949 (item 11 in Table 1) were made within 30 miles of the tagging sites. No distinct north or south movement could be detected (Harry, Table 25) but several recoveries were made at distances greater than 89 miles. Occasional recoveries were made as far north as Cape Flattery (Area 3B) and as far south as Eureka, California (Area 1C).

More recent taggings conducted in inshore Oregon waters between Cascade Head and Cape Lookout (Area 2C–item 10 in Table 1) showed a similar maximum dispersion, northward to Cape Flattery and southward to the northern boundary of Area 1C. This range was established in the first 6 months after tagging but the observations covered an 18-month period (Morgan, personal communication).

From all but one of the taggings conducted in Areas 1B and 1C (California waters) recoveries were made only south of Oregon. The exception involved the November–December tagging in 1958 in Area 1C (item 9 in Table 1). This tagging took place at a time of year when, as we shall see later, the mature petrale sole probably had reached or were close to the southern limit of their seasonal north–south migration. Through January 1963 148 tags had been returned (Best, 1963), and "all recoveries . . . for which fishing information was available came from either the immediate tagging area or north of it. By far the largest number of fish was taken in the immediate vicinity of the tagging area" (either on the inshore ground or in adjacent deep water). Eleven recoveries were made north of California, of which three were taken north of the Columbia River. One of these was recovered on La Perouse Bank in Area 3C, approximately 500 miles from the point of release and some 9 months after tagging.

All of these United States tagging projects were conducted during the inshore phase of the petrale sole's seasonal cycle—generally in the spring to autumn period. The results pointed to existence of numerous populations occupying fairly localized areas on the continental shelf. Relatively few recaptures were made outside the general areas of tagging, but some of these showed movement of as much as 500 miles along the coast.

Unequal distribution of fishing effort in both space and time could be expected to bias the results to some extent. The apparent amount of dispersion from the tagging area would be overstated in adjacent areas of relatively high fishing effort and understated in areas of relatively low fishing effort. More serious, however, is the influence of seasonal variations in effort within any one area. If the petrale sole has a tendency (1) to engage in long migrations to and from spawning grounds during the season of low fishing effort and, (2) to return each spring to a particular inshore bank, then tagging conducted on inshore banks will yield results which suggest that the population is more or less sedentary, if the fishing effort is mainly confined to the inshore banks.

These sources of bias confront interpretation of the United States (and Canadian) taggings conducted prior to the development of deep water winter fishing in the early 1950s. However, even for the more recent inshore taggings adequate assessment of the amount of dispersion is prevented by lack of coordinated information on the distribution of fishing effort.

In gross examination, the results of inshore tagging off the United States coast suggest that contributions to grounds off the Canadian coast are negligible. From the recent (1958–59) inshore taggings off Oregon and northern California, only one tag was recovered on grounds north of Washington and that was in Area 3C. No recoveries were made in Area 3C or other areas farther to the north from the 1948–49 tagging off northern Oregon and southern Washington. To judge from the remarks of Cleaver (1949), tagging in Areas 3A and 3B (Washington coast) failed to reveal significant mingling with populations inhabiting banks in the adjacent Area 3C.

(b) CANADIAN INSHORE TAGGINGS

Results of Canadian taggings conducted on the inshore (summer) banks of Area 3C northward to Area 5D are essentially the same as those obtained in United States studies. Apparently there is a strong tendency, even after a lapse of several years, for tags to be recaptured in the area where they were released. However, dispersion to adjacent areas poses a difficult problem of interpretation.

(i) *Area 3C–lower west coast of Vancouver Island.* In the most southerly statistical area of British Columbia taggings were conducted in the period 1945–1951 inclusive, and then not again until 1962. Because the timing of the taggings in relation to dates of discovery and exploitation of deep-water spawning concentrations has a bearing on the results, it is considered desirable to treat the "early" taggings (1945–51) separately from that of 1962.

Early taggings (1945–51). Between 1945 and 1951, 2673 petrale sole were tagged on various fishing grounds in Area 3C off the lower west coast of Vancouver Island (items 24–34 in Table 1). Tagging took place from May to September, but mostly in the month of June and at depths ranging from 15 to 52 fath. A total of 876 tags was recaptured (excluding those lacking information on area of recapture) of which 91.9% were from Area 3C (Table 2 and Fig. 4). If recoveries made during the first 6 months after tagging are neglected, as in Table 3, the returns in Area 3C are reduced to 88.2%. Dispersion to the north and south of the tagging area as indicated by the latter table, was about equally divided (6.1% to the

TABLE 2. Summary of petrale sole tag recaptures by area and by month (regardless of year) from Canadian taggings conducted in Area 3C between 1945 and 1951 (Recaptures to May 1958).

	Area of recapture														
Month	1C	2A	2B	2C	2D	3A	3B	3C	$3D_{\Delta}$	3D	5A	5B	5C	5D	Total
Apr.	...	...	...	...	...	1	7	34	...	5	2	...	1	...	50
May	...	...	...	...	1	...	2	113	...	9	2	1	...	...	128
June	...	...	...	...	...	...	2	99	...	2	...	...	...	...	103
July	...	1	...	...	1	...	2	226	...	...	2	...	...	...	232
Aug.	...	...	...	...	...	...	3	214	...	1	...	...	...	...	218
Sept.	...	...	...	...	...	...	3	87	...	...	...	...	...	...	90
Oct.	...	...	...	...	...	1	8	24	...	...	...	...	...	...	33
Nov.	...	...	...	...	...	...	...	4	...	...	1	...	...	...	5
Dec.	...	...	...	...	...	...	1	3	...	...	...	...	...	...	4
Jan.	1	...	...	...	...	...	1	...	2	...	1	...	...	...	5
Feb.	...	...	1	...	...	...	...	...	...	...	1	...	...	...	2
Mar.	...	...	...	...	...	1	2	1	2	...	...	...	...	...	6
Recaptured by area	1	1	1	0	2	3	31	805	4	17	9	1	1	0	876
Percentage recaptured by area	0.1	0.1	0.1	0.0	0.2	0.3	3.6	91.9	0.5	2.0	1.0	0.1	0.1	0.0	100.0

TABLE 3. Summary of petrale sole tag recaptures by area and by month (regardless of year) from Canadian taggings conducted in Area 3C between 1945 and 1951, less all recaptures made in the first 6 months after tagging.

	Area of recapture														
Month	1C	2A	2B	2C	2D	3A	3B	3C	$3D_{\Delta}$	3D	5A	5B	5C	5D	Total
Apr.	...	...	...	...	...	1	7	34	...	5	2	...	1	...	50
May	...	...	...	...	1	...	2	113	...	9	2	1	...	...	128
June	...	...	...	...	...	...	2	96	...	2	...	...	...	...	100
July	...	1	...	...	1	...	1	79	...	...	1	...	...	...	83
Aug.	...	...	...	...	...	...	1	59	...	1	...	...	...	...	61
Sept.	...	...	...	...	...	...	2	48	...	...	...	...	...	...	50
Oct.	...	...	...	...	...	1	2	17	...	...	...	...	...	...	20
Nov.	...	...	...	...	...	...	...	...	...	...	1	...	...	...	1
Dec.	...	...	...	...	...	...	1	...	...	...	...	...	...	...	1
Jan.	1	...	...	...	...	...	1	...	2	...	1	...	...	...	5
Feb.	...	...	1	...	...	...	...	...	...	...	1	...	...	...	2
Mar.	...	...	...	...	...	1	2	1	2	...	...	...	...	...	6
Recaptured by area	1	1	1	0	2	3	21	447	4	17	8	1	1	0	507
Percentage recaptured by area	0.2	0.2	0.2	0.0	0.4	0.6	4.1	88.2	0.8	3.3	1.6	0.2	0.2	0.0	100.0

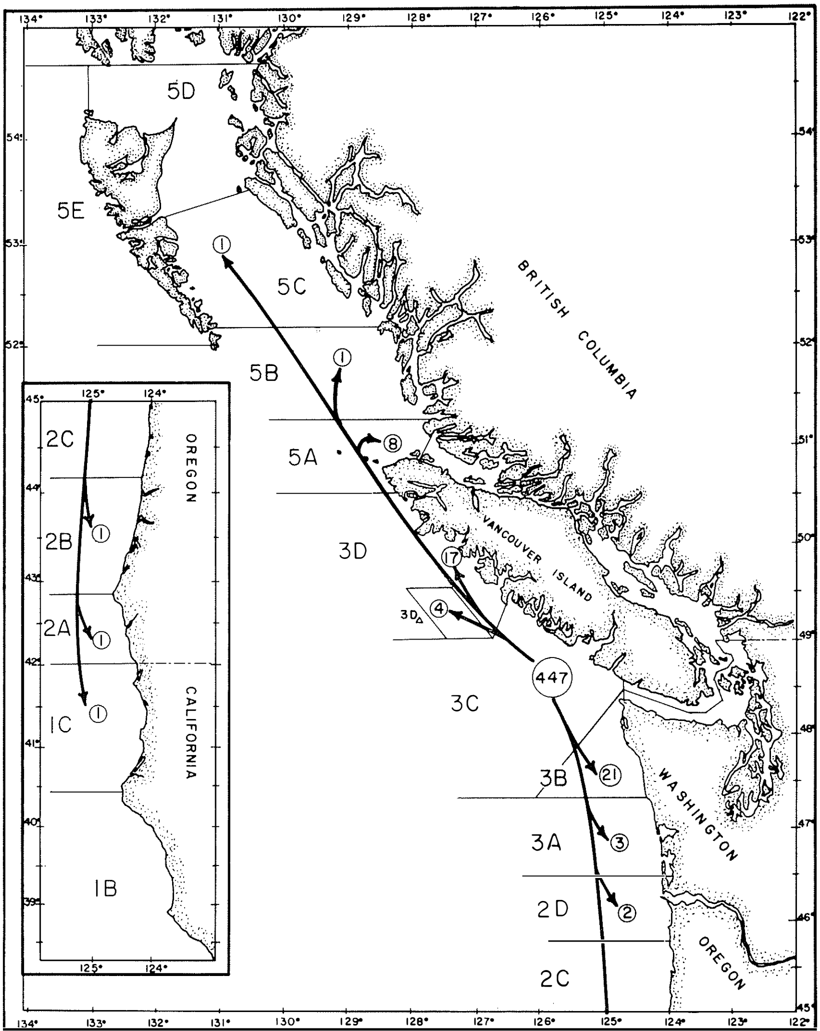


FIG. 4. Distribution of recaptures from petrale sole tagging conducted by the Fisheries Research Board of Canada off the lower west coast of Vancouver Island (Area 3C) from 1945 to 1951, inclusive. (First season recaptures excluded.)

north and 5.7% to the south). One tag was recaptured about 490 miles to the south (Area 1C) and one was recaptured 320 miles to the north (Area 5C). Both of these were confirmed.

Cleaver (1949) and Harry (1956) discuss at length the numerous sources of error in tag returns, among which is inaccurate reporting of place of recapture. The year-round presence of Fisheries Research Board observers at the major Canadian ports of landing has enabled confirmation of most recaptures made by Canadian fishermen. Equally thorough investigation of the reliability of tag reports by United States fishermen has not always been possible. Even after obviously erroneous reports are rejected some errors undoubtedly remain. In the words of Cleaver (1949, p. 22), "it is certain that if none of the tagged fish had left the place of tagging, the recovery reports would nevertheless tend to indicate some migration." Thus, inclusion of unconfirmed tag recaptures may maximize the amount of dispersion, but not necessarily its geographical extent. Tags recaptured at great distance from their origin usually arouse considerable interest, and special efforts are made to "cross-examine" the fishermen regarding the area of capture.

While erroneous reporting of recaptures may tend to maximize the apparent dispersion, there are the countering effects of unequal distribution of fishing effort (between winter and summer) mentioned in the preceding discussion of United States tagging. Canadian inshore taggings under discussion here (1945–51) were conducted 2–8 years prior to the 1953 discovery of winter spawning grounds. Had these taggings been conducted in later years, probably greater numbers of recaptures would have been made in the winter months, and probably more would have been made to the south of the tagging area. As it was, 13 of the tags released on the summer grounds in Area 3C were recaptured in the period December–March outside that area, but only five of these were from depths greater than 100 fath (Table 3, Areas 1C and 3D).

For the years 1954–56, estimates of total fishing effort (hours of trawling) are available from areas fished almost exclusively by vessels from Washington and British Columbia (Areas 3B to 5D). These estimates are shown in Table 4.[8] While they are not strictly applicable to the years involved in the tag recoveries, and involve effort directed to the catch of all species of groundfish, they may be of some value in interpreting the dispersion of tag recoveries from the 1945–51 taggings in Area 3C. To account for differences in fishing effort among areas, an average (1954–56) weighting factor was calculated (column 14, Table 4) and applied to the recaptures shown in the second to last row of Table 2 and Table 3 (excluding those for areas south of Area 3B). Percentage recapture by area was then obtained and compared with recalculated percentages from Tables 2 and 3 (see Table 5).

Of all the recaptures (from tagging in Area 3C) in areas from 3B northward 3.6% were made in Area 3B (or 4.2% if first season recoveries are excluded). Corresponding figures weighted to fishing effort are 1.9% and 2.2%, respectively.

While the applicability of the 1954–56 effort data to earlier recapture periods is open to question, it is known that fishing effort in Area 3B, because of its proximity to Washington ports, has always tended to be high in comparison with that on more distant grounds to the north. Recaptures in Area 3B from taggings in other areas, therefore, tend to be over-rated if examined without reference to fishing effort. Thus, we conclude that petrale sole inhabiting Area 3C show little movement southward to inshore banks off the Washington coast, and that the southern boundary of that area describes, for practical purposes, the southern boundary of the stock or stocks inhabiting British Columbia waters.

[8]Data on the Washington fishery were obtained from manuscript material provided through the courtesy of the Washington State Fisheries Department.

TABLE 4. Total fishing effort (hours) in areas off the Washington and British Columbia coasts with effort in each area expressed as a fraction of the average for all areas.

1	2	3	4	5	6	7	8	9	10	11	12	13	14
	1954				1955				1956				
Area	British Columbia	Washington	Total	Weighting factor[a]	British Columbia	Washington	Total	Weighting factor	British Columbia	Washington	Total	Weighting factor	Mean of columns 5, 9, 13
3B	3	12,380	12,383	0.39	. . .	17,366	17,366	0.35	3	14,745	14,748	0.43	0.39
3C	5,900	2,333	8,233	0.59	5,413	1,941	7,354	0.82	5,636	3,028	8,664	0.73	0.71
$3D_{\Delta}$	. . .	1,904	1,904	2.56	. . .	1,756	1,756	3.42	. . .	1,309	1,309	4.81	3.60
3D	520	2,556	3,076	1.58	1,293	5,121	6,414	0.94	666	4,027	4,693	1.34	1.29
5A	486	2,384	2,870	1.70	839	3,929	4,768	1.26	2,600	5,988	8,588	0.73	1.23
5B	742	5,015	5,757	0.85	613	2,791	3,404	1.77	1,470	3,352	4,822	1.31	1.31
5C	142	543	685	7.11	197	671	868	6.92	864	488	1,352	4.75	6.26
5D	2,152	1,882	4,034	1.21	3,831	2,327	6,158	0.98	4,494	1,694	6,188	1.02	1.07
Total			38,942				48,088				50,364		
Average			4,868				6,011				6,295		

[a]Weighting factor obtained by dividing the average effort for all areas in 1 year by the total effort in a particular area.

TABLE 5. Comparisons of the dispersion of tags from the area of tagging (Area 3C) unweighted and weighted to estimated fishing effort. Recaptures in each area expressed as a percentage of the total recapture.

	Percentage by area of recapture							
	3B	3C	$3D_\Delta$	3D	5A	5B	5C	5D
Unweighted recaptures								
Total	3.6	92.8	2.0	0.5	1.0	0.1	0.1	0.0
At large more than 6 months	4.2	89.6	3.4	0.8	1.6	0.2	0.2	0.0
Weighted recaptures								
Total	1.9	89.5	3.4	2.3	1.7	0.2	1.0	0.0
At large more than 6 months	2.2	83.7	5.8	3.8	2.6	0.3	1.6	0.0

We turn now to the problem of defining (again on the basis of the 1945–51 taggings) the northern limit of petrale sole which are available to the fishery in Area 3C. Tables 2 and 3 show that 3.7% and 6.1%, respectively, of tags recaptured from tagging in Area 3C were recaptured to the north of that area or, if we consider only those areas for which effort data are available, the unweighted recaptures amount to 3.7% and 6.2%, respectively (Table 5). The weighted recaptures, however, amount to 8.6% and 14.1%, respectively. The majority of recaptures were made off the upper west coast of Vancouver Island (Area 3D). Tagging in both Areas 3C and 3D indicate some exchange between the two areas.

Recent tagging in Area 3C (1962). The largest tagging ever accomplished in Area 3C was that of September 1962 on the Forty-Mile Bank (item 26 in Table 1). This tagging (2373 fish released) was distinguished also by the high proportion of juvenile petrale sole (their size distribution appears in Fig. 44). The results (to June 1964) are provided in Table 6 and in Fig. 5, and appear to demonstrate

TABLE 6. Summary of petrale sole recaptures by area and month (regardless of year) from Canadian tagging conducted in Area 3C in 1962 (Recaptures to June 15, 1964).

	Area of Recapture										
Month	2B	2C	2D	3A	3B	3C	$3D_\Delta$	3D	5A	5B	Total
Sept.	...	...	...	...	...	72	...	1	...	...	73
Oct.	...	...	...	...	...	10	...	...	...	...	10
Nov.	...	...	...	...	...	1	...	...	...	...	1
Dec.	...	...	2	...	2	...	...	...	...	...	4
Jan.	...	...	2	...	1	...	1	...	...	...	4
Feb.	1	...	6	...	1	...	1	...	...	...	9
Mar.	...	...	4	...	4	9	1	...	...	...	18
Apr.	...	...	2	...	4	4	1	1	1	...	13
May	...	...	...	...	1	12	...	...	...	1	14
June	...	...	1	...	3	25	...	...	...	...	29
July	...	...	...	...	...	40	...	...	...	...	40
Aug.	...	...	...	...	...	219	...	...	...	...	219
Total	1	...	17	...	16	392	4	2	1	1	434
Percentage	0.2	...	3.9	...	3.7	90.4	0.9	0.5	0.2	0.2	100.0
Recaptured after Nov. 1, 1962											
Total	1	...	17	...	16	330	4	1	1	1	371
Percentage	0.3	...	4.5	...	4.3	88.9	1.1	0.3	0.3	0.3	100.0

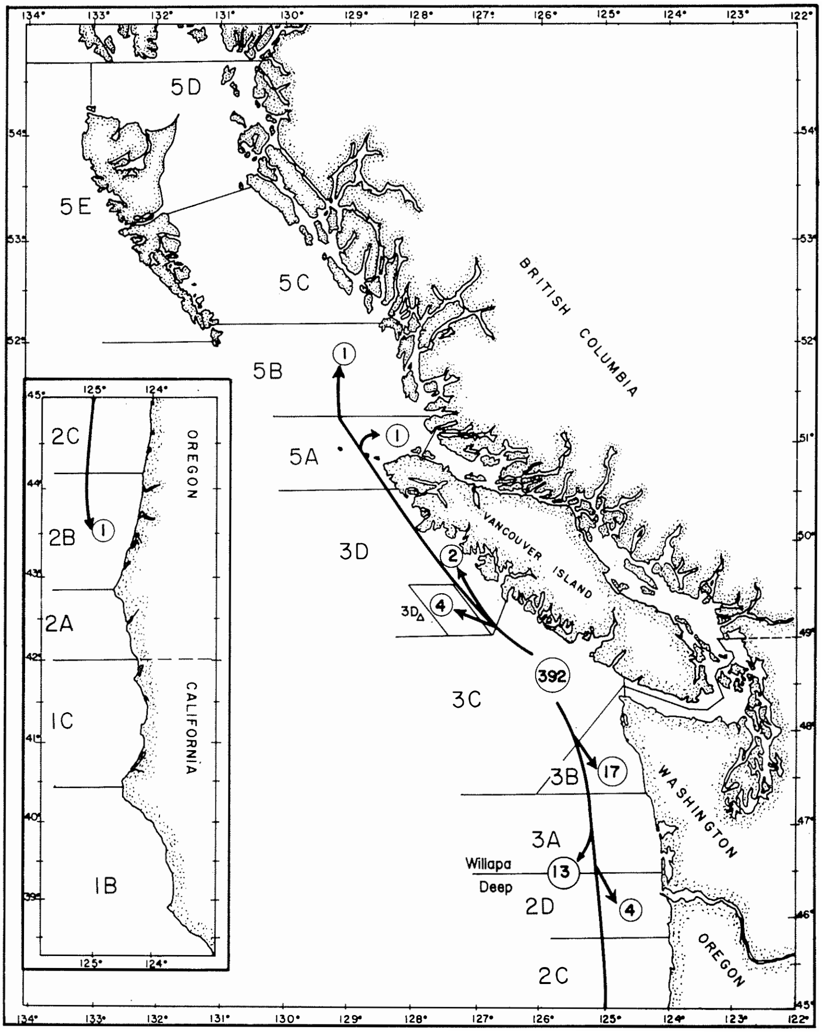


FIG. 5. Distribution of recaptures from petrale sole tagging conducted off the lower west coast of Vancouver Island (Area 3C) in 1962. (First season recaptures excluded.)

a greater amount of southward movement than did previous taggings (cf. Fig. 4), since almost as many recoveries were made to the south in 2 years as were made in all the years succeeding the earlier taggings. Most of the recaptures in Area 3B came in the winter and spring, as did those in Area 2D. There was insufficient information on the recaptures in the former area to determine whether they were made in shallow or deep water. Concerning those made in Area 2D, note in Fig. 4 that the majority came from deep water. Most of the southerly migrants as judged by the size at time of tagging were mature individuals.

These results suggest that at least some of the fish which inhabit Area 3C in the summer months move southward to the spawning area in Area 2D generally known as the Willapa Deep and, according to Westrheim and Morgan (1963), lies on or close to the boundary between Areas 2D and 3A. There may well be other spawning grounds frequented by petrale sole from Area 3C—possibly in Areas 3A, 3B, and in the southern and deeper waters of Area 3C itself. However, more will be said on this matter when we come to discuss recaptures from tagging conducted in deep water (Chapter III (2) below). For the moment it is important to keep in mind that recaptures from inshore taggings in summer and fall in Area 3C occur mainly in that area at about the same time in subsequent years. The occurrence of emigrants is noted mainly during the winter months and in areas to the south of the tagging site. Thus, the definition of "stock" boundaries has to be expressed both in terms of geography and time.

(ii) *Area 3D—upper west coast of Vancouver Island.* A solitary tagging in Area 3D (item 35 in Table 1) resulted in a relatively small number of recaptures—only 50 from over 1000 tagged. The distribution of the returns is shown in Table 7 and Fig. 6. Those in the area of tagging represented 54.0% of the total (or 47.7%

TABLE 7. Summary of petrale sole tag recaptures by area and month (regardless of year) from Canadian tagging conducted in Area 3D in 1947 (Recaptures to August 1957).

	Area of Recapture												
	2B	2C	2D	3A	3B	3C	$3D_{\Delta}$	3D	5A	5B	5C	5D	Total
Apr.	...	...	...	...	...	1	...	7	1	...	...	...	9
May	...	...	...	...	...	...	...	3	4	...	...	...	7
June	...	...	...	...	...	2	...	5	...	...	...	...	7
July	1	...	...	...	...	4	...	3	...	...	...	...	8
Aug.	...	...	...	...	...	...	...	1	...	...	...	...	1
Sept.	...	...	...	...	...	2	...	6	...	...	...	...	8
Oct.	...	...	...	...	...	2	...	...	1	...	...	...	3
Nov.	...	...	...	...	...	...	1	...	...	...	...	...	1
Dec.	...	...	...	...	...	...	...	...	...	...	...	1	1
Jan.	...	...	...	...	...	...	1	...	...	...	...	...	1
Feb.	...	...	...	...	...	...	...	...	...	...	...	...	...
Mar.	...	...	...	...	...	...	...	2	2	...	...	...	4
Total	1	...	...	...	...	11	2	27	8	...	...	1	50
Percentage	2.0	...	...	...	...	22.0	4.0	54.0	16.0	...	...	2.0	100.0
After first Season Total	1	...	...	...	...	11	2	21	8	...	...	1	44
Percentage	2.3	...	...	...	...	25.0	4.5	47.7	18.2	...	...	2.3	100.0

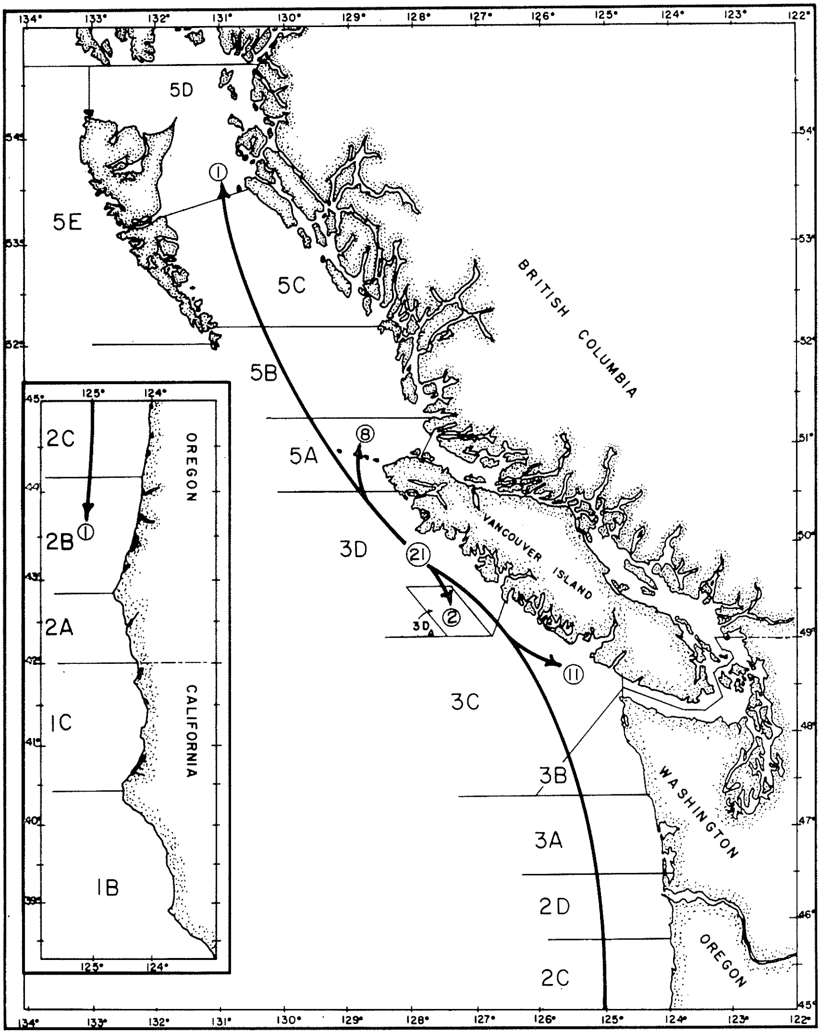


FIG. 6. Distribution of recaptures from petrale sole tagging conducted along the upper west coast of Vancouver Island (Area 3D) in 1947. (First season recaptures excluded.)

neglecting recaptures in the first 6-month season. See last two rows of Table 7). Corresponding figures for recaptures in Area 3C are 22.0% and 25.0% which become reduced to 12.9% and 14.7% when we introduce the correction factor for fishing effort as in column 3 of Tables 8 and 9. Thus, the inshore tagging in Area 3D indicates some movement into Area 3C. Although it is about the same magnitude as that in the reverse direction from Area 3C (1945–51 taggings), the adequacy of the data is questionable because of the poor total recapture from the tagging in Area 3D.

TABLE 8. Weighted percentage recaptures of petrale sole tagged in British Columbia waters — based on all recaptures including first season.

1	2	3	4	5	6	7
	Area of Tagging					
Area of Recapture	$3D_{\Delta}$	3D	5A	5B	5C	5D
3B	...	...	1.2	...	...	...
3C	2.3	12.9	3.4	0.5	...	1.6
$3D_{\Delta}$	73.5	11.9	11.1	18.9	5.7	13.8
3D	11.1	57.3	3.2	3.4	0.7	...
5A	7.6	16.1	68.7	11.3	0.6	2.8
5B	1.9	...	5.5	61.0	0.7	6.0
5C	3.4	...	7.0	4.2	89.5	43.1
5D	0.2	1.8	...	0.7	2.8	32.7

TABLE 9. Weighted percentage recaptures of petrale sole tagged in British Columbia waters — based on all recaptures after first season (6 months).

1	2	3	4	5	6	7
	Area of Tagging					
Area of Recapture	$3D_{\Delta}$	3D	5A	5B	5C	5D
3B	...	...	1.5	...	...	...
3C	1.5	14.7	4.1	0.9	...	2.2
$3D_{\Delta}$	84.4	13.6	13.6	35.6	10.2	18.5
3D	5.0	51.2	4.0	6.4	1.2	...
5A	8.2	18.5	65.9	15.2	1.1	3.8
5B	0.6	...	6.8	40.5	1.2	8.1
5C	...	...	4.3	...	82.8	32.2
5D	0.3	2.1	...	1.4	3.5	35.2

(iii) *Area 5A—Cape Scott.* Usable returns from tagging on the inshore sections of the Cape Scott Bank (Area 5A, item 38–40 in Table 1), like those on grounds farther to the south, were dominantly from the area of tagging (Table 10, Fig. 7). Seventy-three per cent were recovered in that area and 87.4% in areas north of Area 3C. These percentages are changed slightly if we exclude recaptures in the first season (68.7% and 84.5%, respectively).

TABLE 10. Summary of petrale sole tag recaptures by area and month (regardless of year) from Canadian tagging conducted in Area 5A (Cape Scott) in 1949, 1954, and 1960 (Recaptures to June 15, 1964).

	Area of Recapture											
Month	2C	2D	3A	3B	3C	$3D_{\Delta}$	3D	5A	5B	5C	5D	Total
April	...	...	...	...	1	...	1	5	2	...	...	9
May	...	1	...	3	1	...	...	27	7	...	...	39
June	...	...	...	...	2	...	3	16	1	...	...	22
July	...	...	...	2	4	...	...	23	...	1	...	30
Aug.	...	...	...	...	2	...	...	24	1	...	...	27
Sept.	1	...	...	1	4	...	1	12	1	...	...	20
Oct.	...	...	...	1	1	1	...	23	...	...	...	26
Nov.	...	...	...	...	...	...	...	35	1	3	...	39
Dec.	...	...	1	...	1	1	2	1	...	...	...	6
Jan.	1	1	...	2	...	1	...	16	...	...	...	21
Feb.	...	...	...	2	1	2	1	6	1	...	...	13
Mar.	...	...	1	...	...	6	1	12	1	...	...	21
Total	2	2	2	11	17	11	9	200	15	4	...	273
Percentage	0.7	0.7	0.7	4.0	6.3	4.0	3.3	73.3	5.5	1.5	...	100.0
After First Season												
Total	2	2	2	11	17	11	9	156	15	2	...	227
Percentage	0.9	0.9	0.9	4.8	7.5	4.8	4.0	68.7	6.6	0.9	...	100.0

Emigrants from Area 5A were reported as far south as Area 2C, with 6.2% of the total recaptures in Area 3C (or 7.5% excluding first season returns). Recaptures in the latter area are reduced to 3.4% and 4.1% if they are weighted to fishing effort, as in column 4 of Tables 8 and 9.

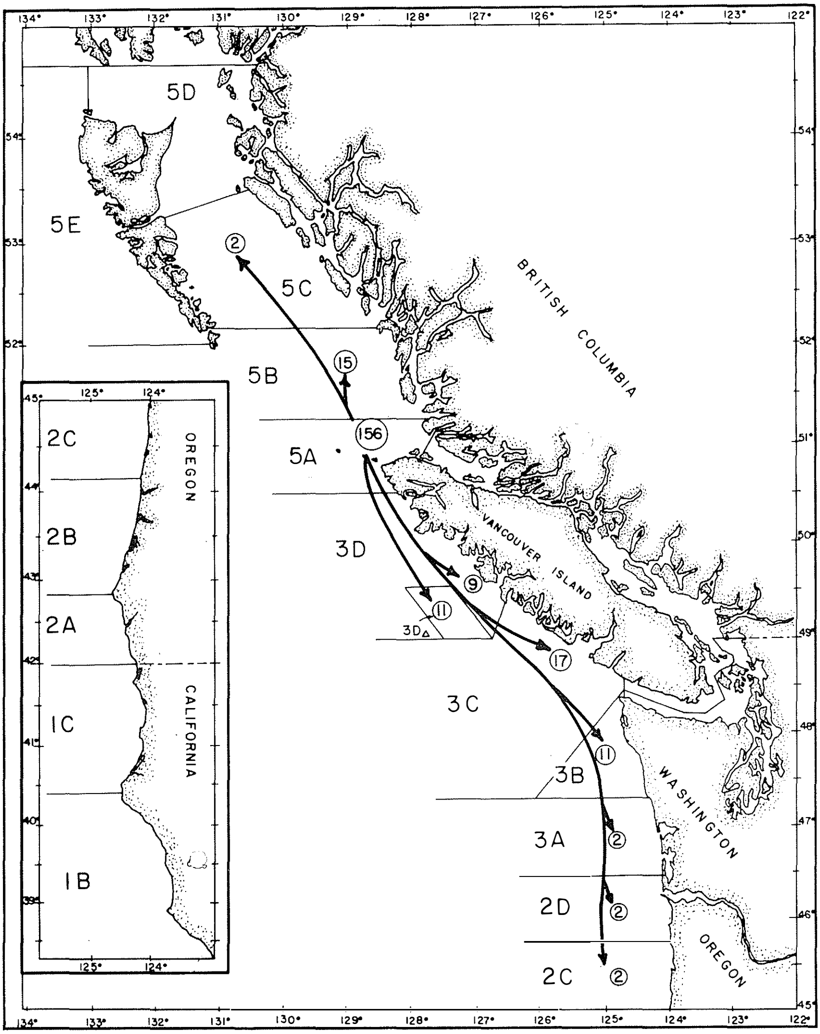


FIG. 7. Distribution of recaptures from petrale sole tagging conducted on the Cape Scott Bank (Area 5A) in 1949, 1954, and 1961. (First season recaptures excluded.)

(iv) *Area 5B—Goose Island.* Table 11 and Fig. 8 show the combined results of three taggings in Area 5B (Goose Island Bank, items 41–43 in Table 1). Seventy-one per cent of the returns were from the area of tagging and 99.0% were from areas north of Area 3C. Excluding first season recaptures, these figures are reduced to 51.0% and 98.0%, respectively. If returns are weighted to fishing effort recaptures in Area 3C from tagging in Area 5B are reduced to less than 1% (column 5, Tables 8 and 9). Thus, there appears to be negligible movement into Area 3C, and likewise from 3C into Area 5B (cf. Table 3).

TABLE 11. Summary of petrale sole tag recaptures by area and by month (regardless of year) from Canadian taggings in Area 5B (Goose Island Bank) in 1952, 1953, and 1954 (recaptures to April 1963).

	Area of Recapture								
Month	3B	3C	$3D_\Delta$	3D	5A	5B	5C	5D	Total
Apr.	...	...	1	1	1	2	...	...	5
May	...	1	...	1	1	5	1	...	9
June	...	...	...	...	...	6	...	...	6
July	...	...	...	...	2	15	...	...	17
Aug.	...	...	...	1	5	20	...	...	26
Sept.	...	...	...	1	...	14	...	...	15
Oct.	...	...	...	...	...	6	...	...	6
Nov.	...	...	...	...	2	2	...	...	4
Dec.	...	...	...	...	...	...	...	...	...
Jan.	...	...	...	...	3	1	...	...	4
Feb.	...	...	5	...	...	...	...	1	6
Mar.	...	...	2	...	...	...	...	...	2
Total	...	1	8	4	14	71	1	1	100
Percentage	...	1.0	8.0	4.0	14.0	71.0	1.0	1.0	100.0
After First Season									
Total	...	1	8	4	10	25	0	1	49
Percentage	...	2.0	16.3	8.2	20.4	51.0	...	2.0	99.9

In the results of tagging in Area 5B, we begin to see more clearly a linkage between the summer (inshore) grounds and the spawning ground in Estevan Deep (Area $3D_\Delta$). Eight out of the 491 tags released in Area 5B were recaptured in $3D_\Delta$. In marked contrast, only four recaptures were made in $3D_\Delta$ from each of the two periods of inshore tagging in Area 3C (cf. Fig. 4 and 5), despite its close proximity to $3D_\Delta$ and also very much heavier tagging. Similarly, recoveries in Area $3D_\Delta$ were proportionately higher from taggings in Area 5A and 3D than those in Area 3C. Thus, the Estevan Deep appears to be more closely associated with inshore grounds to the north than with those immediately to the south.

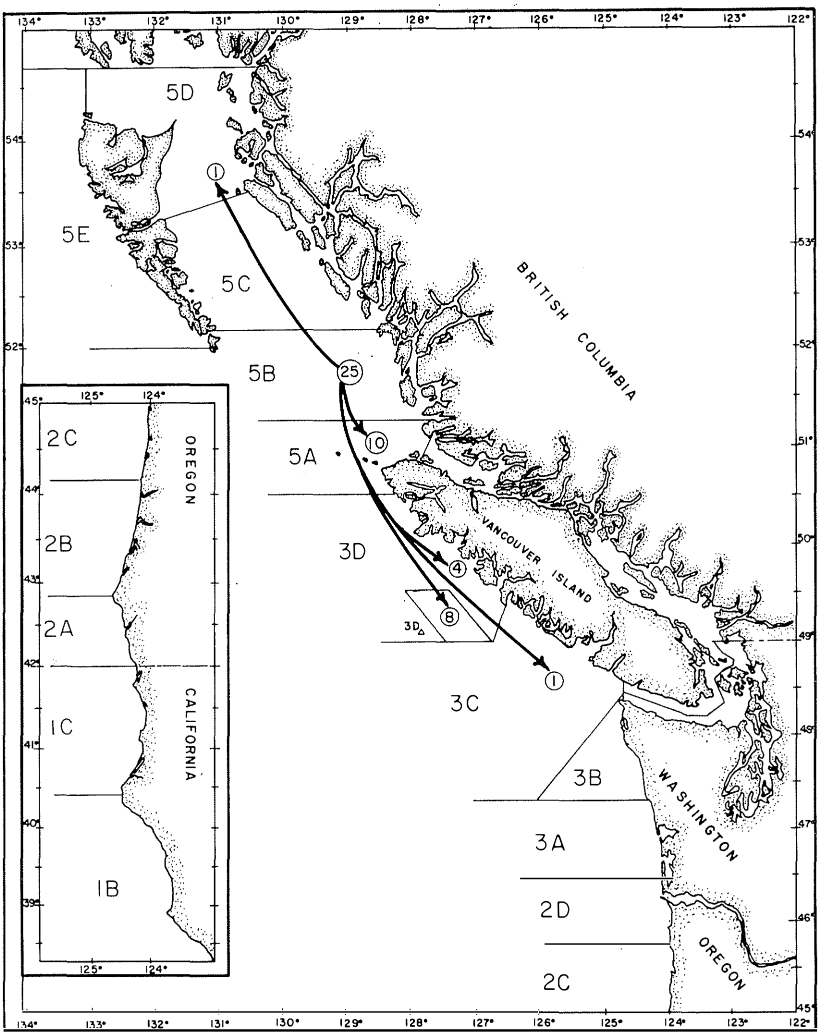


FIG. 8. Distribution of recaptures from petrale sole tagging conducted on the Goose Island Bank (Area 5B) in 1952, 1953, and 1954. (First season recaptures excluded.)

(v) *Area 5C—lower Hecate Strait.* Combined results of two taggings on the Horseshoe ground in Hecate Strait (items 44 and 45 in Table 1) showed no movement south of Area $3D_{\Delta}$ (Table 12 and Fig. 9). Recaptures in the latter area amounted to 7.9% of the total (or 10.0%, excluding first season returns). If we introduce the fishing effort factor the proportions change to 5.7% and 10.2%, respectively (column 6, Tables 8 and 9). These figures are much lower than those calculated for Area 5B taggings (18.9% and 35.6%, respectively, column 5 in Tables 8 and 9), and suggest that contributions to the Estevan spawning are not as great as those from Area 5B.[9]

TABLE 12. Summary of petrale sole tag recaptures by area and month (regardless of year) from Canadian taggings in Area 5C (Horseshoe ground) in August 1946 and June 1952 (Recaptures to December 1962).

	Area of Recapture								
Month	3B	3C	$3D_\Delta$	3D	5A	5B	5C	5D	Total
April	...	...	3	...	...	...	...	...	3
May	...	...	...	...	...	...	...	1	1
June	...	...	...	...	1	1	15	...	17
July	...	...	...	...	...	...	...	1	1
Aug.	...	...	...	...	...	...	5	...	5
Sept.	...	...	...	1	...	...	2	1	4
Oct.	...	...	...	...	...	...	4	...	4
Nov.	...	...	...	...	...	...	...	2	2
Dec.	...	...	...	...	...	...	...	...	...
Jan.	...	...	...	...	...	...	...	...	...
Feb.	...	...	...	...	...	...	...	...	...
Mar.	...	...	...	...	...	...	...	1	1
Total	...	...	3	1	1	1	26	5	38
Percentage	...	...	7.9	2.6	2.6	2.6	71.1	13.2	100.0
After First Season									
Total	...	...	3	1	1	1	14	4	30
Percentage	...	...	10.0	3.3	3.3	3.3	46.7	13.4	100.0

[9]This appears to be a reasonably valid comparison because most of the tagging in Areas 5B and 5C was done in the same year (1952), and just prior to the period used in estimating the fishing effort factor (1954–56). The fact that weighted recaptures in $3D_\Delta$ from tagging in 5A were lower than those from tagging in 5B does not necessarily mean that the 5A fish contribute less to the Estevan spawning. This is probably a reflection of the time difference in tagging. Tagging in Area 5A was done 4 years before discovery of the Estevan spawning ground, and by that time relatively few tags were still available for recapture in the Estevan Deep.

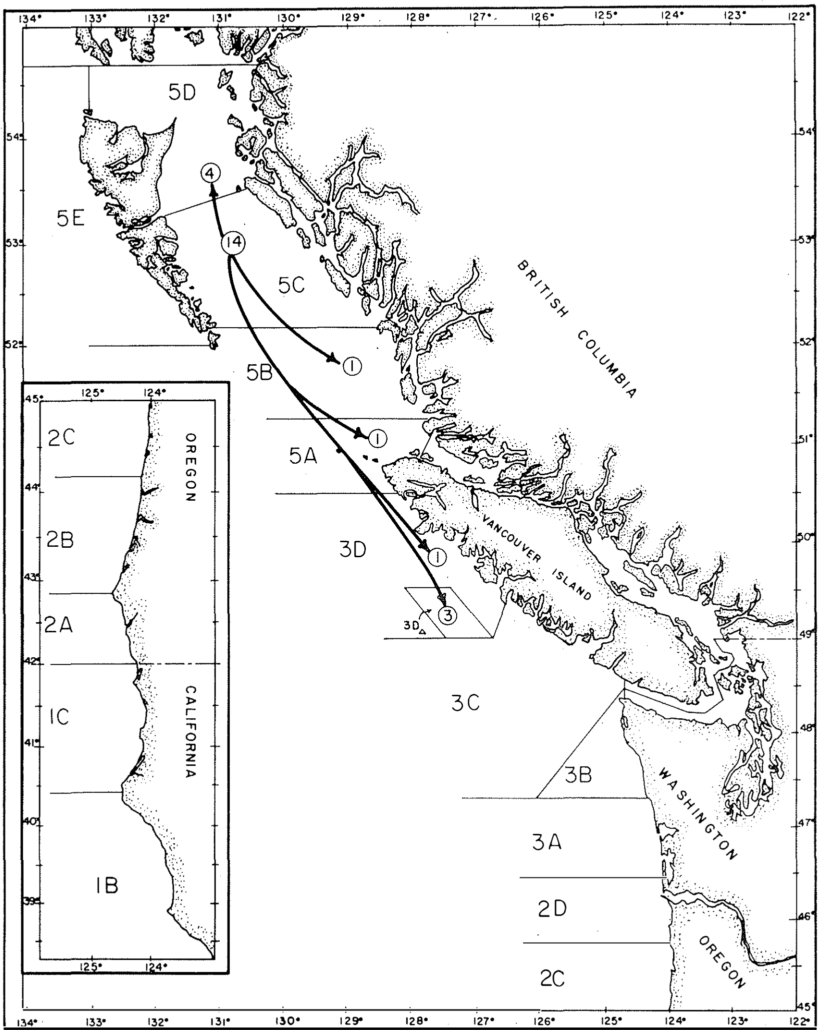


FIG. 9. Distribution of recaptures from petrale sole tagging conducted on the Horseshoe ground in Area 5C in 1946 and 1952. (First season recaptures excluded.)

(vi) *Area 5D—upper Hecate Strait.* The distribution of returns from two taggings on the White Rocks ground (items 47 and 48 in Table 1) are combined in Table 13 and Fig. 10. Again, most of the recaptures were made in the area of tagging. Of the total, 4.5% were made in Area 3C (or 5.6% neglecting first season returns). Applying the correction for fishing effort, Area 3C recaptures become 1.6% and 2.2%, respectively (see column 7, Tables 8 and 9).

As in tagging areas immediately to the south of Area 5D, relatively high numbers of recaptures were made on the Estevan spawning ground, 7.6% of the total recapture or 9.3% neglecting first season returns. Again, applying the fishing

TABLE 13. Summary of petrale sole tag recaptures by area and month (regardless of year) from Canadian taggings in Area 5D (White Rocks grounds) in May 1951 and June 1952 (Recaptures to July 1960).

	Area of Recapture								
Month	3B	3C	$3D_{\Delta}$	3D	5A	5B	5C	5D	Total
April	...	...	...	...	...	...	...	2	2
May	...	1	...	...	...	2	3	5	11
June	...	1	...	...	...	...	2	7	10
July	...	...	...	...	...	1	...	2	3
Aug.	...	...	...	...	3	1	2	3	9
Sept.	...	...	...	...	...	...	2	5	7
Oct.	...	...	...	...	...	2	...	9	11
Nov.	...	...	...	...	...	...	...	5	5
Dec.	...	...	...	...	...	...	...	1	1
Jan.	...	...	2	...	...	...	...	...	2
Feb.	...	...	1	...	...	...	...	...	1
March	...	1	2	...	...	...	...	1	4
Total	...	3	5	...	3	6	9	40	66
Percentage	...	4.5	7.6	...	4.5	9.1	13.7	60.6	100.0
After First Season									
Total	...	3	5	...	3	6	5	32	54
Percentage	...	5.6	9.3	...	5.6	11.1	9.3	59.2	100.0

effort factor, these figures are raised to 13.8% and 18.5%, respectively, suggesting a stronger linkage to the Area $3D_{\Delta}$ spawning ground than that observed in Area 5C tagging, but not as strong as that in Area 5B.

Results of two other taggings not considered in this analysis (items 46 and 52 in Table 1) showed little or no movement south of Area 3D. Two out of 68 returns from the 1947 tagging were reported from south of Area 3D; none of the recaptures from the McIntyre Bay tagging (the northernmost fishing ground in Area 5D) were reported south of the tagging locality.

As no trawl fishery has existed off the coast of southeastern Alaska (to the north of 5D) during the period of study, the apparent dispersion from taggings in Area 5D and in Area 5C is presumably biased to the southward. Information on the existence of petrale populations to the north and west of British Columbia is still lacking. However, within Area 5D itself, petrale sole have been important historically only in the southern one-third of that area. It may well be that this locality represents the northern limit of populations which are of sufficient size to attract discrete fisheries.

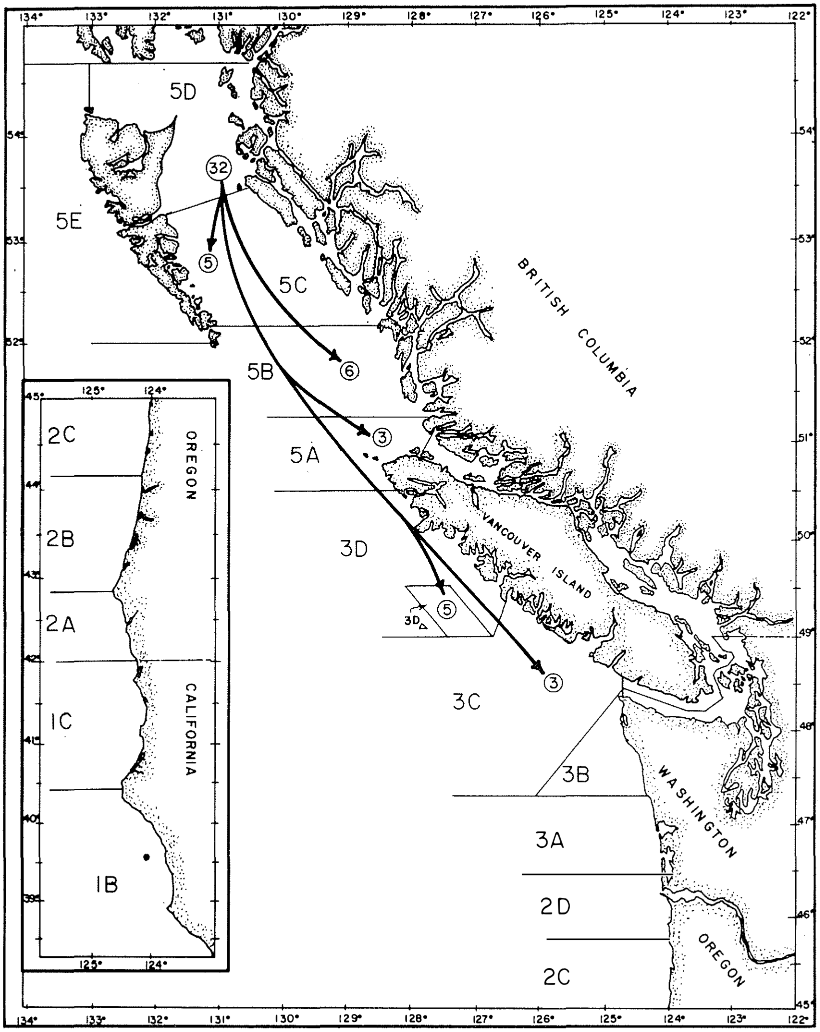


FIG. 10. Distribution of recaptures from petrale sole tagging conducted on the White Rocks ground in Area 5D in 1951 and 1952. (First season recaptures excluded.)

(vii) *Conclusions.* Recaptures from taggings conducted in various inshore or shallow areas along the British Columbia coast, in virtually all cases, have been dominantly from the area of tagging, even when first season returns are neglected. There can be little doubt of the existence of numerous populations which are more or less independent of one another, at least during the inshore (spring to autumn) phase of their seasonal bathymetric cycle of migration. The problem before us is to determine whether or not these populations can be grouped into larger units of stock in a form which would enable a rational examination of the historical record of catch and fishing effort.

In the foregoing presentation, we have alluded to the possibility that fish inhabiting Area 3C, namely the lower west coast of Vancouver Island, can be distinguished as belonging to a stock which is more or less separate from stocks both to the south, off the United States coast, and to the north off the remainder of the British Columbia coast. From tagging inshore in Area 3C, relatively small numbers of tags have been recovered off the United States coast (mostly in winter and in deep water), and tagging in the latter region in summer and in shallow water has resulted in negligible returns from Area 3C. Because of apparent seasonal shifts along the coast it is difficult to make clear-cut definitions of stock according to a somewhat arbitrarily designed system of statistical areas. It is nevertheless sufficient for present purposes to define the southern boundary of Area 3C as the southern limit of stocks available to the fishery along the British Columbia coast.

Petrale sole in Area 3C are to a large extent separate from those in northern British Columbia waters. Only 2.3% of all tags recaptured from taggings in Areas 5B to 5D, inclusive, were reported from Area 3C or farther south. Conversely, only 0.2% of recapture from taggings in Area 3C were reported from Areas 5B to 5D. Thus, we can be certain of two more or less separate units—a *southern stock* and a *northern stock*. On the basis of inshore tagging results alone, however, there is difficulty in arriving at a clear-cut boundary between the two, for there is a certain amount of overlap in intervening Areas 3D and 5A. Gross examination of recaptures from tagging in Area 3D showed as much as a 25% return in Area 3C, and 7.5% from tagging in Area 5A. These figures were reduced to 14.7% and 4.1%, respectively, by introducing a correction factor for fishing effort. On the other hand, only 4.1% and 1.6% of all recaptures from tagging in Area 3C were made in Areas 3D and 5A, respectively. While the results of tagging in Area 3C would allow recognition of fish in that area as a separate stock, tagging in Areas 3D and 5A suggest that a moderate fraction of the fish in those areas contribute to the fishery in Area 3C.

2. Results of Deep-Water Tagging

(a) United States Coast

To the end of 1964 three sizable taggings of petrale sole had been conducted in deep water off the United States coast: (i) near Half Moon Bay, California, in Area 1B, 30–40 miles SSW of San Francisco Lightship; (ii) in the vicinity of Hecata Bank in Area 2B and (iii) in the Willapa Deep near or on the boundary between Areas 2D and 3A (items 1, 2, and 3 in Table 14).[10] To January 1963, only 2% of the fish tagged on the California spawning ground had been recovered; most of these were taken on grounds to the north of the tagging site, but none was from waters north of Area 1B (Best, 1963).

[10]We have already mentioned the November–December 1958 tagging off Eureka, California (Area 1C) in discussion of inshore taggings (p. 17) because most of the tagged fish were released in relatively shallow water. In the succeeding 30 days, three of nine recaptures were made on the spawning ground off Eureka.

TABLE 14. Petrale sole tagging projects conducted on deep water spawning grounds along the west coast of the United States and Canada.

Item	Statistical Area	Locality	Agency	Date		Numbers released	Total release By locality	Total release By area
1	1B	Halfmoon Bay	California	Nov.–Dec.	1960	2,378	2,378	2,378
2	2B	Hecata Bank	Oregon	Feb.– Mar.	1960	5,026	5,026	5,026
3	3A	Willapa Deep	Washington	Feb.	1962	4,461	4,461	4,461
4	3B	Destruction Is.	Washington	Feb.	1962	55	55	55
5	3C	Flattery Spit	Washington (Canada)	Mar.	1955	434	434	434
6	$3D_{\Delta}$	Estevan Deep	Washington (Canada)	Apr.	1954	1,795	3,702	3,702
7			Washington (Canada)	Mar.	1955	2,007		
Total								16,056

The Oregon Fish Commission tagging near Hecata Bank in Area 2B (about 350 miles south of British Columbia) was conducted in February–March of 1960, mostly at depths of 170–200 fath. According to the 1964 report of the Trawl Fishery Committee, 341 tags had been returned by June 30 of that year. In the most northerly statistical area where recaptures were made (Area 3C), there were six returns (or 1.8% of the total). Thirty-six per cent of the recaptures were made in other statistical areas to the north of Area 2B but south of Area 3C.

More recently (February 1962), the Washington State Department of Fisheries conducted tagging on the Willapa Deep. To June 1964, 140 usable recaptures had been reported of which 18 or 12.8% came from the Area 3C inshore fishery. One recapture was made in Area 3D. These results support those obtained from tagging in Area 3C (p. 25) in that there seems to be some association between fish on the summer (inshore) grounds in Area 3C and the winter grounds in Area 3A–2D. At least some of the mature fish available to the inshore fishery in Area 3C contribute to the spawning in Willapa Deep. Others may contribute to spawnings closer at hand, such as in waters adjacent to Destruction Island, Umatilla Reef (Area 3B), and on the Cape Flattery Spit (in Area 3C).

(b) CANADIAN COAST

(i) *Area* $3D_{\Delta}$ *— Estevan Deep.* In April 1954, and again in March 1955, a joint tagging was undertaken on the Estevan Deep (Area $3D_{\Delta}$) by the Washington State Fisheries Department and the Fisheries Research Board of Canada (item

3 and 4 in Table 14). A detailed study of the results has been made by Alverson and Chatwin (1957). In the present analysis these results together with additional information on subsequent recoveries are reexamined from the standpoint of stock definition. Combined data on recaptures from the two taggings are shown in Table 15 and Fig. 11.

TABLE 15. Summary of petrale sole tag recaptures by area and month (regardless of year) from joint United States–Canadian tagging in Area $3D_{\Delta}$ (Estevan Deep) in April 1954 and March 1955.

	Area of Recapture										
Month	2D	3A	3B	3C	$3D_{\Delta}$	3D	5A	5B	5C	5D	Total
Apr.	...	...	...	4	20	17	2	1	...	...	44
May	...	...	...	1	1	13	1	2	...	...	18
June	...	...	...	3	...	3	...	2	...	...	8
July	...	...	...	1	...	1	2	...	...	...	4
Aug.	...	...	...	2	...	8	7	2	3	...	22
Sept.	...	...	...	4	...	2	1	...	...	...	7
Oct.	...	...	...	3	...	...	7	...	...	...	10
Nov.	...	...	...	...	...	...	3	1	...	1	5
Dec.	...	...	...	...	2	...	4	...	...	...	6
Jan.	...	...	...	...	50	...	3	...	...	...	53
Feb.	...	...	...	...	12	...	1	...	...	...	13
Mar.	...	...	...	...	27	3	3	...	...	...	33
Total	...	...	...	18	112	47	34	8	3	1	223
Percentage	...	...	...	8.1	50.1	21.1	15.3	3.6	1.3	0.5	100.0
After First Season											
Total	...	...	...	9	102	17	29	2	...	1	160
Percentage	...	...	...	5.6	63.8	10.6	18.1	1.3	...	0.6	100.0

Eighteen, or 8.1%, of the 223 identifiable returns indicated southward movement into Area 3C or (following the treatment used in other taggings) 5.6%, excluding recaptures in the first season. On the other hand, 41.8% (or 30.6% excluding first season recaptures) were returned from Area 3D or other areas farther north.

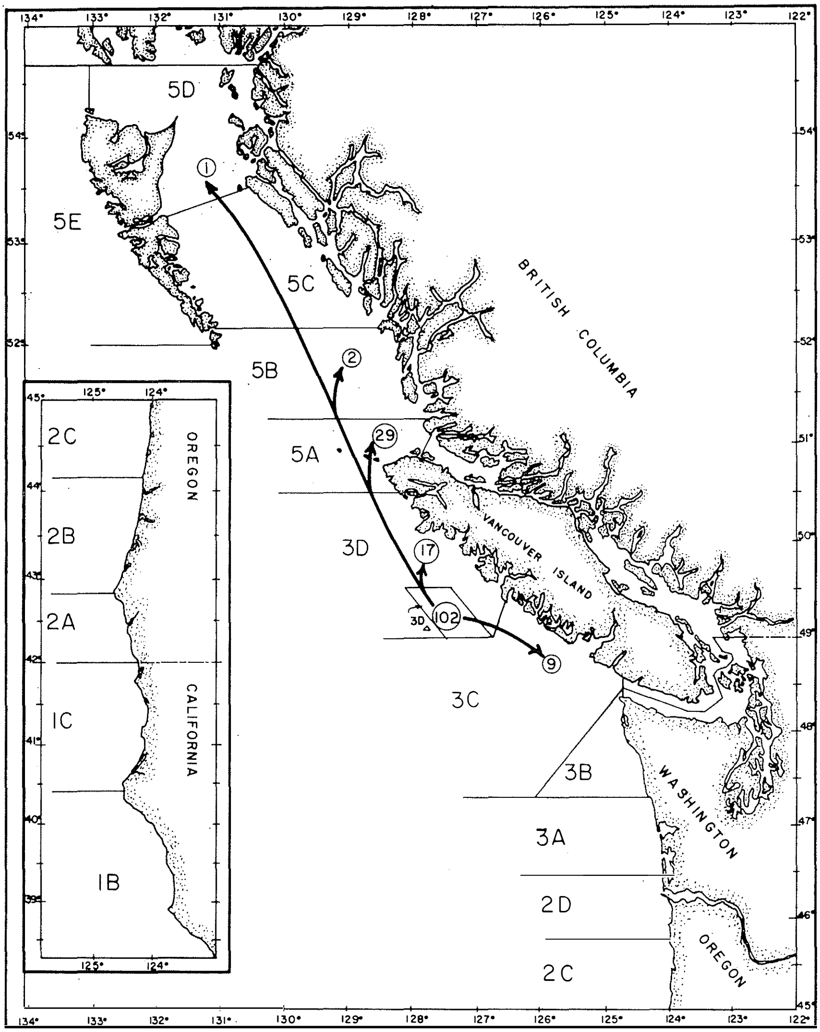


FIG. 11. Distribution of recaptures from petrale sole tagging conducted jointly by the Washington State Department of Fisheries and the Fisheries Research Board of Canada on the Estevan Deep (Area $3D_\Delta$) in 1954 and 1955. (First season recaptures excluded.)

Appropriate weighting of recaptures to fishing effort reduces the recaptures in Area 3C to 2.3%, or 1.5% if we neglect the first season. Clearly, the Estevan spawning concentration is identified not with the inshore banks of Area 3C, but with those farther to the north. In their analysis of the ratio of tagged to untagged fish in the catch, Alverson and Chatwin (1957) showed that spawning fish from the Estevan Deep contributed heavily to the subsequent inshore fishery in Area 3D.[11]

[11]The analysis was based on male fish as they predominated on the Estevan grounds at time of tagging. It has been established by routine sampling of commercial landings that females predominate early in the spawning season and apparently leave before the males. Both taggings were conducted late in the spawning season.

A smaller ratio of tagged to untagged fish in Areas 5A–5D suggested a mingling of Estevan Deep fish with stocks which did not participate in the Estevan spawning, *or* which had participated prior to the time of tagging. It is difficult to say which of these possibilities is more likely. Tagging on the Estevan ground resulted in relatively few recaptures in Areas 5B, 5C, and 5D, but tagging in the latter areas showed fairly heavy contributions to Estevan Deep. This could be explained by differential migration of the sexes or by a tendency for early spawners to migrate greater distances than late spawners. Best (1963, p. 29) notes that in California waters longest migrations are made by mature females.

In any event, it is apparent that the post-spawning migration of petrale sole from the Estevan ground is dominantly to the northward through Area 3D to Area 5A at least. Of the 18 recaptures made in Area 3C, half of them were from the Sydney Inlet grounds, which lie *directly* inshore from Area $3D_{\Delta}$. Hence, only a minor fraction of the recaptures showed a definite indication of a southward movement.

(ii) *Area 3C—Cape Flattery Spit.* In the course of field operations involving the Area $3D_{\Delta}$ tagging in March 1955, 434 petrale sole were tagged on a spawning ground near the southern boundary of Area 3C (item 5, Table 14). This ground, known as the Cape Flattery Spit, is at depths of 146–152 fath. Only seven of the tagged fish were recaptured: one from the area of tagging, a year later; four from the inshore banks of Area 3C (Swiftsure, Firing Range, and Forty-Mile Bank); one questionable recapture from the Estevan Deep (Area $3D_{\Delta}$) 2 years after tagging; one from the tagging area 6.5 years after tagging; and one unknown. Sparse though these recaptures are, they suggest an association between the deep water (spawning) grounds in Area 3C and the inshore (summer feeding) grounds of the same area.

(iii) *Conclusions.* Results of tagging on spawning grounds off the California coast show negligible contribution of adult fish to inshore banks of southern Vancouver Island (Area 3C). Similar results emerged from inshore tagging in that region. Relatively few recoveries were made in Area 3C from taggings conducted inshore and in deep water off central Oregon (Areas 2B, 2C). Farther to the north a closer association was found between the Willapa Deep spawning ground (Area 2D–3A off Washington) and the summer grounds of Area 3C, though most of the recaptures still came from grounds to the south of Area 3C. Likewise, recent tagging in Area 3C demonstrated southward movement of mature fish to the Willapa Deep on the Area 2D–3A boundary in the autumn and winter months. There also appears to be an association between fish on the 3C summer grounds and those on the small spawning ground on the Cape Flattery Spit, and perhaps also with other small spawning grounds between there and the Willapa Deep. The southward displacement of Area 3C petrale sole to grounds off Washington occurs at a time of year when for reasons of bad weather, low availability, or restrictive fishery regulations, the catches of petrale sole are relatively small (Fig. 12). Thus, it would not be inappropriate to regard Area 3C and the catches made there in the spring to autumn period as applying to a stock which is more or less separate from those off the United States coast.

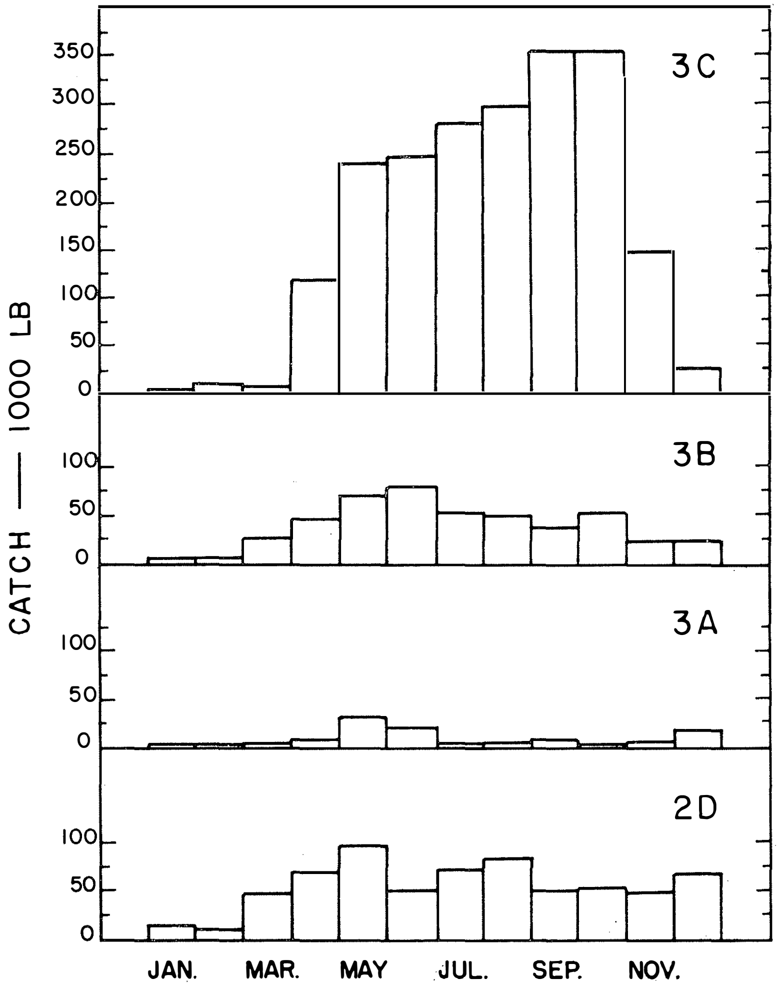


FIG. 12. Average monthly landings of petrale sole (1958–61) from the southern Vancouver Island coast (Area 3C) and from the Washington and northern Oregon coasts (Areas 3B, 3A, and 2D).

While inshore tagging in Areas 3C and 3D indicated small to moderate exchange between these two areas, deep water tagging in Area $3D_{\Delta}$ showed only a small amount of movement southward into Area 3C. Post-spawning migrations from Area $3D_{\Delta}$ were dominantly to the northward with most of the recaptures coming from Areas 3D and 5A. On the strength of this evidence and the relatively low recovery of tags to the northward from inshore tagging in Area 3C, it seems appropriate to recognize Area 3C as containing a stock which is to a large extent separate from those in areas farther to the north. Argument against this conclusion is based mainly on the results of inshore tagging in Area 3D. However, as mentioned before, total return from this tagging was poorer than that from others, and therefore the results cannot be accepted with the same degree of confidence.

3. Boundaries of Stocks

On the basis of the foregoing conclusions from inshore and deep water tagging, the following definitions of stocks are proposed:

Southern stock — inhabiting all waters within the boundaries of Statistical Area 3C. The adult spawning segment of this stock occupies adjacent deep waters in Area 3C as well as those as far south as the Area 3A–2D boundary during the winter months. However, removals by the fishery occur mainly within Area 3C.

Northern stock — inhabiting all waters within the boundaries of Area 3D (including $3D_{\Delta}$) and Areas 5A–5D, inclusive. A close connection has been demonstrated between the Area $3D_{\Delta}$ spawning and adjacent inshore grounds of Area 3D proper. While fish inhabiting inshore grounds farther to the north may be just as dependent on the $3D_{\Delta}$ spawning ground as those in 3D proper, the possibility remains that other (undiscovered) spawning grounds exist in waters to the north of Vancouver Island. In other words, there may be more than one stock involved in what we here define simply as the northern stock.

Obviously, this description is a simplification of what must be a relatively complicated and not necessarily constant relationship between various stocks of petrale sole along the Pacific coast. However, this is unavoidable because the catch statistics do not lend themselves to anything but the most simple of interpretations. While it is apparent that a high percentage of petrale sole tagged in a particular statistical area are recovered in that area even after several years at large, there is a certain amount of dispersion which is difficult to interpret. Much of it is believed to result from directed migrations to and from spawning grounds, but some must be regarded as random diffusion. Detailed results of tagging show that from a particular tagging, recaptures more than a year later are sometimes made more or less simultaneously in widely separated areas. Furthermore, although the majority of recaptures from tagging on a spawning ground are returned from the same ground in the following spawning season, it is apparent that some individuals may occupy different spawning grounds in successive years (Best, 1963, p. 29). Thus, our definition of "stocks" is of necessity a loose one embodying the notion of a general tendency for petrale sole in one area to be separate from those in adjacent areas.

Chapter IV

STATISTICS OF CATCH AND CATCH PER UNIT OF EFFORT

1. General Statistics of Catch

Not until 1956 did all agencies responsible for collection and compilation of groundfish statistics (other than halibut) reach a reasonable degree of effectiveness in recording landings according to area of capture. In that year, as a result of discussions between biologists of Canada and the United States, informal agreement was reached on the definition of statistical areas, encompassing all trawling grounds from southern California to northern British Columbia (reference has already been made to these in discussion of tagging results — see Fig. 2). Since that time, exchange of information has been coordinated through the auspices of the (United States) Pacific Marine Fisheries Commission. For years prior to 1956, when efforts to record catch by area were largely uncoordinated, reliance had been placed on various other sources of information.

(a) United States records

(i) *California and Oregon.* A summary of information on California landings of petrale sole is given in Table 16. The fishery has never extended north of Area 2B off the Oregon coast. The trawl fishery for petrale sole in California developed more slowly than that in Oregon and Washington, apparently because of greater demand for other species. Petrale sole were of minor importance until after World War II. Production reached a peak in 1948–49 and thereafter followed an irregular but somewhat downward course.

In Oregon waters, trawling for petrale sole had its beginning around about 1937, but records of total production were not kept until 1942 (Table 17). Apparently, landings were highest in that year and in the succeeding one, after which there was a generally downward trend.

Historically, the operations of the Oregon trawl fleet have been confined largely to grounds within short running distance of Astoria and other Oregon fishing ports (Harry, 1956, p. 152). However, in recent times occasional small trips have been reported from grounds as far north as Area 3D (northern Vancouver Island). As mentioned earlier (p. 6) some vessels fished in Area 3C in 1945 and 1946, primarily in search of dogfish. Catches of petrale sole are believed to have been relatively small.

TABLE 16. California landings of petrale sole in thousands of pounds, according to area of capture.[a]

	1	2	3	4	5	6	7	8
	California Coast				Oregon Coast			
Statistical Area	1A	1B	1C	2A	2B	2C	2D	Total
1938		1,032	951	4				1,987
1939		1,689	826	28				2,543
1940		926	67	39				1,572
1941		576	287	11				874
1942		143	453	...				596
1943		165	731	1				897
1944		191	737	...				928
1945		445	266	...				711
1946		447	1,175	136				1,758
1947		666	492	11				1,169
1948	33	2,102	2,239	266	442			5,082
1949	291	2,484	1,281	153	650			4,859
1950	244	2,265	1,153	104	571			4,337
1951	233	1,394	951	98	40			2,716
1952	337	1,177	1,299	49	27			2,929
1953	191	1,374	1,317	456	11			3,349
1954	621	2,249	885	162	251			4,168
1955	296	2,131	911	100	178			3,616
1956	487	1,417	626	68	226			2,824
1957	480	1,637	1,150	99	90			3,456
1958	474	1,193	962	339	190			3,158
1959	754	930	717	140	91			2,632
1960	757	998	604	110	6			2,475
1961	843	1,339	972	146	86			3,386
1962	625	1,180	1,060	144	29			3,038

[a]Sources of data:
(1) 1938–53: from Best (1963) and personal communication November 6, 1964.
(2) 1954–62: from records compiled by the Pacific Marine Fisheries Commission.

TABLE 17. Oregon landings of petrale sole in thousands of pounds, according to area of capture.[a]

	1	2	3	4	5	6	7	8	9	
					Washington coast		Vancouver Island coast			
			Oregon coast		Lower	Upper	Lower	Estevan Deep	Upper	
Statistical Area	2A	2B	2C	2D	3A	3B	3C	$3D_{\Delta}$	3D	Total
1938										?
1939										?
1940										?
1941										941
1942										3,745
1943										3,805
1944	*Catch by area not available prior to 1951.*									2,019
1945										1,574
1946										2,984
1947										1,444
1948										2,658
1949										1,515
1950										3,175
1951	...		1,810		240		...	...	...	2,052
1952	...		1,307		160		...	...	...	1,467
1953	...		855		43		...	...	...	898
1954	...		861		438	39	2	2	...	1,342
1955	...		998		283	60	2	37	...	1,380
1956	...	87	416	427	77	16	...	...	...	1,023
1957	...	539	643	547	222	28	...	...	...	1,979
1958	...	975	292	353	16	6	3	...	5	1,650
1959	...	538	187	474	54	22	...	...	...	1,275
1960	6	647	494	766	170	51	5	...	6	2,145
1961	8	317	510	918	54	31	...	...	...	1,838
1962	38	624	593	1,217	106	26	...	...	...	2,604

[a]Sources of data:

(1) *1941–49 inclusive*: Fisheries Statistics of Oregon, Contrib. No. 16, Oregon Fish Commission, 1951.

(2) *1950–62 inclusive*: Totals from records compiled by Pacific Marine Fisheries Commission.

(3) *1951–53 inclusive*: Breakdown by area from manuscript reports of the Oregon Fish Commission and assumes all landings from Areas 3A and 3B were made at the port of Astoria.

(4) *1954–55 inclusive*: Breakdown from manuscript reports of the Oregon Fish Commission and personal communication (Morgan, 1959).

(5) *1956–62 inclusive*: Breakdown from records compiled by the Pacific Marine Fisheries Commission.

(ii) *Washington.* Data on the Washington landings of petrale sole are presented in Table 18. Figures for years prior to 1953 are merely approximations, but they are in general accord with knowledge of the way in which the fishery first developed off the Washington coast and then spread northward to encompass

TABLE 18. Reconstructed history of Washington landings of petrale sole in thousands of pounds, according to area of capture.[a]

	1	2	3	4	5	6	7	8	9	10	11
		Washington coast		Vancouver Island coast			Queen Charlotte Sound		Hecate Strait		
	Oregon	Lower	Upper	Lower	Estevan Deep	Upper	Cape Scott	Goose Island	Lower	Upper	Total[b]
Statistical Area	2D	3A	3B	3C	$3D_1$	3D	5A	5B	5C	5D	
1938	...	...	...	...	...	...	...	...	...	...	2,500
1939	...	...	890	1,410	...	...	...	...	...	...	2,300
1940	...	...	940	1,860	...	...	...	...	...	...	2,800
1941	...	...	1,760	2,640	...	...	...	...	...	...	4,400
1942	...	...	1,760	3,040	...	...	...	...	...	...	4,800
1943	...	280	1,180	4,540	...	...	...	...	...	...	6,000
1944	...	...	561	2,881	...	1,000	668		...	...	5,110
1945	...	3	368	1,223	...	383	1,512	1,678	343	40	5,550
1946	...	260		1,190	...	970	2,020		660		5,100
1947	...	250		1,120	...	910	1,900		620		4,800
1948	...	233		1,528	...	1,922	1,340		1,162		6,185
1949	...	283		1,490	...	487	566		2,044		4,870
1950	...	257		798	...	1,204	968		1,196		4,423
1951	...	430		1,105	...	494	489		882		3,400
1952	...	483		924	...	393	497		1,085		3,382
1953	...	5	220	810	250	240	820	65	35		2,445
1954	...	7	323	793	1,087	318	242	184	649		3,603
1955	...	26	420	534	621	237	814	173	163		2,988
1956	...	49	288	819	465	144	978	91	47		2,881
1957	...	27	232	846	2,673	223	467	69	159		4,696
1958	39	9	566	717	151	195	248	96	78		2,099
1959	52	8	332	1,734	150	337	188	35	62	164	3,062
1960	2	1	329	1,714[c]	90	97	155	62	3	17	2,470
1961	2	73	683	1,992	455	135	106	47	...	11	3,504
1962	...	90	335	1,549	422	174	275	131	4	...	2,980

[a]See text and Appendix III for sources of data and methods of estimating catches prior to 1954.

[b]Excludes small catches from inshore grounds of Area 4A, which normally do not exceed a few thousand pounds annually.

[c]For the years 1960–62, catch in Area 3C includes catches made on newly discovered grounds on the Cape Flattery Spit: 514 thousand lb in 1960, 827 in 1961; 474 in 1962.

the banks off British Columbia. Figures on total catch for years prior to 1954 are from Alverson and Chatwin (1957, Table 1). The breakdown by area for the years 1939–44 is based on the distribution of fishing effort as reported by Cleaver (1949) and on the distribution of catch in 1945 based on Cleaver's unpublished sampling data. Methods of deriving the 1939–47 figures shown in Table 18 are given in Appendix 3. Records for 1948–53 are amended slightly from those of Alverson and Chatwin (1957). For this period of years errors of area designation are known to have existed (see Alverson, 1956, p. 66), but no correction has been attempted except for the year 1953. In the following year an improved system of statistical coverage was adopted in Washington State, and this has since provided a more reliable record of the fishery.

In spite of the errors which may be contained in Table 18, the data are considered to reflect with reasonable accuracy the general development of the fishery. From its early beginnings at the entrance to Juan de Fuca Strait (Areas 3B and 3C), the Washington fishery pressed northward (in 1944) to grounds off northern British Columbia. During this expansion phase (which lasted until about 1949) annual production of pretrale sole was maintained at about 5–6 million lb. In the succeeding 4 years the fishery remained confined to the continental shelf and no major grounds were discovered. During this period production fell sharply. In 1953, the year when Washington vessels discovered and began to exploit concentrations of petrale sole in deep water (Area $3D_{\Delta}$), production from the inshore banks was little more than 2 million lb. For several years catches in Area $3D_{\Delta}$ tended to offset the decline of inshore catches, but after 1957 restrictions were placed on the deep water fishery and total production again declined. In the period 1958–60, the average annual landing by Washington vessels was about 2.5 million lb, or roughly half of that in the peak years of 1943–48.

From 1960 to 1962, catches in Area 3C were bolstered somewhat by discovery and exploitation of grounds south of Forty-Mile Bank on the Cape Flattery Spit. Catches from these new grounds are included with those recorded under Area 3B in Table 18, because there is a possibility that they represent a previously unfished segment of the Area 3C stock and hence should be treated separately for purposes of consistency.

(b) CANADIAN RECORDS

Detailed coverage of the Canadian trawl fishery began in 1945 with the issuance of logbooks to vessel captains. However, this method of sampling was replaced in 1947 by a "trip interview" system which provided a broader and more representative picture of trawling activity. For most of the period of study this method of coverage has accounted for more than 80% of the British Columbia trawler landings.

Estimates of the catch of petrale sole, based on logbook and interview data, for the years 1945–62 are shown in Table 19. Figures for the years 1938–44 are merely approximations based on historical accounts of the rate at which Canadian interest in the trawl fishery for foodfish developed in waters outside of the Strait

TABLE 19. Canadian landings of petrale sole in thousands of pounds, according to area of capture.[a]

	1	2	3	4	5	6	7	8	9	10
	Washington coast		Vancouver Island coast			Queen Charlotte Sound		Hecate Strait		
	Lower	Upper	Lower	Estevan Deep	Upper	Cape Scott	Goose Island	Lower	Upper	
Statistical Area	3A	3B	3C	$3D_{\Delta}$	3D	5A	5B	5C	5D	Total[b]
1938	...	...	100	...	...	...	...	...	...	100
1939	...	...	150	...	...	...	...	...	...	150
1940	...	...	200	...	...	...	...	...	...	200
1941	...	...	250	...	...	...	...	...	...	250
1942	...	...	400	...	...	...	...	...	...	400
1943	...	...	450	...	...	...	...	...	...	450
1944	...	...	400	...	100	...	...	...	...	500
1945	...	...	359	...	213	28	164	16	27	807
1946	...	...	806	...	404	38	714	8	420	2,390
1947	...	...	263	...	124	125	149	264	809	1,734
1948	...	...	1,383	...	156	112	575	748	4,727	7,701
1949	...	...	1,107	...	210	120	259	1,069	510	3,275
1950	...	...	1,084	...	325	130	156	23	324	2,042
1951	...	...	646	...	178	123	106	223	310	1,586
1952	...	...	1,165	...	192	84	92	28	153	1,714
1953	...	...	838	...	29	42	65	...	67	1,041
1954	...	...	668	...	127	33	37	2	11	878
1955	...	...	379	...	193	17	14	17	27	647
1956	...	...	416	...	33	51	44	65	4	613
1957	...	...	522	...	13	148	49	106	212	1,050
1958	...	...	410	...	32	53	103	45	254	897
1959	...	...	408	...	13	44	85	76	175	801
1960	...	...	438	...	19	111	140	123	122	953
1961	...	...	453	...	21	128	96	7	206	911
1962	...	...	326	...	55	166	183	25	334	1,089

[a]Sources of data:

(1) *1938–44 inclusive:* Approximations based on Department of Fisheries records of "sole" landings.

(2) *1945–62 inclusive:* From Thomson and Yates 1960–62; Thomson and Lippa 1963–64.

[b]Excludes small catches from Area 4B, territorial waters of the Strait of Georgia, which amount to a few thousand pounds annually.

of Georgia. Trawlers based at Vancouver made their first appearance on grounds off the lower west coast of Vancouver Island (Area 3C) around about 1938. However, throughout the years of World War II, interest in fishing for petrale sole never reached the level experienced in the State of Washington. The bulk of the Canadian fishing effort was directed to exploitation of dogfish, which reached peak intensity in 1944.

Thereafter, increasing demand for foodfish coupled with declining fishing success for dogfish, resulted in a sharp increase in the production of sole and flounder species which rose from 2 million lb in 1943 to more than 9 million lb in 1946. In 1945 and 1946 the fishery for petrale sole extended rapidly from Area 3C to the waters of Queen Charlotte Sound (5A and 5B), but remained at a much lower intensity than that of the United States.

Working from a base at Prince Rupert and two other ports in northern British Columbia, Canadian vessels were briefly in a better position to attack the previously unexploited accumulations of petrale sole in northern and central Hecate Strait. Heavy concentration of fishing effort in that region raised the total Canadian production to an unprecedented 7.7 million lb in 1948. As shown in Table 19, this was the turning point of the fishery. In 1949 production was less than half of that in the previous year and thereafter it entered a long decline. Attention shifted to less valuable species (English sole, rock sole, and butter sole) which were available in greater abundance.

Throughout its history, the Canadian fishery for petrale sole, unlike that of the United States, has remained confined to the continental shelf. Although Canadian fishermen were aware in 1953 of developments in Area $3D_{\Delta}$ (Estevan Deep), they lacked the economic incentive to participate. Thus, with no compensatory fishing in deep water, Canadian production continued to decline, reaching a low point of 0.64 million lb in 1956. In subsequent years the catch on inshore banks improved, but remained far below the levels achieved in the 1946–49 period.

(c) CATCH WITH REFERENCE TO "STOCKS"

We are now prepared to consider the record of petrale sole production in terms of the stocks defined on p. 42. To obtain a general appreciation of removals from the southern stock in Canadian waters, data from columns 7, 4, and 3 in Tables 17, 18, and 19, respectively, are reproduced and combined in Table 20.

TABLE 20. Estimated removals in thousands of pounds from the southern Canadian stock of petrale sole (Area 3C), by Oregon, Washington, and British Columbia trawlers.[a]

Year	Oregon	Washington	British Columbia	Total	Year	Oregon	Washington	British Columbia	Total
1939	...	1,410	150	1,560	1950	...	798	1,084	1,882
1940	...	1,860	200	2,060	1951	...	1,105	646	1,751
1941	...	2,640	250	2,890	1952	...	924	1,165	2,089
1942	...	3,040	400	3,440	1953	...	810	838	1,648
1943	...	4,540	450	4,990	1954	2	793	668	1,463
1944	...	2,881	400	3,281	1955	2	534	379	915
1945	...	1,223	359	1,582	1956	...	819	416	1,235
1946	...	1,190	806	1,996	1957	...	846	522	1,368
1947	...	1,120	263	1,383	1958	3	717	410	1,130
1948	...	1,528	1,383	2,911	1959	...	1,734	408	2,142
1949	...	1,490	1,107	2,597	1960	5	1,714	438	2,157
					1961	...	1,992	453	2,445
					1962	...	1,549	326	1,875

[a]Consolidated from Tables 17, 18, and 19.

Similar consolidation of data pertaining to the northern stock (Areas $3D_{\Delta}$, 3D, 5A–5D) is shown in Table 21. Here, however, an effort has been made to retain the identity of catches made in certain broad regions occupied by the northern stock, as a means of emphasizing the possibility that subdivisions of this relatively large unit may be biologically just as distinct as the southern stock.

TABLE 21. Combined United States and Canadian removals in thousands of pounds from Statistical Areas representing the Canadian northern stock of petrale sole.[a]

	1	2	3	4	5	6	7	8
	Vancouver Island coast		Queen Charlotte Sound		Hecate Strait			
	Estevan Deep	Upper	Cape Scott	Goose Island	Lower	Upper		
Statistical Area	$3D_{\Delta}$	3D	5A	5B	5C	5D	Total (all areas)	Total (excluding $3D_{\Delta}$)
1944	...	1,100	668 (5A + 5B)		...	...	1,768	1,768
1945	...	596	1,540	1,842	359	67	4,404	4,404
1946	...	1,374	2,772 (5A + 5B)		1,088 (5C + 5D)		5,234	5,234
1947	...	1,034	2,174 (5A + 5B)		1,693 (5C + 5D)		4,901	4,901
1948	...	2,078	2,027 (5A + 5B)		6,637 (5C + 5D)		10,742	10,742
1949	...	697	945 (5A + 5B)		3,623 (5C + 5D)		5,265	5,265
1950	...	1,529	1,254 (5A + 5B)		1,543 (5C + 5D)		4,326	4,326
1951	...	672	718 (5A + 5B)		1,415 (5C + 5D)		2,805	2,805
1952	...	585	673 (5A + 5B)		1,266 (5C + 5D)		2,524	2,524
1953	250	269	862	130	102 (5C + 5D)		1,613	1,363
1954	1,124	445	295	221	662 (5C + 5D)		2,727	1,603
1955	621	376	831	187	207 (5C + 5D)		2,222	1,601
1956	465	177	1,029	135	116 (5C + 5D)		1,922	1,457
1957	2,673	236	615	118	477 (5C + 5D)		4,119	1,446
1958	151	232	301	199	377 (5C + 5D)		1,260	1,109
1959	150	350	232	120	138	339	1,329	1,179
1960	90	116	266	202	126	139	939	849
1961	455	156	234	143	7	217	1,212	757
1962	422	229	441	314	29	334	1,769	1,347

[a]Consolidated from Tables 17, 18, and 19.

The data for the southern and northern stocks (and the subunits of the latter) are illustrated in Fig. 13 for the purpose of showing the difference in the time when the "fishing up" of accumulated reserves occurred in each area. The timing is related to the northward advance of the fishery. The "fishing up" period for the southern stock occurred around about 1943, 1 or 2 years after maximum

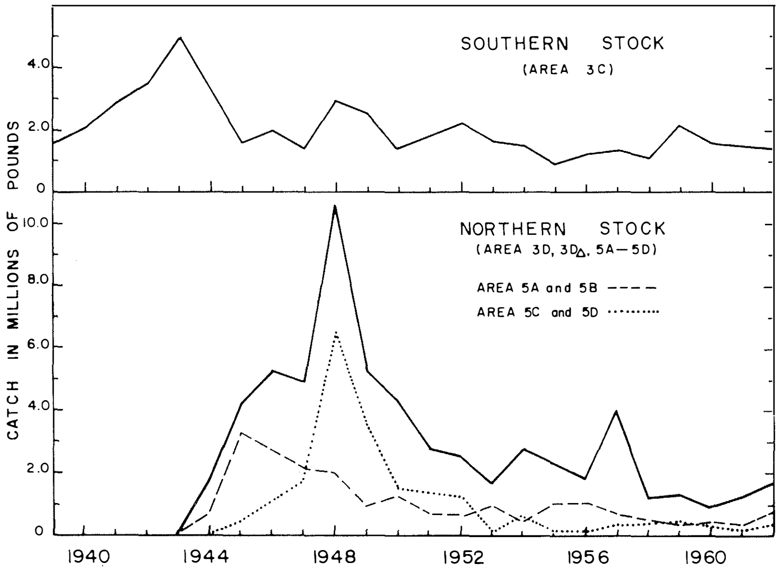


FIG. 13. Estimated total landings from the southern and northern stocks of petrale sole.

production had been achieved on the original fishing grounds off the Washington coast (Table 18, column 3). As production from the southern stock declined, the fishery pressed rapidly northward to Queen Charlotte Sound, where the process was repeated. There, the yield rose rapidly to a peak in 1945 and then started to decline. With the discovery of more attractive fishing grounds still farther to the north, the trawlers (Canadian in particular) converged on Hecate Strait. In that general area, production rose to a great height in 1948, only to fall with almost equal rapidity in the years thereafter. The various fishing grounds for petrale sole in the Queen Charlotte Sound and Hecate Strait areas are shown in Fig. 14.

Doubtless, if more detailed and reliable statistics were available, we would find that heavy production at the outset of fishing, followed shortly by a marked decline, was characteristic of events on individual fishing grounds or in smaller areas than these considered above. In Area 3B (Cape Flattery to Destruction Island on the Washington coast) greatest yield was achieved in 1941 and 1942. Cleaver (1949, p. 37) states that a small ground 12 miles from Cape Flattery furnished heavy sole fishing in the summer of 1941, but failed to supply more than occasional catches in following years.

No detailed information is available on the early history of catch from individual grounds in Area 3C (the southern stock). However, it was apparent to Cleaver that the fishery was being sustained only by spreading to new grounds. Grounds which supported the initial fisheries contained an accumulated supply of fish. Once this was reduced, the grounds never again contributed as heavily to the fishery.

The heavy fishery of 1948 in Hecate Strait was concentrated to a large extent on a 20-mile stretch of the bank between the Oval Hill and White Rocks grounds (Fig. 14).[12] In the following year, most of the catch came from the less accessible Horseshoe ground in lower central Hecate Strait (see column 8, Table 19).

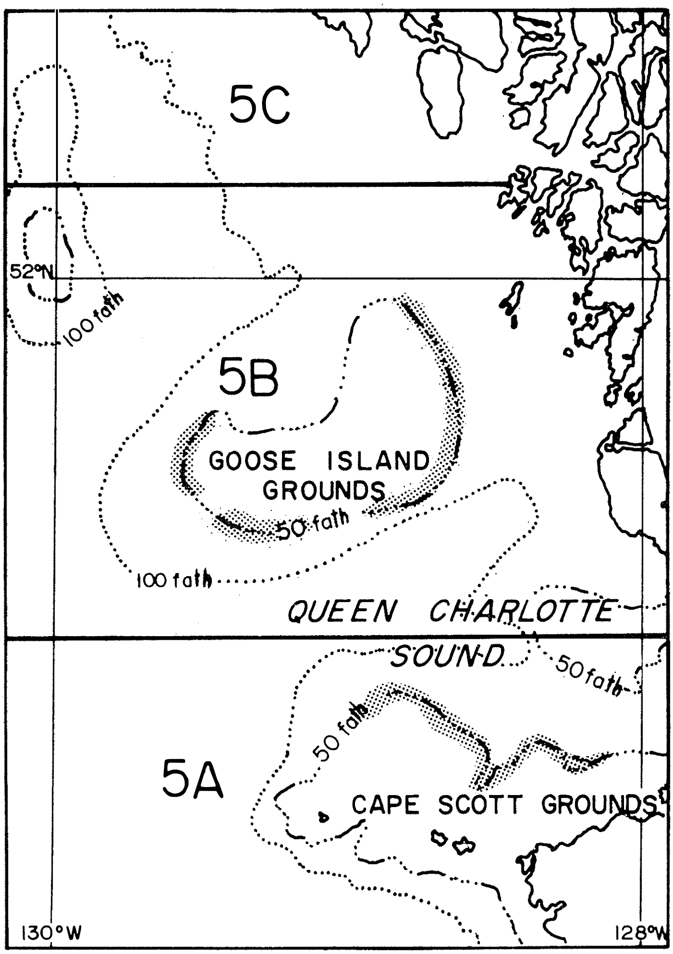


FIG. 14a. Principal fishing areas for petrale sole in Queen Charlotte Sound (Areas 5A and 5B).

[12]The Oval Hill ground itself accounted for a large share of the catch. This ground, a small spit lying at a depth of 39–42 fath (53°51′N, 131°1′W), is little more than a mile in length and $\frac{1}{4}$ mile in width. Yet in the short span of 4 months (from its discovery early in May to the middle of August 1948) it yielded more than 2.4 million lb of petrale sole to Canadian trawlers alone. Catch per effort remained at a high level throughout the summer, in spite of the heavy fishing. Late in August, however, both catch and catch per effort collapsed. From that time until the present, the Oval Hill ground has ceased to be of any importance as a petrale sole ground. In 1949, the catch by Canadian vessels was no more than 25,000 lb.

It is quite unlikely that this sharp change in fishing success was due entirely to the effects of fishing. The high concentration of fish in 1948 was probably the result of unusual environmental conditions which led to a heavy concentration of feed. In subsequent years, the petrale sole was more dispersed within the southern reaches of Area 5D, as well as being greatly reduced in abundance by the fishery, and as we shall see later, by declining recruitment.

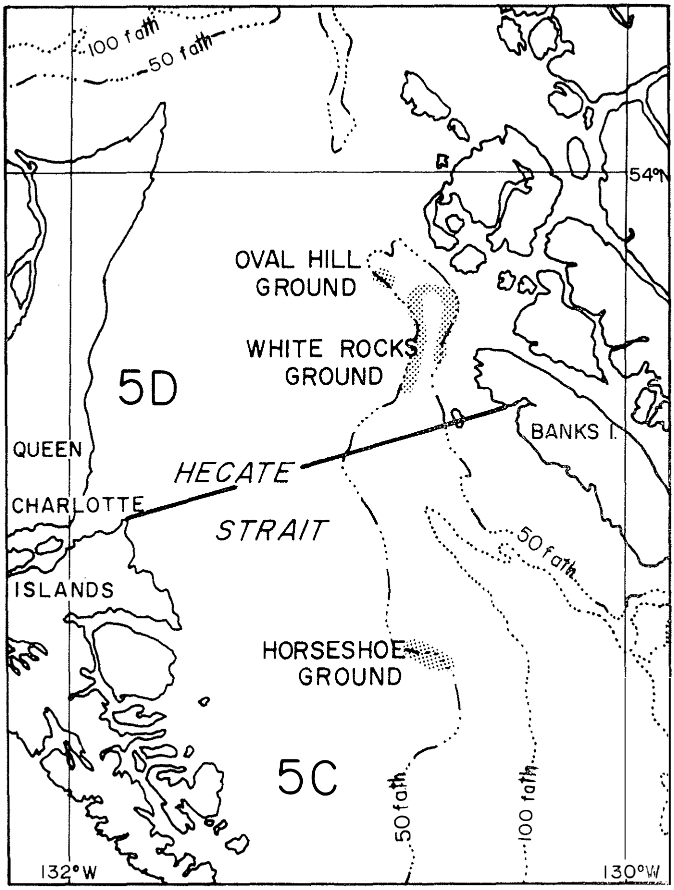


FIG. 14b. Principal fishing areas for petrale sole in Hecate Strait (Areas 5C and 5D).

The year 1949 marked the end of the "bonanza" fishing for petrale sole on inshore banks along the Canadian coast. Heavy concentrations were not to be found again until 1953 when the fishery moved off the continental shelf into the deep water.

2. Statistics of Catch per Unit of Effort

Measures of change in relative abundance of petrale sole are based primarily on records of catch per unit of effort obtained from the Canadian trawler fleet. These data extend in an unbroken series (at least for the southern stock) from 1945 to the present. More or less comparable data for United States trawlers are available in published form only for the period 1939–45 (Cleaver, 1949).

Before we outline the methods and results of catch-effort analysis, it is important to review briefly some of the problems which have to be confronted. In the first place, there is the problem of defining *effective* fishing effort. Rarely is petrale sole fished to the exclusion of other species. In Area 3C, for example, many other species of groundfish contribute to the trawl catch (Fig. 15 and Table 22). Several species, on occasion, have been of greater importance than petrale sole from the standpoint of bulk landed, and as a rule have been taken at about the same time of year and on approximately the same fishing grounds as the petrale sole.

TABLE 22. Canadian otter-trawl production in thousands of pounds from Area 3C, the lower west coast of Vancouver Island. Average by three-year periods.[a]

Species	1945–47	1948–50	1951–53	1954–56	1957–59	1960–62
Petrale sole	476	1,191	883	488	447	403
English sole	73	42	45	51	18	40
Rock sole	5	64	91	130	62	101
Dover sole	440	10	143	96	45	20
Rex sole	...	...	5	5	3	1
Flounder	64	72	56	89	13	48
Other flatfish	9	22	58	45	8	12
Pacific cod	376	440	993	1,515	1,425	570
Lingcod	330	838	765	1,245	1,037	1,030
Sablefish	5	21	38	47	125	149
Rockfish	144	22	69	70	21	30
Misc. species	198	46	41	45	12	32
Dogfish[b]	897	675	524	261	167	611
Animal food[c]	15	14	576	1,352	559	733
Total	3,032	3,457	4,287	5,439	3,942	3,780

[a]Data from Thomson and Yates (1960–62); Thomson and Lippa (1963–64).
[b]Liver weight converted to equivalent whole fish weight.
[c]Mainly turbot (*Atheresthes stomias*) and whiting (*Theragra chalcogramma*).

More so than other species petrale sole finds a ready market, and since World War II it has usually been the prime incentive to Canadian fishing in Area 3C and in some of the areas farther to the north. Yet one cannot overlook the fact that an experienced trawler captain can exert considerable control over the proportions of the various species caught — by selection of particular fishing grounds, depths, tidal stage, time of day, and by modification of his fishing technique. His tactics

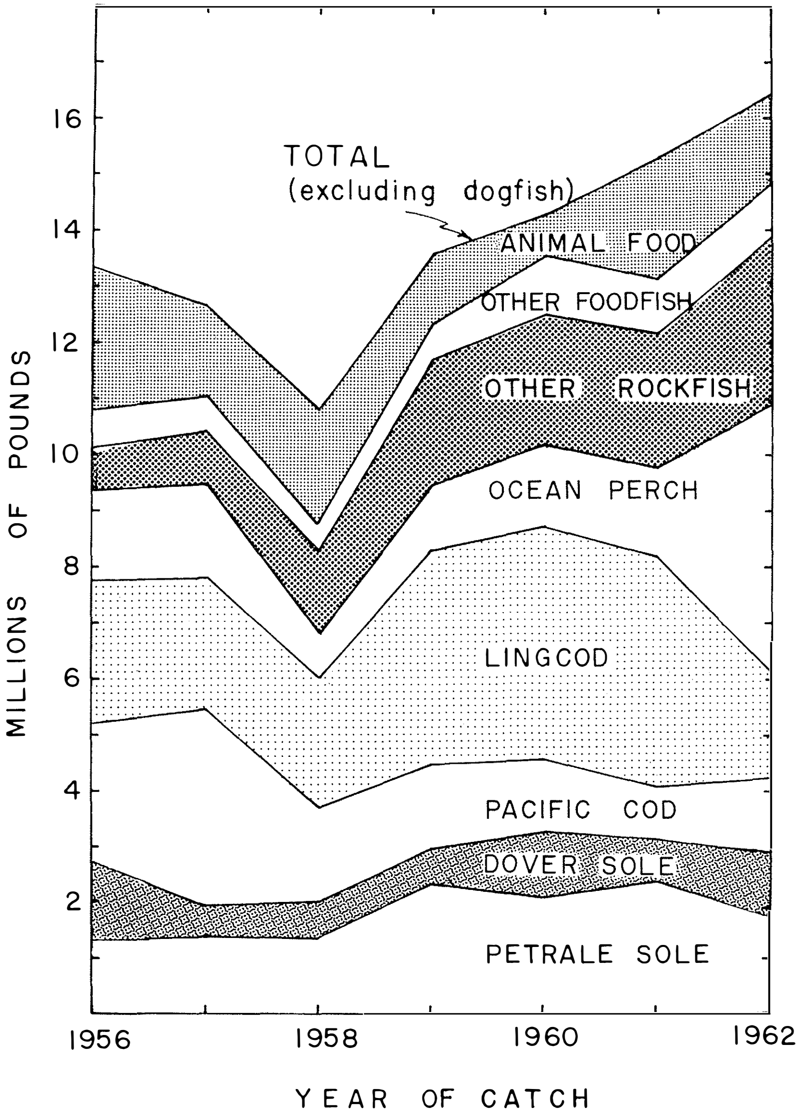


FIG. 15. Species composition of Canadian and United States trawler landings from grounds off southern Vancouver Island (Area 3C).

will be determined not only by current market conditions but also by relative availability of marketable species on the grounds. On occasion he might choose to disregard a species of relatively high unit value, if species of lower value are available in greater quantities. When several species acceptable to the market occur on the same fishing ground at a given time, his fishing technique will be less selective, but it must be presumed that he will endeavour at all times to modify his method of fishing to assure maximum monetary return for the effort expended.

The processes of selection are so dynamic and subtle that it is at times, impossible to make adequate allowance for them in the catch-effort analysis. Nevertheless, if we are to obtain a meaningful measure of abundance, some method must be devised to distinguish the effort directed to capture of petrale sole and to minimize the highly variable influence of fishing for associated species.

Another major problem, although not entirely separate from the above, concerns long-term changes in fishing efficiency, information which is essential to interpretation of trends in catch per effort. From the onset of the Canadian trawl fishery there has undoubtedly been an increase in the efficiency of operation. Through accumulated experience fishermen have become more and more familiar not only with fish behaviour and the peculiarities of particular fishing banks, but also with the methods of modifying their trawling gear to yield the greatest return per unit of effort. Designs of nets and accessory apparatus have changed and vessels have been equipped with more powerful engines and deck machinery. Aids to communication and navigation have improved greatly with the now universal acceptance of radiotelephones and depth recorders, and with the more recent appearance of LORAN and radar. All of these changes have had an important bearing on the development of a more efficient operation, and all have taken place during the relatively short history of the Canadian trawl fishery. From older fishermen one frequently hears the remark that trawling would no longer be economically feasible if original methods of fishing still prevailed. Yet the effects of changing efficiency on statistics of catch per unit of effort are not easy to evaluate in a quantitative way. Gross or unrefined information on catch per effort, if it indicates a long-term decline, presumably is an understatement of the actual situation.

In the sections which follow catch-effort statistics will be treated in such a way as to account, as far as possible, for the more obvious sources of bias which might be of importance in long-term comparisons. Insofar as the southern Canadian stock of petrale sole is concerned, the analysis will be restricted to a particular period of months within each year, to a particular fleet of vessels and type of gear. Data which qualify in this selection process will then be screened for the purpose of assessing effective fishing effort. Treatment of data pertaining to the northern stock will follow somewhat different lines because the region of study is more complex and involves years of discontinuous observation resulting from the low state of the fishery.

(a) SOUTHERN STOCK (AREA 3C) CATCH PER UNIT OF EFFORT

(i) *Selection of a fishing season.* Since its inception the Canadian fishery for petrale sole in Area 3C has been a seasonal one, limited partly by weather and partly by the availability of fish. Virtually all of the annual catch is made during the period April to October, inclusive. While over the long term most of the catch has been accounted for during the months of May to August, there has been a trend towards increased importance of the autumn fishery (Table 23). In some years the success of the fishery has depended largely on events in the months of September and October.

TABLE 23. Monthly distribution of petrale sole catch in thousands of pounds by the Canadian fishery in Area 3C (lower west coast of Vancouver Island).

														May–August	
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total	Catch	Percentage
1945	...	1	...	28	120	93	37	34	40	*	6	...	359	284	79.2
1946	...	...	22	20	392	62	28	119	106	50	...	7	806	601	74.6
1947	*	*	...	5	85	59	7	47	35	11	...	13	263	198	75.3
1948	...	1	2	15	186	177	165	296	410	131	...	...	1,383	824	59.6
1949	...	*	1	40	158	160	270	254	194	26	3	...	1,107	842	76.0
1950	...	...	*	27	137	291	336	212	69	11	*	*	1,084	976	90.0
1951	...	*	*	39	101	127	214	103	57	6	...	...	647	545	84.3
1952	...	...	3	19	64	156	271	197	436	18	1	...	1,165	688	59.0
1953	...	...	8	25	88	249	107	94	258	10	...	...	839	538	64.2
1954	...	2	6	9	111	103	116	114	99	86	22	...	668	444	66.5
1955	*	...	*	4	34	62	115	18	37	107	1	...	379	229	60.4
1956	...	*	*	2	13	42	21	21	68	245	4	...	416	97	23.3
1957	...	...	...	*	19	51	18	78	287	68	1	...	522	166	31.8
1958	...	...	*	*	17	31	45	106	114	94	3	...	410	199	48.6
1959	...	...	*	1	15	23	68	48	148	100	4	...	407	154	37.9
1960	...	...	*	2	13	30	38	101	145	95	15	...	439	182	41.5
1961	...	...	...	9	31	47	101	144	52	65	4	...	453	323	71.3
1962	...	...	...	2	36	30	103	35	95	20	6	...	327	204	62.4

*Less than 500 lb.

Records of the monthly distribution of catch in Area 3C by the United States fleet are incomplete. However, as noted by Cleaver (1949, p. 33), during the early years of the fishery by Washington vessels (1943–45) the bulk of the petrale sole landings occurred between the months of April and October. Information for more recent years, beginning in 1955, suggests that this general pattern has persisted throughout the history of the United States fishery in Area 3C. However, it is known that the United States and Canadian fleets do not fish with equal emphasis on the various grounds within that area, and this is reflected in the marked differences in distribution of catch by month by the two fleets. Monthly catches for sample years (1955–59) are provided in Appendix IV.

Because of the lack of unbroken and detailed information on the United States fishery, it is necessary to confine our consideration to Canadian data. This embodies the rather tenuous assumption that observations on the Canadian fishery are representative of the whole, with respect not only to measures of abundance but also to composition of the catch.

Concerning the Canadian fishery in Area 3C, it might seem logical to adopt a standard fishing season which extended from May through October. However, there are complications. The success of the September–October fishery is highly

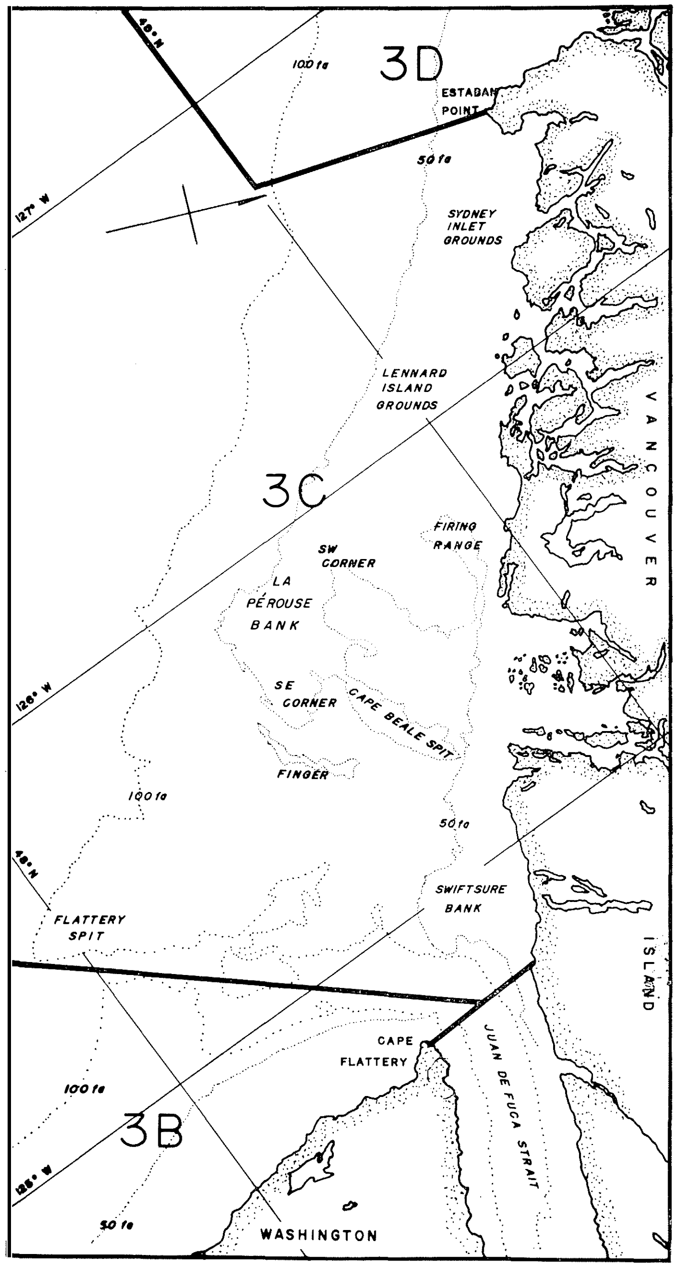


FIG. 16a. Fishing banks along the southern coast of Vancouver Island (Area 3C).

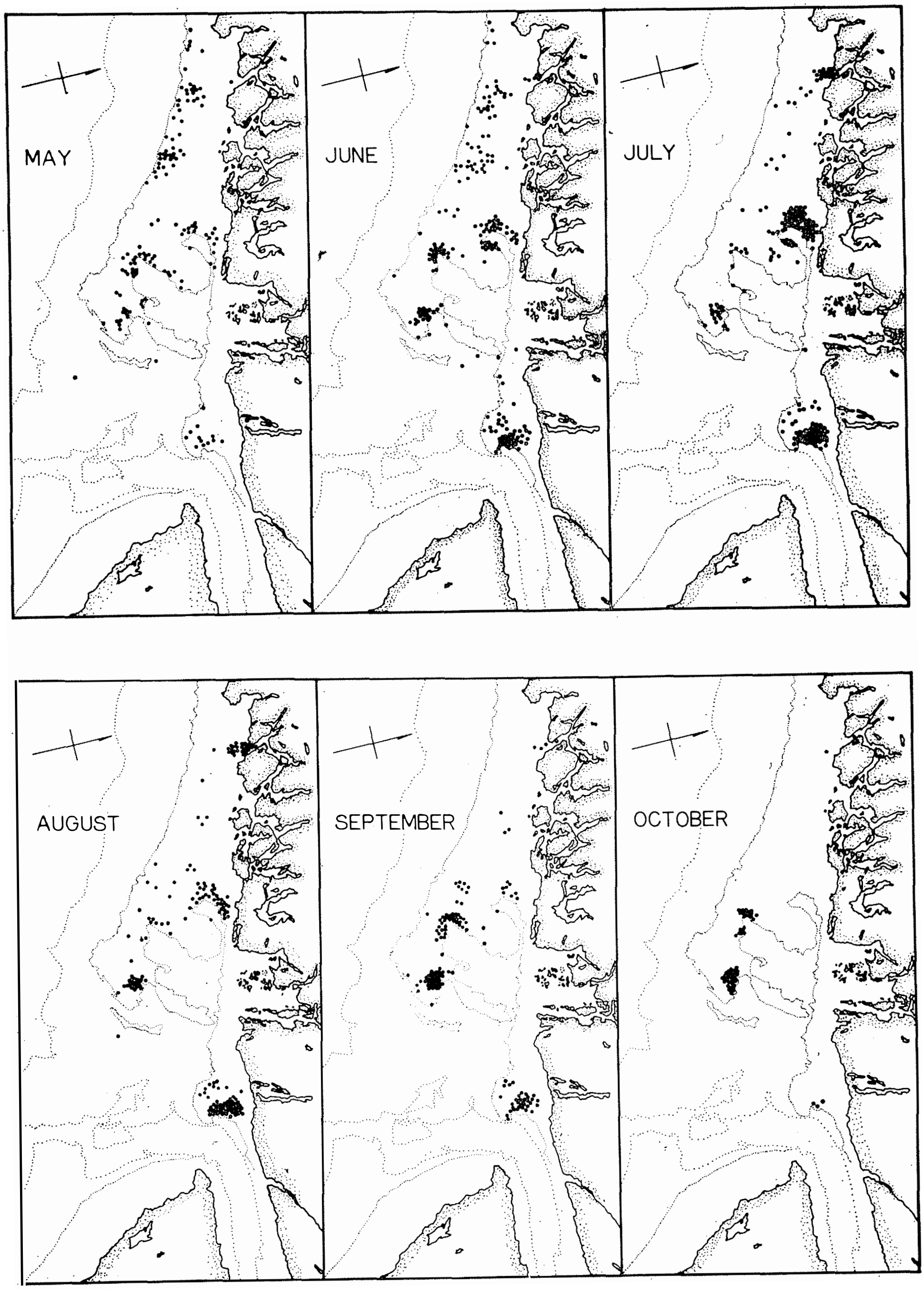


FIG. 16b. Monthly distribution pattern of the fishery for petrale sole in Area 3C. Each dot represents the fishing location of individual Canadian vessels reporting catches of petrale sole.

variable partly because of weather conditions. When autumn fishing is possible, catch per unit of effort is generally much higher than that experienced earlier in the year, because by then the distribution pattern of the fishery (and presumably of petrale sole also) has changed noticeably. This is illustrated in Fig. 16, which has been constructed on the basis of observations made between 1948 and 1953 — years of most active Canadian interest in petrale sole.

The Canadian fishery begins in earnest in the month of May. At that time petrale sole appear to be moving onto the southern Vancouver Island banks on a rather broad front (Fig. 16b). On grounds north of the Firing Range to Estevan Point, most of the fishing occurs close to the 50-fath contour. By June it has spread closer to shore with a noticeable build-up on the Sydney Inlet grounds and on four important grounds farther to the south: the Firing Range, Swiftsure Bank, the SW corner, and SE corner of La Perousse (Forty-Mile) Bank. This pattern is more or less maintained through August. However, in September and October the fishery diminishes greatly on grounds close to shore and becomes concentrated on the SW and SE corners of La Perousse Bank (Fig. 16b). It is concluded that during September and October the petrale sole vacate the inshore grounds and concentrate on La Perousse Bank before making their descent to the deep water spawning areas. This is supported by results of tagging on the inshore banks.

Figure 17 shows the monthly distribution of the Canadian catches on the four main fishing grounds within Area 3C. On the average, May and June are the months of greatest production from the Lennard Island–Sydney Inlet grounds. Emphasis then shifts to the Firing Range and Swiftsure Banks in July and August, and then to La Perousse Bank in September.

Monthly averages of catch per unit of effort (details of which will be discussed later) are shown in Fig. 18 for Area 3C as a whole. These illustrate the highly variable nature of the September–October fishery (concentrated phase) as compared with that in the late spring and summer months (dispersed phase). The sharp variations in catch per effort in the late season must be regarded as changes in the availability of the stock to the fishery, rather than as changes in actual abundance. Accordingly, to minimize the availability factor, it is appropriate to reject initially the September–October data in calculations of seasonal average catch per effort. In a later chapter (p. 69) we shall examine the consequences of using a longer season than that of May to August.

(ii) *Selection of a standard unit of fishing effort.* Along the Pacific coast of North America vessels which engage in ottertrawling are almost exclusively of the seine boat type. In British Columbia they range in size from about 10 to 110

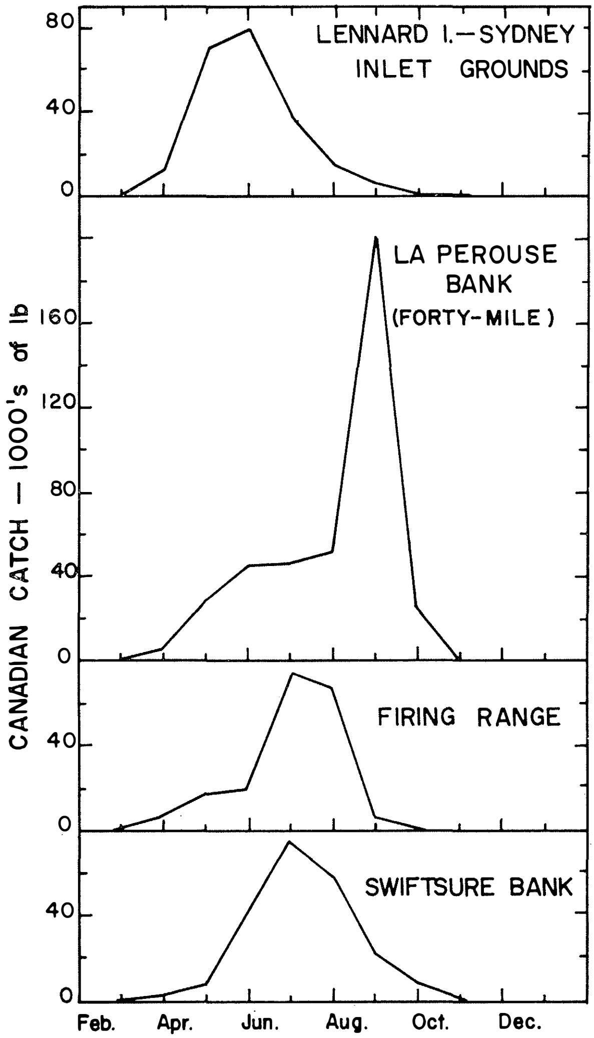


FIG. 17. Monthly distribution of Canadian landings of petrale sole from various fishing grounds within Area 3C.

gross tons, but the majority are within the range of 20–50 gross tons. While this simplifies the problem of establishing a standard size of vessel, we must still contend with the fact that two types of trawling gear of different efficiency are used in the Canadian fishery. The majority of trawlers operating in Area 3C, at least until 1957–58, were rigged with what is popularly referred to as "single-gear." This is in contrast to the so-called "double-gear" or "American gear" used exclusively by United States trawlers and most of the Canadian trawlers which operate on the northern grounds of Queen Charlotte Sound and Hecate Strait. The basic difference between the two types of gear is that in one case the net is towed by two separate warps, and in the other by a single warp with bridle (Forrester and Ketchen, 1963, Fig. 16).[13]

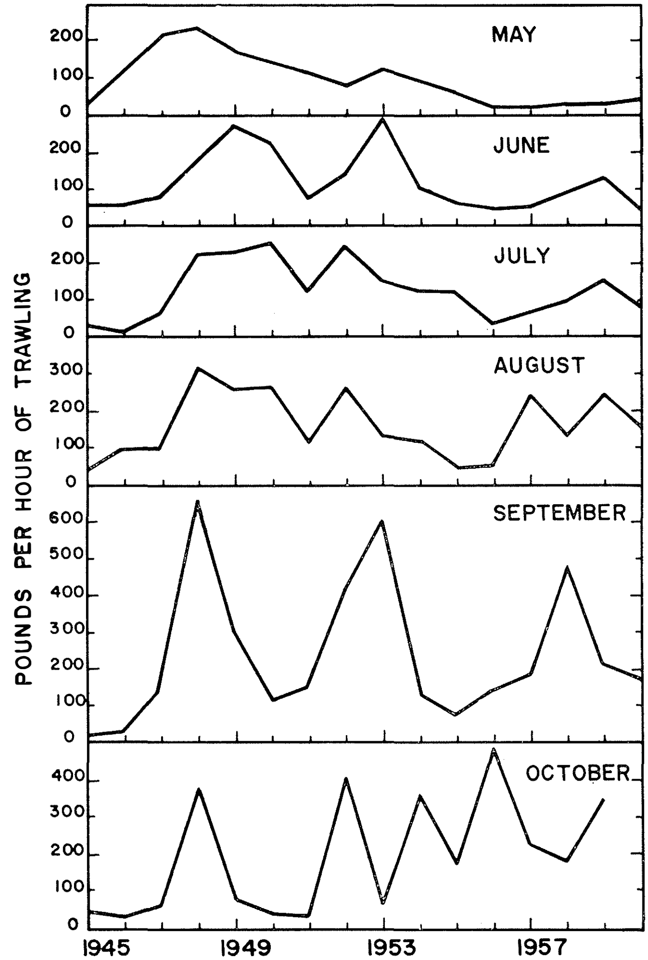


FIG. 18. Average Canadian catch of petrale sole per unit of effort in Area 3C.

[13]There is a tendency for double gear to be more efficient than single gear (particularly in deep water) because of a greater spread between the boards. This is achieved by the independent suspension of the boards and the generally longer warps or extensions between the boards and net. As yet it has not been possible to make a reliable assessment of the difference in efficiency, largely because it is difficult to compare the performance of the gear independent of the personal capabilities of the vessel captains. The ratio of double gear catch per effort to single gear catch per effort varies from as low as 0.5 to as high as 3.0, depending on the area fished and the composition of the fleets compared (Ketchen and Thomson, 1958). In the areas which concern us here, the ratio is usually between 1.2 and 1.6.

During the years when conversion to double gear was taking place, it was apparent that the more successful fishermen were doing so first. Presumably because of their higher efficiency they made more money and hence could better afford the cost of converting to double gear. Thus, the apparent difference between single and double gear is in part due to the fact that it is the more efficient fishermen who operate double gear vessels. In theory, their withdrawal from the single gear class would reduce the average fishing success of that class.

Vessels employing single gear have played a far more consistent role in the Canadian fishery in Area 3C than those with double gear, and the composition of the former group has been more consistent in respect to average gross tonnage (see Table 24). For these reasons and to avoid the effects of a possible increase in efficiency through partial conversion of the fleet to double gear after 1955, the calculations of catch per effort are based on the performance of single gear vessels up to and including 1961. During the period 1958–61 single and double gear vessels were present in about equal numbers and the latter were found to be about 1.5 times more efficient than the former. By 1962 single gear vessels were in the minority, so rather than rely on catch per effort of those vessels, the average catch per effort of double gear vessels was divided by 1.5 to obtain an estimate of catch per effort expressed in terms of single gear.

Within the single gear category, the analysis is restricted to a standard class of vessel — those between 10 and 49 gross tons. As shown in Table 24 their average size has ranged narrowly between 26 and 33 gross tons during the period of study, with no indication of long-term trend. Similarly, there has been no trend in average brake horsepower which has varied between 66 and 88 BHP during the 16-year period.

Thus, selection of single gear vessels of 10–49 gross tons to a large extent rules out the possible changes in efficiency which may be related to type of gear and size of vessel. As mentioned earlier, however, numerous other factors such as accumulated experience of the fishermen, improvement in fishing aids and net designs, cannot be accounted for in a quantitative way. Thus, where there are downward trends in catch per effort over the long term, they are likely to be underestimated to some extent.

(iii) *The problem of defining effective fishing effort.* Having now selected a particular fishing season and class of fishing vessel, we come to the problem of distinguishing between fishing effort which is directed to capture of petrale sole (effective effort) and that which is not. If only those records of catch and effort are used in which petrale sole dominate over all species in an individual landing (i.e. records which leave no doubt as to the intention of the fisherman) the data might fail to demonstrate a decline in abundance (if such were actually occurring) or at least understate it. As the decline progresses, the element of chance encounter becomes more and more important, and the only indication of decreasing abundance would be in the decreasing frequency of landings in which petrale sole predominated.

At the other extreme, if we use all fishing effort, regardless of whether it resulted in the capture of petrale sole, we would expect the decline in abundance to be overstated. As the petrale sole stock declines, more and more emphasis is placed on other species to compensate for decreased production, and this diversion of effort would have an accelerating effect on the apparent decline of petrale sole.

TABLE 24. Frequency distribution by gross tonnage class of Canadian trawlers operating in Area 3C during the months of May–August.

Gross tonnage class	1945	1946	1947	1948	1949	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962
	Numbers of vessels																	
Single Gear																		
10–19	2	3	5	3	2	3	6	6	3	3	6	3	1	2	1	1	3	1
20–29	5	4	4	2	3	4	7	6	4	6	8	5	6	6	4	6	3	2
30–39	10	6	8	7	12	5	4	4	4	7	8	6	5	5	3	3	3	1
40–49	2	3	3	3	2	4	3	2	3	2	2	1	1	...	...	...	1	...
50–59	2	1	...	1	...	1	1	...	1	...	...	...	...	...	...	...	...	...
60–69	2	...	2	2	...	1	1	...	...	1	...	...	...	...	1	1	...	...
70–79	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Total number	24	20	22	18	19	18	22	18	15	19	24	15	13	13	9	11	10	4
Average tonnage																		
all vessels	38	32	33	36	33	35	30	26	33	32	28	29	31	28	32	31	27	26
10–49 class	31	31	30	31	33	32	27	26	31	30	28	29	31	28	28	28	27	26
Double Gear																		
10–19	...	...	...	...	1	1	...	...	...	1	1	1	1	1	...	1	1	...
20–29	...	...	...	...	...	...	...	...	...	1	...	1	1	3	2	2	2	2
30–39	...	...	...	1	1	1	1	...	1	1	1	3	3	3	3	2	4	5
40–49	...	1	...	...	...	1	...	...	1	1	1	2	4	4	5	6	5	3
50–59	1	1	...	...	1	...	1	...	...	...	...	1	...	1	...	1	1	1
60–69	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	2	1
70–79	...	...	1	...	1	...	1	1	1	...	...	1	...	...	...	...	...	1
>100	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1	...
Total number	1	2	1	1	4	3	3	1	3	4	3	9	9	12	10	12	16	13
Average tonnage	55	52	74	35	45	34	56	78	54	28	30	40	37	36	38	34	44	42

Accordingly, it is reasonable to suppose that selection of catch records in which the ratio of petrale sole to other species is somewhere between the above-mentioned extremes would provide catch per effort estimates which more accurately reflect the true trend in abundance. However, when we come to examine the petrale sole data for Area 3C we find a problem of interpretation which is illustrated by Fig. 19. The numbers of landings by single gear vessels in the May–August period of each year have been assigned to three arbitrary groups: the landing of petrale sole constituted (a) 40% or more (by weight) of the total fare, (b) 25% or more, and (c) 10% or more. As shown in the figure, the numbers of trips at all three thresholds declined sharply after 1950. By 1956 no landings qualified at the 40% and 25% thresholds, and only nine (or 15%) of the landings consisted of petrale sole qualifying at the 10% level.

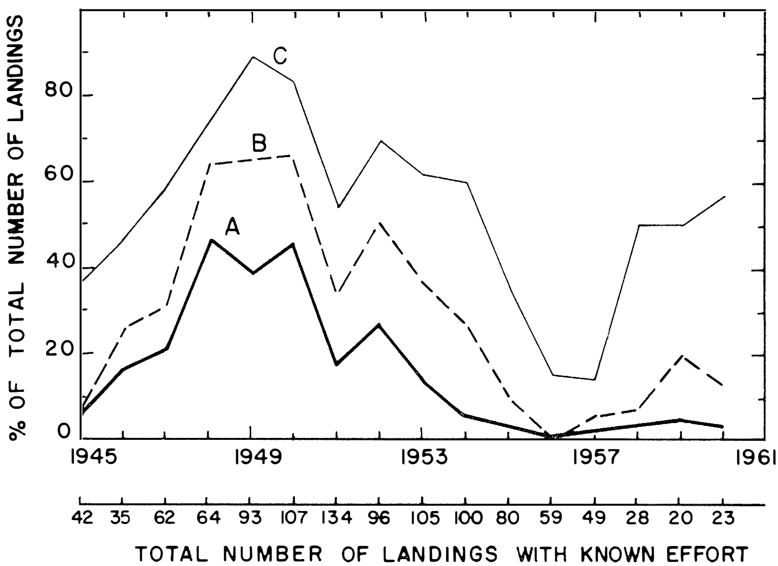


FIG. 19. Percentage of Canadian single-gear trawler landings from Area 3C (May–August, inclusive) where the petrale sole/total catch ratio was (A) 40% or more, (B) 25% or more, and (C) 10% or more.

Clearly, the petrale sole had become relegated to an incidental role in the Area 3C fishery. No basis exists for establishing a continuous criterion of effective or significant fishing effort. Even if we were to use a relatively low threshold value (say, 10%) it would involve such a small number of landings by 1956 and 1957 that little reliance could be placed on the estimates of catch per effort. Therefore, in order to maintain the continuity of observation, it is necessary to reduce the level of qualifications still further, namely, to the point where we include all landing records (and corresponding effort) in which petrale sole were reported, regardless of the absolute amount or its percentage of the total fare. The consequences of such a procedure are considered in the following section.

(iv) *Estimates of seasonal average catch per effort.* Four methods of calculating catch per effort, based on the above-mentioned threshold values of catch, are now to be considered:

Method A. Catch and effort data based on landings in which petrale sole amounted to 40% or more of the landed fare.

Method B. Petrale sole 25% or more of the landed fare.

Method C. Petrale sole 10% or more of the landed fare.

Method D. Petrale sole recorded in the catch (no threshold specified).

TABLE 25. May–August petrale sole catch in thousands of pounds, effort (hours) and catch per effort (pounds) by Canadian single gear vessels operating in Area 3C. Data separated by various methods of computing catch per effort (see text).

	1	2	3	4	5	6	7	8	9	10	11	12
	Method D			Method C			Method B			Method A		
Year	Catch	Effort	C/E	Catch	Effort	C/E	Catch	Effort	C/E	Catch	Effort	C/E
1945	68	1,266	54	54	648	83	22	154	143	19	62	307
1946	93	843	110	90	441	204	70	223	314	66	184	359
1947	188	1,478	127	172	1,087	158	155	754	206	90	392	230
1948	460	1,658	277	456	1,541	296	417	1,242	336	313	872	359
1949	527	2,237	236	522	2,109	248	452	1,656	273	313	961	326
1950	677	3,057	221	670	2,689	249	598	2,184	274	475	1,499	317
1951	480	4,288	112	421	2,721	155	326	1,810	180	184	880	209
1952	479	2,491	192	446	2,101	212	388	1,583	245	264	874	302
1953	452	2,336	194	420	1,829	230	296	1,100	269	144	378	381
1954	381	3,545	107	319	2,472	129	188	1,185	159	61	274	223
1955	182	2,328	78	126	977	129	60	338	178	23	118	195
1956	69	1,275	53	21	251	84	...	...	...	...	...	...
1957	79	898	88	45	168	274	31	65	477	3	7	(428)
1958	75	689	109	59	435	136	4	20	(200)	...	...	...
1959	73	515	142	65	297	219	34	112	303	5	33	(151)
1960	92	863	107	83	593	139	32	159	200	13	43	300

The resulting estimates of seasonal average catch per hour[14] are compared in Fig. 20 (data from Table 25). For a number of years (1947–55, inclusive), there was fairly close agreement as to order of variation and trend in lines B, C, and D. Even line A showed some agreement with the others but, as was to be expected (see page 63), it failed to indicate any overall trend.

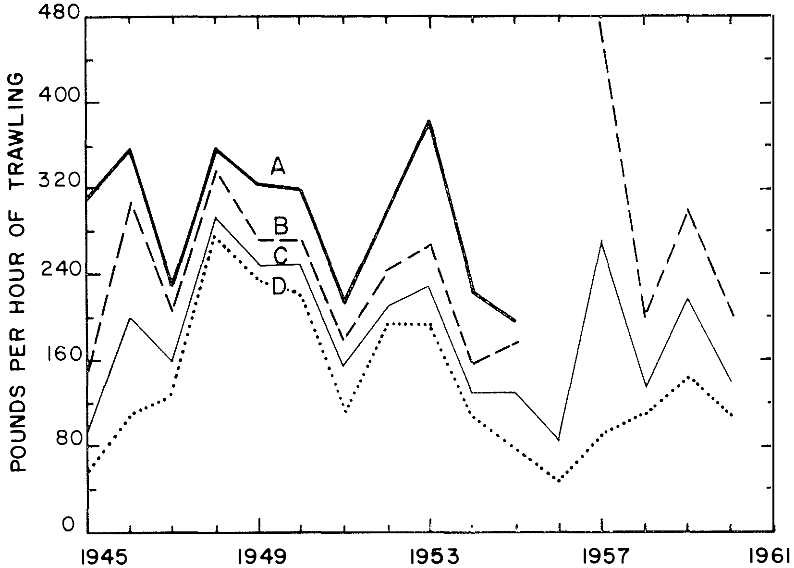


FIG. 20. Seasonal (May–August) average catch per unit of effort in Area 3C based on various thresholds of the ratio of petrale sole to total catch: (A) 40%, (B) 25%, (C) 10%, and (D) any occurrence of petrale sole in catch.

If we were to use the lowest threshold in calculating the index of abundance (Method D) for the 1947–55 period, the conclusions would be essentially the same as those based on higher threshold (10% or 25% — Methods C and B, respectively). After 1955, however, comparisons are impossible because of inadequate data; although line C (with the exception of 1957) still retained some conformity with line D. We have no choice but to accept the results of Method D as being representative of the period 1956–60, and as the only basis from which we can assess the long-term change in catch per effort. As mentioned previously, a downward trend in catch per effort based on all catch and effort will, in theory, tend to overstate the actual decline in abundance. This possible bias is acknowledged, but it will be offset to some extent by bias in the other direction from the effects of known but unquantifiable changes in gear efficiency.

[14]Total Canadian catch of petrale sole in the 4-month period (May–August) was divided by the corresponding total effort to obtain an average catch per effort, weighted to catch.

Acceptance of Method D requires that some adjustment be made for the relatively low levels of catch per effort for 1945 and 1946. The reason for this is to reduce the effects of the fishery for dogfish, which in those 2 years was pursued with such intensity that, during the course of a fishing trip, foodfish were often ignored until just before a vessel had to return to port to refuel and obtain provisions.[15] For convenience of later reference the estimates of seasonal average catch per effort from column 3 of Table 25 are reproduced in Table 26 (and Fig. 21) with the adjusted values for 1945 and 1946.

TABLE 26. Southern stock of petrale sole (Area 3C). Statistics of catch in thousands of pounds, catch per effort (lb per hour)[a] and calculated total effort (hours).

Year	C	C/E	E	Year	C	C/E	E
1945	1,582	161[b]	9,830	1953	1,648	194	8,490
1946	1,996	241[b]	8,280	1954	1,461	107	13,650
1947	1,383	127	10,890	1955	913	78	11,710
1948	2,911	277	10,510	1956	1,235	53	23,300
1949	2,597	236	11,000	1957	1,368	88	15,540
1950	1,882	221	8,520	1958	1,127	109	10,340
1951	1,751	112	15,630	1959	2,142	142	15,080
1952	2,089	192	10,880	1960	1,643	107	15,350[c]
				1961	1,618	112	14,440
				1962	1,401	141	9,940

[a]Seasonal (May–Aug.) average catch per effort based on the performance of single gear trawlers in the 10–49 gross tonnage class.

[b]Adjusted values. See footnote No. 15.

[c]Cape Flattery Spit catches in 1960–62 deleted for purposes of computing total effort.

The latter table contains also the data on total catch from Area 3C (from Table 20) which have been used to compute the total fishing effort in each year. The advisability of this extrapolation deserves some consideration, for it is conceivable that large errors would emerge from the calculation of total effort (f)

[15]Method D eliminates those effort data which involved whole trips spent in fishing exclusively for dogfish (as it did for 1956 when the fishery was sometimes exclusively for scrapfish or lingcod), but does not exclude data involving trips in which a large part (but not all) of the effort was directed to dogfish. Theoretically, this would make the estimates of catch per effort for 1945 and 1946 too low.

In Fig. 20 we note in the years 1947–51 that the values of catch per effort derived by Method A (or Method B) were fairly consistent in their difference from those of Method D. For those years catch per effort from Method D averaged 0.72 times the mean value of Methods A and B. In 1945 and 1946 (the latter in particular) the difference between the mean value from Methods A and B and the value from Method D was relatively great. In 1945 the mean of Method A and B was 225 lb/hr (see Table 25). Using the above-mentioned factor for 1947–51, the corrected value for Method D is 225 $\times$ 0.72 or 161 lb/hr, and the corrected value for 1946 is 336 $\times$ 0.72 or 241 lb/hr.

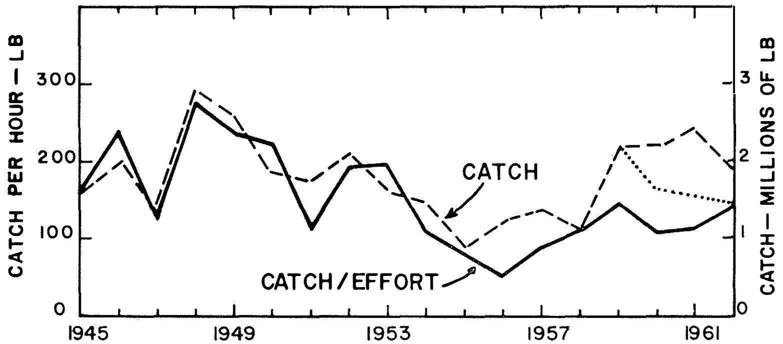


FIG. 21. Petrale sole catch and calculated seasonal (May–August) average catch per unit of effort in Area 3C.

if the amount of known effort (f_k) used in the calculation of seasonal catch per effort (c_k/f_k) were but a small fraction of the residual or unknown effort (f_r). In so doing we are assuming that $c_k/f_k : c_r/f_r : C/f$. Yet, in section (i) above, we chose to reject September and October data from the calculation of seasonal average catch per effort simply for the reason that, on the basis of Canadian data alone, c_k/f_k is not proportional to c_r/f_r.

In the absence of effort data on the United States fishery we can go only so far in exploring the possible error involved in the estimation of total effort. For instance, we can disregard the strict qualifications heretofore employed in analysis of the Canadian data, and recompute seasonal average catch per effort based on a longer season (May–October) and on the performance of all Canadian trawlers regardless of tonnage or type of gear. The results are compared in Fig. 22 with

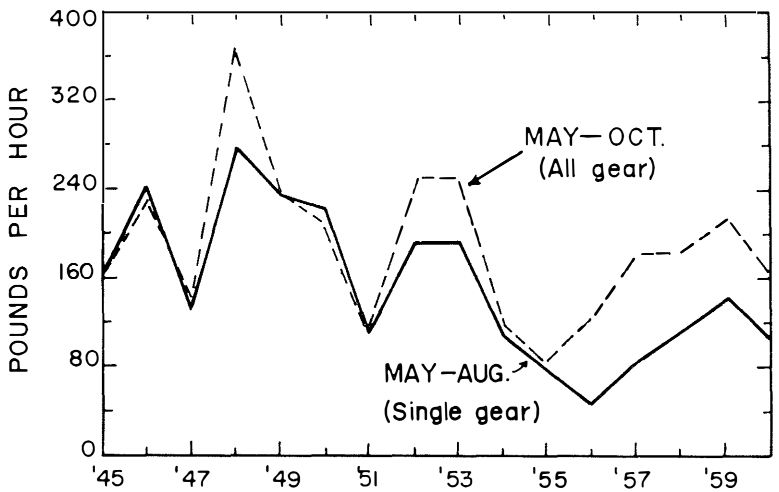


FIG. 22. Comparison of calculated average May–August and May–October catch per unit of effort in Area 3C.

those already provided for the May–August period (from Table 26). The effect is to raise the estimates of catch per effort from 1948, 1952, 1953, and all years subsequent to 1955.

Recalculated estimates of total effort based on the May–October data are provided in column 10 of Table 27. When these are compared with the estimates derived from the May–August data (Table 26), reasonable agreement is found for years up to and including 1955. Thereafter, there is a difference in trend as well as in absolute values. The main reason for this is that after 1955 less than half of the Canadian catch was obtained during the May–August period (see last column of Table 23). As a result, the calculated total effort based on May–August catch per effort tends to rise (irregularly) over the long term, whereas that based on May–October data shows no sign of sustained trend.

TABLE 27. Comparison of catch-effort data for Area 3C, May–October, total effort (hours) obtained by dividing total catch in Table 26 by corresponding figures in Column 9.

	1	2	3	4	5	6	7	8	9	10
	Single Gear			Double Gear			All Gear			Calculated total effort
Year	C	f	C/f	C	f	C/f	C	f	C/f	
	1,000 *lb*	*hr*	*lb*	1,000 *lb*	*hr*	*lb*	1,000 *lb*	*hr*	*lb*	*hr*
1945	78	(490)	(159)	...	...	...	78	(634)	(123)	12,860
1946	107	(477)	(226)	16	(54)	(296)	123	(531)	(231)	8,640
1947	236	1,680	140	1	70	14	237	1,750	135	10,250
1948	780	2,214	352	172	363	474	952	2,577	369	7,890
1949	682	2,957	231	153	543	282	835	3,500	239	10,860
1950	735	3,508	210	146	668	218	881	4,176	211	8,920
1951	543	4,716	115	62	754	82	605	5,470	111	15,780
1952	848	3,340	254	8	80	100	856	3,420	250	8,360
1953	707	2,888	245	40	105	380	747	2,993	250	6,590
1954	556	4,374	127	33	533	62	589	4,907	120	12,170
1955	269	2,998	90	39	605	65	308	3,603	85	10,740
1956	288	2,689	107	92	329	281	380	3,018	126	9,800
1957	207	1,552	133	252	930	271	459	2,482	185	7,390
1958	176	1,002	175	145	730	199	321	1,732	185	6,090
1959	149	805	185	213	905	235	362	1,710	211	10,150
1960	140	1,120	125	231	1,105	209	371	2,225	167	9,840

In Chapters VI and X of this report we shall be concerned with measurements of change in recruitment and mortality rate, which depend on conclusions regarding changes in catch per effort (relative abundance) and fishing effort. Since we are faced with two somewhat different pictures of catch per effort and effort trends, it will be necessary to consider both possibilities in later developments.

(b) NORTHERN STOCK (AREAS 3D, 5A–5D) CATCH PER UNIT OF EFFORT

The method of describing changes in relative abundance of the so-called northern stock of petrale sole is somewhat different from that used on the southern stock, the main reason being the lack of a sufficient volume of data. After the brief period of relatively heavy removals (1945–49), Canadian catch of petrale sole from Area 3D northward to 5D, inclusive, never amounted to more than 1 million lb annually, and by 1956 it had fallen to less than 0.2 million lb. Thus, for this large and geographically complex region of the British Columbia coast there is a scarcity of reliable information, which forces us to be less particular about the selection of a fishing season and a standard unit of fishing gear. Also it is necessary to group the data for individual statistical areas into larger units.

(i) *Selection of areas (substock units) and fishing season.* It will be recalled that results of inshore (summer) tagging showed relatively little exchange between adjacent banks in northern British Columbia waters, which suggested the existence of a number of more or less independent subunits of the northern stock. On the other hand, it is evident that at least some of the petrale sole from each major bank come together during the winter months on the Estevan spawning ground (Area $3D_{\Delta}$). Thus, we cannot say with certainty whether the petrale sole on northern grounds should be treated as one large unit of stock or as a number of relatively independent units. To accommodate these two possibilities, we shall consider catch per unit of effort data for two "substock" units: Queen Charlotte Sound (Areas 5A and 5B combined) and Hecate Strait (Areas 5C and 5D combined), and then consolidate the data into a single picture for the entire northern region (Areas 3D–5D combined).[16]

In referring to the Hecate Strait substock we are dealing with all of Area 5C but only that part of Area 5D to the south of 54°N latitude (see Fig. 14). To the north of that line there is an important trawl fishery for English sole, rock sole, and Pacific cod, where, even in the early days of fishing, petrale sole were only of incidental importance. By excluding this northern part of the Hecate Strait bank, namely, from the Warrior grounds to the Two Peaks grounds, we exclude a large parcel of fishing effort which in none of the years past was devoted specifically to the capture of petrale sole.

The Canadian fishery for petrale sole in Queen Charlotte Sound and Hecate Strait has a longer season than that off southern Vancouver Island. In computing seasonal average catch per effort the period April through October has been used for Queen Charlotte Sound, and April through December for Hecate Strait. Lack of adequate data prevents examination of intra-seasonal differences, as was done with the Area 3C data (Fig. 18).

[16]Area 3D, although included in the overall picture of catch per effort in the northern stock, is excluded from detailed consideration as a substock unit. The main reason for this is that Area 3D, more so than areas farther to the north, seems to be populated at times by transient fish proceeding from the Estevan spawning ground (Area $3D_{\Delta}$) to Queen Charlotte Sound and Hecate Strait, or *vice versa*. As it is impossible to distinguish effectively between transients and residents, it would be inappropriate to treat the data for that area as though they applied to a distinct unit of stock.

(ii) *The unit of fishing effort.* On fishing grounds to the north of Vancouver Island, the conversion of Canadian trawlers from single to double gear occurred much earlier than in the south. By 1948 about half the Canadian catch of petrale sole in both Queen Charlotte Sound and Hecate Strait was taken by double-gear trawlers, and by 1949 the share had increased to 85%.

It is known that in those years double-gear vessels tended to outfish single-gear vessels by 1.5:1. However, insufficient information is available to say how much of this difference in efficiency was due to the type of gear and how much was due to vessel size or to the skill of vessel captains. Up to 1948 most of the double-gear vessels were of a size ranging from 62 to 65 gross tons, whereas single-gear vessels were usually within the range of 33–37 gross tons. Thereafter, as the remaining single-gear trawlers converted to double gear the average tonnage of the latter group decreased (and presumably so also did its average efficiency). As the data are too sparse to permit a reliable correction for changes in efficiency, we are forced to make no distinction between the types of trawling gear used. Thus, it is possible that the decline in catch per unit of effort after 1948 (as shown in section (iv) below) has been understated.

(iii) *Effective fishing effort.* In the initial years of trawling in Queen Charlotte Sound and Hecate Strait, there was no difficulty in distinguishing fishing effort directed to the capture of petrale sole. Landings contained such a high proportion of petrale sole that there could be no doubt as to the intention of the vessel captains. However, this situation changed very rapidly after 1948. By the early 1950s landings in which petrale sole predominated had become a rarity. For example in 1953, out of 81 landings from Queen Charlotte Sound and Hecate Strait in which petrale sole were reported, only six of these consisted of more than 25% petrale sole, and only three of more than 40%. By 1955 there were only seven landings out of 58 which qualified even at the 10% threshold.

Thus, to maintain continuity of observation it has been necessary to follow the same procedure as that used for Area 3C, namely, to compute average catch per effort from those landings (and corresponding effort) in which petrale sole were recorded, regardless of the amount. This treatment corresponds to Method D used for Area 3C (p. 66).[17]

[17] As far as Hecate Strait and Queen Charlotte Sound are concerned, this procedure eliminates fishing effort which in no way (either in the early days of the fishery or later) involved petrale sole — the widespread fishing exclusively for dogfish prior to 1947 and the deepwater fishery for ocean perch in Queen Charlotte Sound which developed after 1954. The effects of the fisheries for English sole, rock sole, and Pacific cod on grounds in Area 5D to the north of 54°N lat (where petrale sole catches have always been incidental) have already been eliminated (see p. 71). The remaining sources of bias involve those grounds to the south of 54°N which are (or have been at some time) cohabited by petrale sole and other marketable species (principally Pacific cod and rock sole). There, catches of petrale sole may be incidental to those of other species, but there is no way of distinguishing them from those that are not incidental. Thus, in the presence of a long-term and pronounced decline in true abundance of petrale sole, incidental catches would tend to increase in proportion to "intentional" ones, and as a result the catch per effort trend would be accentuated, i.e. overstated.

In summary, the computation of catch per unit of effort for the northern British Columbia grounds has been based on, (a) a fishing season extending from April through October in Queen Charlotte Sound, from April through December in Hecate Strait, (b) the performance of Canadian trawlers irrespective of gear type or vessel tonnage (but predominantly double gear after 1948), and (c) only those effort data pertaining to landings in which petrale sole were reported (irrespective of the absolute amount or percentage of the total fare).

(iv) *Estimates of seasonal average catch per effort.* Columns 1–5 of Table 28 provide the available information on seasonal average catch per effort in each of the major statistical areas inhabited by the northern stock of petrale sole.[18] From these we obtain weighted mean values for larger regions. Column 6 (Queen Charlotte Sound) is the mean of columns 2 and 3, weighted to Canadian catch in Areas 5A and 5B (from Table 19, columns 6 and 7). Similarly, column 7 in Table 28 (Hecate Strait) is the mean of columns 4 and 5, weighted to the Canadian catch in Areas 5C and 5D. These weighted values of catch per effort are illustrated in Fig. 23, along with corresponding data on total catch.

TABLE 28. Seasonal average catch of petrale sole (lb) per hour of trawling, by Canadian vessels in areas inhabited by the northern stock. (See text).

	1	2	3	4	5	6	7	8
Area	3D	5A	5B	5C	5D	5A+5B	5C+5D	All Areas
1945	89	234	406	375	399	327	379	243
1946	119	96	395	115	569	380	561	362
1947	197	319	519	530	672	428	637	561
1948	273	222	419	923	1,077	387	1,056	964
1949	387	366	247	938	499	285	796	667
1950	335	295	268	987	448	280	484	373
1951	257	529	208	459	978	380	761	573
1952	303	109	145	224	423	128	392	276
1953	336	131	255	...	367	147	367	278
1954	284	123	139	21	480	130	110	241
1955	201	57	48	305	400	55	363	211
1956	105	52	47	155	...	51	155	94
1957	65	110	70	198	297	104	264	198
1958	115	59	67	106	184	61	172	134
1959	105	57	81	181	209	65	201	155
1960	276	96	79	170	158	89	164	131
1961	85	116	72	39	174	97	170	130
1962	204	122	119	84	346	120	328	224

[18]Since we are dealing here exclusively with the performance of Canadian vessels no comparable data can be given for Area $3D_{\Delta}$, the spawning ground which has been fished only by United States vessels.

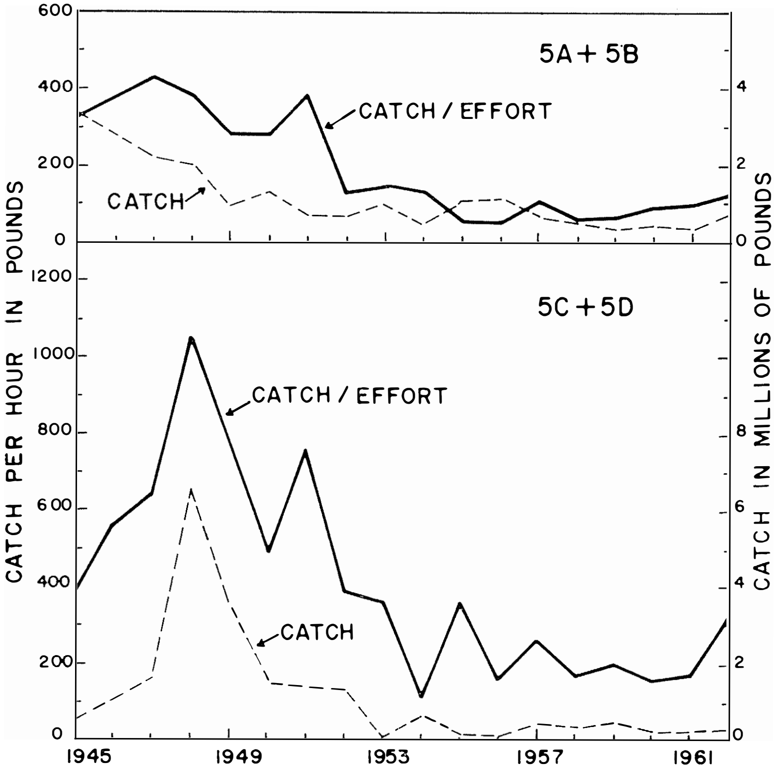


FIG. 23. Petrale sole catch and calculated average catch per unit of effort from the Queen Charlotte Sound (5A and 5B) and Hecate Strait (5C and 5D) segments of the northern stock.

In Queen Charlotte Sound, the highest average catch per effort was recorded in 1947 (428 lb/hr). Thereafter, it declined fairly steadily, and finally stabilized at about 75 lb/hr during the 1956–60 period, i.e. at about 15% of the 1947 value. In Hecate Strait highest catch per effort was recorded in 1948 at 1056 lb/hr. After a rapid decline in the ensuing 6 years, a condition of relative stability was achieved between 1956 and 1960 at about 190 lb/hr, or at 18% of the value in 1948. Thus, the decline in apparent abundance was of about the same order of magnitude in both regions. It compares well with that observed in the southern stock (Area 3C) to the extent that catch per effort there by 1956 was only 16% of that observed in 1948 (based on the May–August single gear estimates from Table 26). However, in the latter case, there was a tendency for it to rise after 1956 rather than stabilize around the level achieved in 1956.

In respect to the northern stock as a whole, a single picture of the change in catch per effort is provided by an average of the estimates given in columns 1–5 of Table 28, weighted to Canadian catch (columns 5–9 in Table 19).[19] This weighted average is given in column 8 of Table 28 and also illustrated in Fig. 24 along with corresponding data on total catch from all northern areas. Catch excluding removals from the Estevan spawning ground (Area $3D_\Delta$) is shown separately. This distinction is appropriate since it is the latter set of data which bears closest correspondence to the data on catch per effort. Both apply to the inshore fishery.

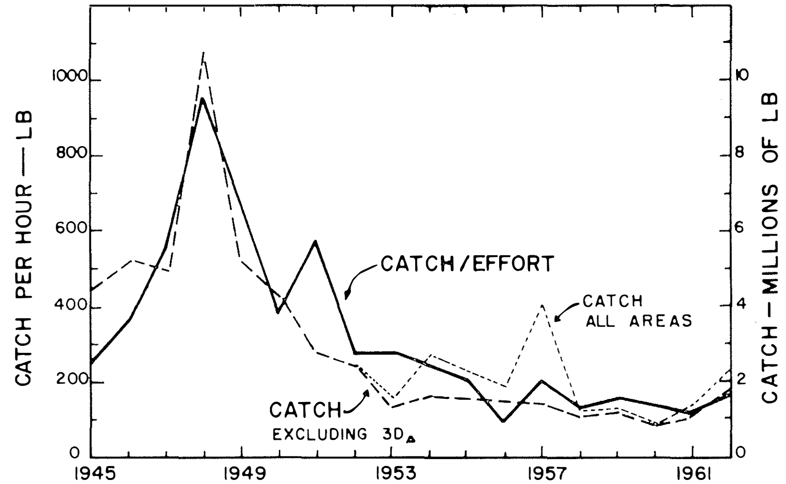


FIG. 24. Combined data on the catch of petrale sole and calculated average catch per unit of effort from the northern stock. Catch excluding that from the Estevan Deep (Area $3D_\Delta$) applies to the traditional inshore fishing grounds.

To complete the presentation of statistics relating to the fishery on the northern stock, estimates of total fishing effort have been calculated for the Queen Charlotte Sound and Hecate Strait regions and for northern British Columbia as a whole (see Table 29). These figures are little more than rough approximations of the true effort, and in some years they are obviously much in error. For example, in 1955 and 1956 unrealistically high effort was calculated for the Queen Charlotte Sound region (Areas 5A and 5B). Canadian catch per effort and catch were low in both years and they applied to a fishery which began in April and ended in September. On the other hand, United States catches were relatively high and were made largely before April and after October in both years. Thus, more so than in other years, the United States fishery corresponded very poorly with the Canadian fishery in point of time. Presumably, catch per effort was relatively high

[19]An alternative procedure is to weight the various estimates to the total catch (rather than just the Canadian catch). This was considered undesirable in view of the uncertainties attending the area designation of United States catches, particularly for the years 1946–52. Nevertheless, the results are essentially the same as those given in Fig. 24.

TABLE 29. Calculated total trawling effort (thousands of hours) in Queen Charlotte Sound (Areas 5A and 5B), Hecate Strait (Areas 5C and 5D), and for all areas occupied by the northern stock of petrale sole.

	Regions				Regions		
Year	5A+5B	5C+5D	All Areas[a]	Year	5A+5B	5C+5D	All Areas[a]
1945	10.3	1.1	18.1	1953	6.8	0.3	4.9
1946	7.3	1.9	14.5	1954	3.8	6.0	6.7
1947	5.1	2.7	8.7	1955	18.5	0.6	7.6
1948	5.2	6.3	11.1	1956	22.8	0.8	15.3
1949	3.3	4.6	7.9	1957	7.1	1.8	7.3
1950	4.5	3.2	11.6	1958	8.2	2.2	8.3
1951	1.9	1.9	4.9	1959	5.4	2.4	7.6
1952	5.3	3.2	9.1	1960	5.3	1.6	6.5

[a]Includes effort in Area 3D (upper west coast of Vancouver Island (but excludes Estevan Deep fishery (Area $3D_{\Delta}$).

in months before and after the April–September period in each year. However, by simply dividing annual total catch by the April–September average catch per effort we are assuming that the latter is representative of other times of the year as well. This assumption obviously did not apply in 1955 and 1956.

If we examine the calculated effort for all regions combined the anomalous situations are considerably reduced.[20] While there remains some need for caution in the interpretation of these data, it appears that total effort followed an irregular, downward trend from 1945 to 1953, and then, with the exception of 1956, remained fairly steady from 1954 to 1960 (varying between 6500 and 8300 hours).

In both the northern and southern stocks the calculated effort for 1956 was exceptionally high (cf. Tables 26 and 29). While part of the explanation is to be found in the type of bias described in the above paragraph, there can be no doubt that in 1956 the availability of petrale sole (the fraction of the stock available to the fishery) was less than in other years. This makes the apparent abundance too low and of course the calculated effort too high.[21]

[20]Note in Table 29 that in some cases effort for "All Areas" is less than the sum of the effort in the other two columns. This is to be expected since catch per effort for "All Areas" was not the sum of the catch per effort for individual areas, but rather a mean value weighted to catch in each area.

[21]These remarks are intended merely to stress the importance of recognizing that, while overall trends in effort or catch per effort are probably reliable indicators of major events, their absolute values or even their relative values for immediately adjacent years may be misleading.

We shall return to the subject of fishing effort in a later section dealing with estimations of mortality rates.

In the foregoing discussion of catch per effort trends in the northern stock, remarks have been limited largely to data pertaining to years subsequent to 1947. It will be noted in Fig. 23 and 24 that catch per effort in 1945 and 1946 was lower than that in years immediately following, in spite of the fact that the fishery was then operating on primitive or only lightly exploited stocks. This raises the question of whether the upward trend in catch per effort was a reflection of increasing abundance as the fishery got underway, or merely a reflection of changing gear efficiency. This same phenomenon was observed in Area 3C and remained evident even after at least partial compensation was made for side-effects of the dogfish fishery (Fig. 21). In Area 3C, however, the petrale sole fishery was no longer in a primitive state, having by 1945 been in existence for 6–7 years.

There can be no doubt that trawl fishermen's preoccupation with dogfish was one of the factors responsible for low catch per effort of petrale sole in 1945 and 1946. But it was not as important in the northern areas as in Area 3C, where fishing grounds for petrale sole and dogfish were virtually identical. Another factor, and perhaps the most important one, was the advent of the depth recorder (echo-sounder). This equipment made its appearance in the Canadian trawl fishery about 1944, but not until 1947 was its adoption more or less universal. Thus, the fact that average catch per effort tended to be lower in 1945 and 1946 than in years immediately following, may have been a reflection of a difference in trawler efficiency, i.e. in the ability of fishermen to find fishable ground and to "hold" a particular depth while trawling. On the other hand, it is known that on grounds off the west coast of Vancouver Island in 1945, petrale sole were unusually scarce, and this was part of the reason for the fishery's rapid expansion northward to Queen Charlotte Sound that year. Thus, some uncertainty attends the interpretation of catch per effort trends prior to 1948. In later discussion of measures of year-class strength we shall consider two possibilities: that the change in catch per effort between 1945 and 1948 was largely a reflection of (i) change in gear efficiency, or (ii) change in actual abundance.

(c) SUMMARY OF CATCH PER EFFORT TRENDS

Between 1948 and 1956 catch per effort respecting the southern and northern stocks of petrale sole underwent a sharp decline, about 80% to 85% in each case. This was paralleled by a decline in the total production of petrale sole by Canadian and United States trawlers. In the short space of 8 years the petrale sole fell from a position of dominance in the fishery to one of only incidental value. While some improvement in catch per effort (as well as total catch) has been observed in the southern stock since 1956, no sign of recovery has been observed in the northern stock.

The decline in catch and catch per effort, superficially at least, is in general accord with classical examples of the response of a stock to fishing. At the outset, yield from the stocks of petrale sole was relatively high, but it could be sustained only by expansion of the fishery to new grounds. Once the expansion had been completed, catch as well as catch per effort began to fall. Annual replacements did not keep pace with annual removals. This condition persisted for a number of years until finally equilibrium was reached, or at least approached, at a very low level of stock. A level below which a fishery specifically for petrale sole was no longer economically feasible.

In theory an initial rapid drop in catch per effort is to be expected, for the fishery soon exhausts the accumulation of old, slow growing fish which comprised the primitive stock. If annual removals do not exceed annual net replacement (growth in weight plus recruitment minus natural mortality), then the stock very quickly reaches a new state of equilibrium, usually at some point considerably below that which prevailed prior to exploitation.

If, however, the stock fails to stabilize quickly, that is, replacements fail to offset removals, then one (or both) of two things may be happening: (i) the rate of exploitation may be persistently increasing beyond the point which provides maximum yield from a given (constant) recruitment, or (ii) recruitment itself is declining.

Chapter V

CHANGES IN LENGTH AND AGE COMPOSITION OF CANADIAN PETRALE SOLE STOCKS

1. Method of Sampling

Observations on year-to-year changes in length and age composition of petrale sole are based primarily on market sampling. In British Columbia the sampling programme had its beginning in 1944 at the port of Vancouver. Thereafter, as techniques were improved and staff facilities expanded, sampling was increased and extended to such ports as Prince Rupert and Victoria. Routine sampling of certain grounds off southern British Columbia actually was initiated by the State of Washington in 1942, but this was discontinued after 1945. Results for those years have been reported by Cleaver (1949).

In order to avoid interference with the handling and processing operation in the fish plants, measurements and otolith samples were taken from the carcasses or "frames" of petrale sole collected at the end of the filleting line. This procedure has been followed throughout the period of study. Comparison of fork lengths of petrale sole before and after filleting showed that frame length is less than 1% more than round length (Forrester, unpublished data).

For various reasons, principally the variable distribution of fishing effort and the sampling demands respecting other species, it was rarely possible to conduct sampling of petrale sole in such a way that the number of fish per sample or the number of samples was proportional to catch or abundance in each area. Samples ranging in size from 150 to 400 fish were taken as frequently as possible and from as many localities as possible. Later, in the laboratory, the sampling data were weighted approximately to the distribution of catch by month and area in order to obtain a reasonably representative picture of the seasonal average size or age composition.

The left-hand or blind-side otolith was used for age determination. The method of collection has been described elsewhere (Ketchen, 1956b, p. 669–670). Where individual samples consisted of large numbers of otoliths, the labor of age determination was reduced by stratified subsampling (see Ketchen, 1949, for method). Where a large number of samples was available for a particular month and area, several samples were selected at random for age determination, and the results were prorated to the length–frequency composition of all samples combined.

The validity of age determination is discussed in a later section (p. 86).

2. Changes in Length Composition

(a) southern stock

The seasonal (May–August) average length of male and female petrale sole belonging to the southern stock, namely, those found in Statistical Area 3C, are illustrated in Fig. 25 (data from Table 30). This is an aggregate picture based on the combination of samples from the six fairly distinct fishing grounds in Area 3C (see Fig. 16a).

Table 30. Average total lengths of male and female petrale sole in Canadian commercial landings from all of Area 3C (southern stock) and from Swiftsure Bank within Area 3C.

1	2	3	4	5	6	7	8	9
	All Area 3C				Swiftsure Bank only			
	Male		Female		Male		Female	
Year	Numbers of fish	Average length	Numbers of fish	Average length	Numbers of fish	Average length	Numbers of fish	Average length
		mm		*mm*		*mm*		*mm*
1944	48	400	136	451	...	...	...	...
1945	281	375	546	437	81	389	135	432
1946	989	385	1,547	428	102	387	188	429
1947	494	361	786	409	100	343	139	377
1948	1,827	379	3,128	420	285	372	439	401
1949	3,274	389	3,491	430	891	386	1,045	422
1950	3,385	387	5,998	438	699	386	2,301	438
1951	1,945	398	4,353	453	308	404	722	445
1952	1,906	403	2,596	453	520	405	539	440
1953	2,691	411	4,315	466	1,007	407	1,544	464
1954	1,640	407	3,314	464	124	408	473	464
1955	882	408	1,975	472	123	428	625	490
1956	804	409	1,360	453	207	422	457	462
1957	795	395	2,723	457	36	388	163	452
1958	2,029	401	3,278	446	246	408	654	446
1959	985	394	1,914	442	102	405	226	451
1960	1,036	388	2,183	437	276	392	479	435
1961	780	384	2,398	433	265	399	897	438
1962	1,431	389	2,711	436	184	401	858	447

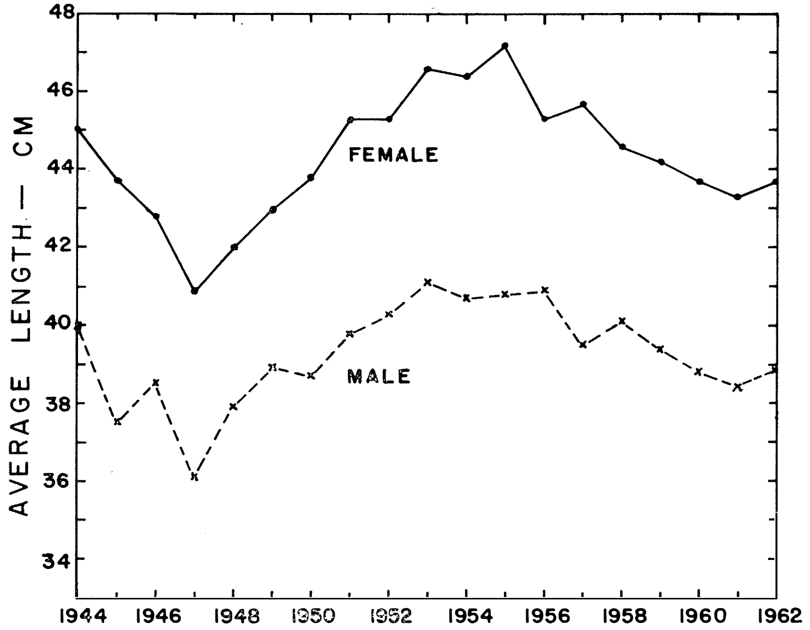


FIG. 25. Variations in average lengths of male and female petrale sole contained in Canadian catches from Area 3C.

In order to make use of data for the early years of the United States fishery in Area 3C, the data for Swiftsure Bank are shown separately in Fig. 26 (data from Table 30).[22]

In the data for Area 3C as a whole and for Swiftsure Bank, identical phenomena are apparent. During the early 1940s, the average lengths of petrale sole declined abruptly. This trend terminated in 1947, after which there was a pronounced increase in average size which was maintained until about 1955. Thereafter there was once again a downward trend, though less abrupt.

The initial decline in average size, which apparently was underway at least as early as 1942, occurred during the period of greatest annual removals from the southern stock. Superficially, it was fully in accord with theory regarding the response of the stock to intensive fishing. Cleaver (1949, p. 40) concluded that the numbers of large fish on the grounds had decreased and that this was probably the result of the fishery.

After 1947, however, average length of fish in the catch, instead of achieving a state of equilibrium at a relatively low level, began to increase rapidly. By 1955 the average lengths of male and female fish apparently were as high as they had been about 1942, near the outset of the fishery. Yet it was in 1955 that catch per unit of effort reached its lowest point on record!

[22]Sampling data for the years 1942–45, inclusive, from the unpublished records collected by Mr F. C. Cleaver, have been made available through the kind cooperation of the Washington State Department of Fisheries.

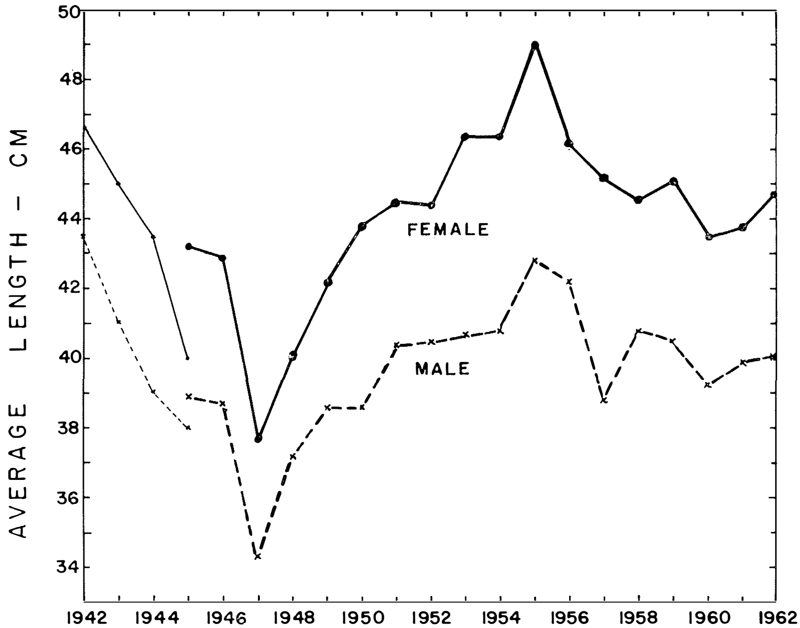


FIG. 26. Variations in average length of male and female petrale sole contained in Canadian landings from Swiftsure Bank in Area 3C (1945–62); United States landings (1942–45) from Cleaver MS.

The most obvious explanation of this phenomenon is that, unlike some of the classical examples from European literature (e.g. the plaice of the North Sea), annual recruitment of young fish to the southern stock of petrale sole had been far from uniform. There have in fact been pronounced trends in the recruitment to the stock (p. 88). Such is also apparent in analysis of length composition. Fig.27 shows the percentage length frequency distribution of male and female fish from the southern stock. For comparison these distributions are plotted as deviations from a 16-year mean (1945–60). A dome of positive anomalies (frequency above the long-term average) occupied the smaller size groups of fish (below 45 cm in female fish) from 1945 to about 1950. Thereafter, this dome progressed to the right of the 45 cm mark, and was still apparent as late as 1959. Obviously, year-classes of better than average strength entered the fishery in the mid forties. They were followed by year-classes of below average strength until at least as late as 1955.

However, it is impossible to say just how much the changes in recruitment affected the change in average size of fish in the catch. Apparently, the fishery began on large accumulations of fish in a primitive state of abundance and proceeded with such intensity that it could not have failed to change the proportions of small and large fish on the grounds. Yet at the same time pronounced changes were taking place in the numbers of recruits becoming available to the fishery each year. It remains to be determined which of these factors was dominant.

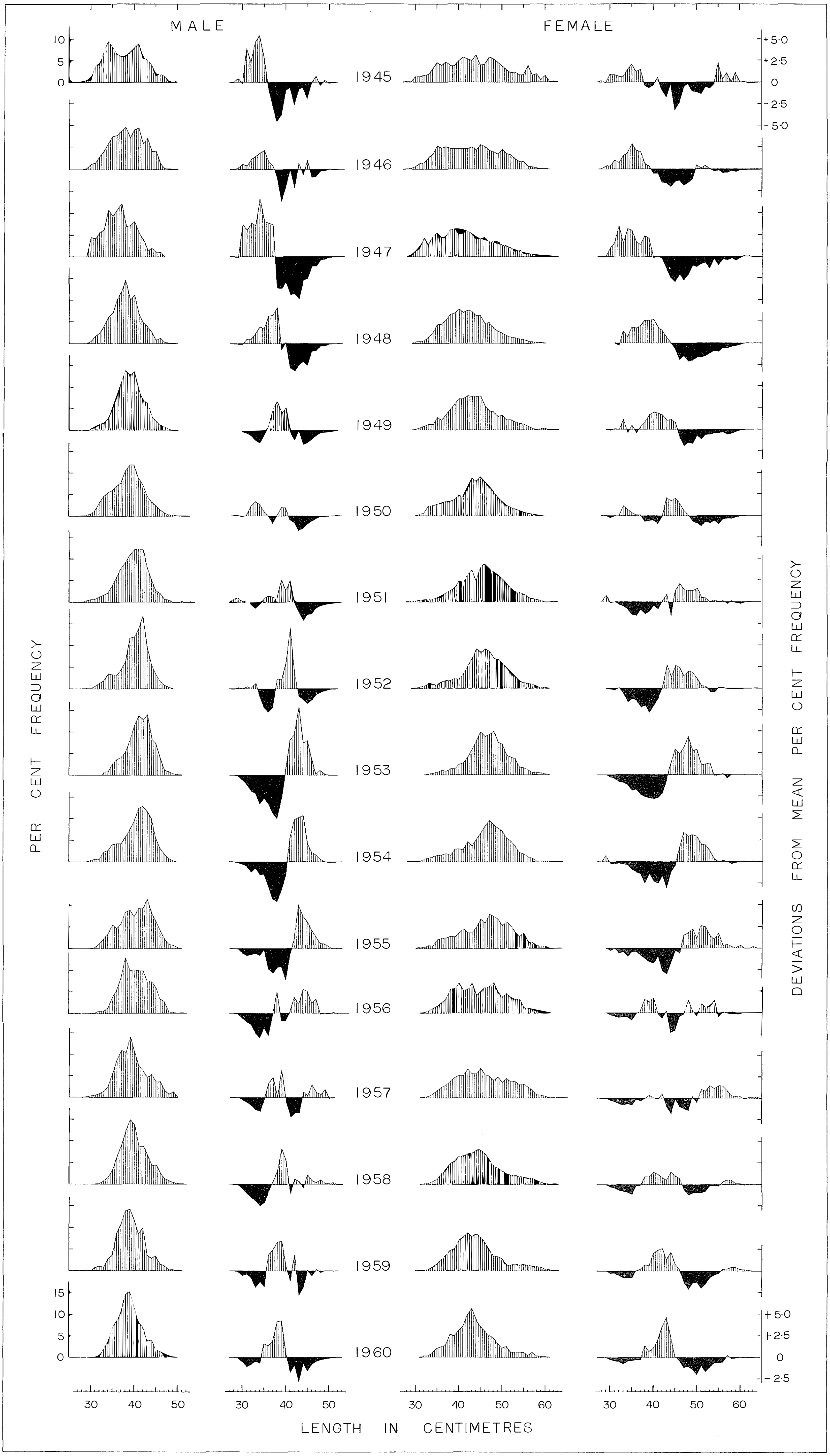


FIG. 27. Length-frequency distribution of male and female petrale sole contained in Canadian landings from Area 3C, with deviations from the long-term mean.

Were information on relative year-class strength lacking, the upward trend in average size after 1947 might be ascribed to progressively heavier culling or to a trend toward the use of larger mesh. However, neither of these things occurred. If anything, there was a downward trend in the minimum size of fish retained for market, and in the Canadian fishery mesh size remained more or less constant throughout the period of study. Furthermore, if changes in selection had occurred, there would have been a noticeable change in sex ratio, towards relatively greater use of the faster growing female fish. Yet this was not apparent in the results of market sampling.

(b) NORTHERN STOCK

Sampling of the northern stock and its components, although not as thorough as that of the southern stock, shows essentially the same sequence of events. There is some suggestion that prior to 1947 average sizes of petrale sole in the catches had been declining, but after that time the trend was upward (Fig. 28 and 29, data from Table 31). However, it will be recalled that the fishery in Hecate Strait (Areas 5C and 5D) was barely underway by 1947, and the heaviest removals occurred in the succeeding 2 years (cf. Fig. 23). In spite of this development average lengths of fish continued to rise, reaching a maximum some time between 1954 and 1956. By that time, in both Queen Charlotte Sound and Hecate Strait, catch per unit of effort reached its lowest level.

TABLE 31. Average total length of male and female petrale sole in Canadian commercial landings from certain areas occupied by the northern stock.

	Queen Charlotte Sound (Areas 5A+5B)				Hecate Strait (Areas 5C+5D)				All areas weighted average length	
	Male		Female		Male		Female			
Year	No. of fish	Average length	No. of fish	Average length	No. of fish	Average length	No. of fish	Average length	male	female
		mm		*mm*		*mm*		*mm*	*mm*	*mm*
1945	76	357	275	438	89	402	234	454	362	440
1946	6	(346)	161	455	515	354	1,001	413	349	438
1947	197	362	160	390	1,367	372	1,989	421	368	422
1948	835	388	1,186	444	6,557	387	6,942	426	387	430
1949	605	392	1,066	432	1,725	399	2,759	448	398	445
1950	830	384	889	425	485	410	1,045	472	398	451
1951	436	390	787	449	288	396	1,880	477	394	468
1952	503	404	569	457	134	393	143	466	397	463
1953	443	411	679	463	366	407	668	468	410	465
1954	265	398	422	454	1	...	28	488	(404)	473
1955	69	(368)	97	(418)	...	...	...	...	...	...
1956	344	416	799	461	53	(413)	295	484	416	463
1957	884	389	1,604	440	1,059	407	2,032	477	397	456
1958	880	379	1,702	426	837	408	1,494	468	391	444
1959	462	384	1,033	429	786	390	582	442	388	436
1960	546	391	1,163	429	673	394	1,327	439	392	432
1961	423	386	1,123	433	831	385	952	428	385	431
1962	1,521	385	2,362	424	1,005	388	1,119	426	386	425

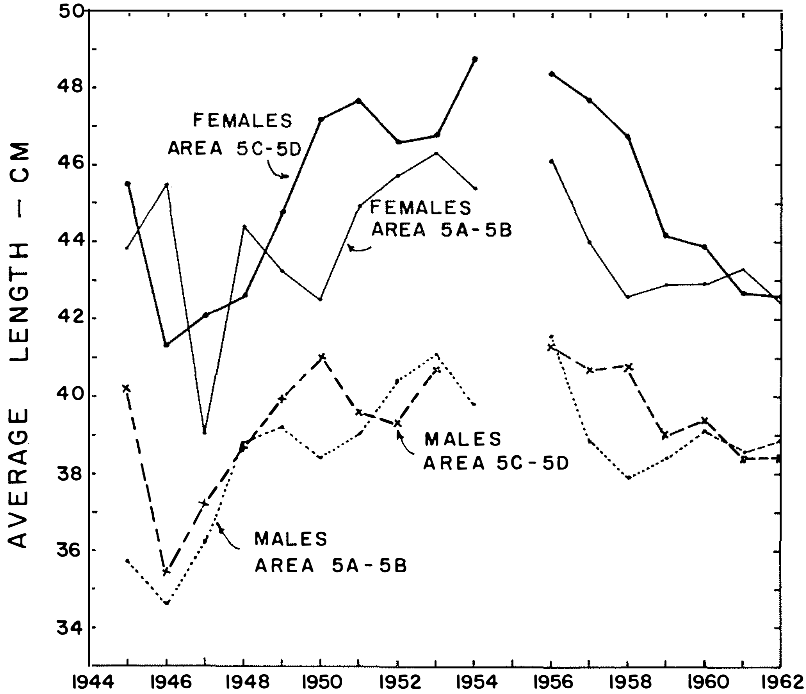


FIG. 28. Variations in average length of male and female petrale sole contained in Canadian landings from Queen Charlotte Sound (Areas 5A and 5B) and from Hecate Strait (Areas 5C and 5D).

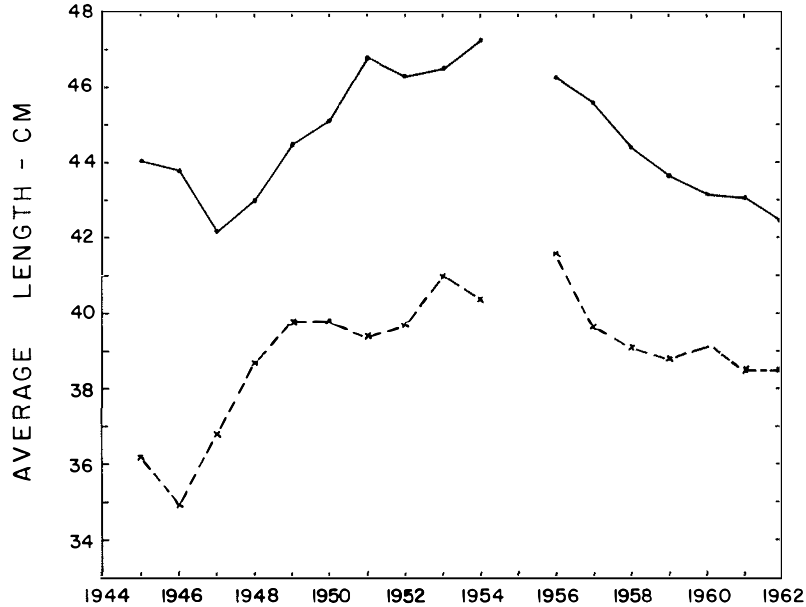


FIG. 29. Variations in average length of male and female petrale sole from the northern stock as a whole.

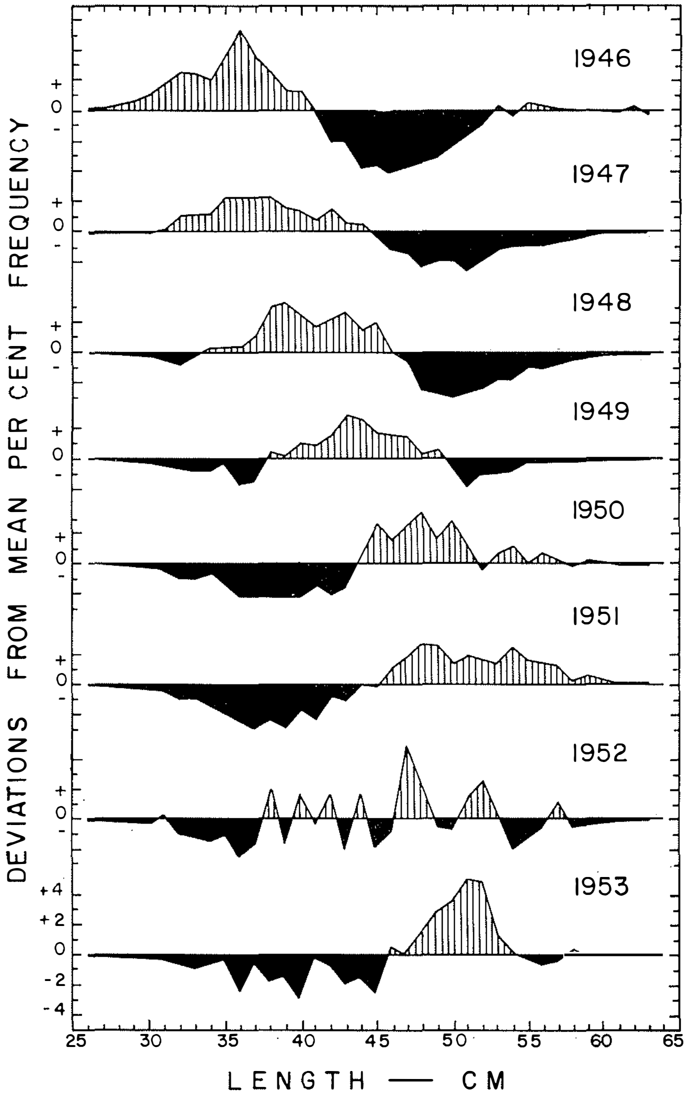


FIG. 30. Length-frequency distribution of female petrale sole from the northern stock expressed as deviations from the 1946–53 mean.

The conclusion to be drawn from these observations is that recruitment rather than the effect of fishing was the dominant factor producing changes in average lengths of fish in the catch. For the few years in which the Hecate Strait segment of the northern stock was effectively sampled, changes in size composition w re essentially the same as those observed in the southern stock (cf. Fig. 27 and 30). Above average numbers of small fish (positive anomalies) were present in the catches at the outset of fishing, and their progression to larger size categories could be traced through the fishery at least to 1953.

If trends in recruitment were the dominant factor in the average size of fish taken subsequent to 1947, some doubt is raised regarding interpretation of events prior to that time. Cleaver (1949, p. 40) concluded that declining average length of fish in the southern stock between 1942 and 1945 was in all probability the result of the fishery. However, it is possible that both the effects of fishing and increasing recruitment were involved in the declining average size.

3. Changes in Age Composition

(a) validity of age determinations

Otoliths appear to provide a reasonably reliable estimation of the age of petrale sole. Errors in age determination fall into two general categories: (i) failure to distinguish between checks which are accessory and those which are truly annual, thus resulting usually in overestimation of age and (ii) failure to detect checks which lie on the periphery of the otolith, thus resulting in underestimation. Such errors may be partly random and partly systematic. They may have occurred to some extent in the age determinations of petrale sole.

Two methods have been used to test the validity of the readings. First, a comparison was made between the deviations from mean length–frequency composition (as given in Fig. 27) and deviations from mean age–frequency. For all but the last 5 of the 16 years of data close agreement was apparent in the trends of positive and negative anomalies. Thus, general reliability of the age determinations was indicated. Departure in recent years seemed to be more the result of a change in growth rate than a change in interpretation of age. More will be said about this matter in a later chapter.

The second method consisted of a comparison of growth rates computed from age–length data and from data on the lengths of fish at time of tagging and at time of recapture. Of course, errors presumably occur in both estimates of growth, but as they probably affect the results in different ways, close agreement is an indication of the reliability of both. In the reading of flatfish otoliths there probably is a greater tendency to underread than to overread and this tendency increases with age of the fish. Thus, growth rate may be overestimated. On the other hand, tagging can be expected to have an inhibiting effect on growth for some time after release. Furthermore, by the time a tagged fish is reported it has usually been stored on ice for many days and this results in shrinkage (about 0.5 cm in fish of 30–43 cm total length according to Harry, 1956; see also Best, 1963). Thus, the increment of growth as measured by the size of fish at time of tagging and at recapture is likely to be underestimated.

Growth rates as determined from otolith readings and from tagging results are compared in Fig. 31 and 32, in a Walford plot of length at a specified time (l_t) against length one year later (l_{t+1}). Both sets of data for male and female fish apply to the period 1947–51 in Area 3C (southern stock). Values of l_t and l_{t+1} at

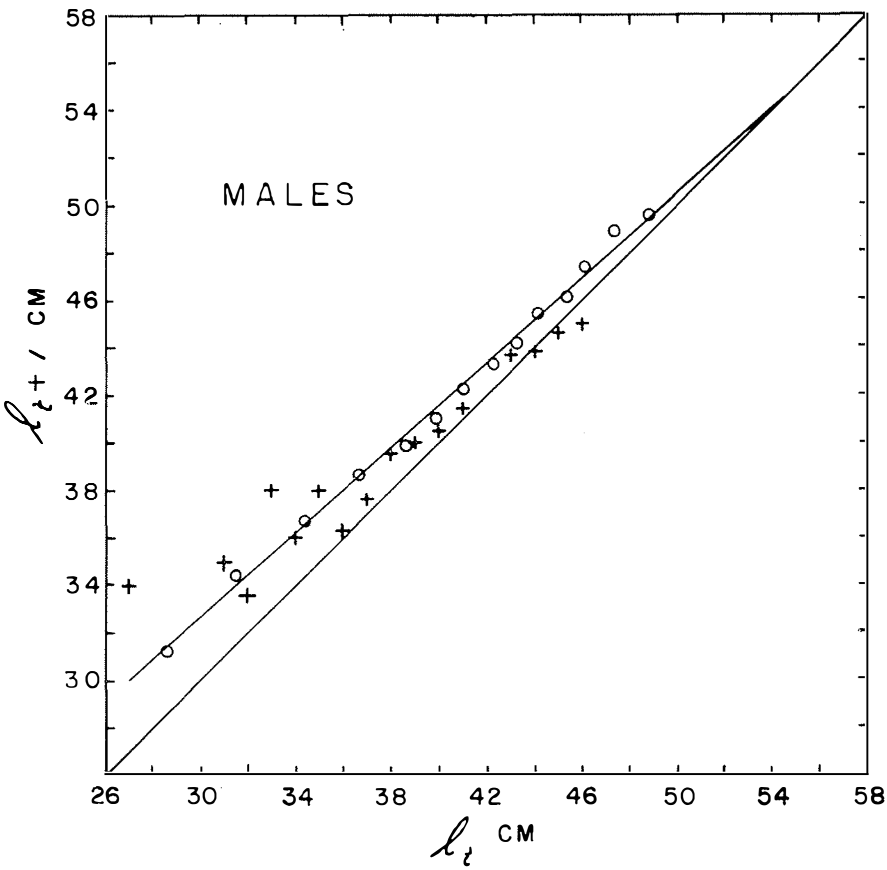


FIG. 31. Comparison of the growth of male petrale sole as derived from otolith readings (circles) and tag returns (crosses). See text for details.

successive ages are averages for that period, with starting points of 29.1 cm for female fish at age III and 28.6 cm for male fish at the same age. Averages also have been used in computing the values of l_{t+1} from tagging data.

Neither for male nor female fish do the points derived from tagging results and otolith readings coincide exactly. As a rule, the former tend to lie slightly below the line fitted (by least squares) to the latter. The difference is not sufficient to arouse concern, and in all likelihood can be attributed to the shrinkage of recaptured tagged fish or to the growth-inhibiting effect of tagging. Variability of the tagging data at l_t values less than 38 cm seems to be the result of an insufficient volume of information.

Thus, there is support for the view that the readings of petrale sole otoliths have provided a reasonably reliable estimation of age.

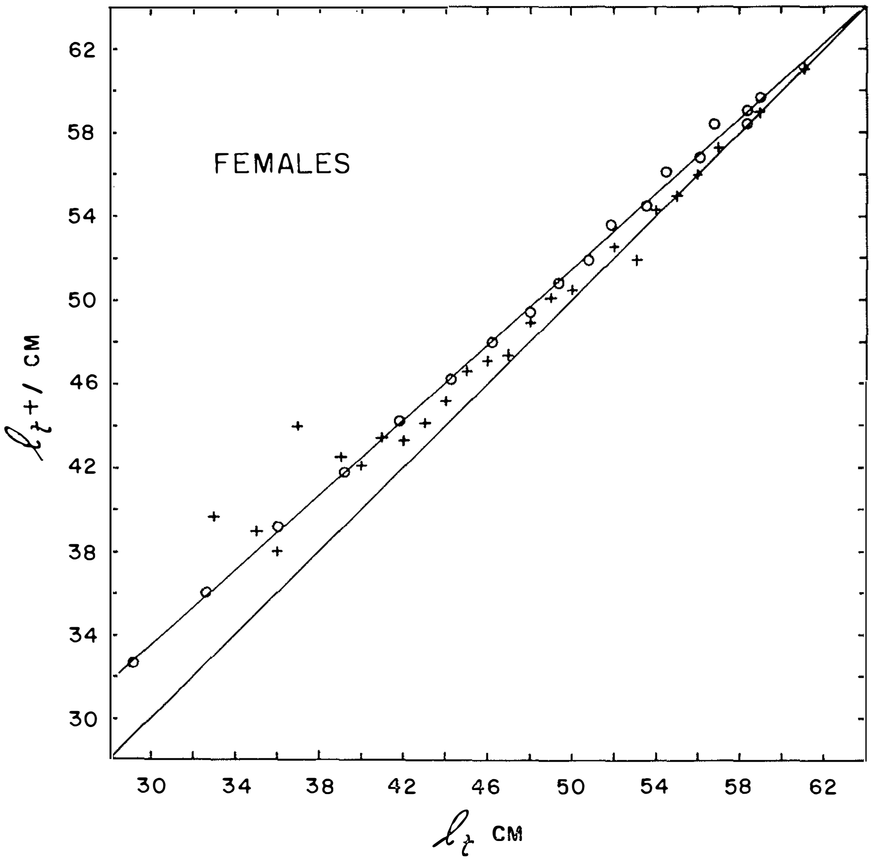


FIG. 32. Comparison of the growth of female petrale sole as derived from otolith readings (circles) and tag returns (crosses). See text for details.

(b) AGE COMPOSITION

Data on the age composition of the southern stock of petrale sole (Area 3C) are assembled in Tables 32 and 33. At this point we need concern ourselves only with some general features of the data. Petrale sole make their first appearance in the catch at age III (completed years). The dominant age-group has varied from age V to age X, tending to be in the lower part of this range between 1944 and 1949 and in the upper part between 1952 and 1956. Maximum age recorded is XXV years, but normally few fish are encountered beyond the age of XX years.

As shown in the last column of Table 32, the average age of female fish declined from 8.7 years in 1944 to 7.1 years in 1948. Thereafter, it rose to about 9 years, remained there until 1955 and then began to decline again. Similar, but less obvious trends were apparent in male fish (Table 33). They accord in a general way with the trends in average length discussed on page 82.

TABLE 32. Age composition (per cent frequency) of female sole in commercial catches from the southern stock (Area 3C).

Age in completed years

Year	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV	XV	XVI	XVII	XVIII	XIX	XX	Over XX	Numbers of fish	Average age (yrs)
1944	0.7	5.2	14.8	16.9	6.6	8.8	8.1	6.6	8.8	6.6	6.6	5.9	1.5	0.7	0.7	1.5	...	...	...	136	8.7
1945	0.5	2.4	19.2	13.9	20.2	10.7	4.4	4.6	6.1	4.1	3.2	3.7	1.7	3.7	0.5	0.7	0.2	0.2	...	411	8.3
1946	0.1	5.7	17.4	21.3	10.5	10.7	8.4	5.0	4.6	5.4	4.5	3.8	1.5	0.9	0.2	...	...	...	...	1,359	7.9
1947	...	5.6	15.6	22.2	19.5	9.7	7.4	6.9	4.2	3.4	2.3	1.9	0.8	0.3	0.1	0.1	...	...	...	647	7.5
1948	...	1.4	19.9	27.3	20.3	13.9	5.0	3.7	2.6	1.6	1.3	1.2	1.1	0.4	0.2	0.1	...	...	...	2,689	7.1
1949	...	1.9	6.6	22.3	23.2	16.2	9.9	6.2	4.3	2.5	2.9	1.8	0.8	0.7	0.5	...	0.1	...	...	2,446	7.9
1950	...	1.5	10.7	7.9	21.4	19.0	14.4	9.9	5.0	3.1	2.3	1.6	1.5	0.9	0.3	0.4	0.1	...	...	3,697	8.3
1951	...	1.5	5.1	9.7	11.9	14.3	15.5	13.5	11.7	4.8	4.2	2.7	1.9	1.5	0.8	0.5	0.2	0.1	0.1	3,631	9.2
1952	...	2.3	5.0	6.3	17.4	15.5	15.8	14.9	9.5	4.9	2.8	1.8	1.6	0.6	0.7	0.3	0.2	0.2	0.2	2,057	9.0
1953	0.1	1.8	5.4	6.1	10.0	18.6	15.8	16.6	10.8	6.6	3.6	2.1	0.9	0.6	0.4	0.2	0.2	0.1	0.1	2,771	9.1
1954	1.0	6.3	6.9	11.1	9.3	11.9	17.3	10.2	12.1	8.1	2.4	1.7	0.6	0.4	0.4	0.1	0.1	...	0.1	2,841	8.6
1955	0.1	4.9	10.7	9.3	9.2	8.8	10.1	12.7	9.6	10.8	8.4	2.4	1.7	0.7	...	0.1	0.1	...	0.4	1,350	9.1
1956	...	1.4	13.2	22.3	11.9	9.5	5.4	6.3	6.7	7.9	5.9	5.0	1.7	1.7	0.7	0.4	...	...	...	903	8.6
1957	0.3	10.6	15.5	21.1	9.9	6.8	5.3	4.1	4.5	6.0	4.1	3.8	3.7	2.4	1.1	0.1	0.2	0.2	0.3	2,560	8.2
1958	...	3.3	17.2	19.0	18.2	12.9	7.2	3.6	3.6	2.0	2.9	2.9	2.4	1.8	1.4	0.7	0.4	0.2	0.3	2,624	8.0
1959	...	1.3	11.3	25.6	26.5	12.9	5.9	3.6	1.6	2.2	2.2	1.4	1.9	1.8	0.7	0.5	0.5	...	0.1	1,688	7.7
1960	...	0.2	8.0	12.5	25.8	20.9	12.3	7.8	4.1	2.1	0.5	1.4	1.4	0.7	1.4	0.4	0.2	0.2	0.1	2,183	8.2
1961	...	1.1	17.3	23.0	15.6	18.9	8.8	6.2	3.4	1.6	0.9	0.4	0.8	0.8	0.5	0.4	0.3	...	...	742	7.5
1962	0.5	7.1	11.6	24.2	15.4	13.0	13.6	5.3	3.0	1.8	1.1	0.7	0.7	0.6	0.6	0.4	0.3	...	0.1	1,085	7.4
1963	...	0.9	25.1	23.3	23.9	7.1	7.7	6.6	2.2	1.1	0.6	0.2	0.2	0.2	0.6	0.3	...	0.1	...	665	7.0

TABLE 33. Age composition (per cent frequency) of male petrale sole in commercial catches from the southern stock (Area 3C).

Age in completed years

Year	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV	XV	XVI	XVII	XVIII	XIX	XX	Over XX	Numbers of fish	Average age (yrs)
1944	...	4.2	6.3	20.9	20.8	14.6	12.5	6.3	2.1	10.4	2.1	...	...	...	...	...	...	...	...	48	7.9
1945	...	10.5	32.5	14.5	15.0	9.0	7.5	1.5	5.0	2.5	1.0	1.0	...	...	...	...	...	...	...	200	6.6
1946	0.2	3.9	16.0	21.7	14.5	12.2	8.6	9.4	6.1	4.0	2.1	1.1	...	0.2	...	...	...	...	...	887	7.6
1947	...	10.7	27.8	25.6	12.7	8.9	6.6	4.3	2.8	0.3	0.3	...	...	...	...	...	...	...	...	394	6.3
1948	...	2.2	23.1	32.4	19.7	9.8	4.9	2.6	1.8	1.9	1.0	0.5	0.1	...	...	...	...	...	...	1,542	6.7
1949	...	1.5	7.5	25.4	23.7	14.9	9.1	5.4	4.7	3.6	2.3	1.4	0.4	0.1	...	...	...	...	...	2,383	7.7
1950	0.1	2.8	16.4	13.6	20.0	19.5	12.3	7.9	3.2	1.8	1.3	0.5	0.3	0.1	0.1	...	...	...	...	2,659	7.5
1951	0.7	2.0	6.3	15.7	17.8	22.4	16.2	9.1	3.2	3.6	1.7	0.7	0.2	0.4	...	...	...	...	...	1,637	7.9
1952	0.9	5.1	7.8	15.6	22.1	17.9	14.6	8.6	3.5	2.4	0.3	1.0	0.1	...	0.1	...	...	...	...	1,386	7.6
1953	...	1.1	8.6	13.8	16.1	20.0	17.8	12.0	6.1	2.9	1.1	...	0.1	0.4	...	...	...	...	...	1,684	8.1
1954	0.8	9.2	13.9	12.1	13.8	16.5	13.4	8.4	7.5	2.1	1.5	0.7	0.1	...	...	...	...	...	...	1,516	7.5
1955	0.1	7.8	17.2	12.7	9.7	9.5	10.1	10.7	10.4	5.8	3.1	1.5	1.2	0.2	...	...	...	...	...	759	8.0
1956	...	2.6	20.1	20.8	12.9	9.0	9.8	11.1	7.5	3.5	1.1	0.5	0.8	...	0.3	...	...	...	...	597	7.6
1957	0.5	21.8	26.2	17.0	10.0	6.9	3.6	3.4	2.9	4.0	0.5	1.5	0.7	0.8	...	...	0.2	...	...	759	6.5
1958	0.2	4.9	22.1	26.5	18.6	8.6	4.0	4.2	2.2	2.1	3.0	1.7	1.7	...	0.1	...	0.1	...	...	1,783	7.1
1959	...	2.8	22.1	30.6	20.5	8.9	5.3	2.0	2.1	2.8	0.6	0.7	1.2	0.3	0.1	...	...	...	...	883	6.9
1960	...	1.0	12.7	24.8	31.3	14.6	4.5	3.1	2.0	2.4	2.4	0.9	...	0.3	...	...	...	...	...	1,036	7.2
1961	...	3.4	32.4	25.9	17.1	11.8	4.4	0.5	1.0	2.0	1.0	...	0.5	...	...	...	...	...	...	204	6.4
1962	0.6	14.4	20.5	29.7	15.0	6.4	6.8	2.8	1.6	0.4	0.6	0.6	0.6	...	...	...	...	...	...	501	6.3
1963	0.2	2.5	30.8	26.5	18.9	9.0	4.0	4.5	1.1	1.6	0.5	0.4	...	...	...	...	...	...	...	445	6.5

TABLE 34. Age composition (per cent frequency) of petrale sole in commercial catches from Queen Charlotte Sound (Areas 5A and 5B).

Age in completed years

Year	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV	XV	XVI	XVII	XVIII	XIX	XX	Over XX	Numbers of fish	Average age (yrs)
Male																					
1945	...	6.7	14.2	6.7	5.8	10.8	7.5	10.8	10.0	11.7	10.8	4.2	0.8	...	...	...	...	...	...	120	9.0
1946	1.0	3.9	25.2	28.1	17.5	4.9	6.8	3.9	5.8	2.9	...	...	...	...	...	...	...	...	...	103	6.7
1947	...	3.6	22.1	43.1	20.6	5.7	2.1	0.4	1.8	0.7	...	...	...	...	...	...	...	...	...	281	6.2
1948	...	0.5	12.3	29.2	33.4	13.6	5.1	3.4	0.9	0.9	0.6	0.1	...	...	...	...	...	...	...	799	6.9
Female																					
1945	...	4.5	16.4	6.0	9.7	12.7	7.5	5.2	11.9	5.2	10.5	7.5	2.2	0.8	...	...	...	...	...	134	9.0
1946	...	2.2	11.4	15.9	15.5	11.1	11.8	9.2	6.3	8.9	4.4	1.5	0.7	1.1	...	...	...	...	...	271	8.4
1947	...	1.9	12.7	24.0	22.4	13.9	6.9	5.4	3.2	2.8	2.6	2.2	1.1	0.4	0.4	0.2	...	...	...	537	7.6
1948	...	0.6	6.8	13.9	27.2	23.1	9.3	9.1	6.0	2.2	1.0	0.6	0.2	0.1	...	...	...	...	...	973	7.9

TABLE 35. Age composition (per cent frequency) of petrale sole in commercial catches from Hecate Strait (Areas 5C and 5D).

Age in completed years

Year	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV	XV	XVI	XVII	XVIII	XIX	XX	Over XX	Numbers of fish	Average age (yrs)
Male																					
1946	6.2	14.0	27.0	24.7	7.9	2.2	5.1	3.9	5.6	1.1	2.2	...	...	...	...	...	...	...	...	178	6.2
1947	0.4	10.8	27.3	31.2	19.2	4.4	2.1	2.6	1.3	0.5	0.1	...	...	...	...	...	...	...	...	816	6.1
1948	...	1.5	12.2	23.1	23.7	14.7	5.3	4.4	4.0	4.7	3.4	1.7	1.0	0.2	0.2	...	...	...	...	1,001	7.0
1949	...	...	6.4	28.0	26.3	19.5	8.9	4.2	2.1	2.1	2.1	...	...	0.4	...	...	...	...	...	236	7.4
1950	...	1.7	9.5	17.2	20.7	19.8	11.2	10.4	4.3	4.3	...	...	...	...	...	0.9	...	...	...	116	7.8
Female																					
1946	1.1	6.4	16.8	24.3	11.8	6.8	5.4	5.4	6.8	6.4	6.4	1.4	1.1	...	...	...	...	...	...	280	7.7
1947	0.2	5.2	16.6	23.7	22.0	14.3	5.4	4.3	4.8	3.0	0.4	0.1	...	0.1	...	...	...	...	...	987	7.0
1948	0.1	0.6	6.1	16.2	18.4	20.9	11.9	7.7	4.5	4.5	2.5	1.9	2.8	1.1	0.2	0.2	0.2	0.2	...	883	8.5
1949	...	0.3	2.6	9.2	19.4	28.6	14.4	8.4	7.1	2.9	3.2	0.5	1.0	0.8	1.0	0.3	0.3	...	...	381	8.6
1950	...	1.6	3.5	2.7	17.5	18.3	24.1	7.0	5.4	5.4	4.7	3.1	2.3	0.8	1.6	0.8	0.8	0.4	...	257	9.4

Regarding the northern stock of petrale sole, the record of age composition has been completed only for the years 1945–50 (Tables 34 and 35). Age material is available for most of the later years, but remains unanalysed. Nevertheless, it will be possible to draw some inferences regarding the trend in recruitment, from what we know of changes in average length and from changes in recruitment observed in the southern stock.

Chapter VI

MEASURES OF RECRUITMENT

A method of estimating recruitment is to measure the contribution of each year-class to the catch per unit of effort at a given age or age in successive years. There are two basic assumptions, the first of which is that catch per unit of effort is a reliable measure of abundance, and the second, that the annual amount of fishing mortality (and natural mortality) has been free from substantial trends during the period of study. The former, as far as the two major divisions of petrale sole stock are concerned, is not satisfied year by year. Sharp changes in catch per effort as exhibited in 1947 and 1951 by the southern stock (Fig. 21) applied to all age groups and therefore can be attributed to a change in catchability of the fish by the fishing gear. However, the long-term trends of catch per effort are presumed to be a reasonable reflection of trends in abundance. By measuring the performance of a year-class over a number of years, the effects of short-term variations in availability will be minimized. Regarding the second assumption, if fishing effort is proportional to rate of fishing and has followed a trend, estimates of year-class strength may be biased. For example, consider two year-classes of equal size at age III, of which A is subject to twice as great a rate of fishing as B from that age onward. Then at age VIII (say) the catch per unit of effort from year-class A will be less than from year-class B, because more individuals have been captured from it in previous years. The best information available on fishing effort in the southern area (Table 26) suggests that there was an irregular upward trend between 1945 and 1960. The effect would be to underestimate the strength of recent year-classes. On the other hand, strengths based on catch rather than on catch per effort will be biased in the opposite direction. Thus, it is constructive to examine both methods of calculation.

1. Length–Weight Relationship

Conversion of pounds of fish per unit of effort to numbers of fish per unit of effort requires information on the average length of fish in the catch and the corresponding average weight. Length–weight data for petrale sole have been collected mainly by sampling at sea, and to a lesser extent from market sampling — in both cases only during the summer months. The relationship for male and female fish is illustrated in Fig. 33. For each length interval the weight given

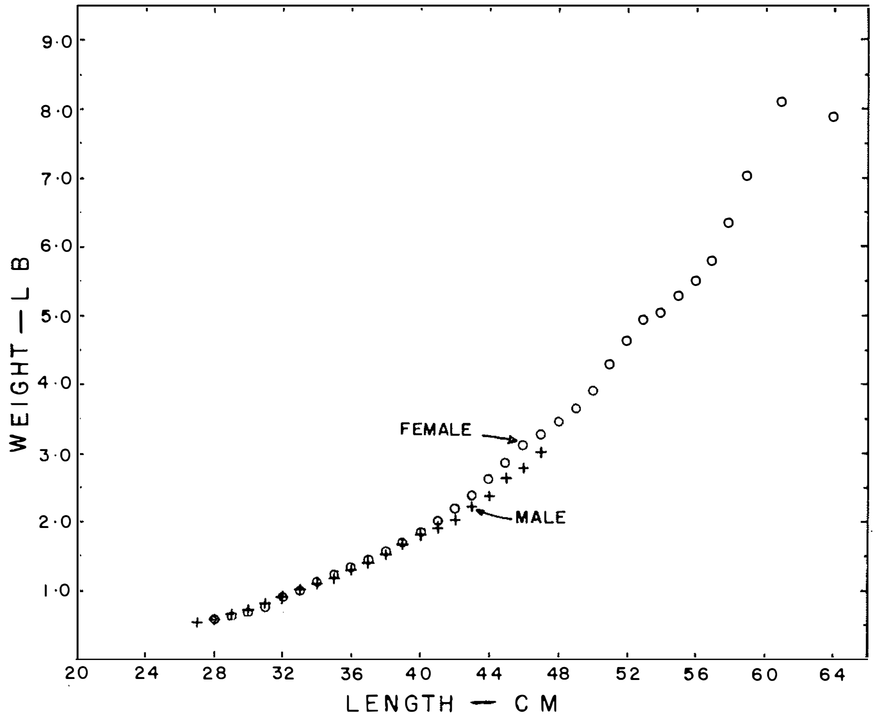


FIG. 33. Relationship between length and weight in male and female petrale sole.

is an average of a number of observations (Appendix V). From the regression of weight on length (least squares of logarithms), we obtain the allometric formula relating weight (w in oz) to length (l in cm), which for male petrale sole is expressed as

$$w = .000272\ l^{3.135}$$

and for females as

$$w = .000127\ l^{3.352}$$

In passing, it should be noted that the exponent is considerably (perhaps significantly) greater than 3 for female fish. The observation that growth is not strictly isometric accords with that of Cleaver (1949), who found values of 3.214 and 3.577 for petrale sole less than and greater than 40 cm, respectively (sexes combined).

2. Conversion to Numbers of Fish per Unit of Effort

Average lengths of male and female petrale sole in samples from each year's commercial landing, as given in columns 3 and 5 of Table 30, have been converted to average weights by means of the formulae presented in the foregoing section.

TABLE 36. Calculation of numbers of male and female petrale sole per unit of effort (southern stock — Area 3C).

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	Males			Females						Catch/100 hr				
										Weight			Numbers	
Year	Numbers in sample	Average wt	Total wt	Numbers in sample	Average wt	Total wt	Total wt males females in sample	Percentage male by wt	Percentage female by wt	Total	Males	Females	Males	Females
		lb	*lb*		*lb*	*lb*	*lb*			*lb*	*lb*	*lb*		
1945	200	1.40	280	411	2.55	1,048	1,328	21.1	78.9	16,100	3,397	12,703	2,430	4,980
1946	887	1.59	1,410	1,359	2.34	3,180	4,590	30.7	69.3	24,100	7,399	16,701	4,650	7,140
1947	394	1.35	532	647	2.13	1,378	1,910	27.9	72.1	12,700	3,543	9,157	2,620	4,300
1948	1,542	1.53	2,359	2,689	2.25	6,050	8,409	28.1	71.9	27,700	7,784	19,916	5,090	8,850
1949	2,383	1.66	3,956	2,446	2.43	5,944	9,900	40.0	60.0	23,600	9,440	14,160	5,690	5,830
1950	2,659	1.62	4,308	3,697	2.53	9,353	13,661	31.5	68.5	22,100	6,962	15,139	4,300	5,980
1951	1,637	1.76	2,881	3.631	2.87	10,420	13,301	21.7	78.3	11,200	2,430	8,770	1,380	3,060
1952	1,386	1.83	2,536	2,057	2.92	6,006	8,542	29.7	70.3	19,200	5,702	13,498	3,120	4,620
1953	1,684	1.99	3,351	2,771	3.13	8,673	12,024	27.9	72.1	19,400	5,413	13,987	2,720	4,470
1954	1,516	1.90	2,880	2,841	3.07	8,722	11,602	24.8	75.2	10,700	2,654	8,046	1,400	2,620
1955	759	1.87	1.919	1,350	3.07	4,145	6,064	31.6	68.4	7,800	2,465	5,335	1,320	1,740
1956	597	1.85	1,104	903	2.73	2,465	3,569	30.9	69.1	5,300	1,638	3,662	890	1,340
1957	759	1.73	1,313	2,560	2.92	7,475	8,788	14.9	85.1	8,800	1,311	7,489	760	2,560
1958	1,783	1.79	3,192	2,624	2.69	7,059	10,251	31.1	68.9	10,900	3,390	7,510	1,890	2,790
1959	883	1.70	1,501	1,688	2.59	4,372	5,873	25.6	74.4	14,200	3,635	10,565	2,140	4,080
1960	1,036	1.60	1,658	2.183	2.50	5,458	7,116	23.3	76.7	10,700	2,493	8,207	1,560	3,280
1961	204	1.54	314	742	2.39	1,773	2,087	15.0	85.0	11,200	1,680	9,520	1,090	6,180
1962	510	1.47	736	1,085	2.42	2,626	3,362	21.9	78.1	14,100	3,088	11,012	2,100	7,490
1963	445	1.70	757	665	2.42	1,609	2,366	32.0	68.0	13,000	4,160	8,840	2,450	5,200

TABLE 37. Numbers of male petrale sole/100 hr of trawling in Area 3C (southern stock), arranged by age groups.

Age in completed years

Year of catch	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV	XV	XVI	XVII	XVIII	XIX	XX	Over XX
1945	...	267	826	368	381	229	191	38	127	64	25	25	...	...	...	...	...	...	...
1946	9	180	737	1,000	668	562	396	433	281	184	97	51	...	9	...	...	...	...	...
1947	...	303	788	725	360	252	187	122	79	8	8	...	...	...	...	...	...	...	...
1948	...	115	1,213	1,701	1,034	514	257	136	94	100	52	26	5	...	...	...	...	...	...
1949	...	85	424	1,435	1,339	842	514	305	266	203	130	79	23	6	...	...	...	...	...
1950	4	102	595	494	726	708	446	287	116	65	47	18	11	4	4	...	...	...	...
1951	10	28	87	218	247	310	225	126	44	50	24	10	3	6	...	...	...	...	...
1952	30	172	264	527	747	605	494	291	118	81	10	34	3	...	3	...	...	...	...
1953	...	31	241	387	451	560	499	336	171	81	31	...	3	11	...	...	...	...	...
1954	11	122	184	160	183	218	177	111	99	28	20	9	1	...	...	...	...	...	...
1955	1	67	147	108	83	81	86	91	89	49	26	13	10	2	...	...	...	...	...
1956	...	21	159	165	102	71	78	88	59	28	9	4	6	...	2	...	...	...	...
1957	4	164	197	128	75	52	27	26	22	30	4	11	5	6	...	...	2	...	...
1958	4	87	393	471	331	153	71	75	39	37	53	30	30	...	3	...	2	...	...
1959	...	59	464	643	431	187	111	42	44	59	13	15	25	6	2	...	...	...	...
1960	...	15	197	384	485	226	70	48	31	37	37	14	...	5	...	...	...	...	...
1961	...	42	402	321	212	146	55	6	12	25	12	...	6	...	...	...	...	...	...
1962	13	301	430	622	314	134	142	59	34	8	13	13	...	13	...	...	...	...	...
1963	5	61	755	649	463	221	98	110	27	39	12	10	...	...	...	...	...	...	...

TABLE 38. Numbers of female petrale sole/100 hr of trawling in Area 3C (southern stock) arranged by age groups.

Age in completed years

Year of catch	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV	XV	XVI	XVII	XVIII	XIX	XX	Over XX
1945	25	119	950	687	999	529	218	228	302	203	153	183	84	183	25	35	10	10	...
1946	7	410	1,253	1,533	756	770	605	360	331	389	324	274	108	65	14	...	...	...	...
1947	...	253	703	1,001	879	437	334	311	189	153	104	86	36	14	5	5	...	...	...
1948	...	126	1,791	2,458	1,828	1,252	450	333	234	144	117	108	99	36	18	9	...	...	...
1949	...	114	398	1,343	1,398	976	596	373	259	151	175	108	48	42	30	...	6	...	...
1950	...	97	689	509	1,378	1,223	927	637	322	200	148	103	97	58	19	26	6	...	...
1951	...	47	158	301	369	444	481	419	363	149	130	84	59	47	25	16	6	3	3
1952	...	106	230	290	801	713	727	686	437	225	129	83	74	28	32	14	9	9	9
1953	4	81	242	274	449	835	709	745	485	296	162	94	40	27	18	9	9	4	4
1954	27	169	185	297	249	318	463	273	324	217	64	45	16	11	11	3	3	...	3
1955	2	94	204	178	176	168	193	243	183	206	160	46	32	13	...	2	2	...	8
1956	...	19	177	298	159	127	72	84	90	106	79	67	23	23	9	5	...	...	...
1957	8	274	401	546	256	176	137	106	116	155	106	98	96	62	28	3	5	5	8
1958	...	95	493	545	522	370	206	103	103	57	83	80	69	52	40	20	9	6	9
1959	...	53	461	1,044	1,081	526	241	147	65	90	90	57	78	73	29	20	20	...	4
1960	...	7	262	409	844	683	402	255	134	69	16	46	46	23	46	13	7	7	3
1961	...	42	661	878	596	722	336	237	130	61	34	15	31	31	19	15	11	...	...
1962	23	323	527	1,100	700	591	618	241	136	82	50	32	32	27	27	18	14	...	4
1963	...	46	1,304	1,212	1,243	368	400	343	114	57	31	10	10	10	31	16	...	5	...

These weights are shown in columns 3 and 6 of Table 36.[23] A ratio of the weight of male to female fish in the commercial samples (columns 9 and 10) is then applied to the catch per effort data for the southern stock (column 11 obtained from Table 26) to estimate the weight of males and weight of females per unit of effort in each year (columns 12 and 13). Dividing the weight of males and females by the respective average weights for individual fish gives the numbers of males and females per unit of effort (columns 14 and 15).[24] These numbers are now applied to the percentage frequency distribution by age (Table 32 and 33) to obtain the age composition in terms of numbers of fish per unit of effort as shown in Tables 37 and 38.

Working diagonally across these tables, the data can be rearranged to show the performance of individual year-classes, as in Tables 39 and 40, respectively.

3. Variations in Year-Class Strength in the Southern Stock

Measures of year-class strength based on catch per unit of effort have been obtained in three ways from arbitrary summation of the numbers per unit of effort at: (i) ages IV through VII, (ii) ages VIII through XI and (iii) ages IV through XI. These sums are shown in the bottom three rows of Tables 39 and 40. Combining the data for the two sexes we get the values shown in Table 41 and these are illustrated in Fig. 34.

Estimates of year-class strengths obtained from the contribution at ages IV–VII differ in detail from those estimated from the contribution at ages VIII–XI, but there are some general similarities: (i) year-classes of 1940–43 apparently were much stronger than those produced in later years — roughly five times as strong as the year-classes of 1947–50, (ii) there is some suggestion that year-classes produced prior to 1940 were weaker than those of the early 1940s and (iii) subsequent to 1948 or 1949 the strengths of the year-classes began to increase again.

It will be recalled from the chapter dealing with the calculation of catch per unit of effort (p. 68) that an upward adjustment was made in the catch per effort estimates of 1945 and 1946 to minimize the possible influence of the fishery for dogfish. The effect is to raise the estimated strengths of the earlier year-classes (particularly those prior to 1940). If, in fact, the raw data for 1945 and 1946 were more valid than the adjusted data, then the difference between the strengths of year-classes prior to 1940 and those immediately following was even greater than that depicted in Fig. 34.

Several other sources of bias have to be considered in assessing the rate of decline in year-class strength from 1940 to 1947. In the first place, the method of calculating catch per effort, which of necessity involved a low threshold of

[23]It is recognized that some bias is introduced by this procedure since the average weight of all fish in the sample of the landing is practically always greater than the average weight of a groud of individual fish whose lengths are each exactly equal to the average length for the sample as a whole. However, the fact that, in subsequent calculations, the average weights are reconverted to lengths using the same formula, tends to cancel out the error.

[24]For convenience of calculation, the unit of effort has been increased from one hour to one hundred hours of trawling.

TABLE 39. Numbers of male petrale sole/100 hr of trawling in Area 3C, arranged by year-classes.

Age Years	Year-class 1933	1934	1935	1936	1937	1938	1939	1940	1941	1942	1943	1944	1945	1946
III	...	...	...	...	...	...	...	...	...	...	9	...	...	...
IV	...	...	...	...	...	...	(133)*	(209)	267	180	303	115	85	102
V	...	...	...	...	...	...	(494)	826	737	788	1213	424	595	87
VI	...	...	...	...	...	...	368	1000	725	1701	1435	494	218	527
VII	...	...	...	...	...	381	668	360	1034	1339	726	247	747	451
VIII	...	...	...	(539)	229	562	252	514	842	708	310	605	560	218
IX	...	...	...	191	396	187	257	514	446	225	494	499	177	86
X	...	...	38	433	122	136	305	287	126	291	336	111	91	88
XI	...	127	281	79	94	266	116	44	118	171	99	89	59	22
XII	64	184	8	100	203	65	50	81	81	28	49	28	30	37
XIII	97	8	52	130	47	24	10	31	20	26	9	4	53	13
XIV	...	26	79	18	10	34	...	9	13	4	11	30	15	14
XV	5	23	11	3	3	3	1	10	6	5	30	25	...	6
XVI	6	4	6	...	11	...	2	...	6	...	6	5	...	13
XVII	4	...	3	...	...	...	2	...	2	2	...	...	...	...
XVIII	...	...	...	...	...	...	...	...	...	...	...	...	...	...
XIX	...	...	...	...	...	2	2	...	...	...	...	...	...	...
XX	...	...	...	...	...	...	...	...	...	...	...	...	...	...
>XX	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Sum by grouped ages														
IV–VII	...	...	...	...	...	...	(1663)	(2395)	2763	4008	3677	1280	1645	1167
VIII–XI	...	...	...	(1242)	841	1151	930	1359	1532	1395	1239	1304	887	414
IV–XI	...	...	...	...	...	...	(2593)	(3754)	4295	5403	4916	2584	2532	1581

Age Years	Year-class 1947	1948	1949	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960
III	4	10	30	...	11	1	...	4	4	...	...	...	13	5
IV	28	172	31	122	67	21	164	87	59	15	42	301	61	...
V	264	241	184	147	159	197	393	464	197	402	430	755	...	...
VI	387	160	108	165	128	471	643	384	321	622	649	(1099)	...	...
VII	183	83	102	75	331	431	485	212	314	463	(482)	(926)	...	...
VIII	81	71	52	153	187	226	146	134	221	...	...	...	...	...
IX	78	27	71	111	70	55	142	98	...	...	...	...	...	...
X	26	75	42	48	6	59	110	...	...	...	...	...	...	...
XI	39	44	31	12	34	27	(44)	...	...	...	...	...	...	...
XII	59	37	25	8	39	...	...	...	...	...	...	...	...	...
XIII	37	12	13	12	...	...	...	...	...	...	...	...	...	...
XIV	...	13	10	...	...	...	...	...	...	...	...	...	...	...
XV	...	...	...	...	...	...	...	...	...	...	...	...	...	...
XVI	...	...	...	...	...	...	...	...	...	...	...	...	...	...
XVII	...	...	...	...	...	...	...	...	...	...	...	...	...	...
XVIII	...	...	...	...	...	...	...	...	...	...	...	...	...	...
XIX	...	...	...	...	...	...	...	...	...	...	...	...	...	...
XX	...	...	...	...	...	...	...	...	...	...	...	...	...	...
>XX	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Sum by grouped ages														
IV–VII	862	656	425	509	685	1120	1685	1147	891	1502	(1603)	(3081)	...	...
VIII–XI	224	217	196	324	297	367	(442)	...	...	...	...	...	...	...
IV–XI	1086	873	621	833	982	1487	(2127)	...	...	...	...	...	...	...

*Data in parentheses are projected values based on average performance of year-classes for which information is complete.

TABLE 40. Numbers of female petrale sole/100 hr of trawling in Area 3C, arranged by year-classes.

Age Years	Year-class 1933	1934	1935	1936	1937	1938	1939	1940	1941	1942	1943	1944	1945	1946
III	...	...	...	...	...	...	...	...	...	25	7	...	...	...
IV	...	...	...	...	...	...	(111)*	(201)	119	410	253	126	114	97
V	...	...	...	...	...	...	(512)	950	1253	703	1791	398	689	158
VI	...	...	...	...	...	...	687	1533	1001	2458	1343	509	301	290
VII	...	...	...	...	...	999	756	879	1828	1398	1378	369	801	449
VIII	...	...	...	(457)	529	770	437	1252	976	1223	444	713	835	318
IX	...	...	...	218	605	334	450	596	927	481	727	709	463	193
X	...	...	228	360	311	333	373	637	419	686	745	273	243	84
XI	...	302	331	189	234	259	322	363	437	485	324	183	90	116
XII	203	389	153	144	151	200	149	225	296	217	206	106	155	57
XIII	324	104	117	175	148	130	129	162	64	160	79	106	83	90
XIV	86	108	108	103	84	83	94	45	46	67	98	80	57	46
XV	99	48	97	59	74	40	16	32	23	96	69	78	46	31
XVI	42	58	47	28	27	11	13	23	62	52	73	23	31	27
XVII	19	25	32	18	11	...	9	28	40	29	46	19	27	31
XVIII	16	14	9	3	2	5	3	20	20	13	15	18	16	...
XIX	9	9	3	2	...	5	9	20	7	11	14	...	...	...
XX	4	...	...	...	5	6	...	7	...	...	5	...	...	...
>XX	3	8	...	8	9	4	3	...	4	...	...	...	...	...
Sum by grouped ages														
IV–VII	...	...	...	...	...	...	(2066)	(3563)	4201	4969	4765	1402	1905	994
VIII–XI	...	...	...	(1224)	1679	1696	1582	2848	2759	2875	2240	1878	1631	711
IV–XI	...	...	...	...	...	...	(3648)	(6411)	6960	7844	7005	3280	3536	1705

Age Years	Year-class 1947	1948	1949	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959
III	...	...	...	4	27	2	...	8	...	...	...	...	23
IV	47	106	81	169	94	19	274	95	53	7	42	323	46
V	230	242	185	204	177	401	493	461	262	661	527	1304	...
VI	274	297	178	298	546	545	1044	409	878	1100	1212	(1886)	...
VII	249	176	159	256	522	1081	844	596	700	1243	(982)	(1938)	...
VIII	168	127	176	370	526	683	722	591	369	...	...	...	...
IX	72	137	206	241	402	336	618	400	...	...	...	...	...
X	106	103	147	255	237	241	343	...	...	...	...	...	...
XI	103	65	134	130	136	114	(272)	...	...	...	...	...	...
XII	90	69	61	82	57	...	...	...	...	...	...	...	...
XIII	16	34	50	31	...	...	...	...	...	...	...	...	...
XIV	15	32	10	...	...	...	...	...	...	...	...	...	...
XV	32	10	...	...	...	...	...	...	...	...	...	...	...
XVI	10	...	...	...	...	...	...	...	...	...	...	...	...
XVII	...	...	...	...	...	...	...	...	...	...	...	...	...
XVIII	...	...	...	...	...	...	...	...	...	...	...	...	...
XIX	...	...	...	...	...	...	...	...	...	...	...	...	...
XX	...	...	...	...	...	...	...	...	...	...	...	...	...
>XX	...	...	...	...	...	...	...	...	...	...	...	...	...
Sum by grouped ages													
IV–VII	800	821	603	927	1339	2046	2655	1561	1893	3011	(2763)	(5451)	...
VIII–XI	449	432	663	996	1301	1347	(1955)	...	...	...	...	...	...
IV–XI	1249	1253	1266	1923	2640	3393	(4610)	...	...	...	...	...	...

*Data in parentheses are projected values based on average performance of year-classes for which information is complete.

TABLE 41. Measures of year-class strength in the southern stock of petrale sole.

	Numbers of fish/100 hr of trawling						
	IV–VII			VIII–XI			IV–XI
Year-class	Male	Female	Total	Male	Female	Total	Total
1936	...	...	...	...	...	...	...
1937	...	...	...	841	1,679	2,520	...
1938	...	...	...	1,151	1,696	2,847	...
1939	1,663	2,066	3,729	930	1,582	2,512	6,241
1940	2,395	3,563	5,958	1,359	2,848	4,207	10,165
1941	2,763	4,201	6,964	1,532	2,759	4,291	11,255
1942	4,008	4,969	8,977	1,395	2,875	4,270	13,247
1943	3,677	4,765	8,442	1,239	2,240	3,479	11,921
1944	1,280	1,402	2,682	1,304	1,878	3,182	5,864
1945	1,645	1,905	3,550	887	1,631	2,518	6,068
1946	1,167	994	2,161	414	711	1,125	3,286
1947	862	800	1,662	224	449	673	2,335
1948	656	821	1,477	217	432	649	2,126
1949	425	603	1,028	196	663	859	1,887
1950	509	927	1,436	324	996	1,320	2,756
1951	685	1,339	2,024	266	1,352	1,618	3,642
1952	1,120	2,046	3,166	367	1,374	1,741	4,907
1953	1,685	2,655	4,340	(442)	(1,955)	(2,397)	(6,737)
1954	1,147	1,561	2,718	...	...	...	...
1955	891	1,893	2,784	...	...	...	...
1956	1,502	3,011	4,513	...	...	...	...
1957	(1,603)	(2,763)	(4,366)	...	...	...	...
1958	(3,081)	(5,451)	(8,532)	...	...	...	...

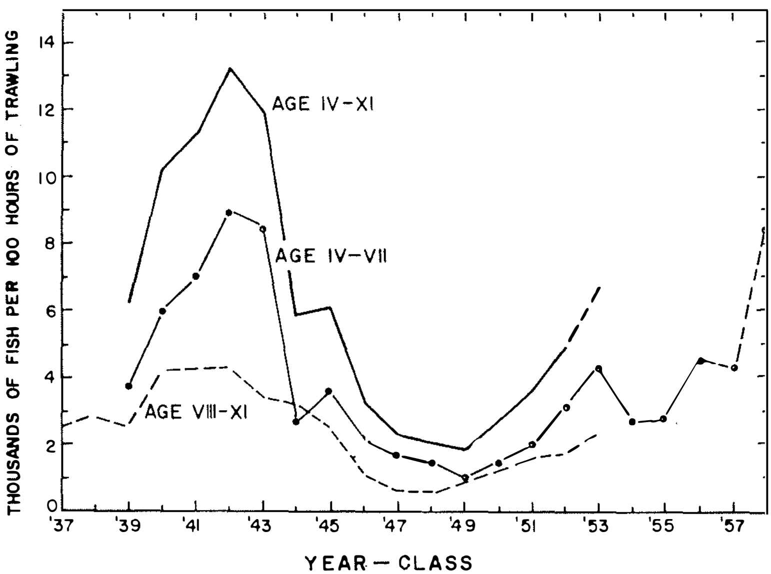


FIG. 34. Measures of year-class strength in the southern stock of petrale sole, based on contributions to the catch per unit of effort from ages IV through VII, VIII through XI, and IV through XI.

catch (p. 67) and excluded late season data (p. 70), may have overstated the decline in catch per effort and hence the decline in year-class strength. Furthermore, as mentioned at the beginning of this section, increasing fishing effort during the period of study (and hence presumably an increasing rate of fishing) would likewise tend to overstate the decline in year-class strength by underestimating strengths of recent year-classes.

These objections can be partially satisfied by calculating year-class strength on the basis of a contribution to the catch, rather than on the basis of catch per unit of effort. There is an insufficient run of data to provide estimates of virtual populations (total contribution of a year-class throughout its life in the fishery, after Fry, 1949), but we can compute the contribution for a series of ages say from first appearance in the fishery to age XI. This, however, leads to essentially the same result as that obtained from catch per effort data for as shown in Fig. 21, trends in catch and catch per effort were similar. The only difference that can be expected is that the upward trend in strength shown in Fig. 34 for year-classes subsequent to 1947 or 1948 would be more pronounced if based on catch rather than on catch per unit of effort.

The basic assumption in estimating virtual populations is, of course, that effort remains constant (or at least variable without trend). This assumption is satisfied by the use of the total catch. All but a small fraction of total catch is taken in May–October, and calculated total effort based on catch per effort for this period (Table 27) is without noticeable trend (in contrast to that based on May–August catch per effort, which trends upward (Table 26)).

The conclusion to be drawn from the data on year-class strength in the southern stock is that year-classes produced in the early 1940s were stronger than those of the late 1930s, and that a pronounced decline took place during the mid 1940s, reaching a low point in 1948 or 1949. Thereafter, there was an irregular upward trend in strength. Projected estimate of the strength of the 1958 year-class suggests that it is as strong as those produced in 1942 and 1943. Further discussion of this matter will be deferred to a later chapter which deals with causes of variations in recruitment (Chapter XIII).

4. Variations in Year-Class Strength in the Northern Stock

Age composition data for the northern stock of petrale sole have been analysed only for the few years when the fishery was particularly active (1946–50). Despite this limited coverage, it is possible to make a reliable assessment of what has transpired. Using the Hecate Strait region (Areas 5C and 5D) as an example, and following the same procedure as that used for the southern stock, average lengths of male and female fish (Table 31) are first converted to average weights to obtain the proportions of the two sexes (by weight) in the commercial samples and then in the catch per unit of effort (from data in Table 28). With this information, the age composition of the catches (Table 35) is converted from percentage frequency to numbers of fish per 100 hr of fishing. The results are shown in Table 42.

TABLE 42. Numbers of petrale sole/100 hr of trawling — Hecate Strait region (Areas 5C and 5D).

Year of catch	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV	XV	XVI	XVII	XVIII	XIX	XX	Total
Males																			
1946	665	1,502	2,897	2,650	848	236	547	418	601	118	236	...	...	...	...	...	...	...	10,718
1947	53	1,426	3,604	4,118	2,534	581	277	343	172	66	13	...	...	...	...	...	...	...	13,187
1948	...	392	3,184	6,029	6,186	3,837	1,383	1,148	1,044	1,227	443	261	52	52	...	...	...	...	26,125
1949	...	...	832	3,640	3,419	2,535	1,157	546	273	273	273	...	...	52	...	...	...	...	13,000
1950	...	94	523	946	1,139	1,089	616	572	237	237	...	...	...	...	...	50	...	...	5,503
Females																			
1946	229	1,331	3,494	5,054	2,454	1,414	1,123	1,123	1,414	1,331	1,331	291	229	...	...	...	...	...	20,818
1947	40	1,040	3,320	4,740	4,400	2,860	1,080	860	960	600	80	20	...	20	...	...	...	...	20,020
1948	28	166	1,690	4,487	5,096	5,789	3,296	2,133	1,247	1,247	693	526	776	305	55	55	55	55	27,699
1949	...	62	541	1,914	4,035	5,949	2,995	1,747	1,477	603	666	104	208	166	208	62	62	...	20,799
1950	...	187	410	316	2,048	2,141	2,820	819	632	632	550	363	269	94	187	94	94	47	11,703

It is obvious that availability was high in 1948, for the catch per unit of effort from all year-classes was higher than that in the preceding year. This factor of changing availability makes it impossible to obtain a valid comparison of year-classes even over a short range of ages. Nevertheless, it is apparent that the year-classes of 1940–43 played a prominent role in the fishery during the period 1946–50.

In 1948, the year of exceptionally large catch, the removals amounted to 6,640,000 lb, or approximately 3,400,000 fish (sexes combined). Of this number, more than 70% belonged to the 1940–43 year-classes. The fact that 1948 was the beginning of a period of sharply decreasing catch per unit of effort and sharply increasing average size of fish in the catches can mean only one thing, that year-classes produced in the middle and late 1940s were substantially weaker than those produced between 1940 and 1943. In other words, the decline in recruitment to the northern stock in all probability paralleled closely that observed in the southern stock. The fact that catch per unit of effort in the north failed to recover after 1956 as it did in the south (cf. Fig. 21 and 24) suggests that there was no improvement in the strengths of year-classes produced after 1948 or 1949. On the other hand, it is apparent from changes in the average size of fish in the catch that after 1956 in both southern and northern stocks, average size began to decrease (cf. Fig. 25 and 29) thus indicating an increased entry of young fish into the fisheries, or more precisely, increased dependence of the fishery on young fish.

5. Summary

Large variations in recruitment with noticeable trends have been observed in both the southern and northern stocks of petrale sole. Year-classes produced in the early 1940s were probably five times as strong as those produced in the latter part of that decade. The timing of the decline was essentially the same in the two stocks in spite of markedly different histories of exploitation. If fishing had been responsible for the decline (i.e. if it had had sufficient impact on the stock of mature fish that it reduced the production of young), then the effect would have appeared later in the northern stock than in the southern one. The simultaneous decline in strengths of broods produced after the early 1940s suggests that some unfavourable feature of the environment common to the areas inhabited by the two stocks was the dominant factor in the declining success of reproduction. Alternatively, a density-dependent oscillation was proceeding simultaneously in both stocks.

The effects of this reduced recruitment did not become apparent until about 1948, at which time average size of fish began to increase in company with declining catch per unit of effort. In all regions except Hecate Strait, catches had been declining before that time, but for other reasons: (i) because removals from the accumulated virgin stocks were in excess of annual replacements and/or (ii) because the fishery was operating at an intensity greater than that which provided the maximum yield from a given recruitment.

Chapter VII

GROWTH OF THE PETRALE SOLE

Estimates of the growth rate of petrale sole in the southern stock have been obtained from the relationship between length and age as determined from otolith readings. Observations based on samples from commercial catches cover the years 1944–61, inclusive. Average lengths at each age for each of these years are provided in Appendix VI, from which long-term mean values have been obtained as shown in Fig. 35 and Table 43. These growth curves are of course biased by the effects of selection in the younger age groups. Average lengths there will be higher than those for the population as a whole.

Before attempting to obtain an unbiased estimate of growth, it is instructive to examine the variability of growth as determined from commercial catches. In Fig. 36, average sizes at each age are arranged by year-classes and expressed as deviations from the long-term mean. The diagonal guide lines separate the years of fishing by 6-year periods. In the period 1947–52, average lengths tended to be below the long-term mean, while those in the period 1952–57 tended to be above the mean. The fact that petrale sole were more abundant during the former

TABLE 43. Average length (mm) at each age of fish contained in commercial catches, for the southern stock of petrale sole (1944–61, inclusive).

Age	Male	Female	Age	Male	Female
III	304	315	XIII	458	522
IV	337	342	XIV	461	538
V	359	376	XV	475	551
VI	377	404	XVI	462	563
VII	393	428	XVII	489	566
VIII	407	449	XVIII	...	581
IX	420	467	XIX	...	585
X	428	483	XX	...	573
XI	437	495	XXI	...	589
XII	448	507	XXII	...	599

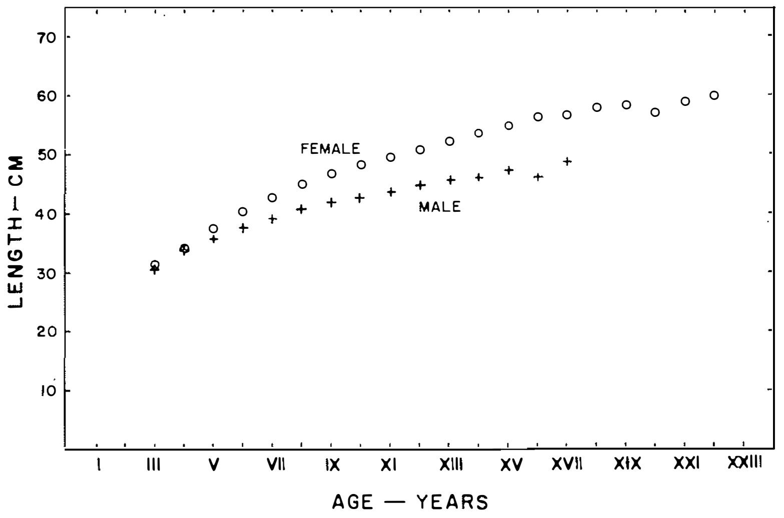


FIG. 35. Long-term (1944–61) average lengths of petrale sole by age in landings from Area 3C.

period than in the latter, suggests at least superficially that growth is density dependent. However, it is difficult to prove this point because little is known about the extent of intra- and inter-specific competition for food. The petrale sole feeds mainly on euphausiids, herring, and sand lance, but so also do several other species, such as dogfish, hake, Pacific cod, turbot, and lingcod. (For further discussion of the food habits of the petrale sole, see Chapter VIII below.)

It is quite possible that the changes were induced by the physical environment, for the period 1947–52 was marked by somewhat below average temperatures along the British Columbia coast, at least in surface waters (Ketchen, 1956a; Hollister, 1964). However, the whole subject of variation in growth and its causes deserves more thorough consideration than can be given here. For present purposes we are assuming that the long-term average picture of growth provides a meaningful working basis for discussion of yield per recruitment.

To complete the information on growth throughout the entire life span of the petrale sole, and to correct at least partially for biased average lengths of those age groups entering the exploited phase, lengths in age groups I–IV have been calculated from otolith measurements. In the absence of otolith collections from young fish, samples collected in 1956 from the commercial catch were used for this purpose and the details of the calculations are given in Appendix 7. The estimates given in Table 44 are approximations of the average lengths at the completion of ages I–IV. In contrast, the lengths for age presented in Fig. 35 are based on summer-time observations and hence are higher than would be expected if observations had been made at the completion of the growing season.

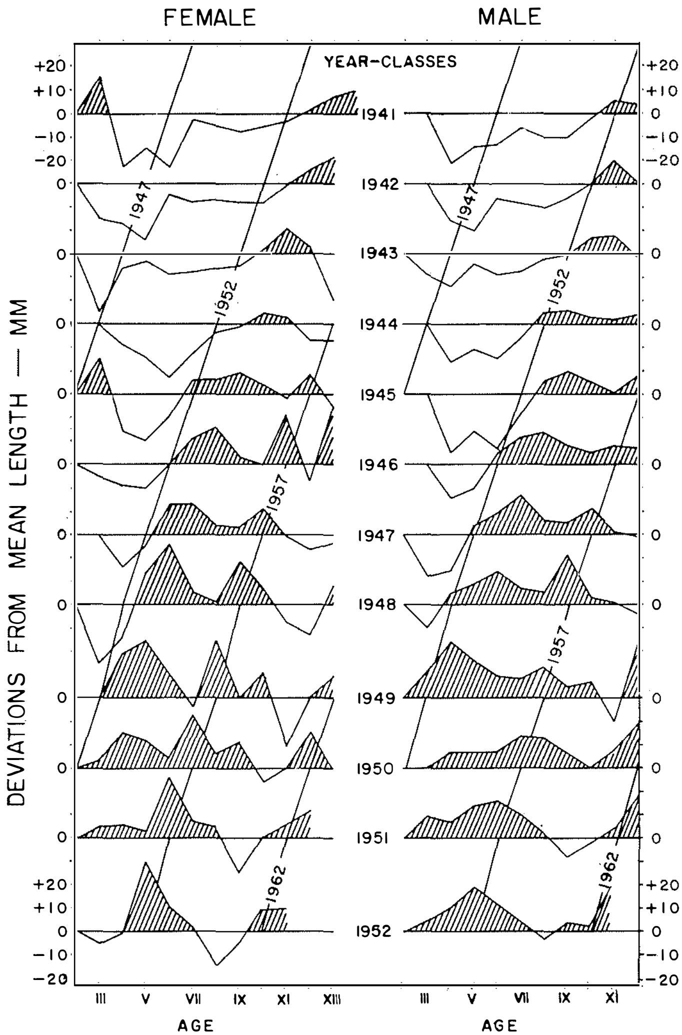


FIG. 36. Average length at each age expressed as deviations from the long-term mean (1944-61) and arranged by year-class.

TABLE 44. Calculated lengths of petrale sole for early age groups as based on otolith measurements.

	Average length (mm)	
Age	Males	Females
I	107	106
II	186	184
III	261	250
IV	316	309

To make these observations comparable in time with those lengths calculated from otolith measurements, we have assumed that by mid summer half of the annual growth has been completed. The points describing the growth curves in Fig. 35 were then shifted $\frac{1}{2}$ year to the right and values for completed years were obtained by interpolation. These new, observed values are shown in columns 2 and 4 of Table 45 for ages V and older, together with the calculated lengths for ages I–IV from Table 44.

TABLE 45. Observed and calculated lengths (mm) at each age. Southern stock of petrale sole.

1	2	3	4	5
	Male		Female	
Age Completed years	Observed	From growth equation	Observed	From growth equation
I	105	215	110	111
II	185	250	190	185
III	260	285	250	246
IV	315	315	300	298
V	346	345	345	343
VI	368	366	385	380
VII	385	385	415	412
VIII	401	400	440	438
IX	414	413	460	461
X	425	425	477	481
XI	434	434	492	496
XII	442	443	506	510
XIII	450	450	519	522
XIV	458	456	522	532
XV	463	461	545	540
XVI	468	465	554	547
XVII	473	469	563	553
XVIII	...	...	572	558
XIX	...	...	582	563

No consideration is given here to the possibility of general underestimation of growth through use of size at age. Such presumably arises from earlier mortality of the fast-growing part of each year-class, from natural causes and/or fishing.

1. GROWTH EQUATIONS

To obtain a mathematical expression of growth in terms of the von Bertalanffy equation the following procedure (outlined by Ricker, 1958, p. 194–197) was adopted:

(a) For each sex, a Walford line was constructed, with l_{t+1} plotted against l_t, where l_t is the length at a particular age and l_{t+1} is the length at the succeeding age. From this line was obtained a trial estimate of the slope and l_∞, the asymptotic length.

(b) A graph of $\log_e (l_\infty - l_t)$ against t was then constructed and other trial values of l_∞ were inserted to find which one gave the best (straightest) line, the equation of which is:

$$\log_e (l_\infty - l_t) = \log_e l_\infty + Kt_o - Kt$$

where K (the slope) is the growth coefficient and t_o is the time at which the fish would have been zero length if it had always grown in the manner described by the equation. Values of l_∞ which by visual inspection gave the straightest line are shown in the following tabulation with corresponding values of K and t_o:

	l_∞	K	t_o
Males	49.0 cm	.160	−2.60 yr
Females	58.6 cm	.167	−0.27 yr.

Substituting these values in the von Bertalanffy growth equation

$$l_t = l_\infty \left[1 - e^{-K(t-t_o)}\right]$$

we obtain the following expression for males:

$$l_t = 49.0 \left[1 - e^{-.167(t-2.60)}\right]$$

and for females:

$$l_t = 58.6\left[1 - e^{-.160(t-0.27)}\right]$$

from which are obtained the calculated values for length at each age given in columns 3 and 5, respectively, of Table 45. These equations are graphed in Fig. 37 and compared with "observed" values of length at each age.

The calculated curve for female fish conforms closely with the observed data over all but the extreme ages, while that for males fits the observed data only from age IV onwards. Further study is required to determine whether this difference is real or merely the result of inherent weaknesses in the techniques of sampling and backcalculation.

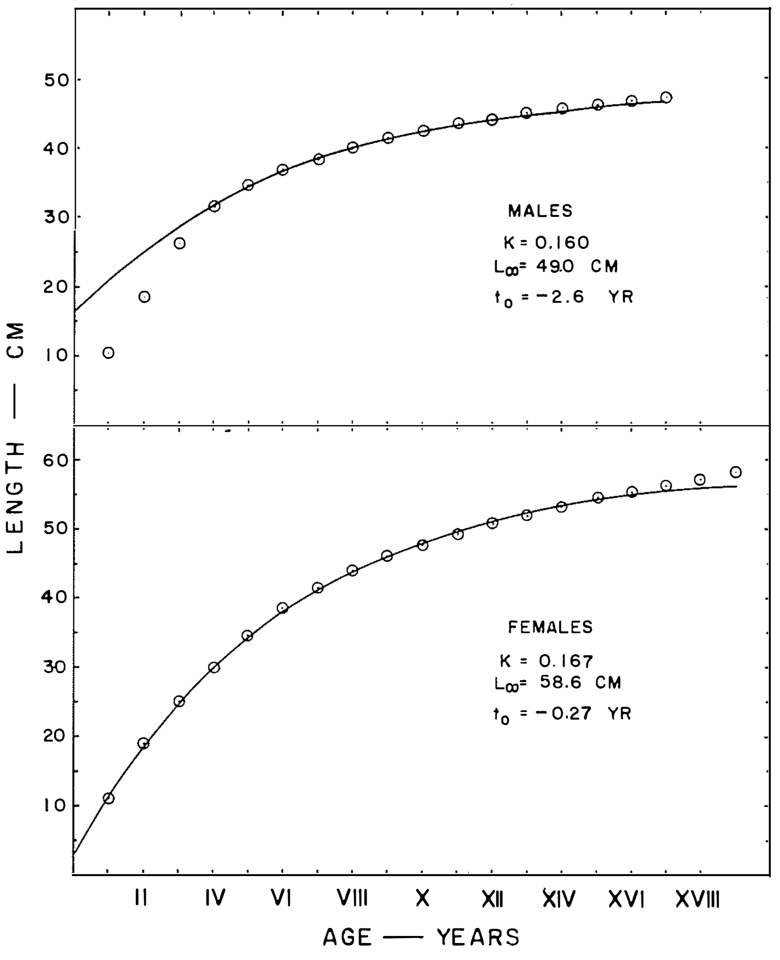


FIG. 37. Growth curves of male and female petrale sole fitted by the von Bertalanffy growth equation.

Chapter VIII

FOOD HABITS OF THE PETRALE SOLE

The flounder family may be divided into two groups based on mouth size and dentition. Small-mouthed flounders have relatively weak dentition and, with a few notable exceptions, prey largely on small invertebrates such as annelid worms, clams, and brittle stars. The large-mouthed flounders, to which group belongs the petrale sole, have strong dentition and feed predominantly on fish and pelagic or semi-pelagic invertebrates.

As part of the routine program of sampling landings of petrale sole, qualitative information is recorded on stomach contents, namely, a listing of species or groups of species encountered. Sampling of landings from the area of the southern stock (Area 3C) has been conducted mainly during the spring and summer months over the past 18 years. The incidence (number of occasions when occurrence was noted) of various food items is summarized in Table 46. Euphausiids were the predominant food, being recorded on over 40% of the occasions when sampling was conducted. Herring (*Clupea pallasii*), sand lance (*Ammodytes hexapterus*), and shrimp (pandalids) follow in order of importance.

TABLE 46. Incidence of various species or groups of organisms as food of petrale sole taken off the lower west coast of Vancouver Island (Area 3C).

Month	Euphausiids	Herring	Sand lance	Shrimp	Crabs	Other fish[a]	Other invert.[b]	Total
Apr.	9	8	3	...	2	2	2	26
May	50	24	11	18	7	3	3	116
June	47	23	17	11	2	2	3	105
July	62	38	32	10	12	6	1	161
Aug.	48	25	20	5	6	8	2	114
Sept.	20	15	7	5	1	...	1	49
Oct.	4	8	2	4	...	...	...	18
Total	240	141	92	53	30	21	12	589
Percentage	40.8	23.9	15.6	9.0	5.1	3.6	2.0	

[a]In order of incidence: Pacific cod, rockfish, smelts, Dover sole, seapoacher.
[b]In order of incidence: Clams, squid, copepods, brittlestars.

It has been observed that, during the later spring and summer months, petrale sole gorge heavily on euphausiids, a fact confirmed by earlier studies conducted by Cleaver (1949). It is not possible with available data to determine the extent of within-season changes or between-year changes in the relative contribution of various organisms to the diet of petrale sole, though such are quite likely to occur.

Sampling of the food habits of petrale sole belonging to the northern stock, though not as extensive as in the south, covers a longer period of the year and indicates some seasonal changes in diet (Table 47). During the late spring and summer, the dominant food item is sand lance, followed by euphausiids and herring. In the late fall, emphasis shifts more to herring.

TABLE 47. Incidence of various species or groups of organisms as food of petrale sole taken in Queen Charlotte Sound and Hecate Strait (Areas 5A to 5D).

Month	Sand lance	Herring	Euphausiids	Shrimps	Other fish[a]	Other invert.[b]	Total
Feb.	...	...	1	...	...	...	1
Mar.	...	...	1	...	...	1	2
Apr.	1	2	2	1	1	...	7
May	21	1	10	4	...	2	38
June	30	8	6	6	...	1	51
July	16	6	8	1	...	1	32
Aug.	10	2	...	1	...	...	13
Sept.	4	3	2	2	3	2	16
Oct.	3	7	3	3	7	...	23
Nov.	3	13	2	4	5	2	29
Dec.	2	4	...	3	1	2	12
Total	90	46	35	25	17	11	224
Percentage	40.2	20.5	15.6	11.2	7.6	4.9	

[a]In order of incidence: small rockfish, smelts, small Pacific cod, small whiting, seapoacher.
[b]In order of incidence: clams, squid, worms.

Chapter IX

SIZE AND AGE AT MATURITY

Determination of the size and age at which the petrale sole reaches maturity is complicated by differential behaviour and distribution of the immature and mature elements of the stock. In summer months and on the inshore feeding grounds intermingling of matures and immatures is greatest, but at that time of year there is least certainty of accurately distinguishing by gross visual observation the stage of gonad development. By late fall or winter, gonads are developed sufficiently to permit estimation of whether an individual will spawn that year, but by then segregation of the mature and immature elements is underway. Hence, there is uncertainty concerning the extent to which field observations reflect the true proportion of mature to immature (for a particular size group) in the population as a whole.

Sampling by the Fisheries Research Board has been conducted mainly during the winter months, and almost entirely in the northern area (particularly in Hecate Strait). The results, involving 858 male and 1029 female petrale sole are illustrated

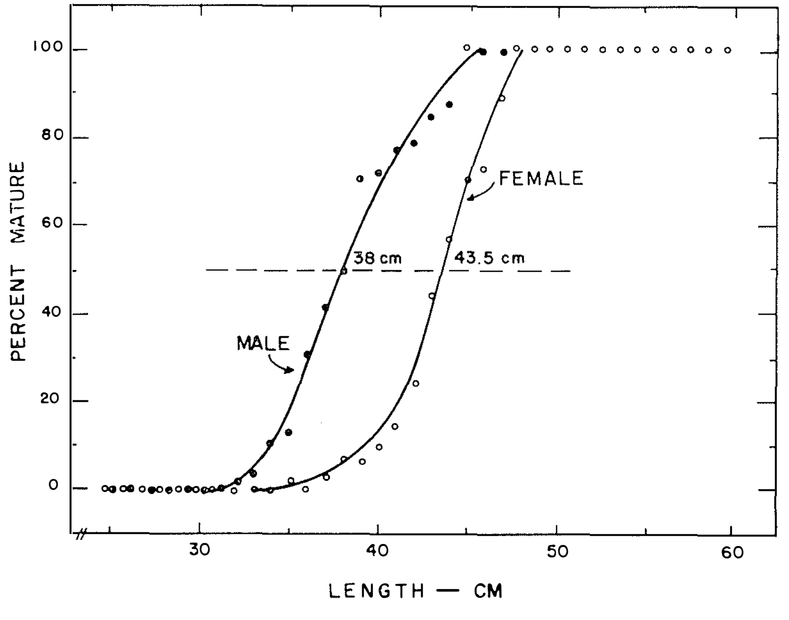


FIG. 38. Percentage maturity by size of male and female petrale sole.

in Fig. 38. They suggest that amongst male fish about 50% are mature by the time they reach 38 cm in length, while the corresponding point for females is about 44 cm. These sizes correspond approximately to ages VII and VIII (cf. Fig. 37).

Earlier sampling by Cleaver (1949) in the southern area (Area 3C — Swiftsure Bank) and also in the winter months suggested the 50% point for males was in the general vicinity of 32 cm, while that for females was close to 42 cm. Winter sampling conducted by Harry (1959) in the vicinity of the Columbia River estuary (Area 2D) showed the 50% point to be at 35 cm and 40 cm for males and females, respectively.

The minimum observed size of mature fish and maximum size of immature fish as recorded by Cleaver and Harry are compared with samples from Hecate Strait in Table 48.

TABLE 48. Size of petrale sole in relation to maturity in several areas along the Pacific coast (lengths in millimeters).

Area	Length at 50% maturity		Minimum length mature		Maximum length immature	
	Male	Female	Male	Female	Male	Female
Hecate Strait	380	440	320	350	430	470
Swiftsure Bank (Cleaver, 1949)	320	420	300	370	400	470
Columbia River (Harry, 1959)	350	400	290	310	380	460

In sampling conducted on the Estevan Deep spawning ground (Area $3D_{\Delta}$), Alverson and Chatwin (1957) noted the absence of small immature fish. All male petrale sole were mature (range: 33–48 cm) and all but ½ of 1% of the females were mature (range: 35–60 cm). The minimum sizes (33 and 35 cm) agree well with those observed in the inshore Hecate Strait sampling.

In summary, it appears that in British Columbia waters the point of 50% maturity is reached at about age VII in males and age VIII in females (38 cm and 44 cm, respectively). Some females mature as early as age V (35 cm) and some males at age IV (32 cm). At the other extreme some individuals of both sexes may still be immature at age X. These age extremities are based on the untested assumption that early and late maturing individuals have a growth rate comparable to that of the population as a whole.

There may be a latitudinal trend in size and age at maturity, namely, earlier maturation in southern waters, or at least at a smaller size (Table 48). Best (1961, p. 37) notes that in California waters 50% of female petrale sole are mature at approximately 14 inches (35.5 cm) and all are mature at 16 inches (40.6 cm).

Chapter X

MORTALITY RATES

In the section dealing with recruitment, evidence was brought to light which suggests that recruitment to both the southern and northern stocks of petrale sole has not only been variable but has followed a distinct trend over a period of years. Since the trend has been downward throughout most of the period of study the right-hand limb of a simple catch curve (logarithm of numbers at successive ages) based on age composition data for a particular year would yield a total mortality rate which is too low. Thus, analyses of this kind must be treated with caution.

To circumvent the difficulty created by changing recruitment, we may examine data on the catch per unit of effort of individual year-classes in successive years of their existence. Before doing so, however, it is worth mentioning some of the sources of error which may be involved. In the first place, there are likely to be random as well as systematic sampling errors involving both the estimates of catch per unit of effort and the age composition data. These have already been discussed in the appropriate chapters above. Then there are the effects of variation in availability which are apparently of random, short-term (annual) occurrence. Their presence precludes the estimation of mortality during short periods (say 2 successive years). Use of longer periods will reduce these effects, but will still require that judgment be exercised in determining whether weighted or unweighted estimates of mortality reflect most accurately the actual events.

1. Estimates of Total Mortality Rate

In obtaining estimates of total mortality rate from age composition the analysis has been confined to 10 year-classes, 1938 through 1947. As shown in columns 2 and 3 of Table 49, the age at which the numbers of fish per unit of effort reached a maximum ranged from age VI to VIII in male fish and V–VIII in female fish (this information is derived from inspection of Tables 39 and 40). To avoid the effects of incomplete recruitment or gear selectivity and also the possible effects of change in mortality rate with age, a fixed range of ages VIII–XIV has been used to assess the performance of each year-class. In eight out of the 10 year-classes, of each sex, the age of maximum occurrence was excluded from the calculations by this procedure.

TABLE 49. Estimates of the instantaneous total mortality rate (Z) by year-class.

1	2	3	4	5	6	7	8
	Age of maximum Numbers per effort			Weighted (Jackson) estimates		Unweighted estimates	
Year-class	Male	Female	Ages Utilized	Male	Female	Male	Female
1938	8	7	8–14	0.56	0.41	0.47	0.32
1939	7	7	8–14	0.29	0.20	0.63	0.29
1940	6	6	8–14	0.42	0.46	0.68	0.49
1941	7	7	8–14	0.71	0.35	0.68	0.53
1942	6	6	8–14	0.67	0.44	0.79	0.43
1943	6	5	8–14	0.26	0.15	0.71	0.37
1944	8	8	8–14	0.56	0.36	0.72	0.40
1945	7	8	8–14	0.83	0.54	0.51	0.43
1946	6	7	8–14	0.58	0.38	0.46	0.28

Two methods of analysis were employed. First there is the Jackson (1939) method which provides a weighted estimate of annual survival rate (S),

$$S = \frac{Y_9 + Y_{10} + Y_{11} + ---- + Y_{14}}{Y_8 + Y_9 + Y_{10} + ---- + Y_{13}}$$

where Y_n is the number of fish per unit effort at age n.

As an example, from Table 40 which provides data on numbers of fish per unit of effort, the survival rate of female petrale sole of the 1938 year-class, for ages VIII–XIV is as follows:

$$S = \frac{334 + 333 + 259 + 200 + 130 + 83}{770 + 334 + 333 + 259 + 200 + 130} = 0.661.$$

Annual mortality rate, 1-S, equals 0.339 and the corresponding instantaneous rate of total mortality Z is 0.41, as obtained from the expression

$$S = e^{-Z}.$$

These weighted estimates of Z appear in columns 5 and 6 of Table 49.[25]

[25]Following the notation recommended by Holt et al. (1959), Z is equivalent to the sum of the instantaneous rates of fishing and natural mortality, F and M, respectively.

The unweighted estimates (columns 7 and 8) were obtained by first transforming the numbers of fish per unit of effort at each age to logarithms (base 10). Using the above example, the line of best fit has a slope of –.1408 (survival rate). With sign changed, this figure multiplied by 2.3026 equals 0.32, the instantaneous total mortality rate (Z). Catch curves of a number of year-classes are illustrated in Fig. 39.

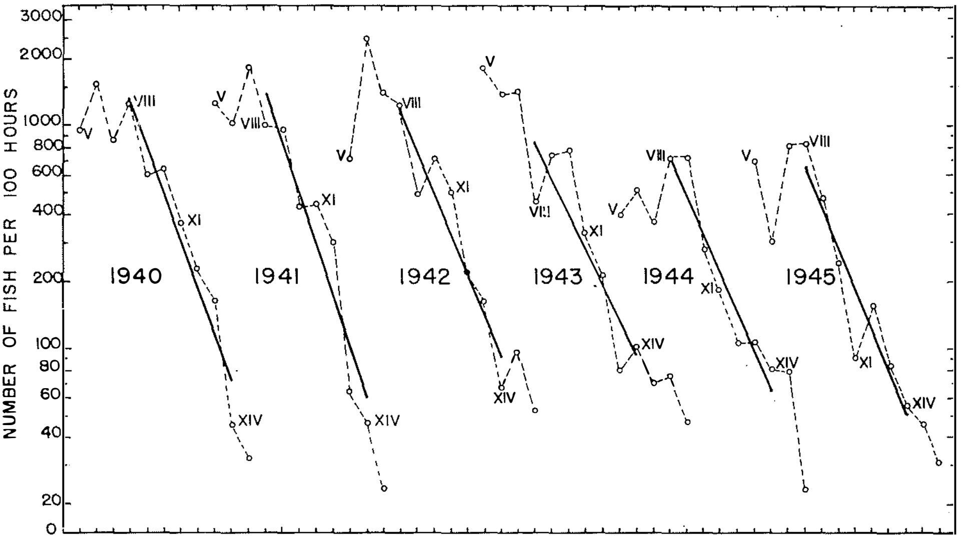


FIG. 39. Catch curves of several year-classes (females) derived from data in Table 40. Solid lines fitted by least squares to data for ages VIII–XIV, inclusive.

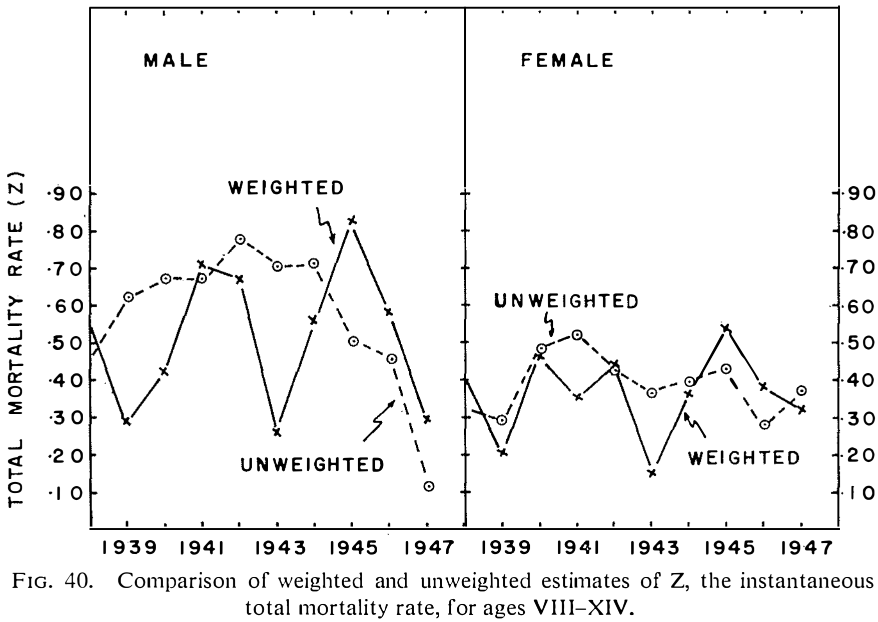


FIG. 40. Comparison of weighted and unweighted estimates of Z, the instantaneous total mortality rate, for ages VIII–XIV.

The weighted and unweighted estimates of Z are compared in Fig. 40. The latter exhibit more stability between adjacent year-classes than the former, and for this reason it is assumed that unweighted estimates are more reliable than weighted ones. For the 1940–44 year-classes, values of Z for males ranged from 0.68 to 0.79 and for females, from 0.37 to 0.49. As far as can be discerned, these ranges establish an approximate upper limit to the total mortality rate reached during the late 1940s and early 1950s when petrale sole were still the prime object of fishing in the southern area (Area 3C).

As shown in Fig. 40, the apparent rate of mortality for year-classes subsequent to 1944 was lower than for earlier classes, particularly amongst male fish. This change becomes more evident if we recompute unweighted estimates of Z for a shorter range of ages (VIII–XII) and thereby draw in data for the 1948 and 1949 year-classes (Table 50).

TABLE 50. Estimate of instantaneous total mortality rate (Z) from year-classes 1944–49, inclusive.

	Year-class					
	1944	1945	1946	1947	1948	1949
Male	0.81	0.70	0.49	0.13	0.08	0.23
Female	0.52	0.50	0.40	0.09	0.20	0.26

There are two possible explanations for this change: in the later years of the fishery (subsequent to 1952 or 1953) petrale sole declined in importance in the trawl fishery and fishing effort was directed more to other species, which though less valuable, were in greater relative abundance. Also, growing abundance of dogfish in Area 3C had increasingly hampered effectiveness of fishing operations. Thus, it is reasonable to conclude that fishing pressure on petrale sole decreased and hence that a decreased rate of fishing mortality would be reflected in reduced total mortality rate. It is true, however, that crude estimates of total fishing effort do not support this contention (Chapter IV). The second reason, not wholly separate from the first, concerns the inherent weaknesses in the estimates of changes in stock size. In the later years of the fishery (subsequent to 1953) as emphasis shifted more and more to other species, the reliability of the estimates of catch per effort for petrale sole decreased. Thus, the upward trend in catch per effort between 1956 and 1959 (Fig. 21) may not have been an accurate reflection of change in stock size. If in fact stock size did not increase, then mortality rates based on the catch per unit of effort of year-classes produced subsequent to 1946 would be underestimated.

Values of Z, based on the age range of VIII–XII years for the 1947–49 year-classes, as shown above were relatively low. Indeed, as we shall see later, they approach, if not fall below, the best estimates of M (instantaneous natural mortality rate). Thus, while it is quite likely that Z for these later year-classes was less than for the earlier ones, the decline could not have been as great as these estimates suggest.

2. Estimates of Natural Mortality Rate

(a) calculations based on primitive age structure

In theory, the right-hand limb of the catch curve obtained from samples collected at the onset of fishing, or shortly thereafter, should provide an indication of the natural survival rate, whence estimates of the instantaneous rate of natural mortality (M). This would be true of course, only if the full range of exploitable ages in the virgin population were available to trawls on grounds first exposed to fishing and if recruitment to the stock in the years prior to fishing had not been affected by natural trends. The first of these conditions is difficult to assess, but it is reasonable to suppose that in the initial stages of fishing, lack of familiarity with the fishing grounds and lack of knowledge regarding the true distribution of the population in space and time, might result in catches which were unrepresentative of the primitive age structure. In any event, there is sufficient evidence from the later history of the petrale sole fishery to shed doubt on the second qualification, namely, the requirement of uniform recruitment. In view of the information on the trends in recruitment which occurred in the late 1940s and 1950s, there is no reason to suppose that recruitment was without trend in earlier years.

Thus, while it is instructive to examine catch curves based on data for the early years of the fishery, the results bearing on estimates of natural mortality must be viewed with caution.

(i) *United States data.* Earliest sampling in the region inhabited by the southern stock of petrale sole (Area 3C) was conducted by the Washington State Department of Fisheries. Age composition data published by Cleaver (1949) make no distinction between the sexes; thus, it has been necessary to examine his manuscript data.

Sampling was conducted on catches from Swiftsure Bank in 1943, 1944, and 1945 (months of May–August in the first 2 years and May–July in 1945). The average age composition of males and females in the catches for those 3 years is provided in Table 51. These combined data are used to compute mortality rates over given ranges of age.

Following the same procedure as in the preceding section, weighted and unweighted estimates of Z for the age range VIII–XIV years are as follows: male. 0.39 and 0.90; female, 0.23 and 0.33 weighted and unweighted, respectively.

TABLE 51. Percentage age composition of petrale sole in catches landed by Washington trawlers from Swiftsure Bank (1943–45 average).[a]

Age	Male	Female
III	0.7	0.9
IV	11.3	7.9
V	21.6	19.5
VI	19.1	20.2
VII	10.5	12.0
VIII	12.1	8.6
IX	12.2	7.1
X	8.4	9.0
XI	3.4	5.1
XII	0.7	5.2
XIII	0.2	2.9
XIV	0.1	0.9
XV	...	0.6
XVI	...	...

[a]Data from Cleaver manuscript.

Again we are faced with considerable disparity between weighted and unweighted estimates of Z. The marked difference in estimates for male fish arises from the low representation of ages XII and older, which may reflect increasing natural mortality with age or underestimation of ages of older fish. Other combinations of ages, e.g. VII–XIII yield weighted and unweighted estimates of 0.24 and 0.67, respectively, for males and 0.21 and 0.20, respectively, for females. Restricting the age range to VII–XI years yields estimates of 0.18 and 0.26 for males and 0.21 and 0.19 for females.

It is difficult to say how closely these estimates approach the situation where total mortality rate is in fact an expression of the natural mortality rate. According to Cleaver, the Swiftsure Bank fishery began about 1938 and increased in intensity through subsequent years to 1943. Presumably, age composition data for 1943–45 would reflect some effect of fishing, i.e. a steepening of that part of the right-hand limb of the catch curve near the dome. This would lead to overestimation of M (for further discussion of effects of changes in fishing mortality see Ricker, 1958, p. 61).

Concerning the effects of trends in recruitment, if the strengths of the 1930–37 year-classes followed an upward trend, values of M would be overestimated, or underestimated if the trend had been in the other direction.

We are left with the tentative conclusion that the value of M for female petrale sole is somewhere in the vicinity of 0.20 (possibly lower) and that the value for males is somewhat higher than 0.20.

(ii) *Canadian data.* Data from the early stages of the Canadian fishery on the southern stock (Area 3C) have been treated in a similar manner to those of the United States. The average percentage composition of catches taken in 1944, 1945, and 1946 has been computed from Tables 32 and 33. Various estimates of Z are shown in Table 52.

TABLE 52. Estimates of Z (instantaneous total mortality rate) based on average age composition of the Area 3C stock in the years 1944–46.

Age range		Male	Female
VIII–XIV	weighted	0.34	0.15
	unweighted	0.44	0.11
VII–XIII	weighted	0.34	0.17
	unweighted	0.35	0.15
VII–XI	weighted	0.33	0.18
	unweighted	0.34	0.19
Average		0.36	0.16

These results suggest that M for female petrale sole is less than 0.20, probably in the vicinity of 0.16, while that for males is in the vicinity of 0.36.

Sampling of the Queen Charlotte Sound segment of the northern stock (Areas 5A and 5B) began in 1945, the year of first significant exploitation by either the United States or Canadian trawler fleets. Age composition data for the years 1945, 1946, and 1947 (from Table 34) have been averaged and treated in the same way as above to obtain weighted and unweighted estimates of Z. These are shown in Table 53.

As far as females are concerned, the rates are in general agreement with those obtained from the southern stock, suggesting that M is in the vicinity of 0.20 or slightly less. All three of the unweighted and one weighted estimate for male fish

TABLE 53. Estimates of Z based on average age composition of petrale sole in Queen Charlotte Sound for the years 1945–47.

Age range		Male	Female
VIII–XIV	weighted	0.20	0.21
	unweighted	0.20	0.16
VII–XIII	weighted	0.29	0.20
	unweighted	0.18	0.17
VII–XI	weighted	0.31	0.22
	unweighted	0.22	0.23
Average		0.23	0.20

suggest that M is approximately the same as for females. Two of the weighted estimates support those obtained from the southern stock, namely, that M is closer to 0.30 than to 0.20.

Estimates for the remaining part of the northern stock (Hecate Strait), based on samples collected in 1946 and 1947 (Table 35), as shown in Table 54, are in most cases substantially greater than those obtained from areas farther to the south.

TABLE 54. Estimates of Z based on average age composition of petrale sole in Hecate Strait for the years 1946 and 1947.

Age range		Male	Female
VIII–XIV	weighted	0.24	0.33
	unweighted	0.51	0.32
VII–XIII	weighted	0.59	0.33
	unweighted	0.37	0.23
VII–XI	weighted	0.56	0.35
	unweighted	0.28	0.29
Average		0.42	0.31

One would expect Hecate Strait estimates, like those for Queen Charlotte Sound, to be more reliable than those for the southern stock, because sampling was conducted at the onset of fishing and hence the right-hand limb of the catch curve should be an accurate reflection of stock composition in the unfished state. By 1946 and 1947 in Hecate Strait, however, relatively strong year-classes were entering the fishery and these had the effect of decreasing the apparent rate of survival or conversely, increasing the apparent rate of mortality. Thus, the Hecate Strait estimates must be regarded as unreliable.

Since the Queen Charlotte Sound segment of the northern stock appeared to be less affected by variable recruitment than the Hecate Strait segment, and less affected (if at all) by fishing than the southern stock at the time when sampling began, it is assumed that the mortality estimates for Queen Charlotte Sound come closest to an accurate expression of natural mortality rate. Thus, for purposes of later calculations a value of 0.20 will be accepted as the natural mortality rate of female petrale sole, and a higher rate, 0.25, for males.

3. Estimates of Fishing Mortality Rate

Estimates of fishing mortality rate of a series of year-classes have been obtained by subtracting the estimated natural mortality rate (0.20 for females and 0.25 for males) from the unweighted total mortality rates given in Table 49. These are given in Table 55.

Table 55. Estimates of instantaneous fishing mortality rate (F) in the southern stock of petrale sole (Area 3C).

Year-class	Males	Females
1938	0.22	0.12
1939	0.38	0.09
1940	0.43	0.29
1941	0.43	0.33
1942	0.54	0.23
1943	0.46	0.17
1944	0.47	0.20
1945	0.26	0.23
1946	0.21	0.08
1940–43 Average	0.465	0.255

The rates for the four strong year-classes (1940–43) average close to 0.45 and 0.25 for males and females, respectively. These figures are taken as being representative of the rates which prevailed in the late 1940s and early 1950s in the fishery on the southern stock.

As mentioned earlier (p. 122), total mortality rates for more recent year-classes appear to be much lower than those exhibited by their predecessors. While there is basis for believing that fishing pressure on petrale sole had eased as interest shifted to other species, there is some doubt regarding the accuracy of measurements of abundance for recent years. If these have been overestimated, then the total mortality rates have been underestimated. Of course, we cannot ignore the possibility that there are substantial variations in natural mortality and that the reduced total mortality rate of the recent year-classes is a reflection of such variation. In any event, it is not possible at the present time to deduce an up-to-date rate of fishing mortality (i.e. for years subsequent to the middle 1950s).

The conclusion that F for males is very much higher than that for females is at least superficially in conflict with certain observations on the biology of the petrale sole and on the fishery itself. In the first place, it is apparent from observations on the spawning habits of the petrale sole (as well as other flatfish) that males tend to remain on the spawning ground longer than females (Alverson and Chatwin, 1957), and hence are slower to appear on the inshore fishing grounds in the spring. As shown in Table 56, the early spring fishery depends mainly on females and as the season progresses their proportion in the catches decreases. Thus, in the years prior to the development of an extensive fishery on the spawning grounds (the years which to a large extent apply to the catches of the 1940–43 year-classes), it would appear that males should have been subject to a lower rate of fishing mortality than the females, unless, of course, during their inshore phase they were more vulnerable to capture. This brings us to our second observation concerning the fishery itself.

TABLE 56. Average (1948–53) percentage of males in the Canadian catches of petrale sole by month and by ground within Area 3C.

Fishing ground	Month								
	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Swiftsure Bank	41.8	33.1	38.7	37.2	45.6	42.0	31.3	...	...
Forty-mile Bank	22.4	36.8	36.0	48.2	41.1	45.0	40.9	...	...
Firing Range	17.2	26.7	23.5	36.6	28.1	...	...	...	...
Lennard I.–Sydney Inlet	43.1	41.6	47.1	37.0	27.6	10.0	...	...	...
Weighted mean for Area 3C	33.0	38.0	40.1	39.2	36.9	44.0	38.2	...	...

As shown in Fig. 41, at no age during their life span did the calculated catch of males (1940–43 year-classes combined) exceed the catch of females. From ages V through VIII (ages of greatest contribution) the proportion of males ranged from 39 to 44% (average 41.5%).

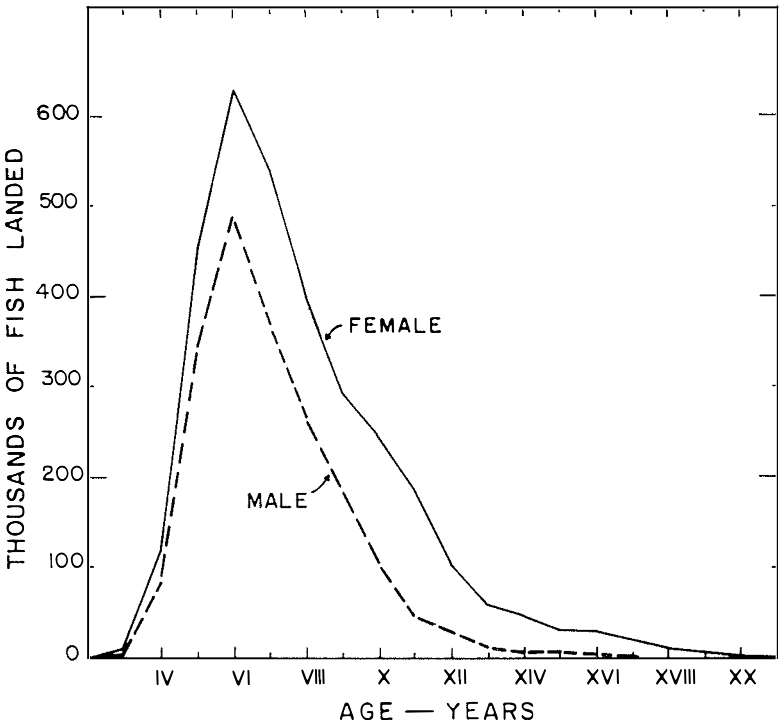


FIG. 41. Calculated numbers of fish caught at each age (1940-43 year-classes combined).

The explanation for this phenomenon, if F for males is greater than that for females, is that coupled with a higher vulnerability to fishing there is a natural imbalance in the sex ratio favouring females, or, as appears to be the case with some other species such as Dover sole (Westrheim and Morgan, 1963), a segment of the male petrale sole population remains perpetually beyond the range of the Canadian inshore fishery. Such assumptions are difficult to test. It will be recalled (Chapter IV, 2) that in the absence of detailed information on the United States fishery, there may be some danger in assuming that the within-year pattern of fishing by the Canadian fleet was similar to that of the United States fleet and hence that observations based on the catches by the former may not be representative of the whole. If, as suggested, the United States fleet fished with greater emphasis than the Canadian fleet on the Lennard Island–Sydney Inlet grounds (in the spring) and on the Forty-Mile Bank and Swiftsure Bank (summer and autumn), then it is possible that the proportion of males in the total catch from the 1940–43 year-classes was higher than that recorded by the Canadian sampling. As shown in Table 56, the percentage of males on the Lennard Island grounds was highest in the spring and early summer months, and highest in the late summer to autumn months on the Swiftsure and Forty-Mile Banks. From October to the end of the year there is little information on sex ratio because of the lack of Canadian landings. Yet it is known that substantial catches are made by the United States fleet in this period (see Appendix 4), and these may contain a high proportion of males. Alverson and Chatwin (1957) noted, with regard to the Estevan spawning ground, that females predominated there in the month of January 1954 (80%). If this is a usual phenomenon and true of spawning grounds associated with the Area 3C stock, then there is some basis for believing that a late autumn or early winter fishery on the inshore grounds depends largely on male fish. Although this remains to be demonstrated, it serves as a plausible explanation for the apparently higher rate of fishing mortality on males in face of the fact that the composition of the inshore catches (based on Canadian data) shows a higher percentage of females.

4. Summary

For the purpose of later discussion of utilization of the Area 3C or southern stock of petrale sole, it has been assumed that the performance of the four strong year-classes of 1940–43 most accurately reflects the fishing mortality exerted during the period when petrale sole was the species of principal interest to the fishery. At that time, total mortality rates (Z) were estimated to be in the vicinity of 0.70 for males and 0.45 for females. Subtracting the estimates of natural mortality rate (0.25 and 0.20, respectively), it is estimated that the rate of fishing (F) during the late 1940s and early 1950s was about 0.45 for males and 0.25 for females.

Some doubt is entertained regarding the validity of the difference in F for the two sexes. In later calculations of yield per recruitment we shall consider the alternative possibility that the differential in Z between males and females is due largely to a differential in M, namely, M is 0.20 for females and 0.45 for males, whence F for both sexes is 0.25.

Chapter XI

PATTERN OF RECRUITMENT TO THE FISHERY

To complete the assemblage of information on the population parameters which are necessary for examination of simple population models, there remains the problem of defining the size and age at which the petrale sole enters the exploited phase of the population. Following the terminology of Holt et al. (1959), we may define the age of recruitment, t_r, as the age at which fish enter the area where fishing is in progress (the corresponding length is l_r). In the case where nursery grounds are separated from the main fishing grounds and recruitment is accomplished by migration to the latter, Beverton and Holt (1957) distinguish two main phases: prerecruit phase and postrecruit phase. Upon entry into the latter (t_r) the fish are liable to encounters with the gear. They may not be immediately liable to capture because of the selective properties of the gear, in which case they remain for a time in what is called the preexploited phase. At a certain average age (t_c), or length (l_c), they become liable to capture and hence enter the exploited phase.

As we shall see in the sections which follow, the petrale sole shows somewhat of a departure from this generalized schedule, partly because entry into the so-called exploited phase appears to occur at a size which is above the selection range, that is, the range of sizes over which the probability of capture varies in accordance with the selective property of the gear. In other words, entry into the exploited phase is determined to a large extent by the recruitment pattern. However, added to this is the complication created by rejection of certain sizes of fish at sea to meet the minimum market requirements.

1. Size and Age of Recruitment to the Fishing Grounds

(a) NURSERY AREAS

In the early stages of the petrale sole investigation it was considered possible, in light of knowledge of the life history of other important species (particularly English sole, as well as lingcod and starry flounder) that the demersal stage in the first year of life (O-group) was spent in shallow water — within or close to the inter-tidal zone. During the summer of 1947, several sets were made with beach seines in bays close to the open sea along the west coast of Vancouver Island. Other sets were made in later years on beaches bordering Hecate Strait to the north. None of these revealed the presence of petrale sole, even as isolated individuals. Earlier investigation by Cleaver (1949) of beaches along the Washington coast and by Westrheim (1955) in the shallow water of Yaquina Bay, Oregon, likewise yielded negative results.

On various occasions between 1952 and 1962, research vessels of the Nanaimo Station have been used to survey grounds along the British Columbia coast for the purpose of defining the distribution of the juveniles of various species of groundfish. In all but a few instances, the gear used was a four-sided trawl having a 36-foot rope-wrapped groundline and constructed of small mesh ($1\frac{1}{2}$ inch in the wings and body and 1 inch in the cod-end). All of the sampling was conducted between May and August and, as a rule, drags were of 15–20 min duration, the maximum being 30 min.

Catches of petrale sole as obtained in these surveys are summarized by depth zones and size categories in Table 57. Although age determinations were not made of all fish caught, subsampling has shown that for practical purposes, individuals in the categories 0–9 cm and 10–14 cm[26] represent age I (second year of growth), while those in the categories 15–19 cm and 20–24 cm represent age II. Some overlapping of the size ranges of these age-groups results from the necessity of combining data from different years and different localities within the major areas. This overlapping increases in the larger size categories, such as 25–29 cm and 30–34 cm which contain fast growing age II fish and representatives of ages III and IV.

TABLE 57. Numbers of petrale sole by size categories taken in small meshed (shrimp) trawl at various depths in major fishing areas along the British Columbia coast.

Major Area	Year of sampling	Depth zone fath	No. of drags	Total hr	Size groups (cm)						
					0–9	10–14	15–19	20–24	25–29	30–34	>34
Area 5D	1952	2–9	66	17.13	...	...	...	...	...	...	5
–Northern	1953	10–19	46	10.83	...	...	...	...	...	...	8
Hecate Strait	1954, 1958	20–29	12	4.10	...	...	...	1	...	2	47
	1959	30–39	19	6.07	...	...	...	...	...	2	27
	1961	40–49	12	3.50	...	...	...	...	...	2	16
	1961	50–59	8	1.75	...	...	...	...	...	...	11
		60–99	13	3.62	...	...	...	...	...	5	24
		>99	1	0.50	...	...	...	...	...	...	...
		Total	177	47.50	...	...	...	1	...	11	138
Area 5C	1954	2–9	...	...	...	...	...	...	...	...	...
–Southern		10–19	...	...	...	...	...	...	...	...	...
Hecate Strait		20–29	2	0.67	...	...	...	1	...	...	...
		30–39	5	1.58	...	...	...	12	8	...	19
		40–49	5	1.58	...	...	2	6	6	...	9
		50–59	2	0.66	...	...	...	...	...	...	...
		60–99	1	0.33	...	...	...	...	...	...	...
		>99	...	...	...	...	...	...	...	...	...
		Total	15	4.82	...	...	2	19	14	...	28

(*Continued*)

[26]In the 0–9 cm category no individuals were encountered which were less than 8 cm.

TABLE 57. Numbers of petrale sole by size categories taken in small meshed (shrimp) trawl at various depths in major fishing areas along the British Columbia coast. (*Concluded*).

Major Area	Year of sampling	Depth zone fath	No. of drags	Total hr	Size groups (cm) 0-9	10-14	15-19	20-24	25-29	30-34	>34
Area 5B	1953	2-9	...	...	...	...	...	...	...	...	...
-Goose Island	1954	10-19	...	...	...	...	...	...	...	...	...
Bank		20-29	2	0.40	...	...	...	...	...	...	...
		30-99	8	3.07	...	41	5	12	9	4	...
		40-49	6	2.58	2	8	9	...	2	...	...
		50-59	8	4.17	...	1	5	2	...	...	...
		60-99	14	5.50	...	...	...	1	12	11	10
		>99	1	0.25	...	...	...	...	...	...	...
		Total	39	15.97	2	50	19	15	23	15	10
Area 5A	1954	2-9	...	...	...	...	...	...	...	...	...
-Cape Scott		10-19	...	...	...	...	...	...	...	...	...
Bank		20-29	...	...	...	...	...	...	...	...	...
		30-39	...	...	...	...	...	...	...	...	...
		40-49	5	2.08	...	...	4	3	...	...	3
		50-59	8	2.93	...	...	...	1	6	7	11
		60-99	9	3.17	...	...	2	...	...	1	5
		>99	...	...	...	...	...	...	...	...	...
		Total	22	8.18	...	...	6	4	6	8	19
Area 3D	1952	2-9	...	...	...	...	...	...	...	...	...
-Upper West	1962	10-19	7	2.16	9	1	4	1	1	...	...
coast of		20-29	4	1.33	...	...	...	...	...	...(8)**	2
Vancouver		30-39	6	1.50	...	1	1	...	1	...	1
Island		40-49	5	1.55	...	...	...	...	...	...	5
		50-59	2	0.51	...	...	...	...	...	...	...
		60-99	5	1.73	...	...	...	...	...	...(3)	...
		>99	...	...	...	...	...	...	...	...	...
		Total	29	8.78	9	2	5	1	2	...(11)	8
Area 3C	1952	2-9	...	...	...	...	...	...	...	...	...
-Lower west	1959	10-19	4	0.92	...	...	1	2	3	1	6
coast of	1962	20-29	5	0.83	3	1	5	2	1	...(4)	...
Vancouver	1963	30-39	7	3.06	...	...	...	1	6	9(8)	1
Island		40-49	3	1.08	...	...	...	...	6	4	17
		50-59	3	1.25	...	...	...	...	1	...(12)	...
		60-99	14	5.37	...	...	...	...	...	2(6)	4
		>99	8	3.44	...	...	...	...	...	...	...
		Total	44	15.95	3	1	6	5	17	16(30)	28

**Figures in parenthesis indicate numbers greater than 30 cm for which the separation of those greater than 34 cm was not available.

Extensive sampling of northern Hecate Strait (Area 5D) grounds[27] failed to reveal the presence of young juveniles either within the range of depths covered by the commercial fishery (see Table 58) or in very shallow water close to shore. In 176 drags only one petrale sole was found which was less than 30 cm. Although the possibility exists that more young fish would have been encountered had sampling been conducted in years when strong year-classes were being produced, it appears that the northern Hecate Strait region is not a rearing area for petrale sole. Barring the possibility that juvenile petrale sole are accustomed to inhabiting rough, untrawlable bottom, there is no question concerning the efficiency of the gear on smooth bottom. Large catches of juveniles of other flatfishes were of common occurrence (sometimes as many as 350 per drag) both in Hecate Strait and in regions farther to the south. The presence of relatively large petrale sole in the small-meshed trawl catches rules out the possibility that young fish can actively escape capture, as such a facility in all likelihood increases with size rather than the reverse.

TABLE 58. Percent distribution of Canadian trawling effort by depth zones in major statistical areas (average 1954–62).

Depth zone	3C	3D	5A	5B	5C	5D
(*fath*)						
0–9	5.2	0.1	...	...	...	...
10–19	3.9	5.9	...	...	1.9	14.6
20–29	9.6	6.9	2.7	...	46.1	6.6
30–39	31.9	34.5	9.3	1.5	19.9	12.7
40–49	39.8	28.9	42.3	17.6	25.9	25.1
50–59	5.8	20.1	24.4	47.4	5.8	28.0
60–69	0.9	1.1	15.0	17.6	0.4	10.1
70–79	0.3	1.4	4.5	3.2	...	2.2
80–89	1.0	0.6	0.3	0.7	...	0.6
90–99	1.4	...	0.7	1.6	...	0.1
100–109	0.1	...	0.4	3.6	...	...
110–119	...	...	...	2.3	...	...
120–129	...	0.5	0.4	3.6	...	...
130–139	0.1	...	...	0.9	...	...
140–149	...	...	...	...	...	...
150–159	...	...	...	...	...	...
Mean depth	38.7	41.6	51.4	62.6	33.8	43.8

[27]Localities covered included the shallow water of MacIntyre Bay seaward into the deep water of Dixon Entrance; the shallow expanse ("flats") to the east of Graham Island in Hecate Strait; the important trawling grounds along the edge of the "flats" from the Two Peaks southward to the Butterworth-Warrior grounds, Freeman's Pass and White Rock ground. Excluded from consideration here were the results of 45 drags (17.06 hr) in inlets bordering on Hecate Strait. None contained petrale sole.

Sampling on the very limited grounds accessible to trawls in southern Hecate Strait (Area 5C), namely, on the Horseshoe ground and "Ole Spot" produced small numbers of petrale sole which were mostly of age II (with some age III), and most of these were encountered between depths of 30 and 40 fath. As shown in Table 58, over 90% of the Canadian commercial trawling effort in Area 5C occurs within the zone range of 20–29 fath to 40–49 fath. Thus, it is apparent that at least some petrale sole become liable to encounters with the gear at ages II and III.

In Area 5B, sampling was confined to the mainland side of the Goose Island Bank (the eastern edge). There, age I fish (9–14 cm) were encountered in modest numbers, mainly at depths of 30–39 fath. Age II and older fish occurred in this depth range as well as in the 40–59 fath range. As shown in Table 58, negligible commercial trawling occurs at depths less than 40 fath. Thus, the depths occupied by age I and II petrale sole are partly within and partly without the fishing area.

Sampling along the northeastern edge of the adjacent Cape Scott Bank (Area 5A) was restricted to depths greater than 39 fath because of the difficulty of finding suitable trawling bottom in shallower water. Again, only small numbers of petrale sole were found (age II and older). As indicated in Table 58, a large part of the Canadian fishing effort occurs between depths of 40 and 70 fath. Thus it appears that age II petrale sole are liable to encounters with the gear in the Cape Scott area. On occasion fishermen have noted the gilling of substantial numbers of small petrale sole (reportedly of 4–7 inches in length) in their nets while fishing in this area and also on the Goose Island Bank. However, the subject of the selective properties of Canadian commercial trawling gear will be considered in the next section.

Farther to the south, on grounds along the upper west coast of Vancouver Island, small numbers of age I and II petrale sole were found at depths of 10–19 fath with traces at 30–39 fath (Table 59). Here, according to Table 58, only 6% of Canadian fishing effort is expended at depths less than 20 fath. One must conclude from the sparse data on distribution that age I and II petrale sole occur both inside and outside the area of fishing.

In Area 3C (lower west coast of Vancouver Island, the area of the southern stock), small numbers of age I and II fish were found in the 20–29 fath range. Age II fish were also found in shallower and deeper water. Most of these young fish occurred at depths where less than 20% of Canadian fishing effort is expended (Table 58).[28]

[28]In the major areas which have been discussed, reference has been made only to Canadian fishing effort. United States effort tends to be distributed more towards deep water. Thus, in the total picture, the percentage of effort directed to shallow water is actually less than that depicted by the Canadian data.

(b) CONCLUSIONS

Several conclusions may be drawn from the foregoing results of small-meshed trawl surveys: (i) Small petrale sole, of ages I and II, appear to be thinly dispersed on banks along the British Columbia coast during the summer months. (ii) Few occur beyond depths of 60 fath or less than 20 fath, though this range may vary depending on locality. (iii) Again depending on locality, age I and II fish may occur wholly within or only partially within the area where they are liable to encounters with the gear.

There is no way, on the basis of the trawl survey information, to determine the age of entry to the fishing area, in the strict sence of the definition of t_r, namely, the age at which 50% of the individuals are liable to encounters with the gear. Obviously, entry into the preexploited phase has begun, at least by the time an age-group is in its second year of growth, but the proportion of individuals entering remains unknown. It may well be that fish of the O-group are involved too. Although none was caught in the surveys, they may have been too small to be captured by the 1-inch trawls. Further discussion of t_r is reserved for a later chapter.

2. ENTRY TO THE EXPLOITED PHASE

According to Beverton and Holt's definition, the age of entry to the exploited phase t_c, is determined by the size at which 50% of the individuals are retained by the fishing gear. In the case of the North Sea plaice and haddock, this size is achieved subsequent to t_r (50% recruitment) but nevertheless before recruitment is complete. Thus, the selection curve is a resultant of the pattern of recruitment and the selective properties of the mesh size in use at that time. The situation as described by Beverton and Holt is relatively simple, since few of the fish retained by trawls are below the market minimum size and hence rejections at sea pose no serious problem.

In the case of the petrale sole, the size of mesh now in use by the Canadian fleet is capable of retaining sizes of fish which are far below the minimum market size. Thus we must contend with an *age at market retention* as distinct from an *age at capture*, both of which are confounded by a problematical *age at recruitment*, as has been discussed in the preceding section. To distinguish age at market retention from age at capture (mesh retention) we shall use the symbols t_m and t_c respectively, with corresponding lengths l_m and l_c.

(a) MESH SELECTION

Mesh experiments have been conducted on a number of flatfishes in the northeastern Pacific Ocean, but information on the selectivity respecting petrale sole remains scanty, largely because of the difficulty which has been encountered in locating sufficient concentrations of that species in the size range affected by mesh selection. The States of Washington, Oregon, and California in 1952 conducted a joint experiment (coordinated by the Pacific Marine Fisheries Commission) on petrale sole off the Washington coast (Area 3B). The few successful petrale sole drags indicated that the fish in that particular area were large enough to be completely retained by 3.1 inch (7.9 cm)[29] and 3.9 inch (9.9 cm) cod-ends and no selection took place until larger cod-ends were used, namely, 4.9 inch (12.5 cm) and 5.5 inch (14.0 cm). The results as reported by Best (1961) showed that the 50% selection lengths for the 4.9 inch and 5.5 inch cod-ends were 27.1 cm and 30.4 cm, respectively. In both cases the selection factor, as determined by the expression:

$$\text{Selection Factor} = \frac{50\% \text{ retention length (cm)}}{\text{mesh size (cm)}}$$

was found to be 2.18 — a figure which is identical with that determined for the plaice of the North Sea (Beverton and Holt, 1957, p. 225).

That the selection factors for petrale sole and plaice should be fairly similar is indicated by the similarity between the two species with respect to the maximum girth for a given length. Available data for the two species, though the size ranges barely overlap, suggest that the length–girth relationships are approximately the same (Fig. 42).

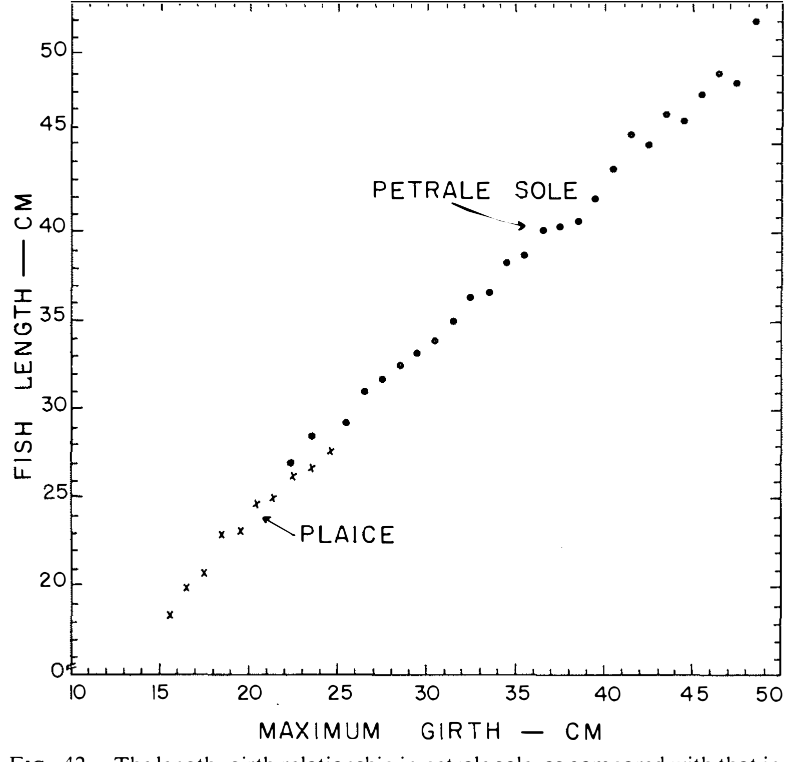


FIG. 42. The length–girth relationship in petrale sole, as compared with that in the North Sea plaice.

[29]Internal measurement on the longitudinal axis. Cod-ends were of single strand construction, 120 thread cotton.

Amongst Canadian trawlers which fish for petrale sole, there is some variation in the mesh size of cod-ends which are employed. In the past few years greatly increased use has been made of cod-ends constructed of synthetic fibres, whereas formerly they were made of manila or cotton. Manila cod-ends (usually knitted in doubled strand) had mesh sizes of 3.5–3.75 inches (9.0–9.5 cm). Though some of the modern cod-ends may be as much as 4.25 inches (10.8 cm), the majority are in the vicinity of 4.0 inches (10.2 cm).

For purposes of computations which follow, it will be assumed that 4.0 inches or 10.2 cm is the mesh size currently in use in offshore waters of British Columbia.[30] Using the selection factor of 2.18, the 50% retention length (l_c) is found to be 22.2 cm.

According to the Report of the ad hoc Committee established at the fourth meeting of the Permanent Commission (International Fisheries Convention 1946) (Anon. 1957b), approximation of the selection range (range of length of fish over which partial retention occurs) may be expressed by defining the 75% and 25% mesh retention lengths, viz. 50% retention length plus or minus 1.2 cm (for plaice). Using this value, we obtain estimates of 23.4 cm and 21.0 cm, respectively, for the 75% and 25% retention lengths of petrale sole. The 10.2 cm mesh selection ogive illustrated in Fig. 43, with the tails of the curve (of questionable accuracy) shown by the broken part of the line.

In preparation for later discussion of the possible consequences of change in mesh size, the retention lengths for various sizes of mesh are shown in Table 59, again based on the selection factor of 2.18.

The pattern of within-year rate of growth of juvenile petrale sole has not been accurately defined. However, as judged from examination of otolith zone formation and from sampling for age at sea in late summer, it is believed that all of the annual growth is attained by the end of September and probably begins in the month of March. On this basis it can be estimated that two-year-old petrale sole (which on the average are 19 cm in length at completion of the second year) would reach the 50% retention length (with a 10.2 cm mesh) at about age 2.2–2.3 years if, before that time, they had become completely recruited to the fishing area. However, as pointed out in the preceding section, the small numbers of two-year-olds present on the commercial fishing grounds suggest recruitment is only just beginning. Thus, the question of the selective properties of the 4-inch trawl must be regarded as of only academic interest. The age at which 50% of the individuals could be retained by the gear (t_c) is about 2.3 years, but few fish of such age

[30]British Columbia Fisheries Regulations specify a minimum trawl cod-end mesh size of 4 inches, except for inshore waters of the Strait of Georgia where it is 4.5 inches.

In the State of Washington a mesh size of 4.5 inches was enforced for several years, but has now been reduced to 3.5 inches following strong protests from the industry. In offshore waters, particularly Areas 3B and 3C, the use of a relatively large mesh has been found to be impractical because of the tendency for dogfish to gill in the meshes to such an extent that it prevents effective use of a splitting strap (a device which permits the lower portion of the cod-end to be choked off so that the catch may be brought aboard in a number of small lifts rather than all at once).

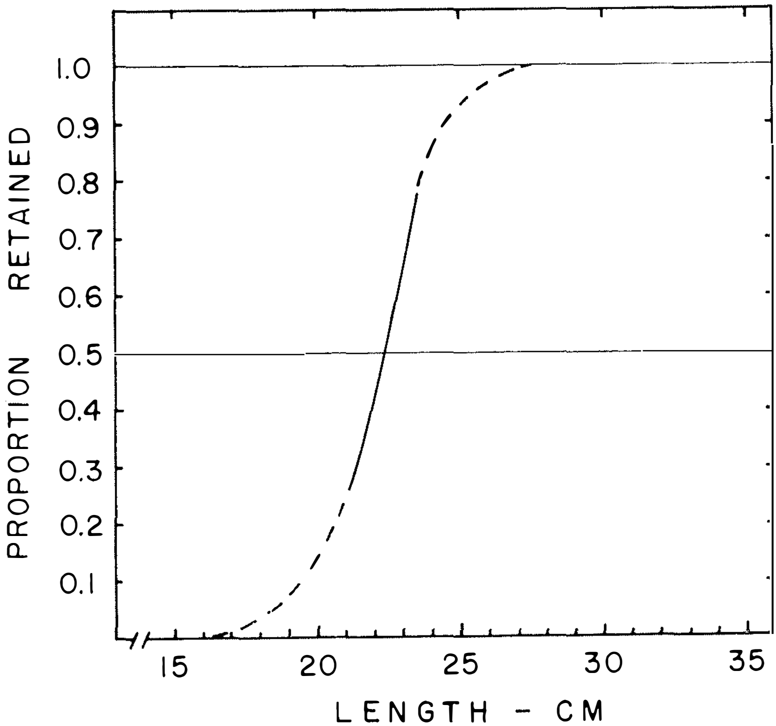


FIG. 43. Calculated mesh selection ogive for petrale sole with 4-inch (10.2 cm) meshed cod-end.

TABLE 59. Retention lengths of petrale sole obtained with various codend mesh sizes (internal, stretched measure).

Mesh size		Retention length (cm)		
inches	cm.	25%	50%	75%
3.5	8.9	18.2	19.4	21.5
4.0	10.2	21.0	22.2	23.4
4.5	11.4	24.4	25.6	26.8
5.0	12.7	26.5	27.7	28.9
5.5	14.0	29.3	30.5	31.7

are as yet vulnerable to capture. It remains, therefore, to determine what sizes of fish are actually caught by the commercial fleet and either retained or rejected at sea.

(b) SIZE AND AGE AT CAPTURE AND RETENTION FOR MARKET

There have been only about seven occasions when the Nanaimo Station's research vessels (either the *Investigator No. 1* or the *A. P. Knight*) have conducted intensive sampling of petrale sole (with commercial trawl nets) on grounds being fished more or less contemporaneously by commercial vessels, the landings of which were subsequently sampled at the market. This technique of comparison has certain deficiencies which could have been avoided had sampling been conducted directly aboard the commercial vessels. Length and sex composition may vary with slight change in depth of fishing, and there may be day to day variations or trends in composition over several days at a given depth. Such dynamic situations pose troublesome problems when an attempt is made to compare the catch of one vessel with the catches of other vessels.

Common to both techniques is the problem of determining whether or not the sampling in one particular locality is typical not only of other times within a season or of other years, but also of other localities within the area inhabited by the stock of fish which is under investigation. Large variations in petrale sole year-class strength have already been noted. To judge from the marked changes which have occurred during the past 2 decades in the size composition of the market landings, substantial changes have occurred in the composition of the catches at sea. Furthermore, it is known that the proportions of "small" to "large" petrale sole caught are not constant from ground to ground within any 1 year or even within a season. Still further, it is presumed that the practice of culling or discarding of unmarketable sizes of fish at sea may vary from season to season or year to year, depending on the size as well as the size composition of the catches landed on deck. (Culling may be more severe when catches are large than when they are small, and more severe when the average size of fish in the catch is large than when it is relatively small.)[31]

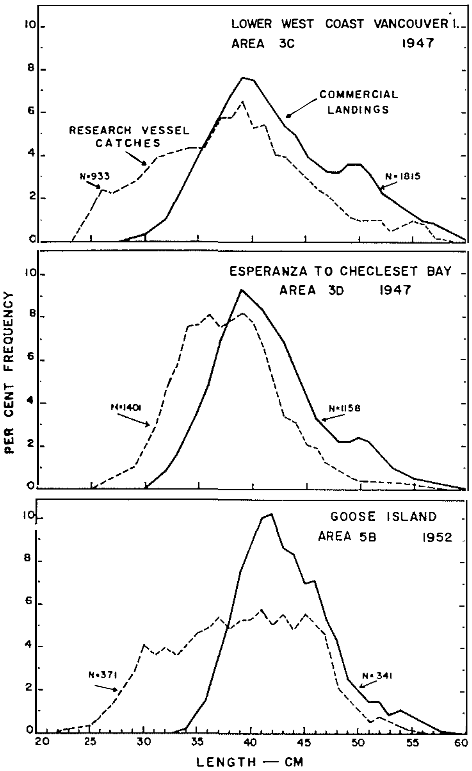
For these and numerous other reasons, anything short of intensive sampling on all grounds in all years and at frequent intervals within, renders difficult the problem of defining the average size composition of petrale sole available to trawl gear and the problem of comparing this with the average composition of the commercial landings.

Figure 44 (data from Table 60) compares the length–frequency composition of research vessel catches with landings of commercial vessels taken on approximately the same fishing grounds at the same time of year. In addition to these five examples, there were two occasions in Area 3C (Sydney Inlet–Lennard Island grounds in 1948 and the "Firing Range" in 1950) when the research vessel catches

[31]As noted earlier, the authors are not aware of any change in market demand which prompted, on the part of the fishermen, a conscious change in culling practice.

TABLE 60. Length frequency distributions of petrale sole (percentage smoothed by 3s) from commercial (C) and research vessel (R) catches.

	Area 3C–1947		Area 3D–1947		Area 3C–1962		Area 5A–1960		Area 5B–1952	
Length	C	R	C	R	C	R	C	R	C	R
(*cm*)										
23	...	...	...	...	...	0.3	...	...	...	0.2
24	...	0.8	...	...	...	1.0	...	...	...	0.2
25	...	1.4	...	...	...	1.8	...	...	...	0.3
26	...	2.4	...	0.3	...	2.5	...	...	...	0.8
27	...	2.3	...	0.5	...	3.3	...	...	...	1.2
28	...	2.6	...	0.8	...	4.3	...	0.2	...	2.0
29	0.2	2.8	...	1.0	...	6.1	...	0.5	...	2.7
30	0.3	3.3	...	1.9	...	7.8	...	1.1	...	4.1
31	0.6	3.9	0.5	3.1	0.2	9.3	...	2.3	...	3.7
32	1.0	4.1	0.8	4.8	0.3	10.3	...	3.5	...	4.0
33	2.0	4.2	1.6	5.8	0.8	10.1	1.1	4.4	...	3.6
34	2.9	4.3	2.5	7.6	1.7	9.2	2.6	5.3	0.2	4.1
35	3.9	4.3	3.6	7.7	3.3	7.2	4.3	5.3	0.9	4.6
36	4.8	4.9	5.0	8.1	5.2	5.8	6.5	6.3	1.6	4.9
37	5.9	5.7	6.9	7.6	6.4	4.1	7.3	6.5	3.8	5.4
38	6.8	5.8	8.2	7.8	7.1	3.2	7.9	7.0	5.1	4.9
39	7.6	6.5	9.3	8.2	7.7	2.4	7.6	6.7	7.5	5.3
40	7.5	5.3	8.9	7.8	8.0	1.8	7.9	6.2	9.0	5.4
41	6.8	5.4	8.3	6.6	8.1	1.7	9.1	6.3	10.1	5.8
42	6.1	4.1	7.4	5.1	7.2	1.3	9.2	6.2	10.2	5.1
43	5.3	3.9	6.8	3.4	7.1	1.5	9.0	7.1	8.6	5.6
44	4.9	3.3	5.7	3.1	6.5	1.3	7.7	6.6	8.4	4.9
45	4.0	2.9	4.3	2.1	6.2	1.1	6.3	5.9	7.0	5.6
46	3.5	2.5	3.3	1.9	5.2	0.7	4.7	4.0	7.1	4.1
47	3.2	2.2	2.7	1.2	4.3	0.4	2.9	3.0	5.3	3.5
48	3.2	1.7	2.2	0.9	3.5	0.4	1.8	1.7	4.3	2.2
49	3.6	1.2	2.2	0.6	2.9	0.3	1.1	1.0	2.5	1.5
50	3.6	1.0	2.4	0.4	2.1	0.2	0.8	0.5	2.1	1.1
51	3.1	1.1	2.2	0.4	1.5	0.1	0.6	0.5	1.5	0.6
52	2.3	0.9	1.6	0.4	1.1	0.0	0.5	0.5	1.5	0.8
53	1.8	0.5	1.0	0.3	0.9	...	0.3	0.3	0.9	0.5
54	1.5	0.8	0.7	0.3	0.7	...	0.2	0.3	1.1	0.3
55	1.2	0.9	0.5	0.2	0.5	...	0.1	0.2	0.9	0.2
56	0.9	0.8	0.4	0.1	0.4	...	0.1	0.2	0.6	...
57	0.8	0.2	0.3	...	0.3	...	...	...	0.3	...
58	0.5	0.1	0.2	...	0.1	...	...	...	...	...
59	0.2	...	0.1	...	0.1	...	...	...	...	...
60	...	...	0.1	...	0.1	...	...	...	...	...
61	...	...	...	...	0.1	...	...	...	...	...
62	...	...	...	...	0.1	...	...	...	...	...
Number	1,815	933	1,158	1,401	1,233	2,399	757	735	341	373



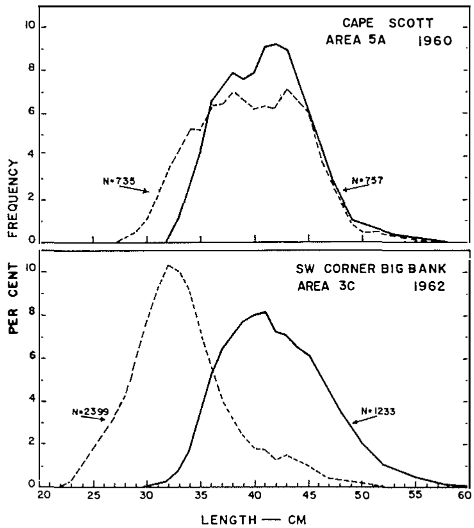


FIG. 44. Comparison of length-frequency distributions of petrale sole contained in research vessel catches and commercial vessel landings.

contained proportionately fewer small fish than the landings of the commercial vessels. These have been dismissed from consideration, although they serve to emphasize the difficulty of reproducing effectively the fishing practice of the commercial vessels.

The several examples shown in the figure suggest that in certain areas and at certain times, variable amounts of small petrale sole are caught and discarded. The minimum market size as posted by fish buyers is 12 inches (30.5 cm),[32] and this explains the absence from commercial landings of fish much below that size. It is obvious that selection takes place over a considerable range of size above the market minimum.

Four of the graphs in Fig. 44 lend themselves to estimation of the retention size, namely, those in which the sizes of petrale sole (above about 40 cm) contained in catches by the research vessel covered approximately the same range

[32]Such a size is also specified in the British Columbia Fisheries Regulations. This was established in 1957 at a time when demand for scrapfish for minkfood was on the increase and fear arose that petrale sole of a size below the market minimum (as well as other important flatfishes used as foodfish) would be utilized by the more or less indiscriminate fishery for minkfood.

as those of the commercial vessels (those histograms excluding Area 3C, 1962). Adjusting the percentage frequency scale of the research vessel catches, so that the descending limb of the frequency distribution is more or less superimposed on the descending limb of the commercial data, permits a rough calculation of the percentage retained amongst the size categories involved in the ascending limb. The percentages are graphed in Fig. 45 and ogives are fitted by eye. Four estimates of the 50% retention size are 33.8 cm, 34.0 cm, 36.4 cm, and 37.9 cm. An average ogive constructed from the four sets of data suggests that the 50% length at retention (l_m) is approximately 35 cm. This figure, which will be used as a working average in later calculations, corresponds to an age (t_m) of V+ years (for both sexes). The 25% length corresponds to age IV, while the 75% length corresponds to age VI for females and age VII for males.

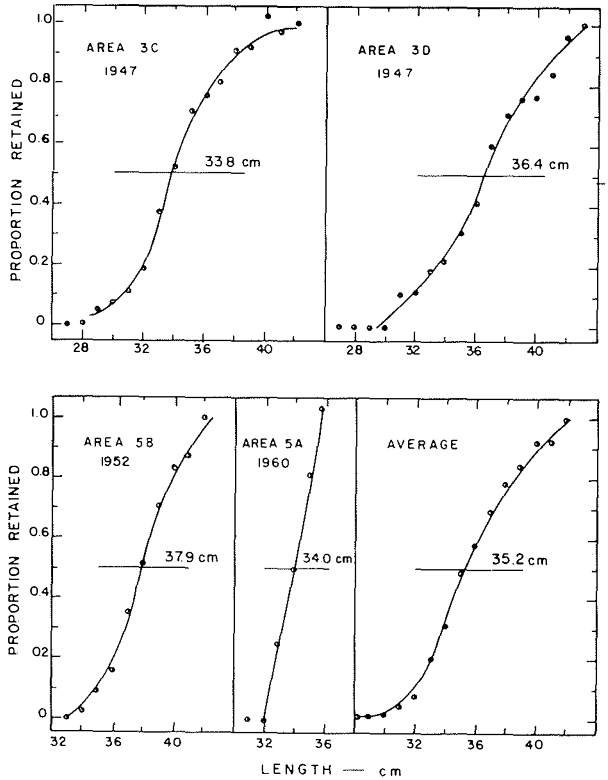


FIG. 45. Approximate market selection ogives calculated from the data in Fig. 44.

If we assume that negligible numbers of fish caught and discarded at sea die from the effects of capture, then the ordinate scale in Fig. 45 (proportion retained) may be considered equivalent to the proportion of full fishing mortality. In other words, at a length of about 35 cm (or age V+) petrale sole are subject to 0.5 of the prevailing fishing mortality rate. However, the assumption of negligible mortality amongst discards probably is unrealistic and, therefore, this estimate must be regarded as a minimum.

(c) SUMMARY

As a means of summarizing the foregoing discussion of the size and age of entry into the exploited phase, the ogive of mesh selection from Fig. 43 and the average ogive of retention from Fig. 45 are reproduced as curves A and B, respectively, in Fig. 46. Included also are three hypothetical curves (C_1, C_2, and C_3) depicting possible patterns of recruitment to the area of fishing. Curve C_1 accounts, at least in part, for the fact that some age I and II petrale sole are liable to encounters with the gear. The evidence from the five examples in Fig. 44 shows that no fish less than 23 cm was present in the research vessel catches, in spite of the fact that the 50% retention length of the gear is about 22 cm. This tends to refute the shape of C_1 as drawn. If, as postulated, the tails of the curve terminate at 9 and 33 cm, then the shape of the curve must have a high degree of asymmetry with a 50% length at some value greater than 26 cm.

Curve C_2 has been made to conform more or less with the shape of the ascending limb of the research vessel catch in Area 3C (1962), and curve C_3 with the combined data for Area 3C and 3D (1947) as presented previously in Fig. 45. The 50% length on curve C_2 is 30 cm. The particular sample upon which this curve is based was obtained from the SW corner of La Perouse Bank in the month of September. It is of questionable representativeness either of that ground for the whole 1962 season, or of Area 3C as a whole and of years other than 1962. To some extent the 50% recruitment length of 30 cm may be an underestimate, for it was influenced by the appearance of the 1958 year-class (age IV) which, as mentioned earlier (p. 105), is entering in greater strength than any of the preceding year-classes so far examined.

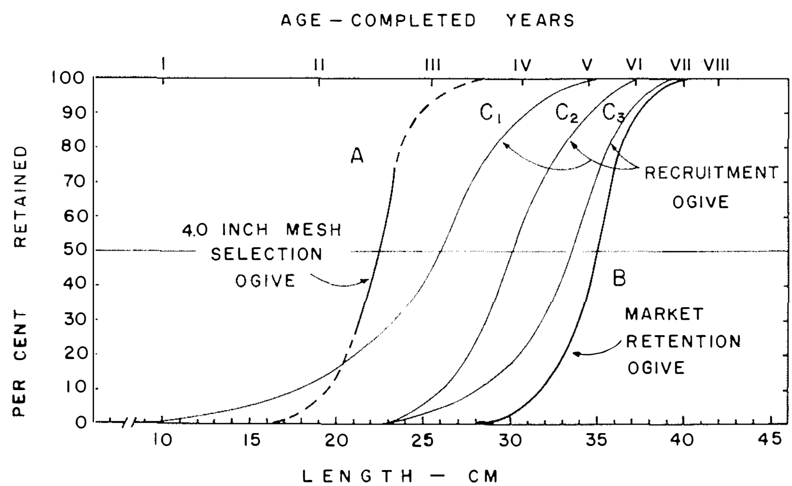


FIG. 46. Mesh selection ogive (A), market retention ogive (B) and three hypothetical recruitment ogives (C_1, C_2, and C_3).

It is the opinion of the authors that the 50% recruitment length, l_r, is most likely to lie, on the average, somewhere between 32 and 34 cm. The upper half of curve C_3 probably is in best accord with the facts. The reliability of the lower half is in doubt, but in light of the results of the small-mesh trawl surveys, it is clear that the curve is more asymmetrical than that depicted in Fig. 46.

Obviously, recruitment to the area of fishing takes place over a span of several years, beginning at age I and reaching the 50% point no earlier than age III and possibly as late as age V. Fifty per cent recruitment at some time between age IV or V means that the market retention ogive (curve B) is a resultant of both the pattern of recruitment and the practice of culling for market.

The following tabulation summarizes the best estimates of the parameters of "entry":

	50% point	
	Length (cm)	Age (yrs)
Vulnerable to 4-inch mesh (in theory)	l_c = 22.2	t_c = 2.2–2.3
Recruitment to the fishery area	l_r = 32–34	t_r = 4+
Market retention	l_m = 35.0	t_m = 5+.

Chapter XII

YIELD PER RECRUITMENT

1. Introduction

By means of simple mathematical models, various authors (principally Ricker, 1945 and 1958; Beverton and Holt, 1957) have demonstrated the theory and application of parameters of growth, age of entry, natural mortality, and fishing mortality in computation of the yield to be expected from a given amount of recruitment. Such models serve as a useful guide in assessing not only the current status of a fishery but also, by manipulation of the parameters, permit examination of the possible consequences of increased or decreased fishing, and changes in age of entry whether dictated by custom or law.

The fundamental assumption in computations of this kind is that the stock is in a state of equilibrium, although both Ricker and Beverton and Holt give attention to nonequilibrium states. According to Ricker (1958, p. 205), "equilibrium" is defined by the conditions which exist after the specified conditions (including recruitment) have been in effect long enough to affect all ages for the whole of their exploited life. A state of equilibrium is equivalent to the "steady state" as defined by Beverton and Holt (1957, p. 37), ". . . . when a population or a fishery is not in the process of changing either in character or size; the term allows for the existence of fluctuations with a periodicity of 1 year, and also for the year to year variations caused by fluctuations in factors such as the annual recruitment (which will inevitably be present), provided they are not excessive."

Clearly, it would be incorrect to assume that the petrale sole stocks of British Columbia or the fisheries on them have been in a "steady state" during the period of study. Not only have fluctuations in recruitment been large but they have been of a secular nature, that is, persistent with trend, as opposed to short-term fluctuations without trend from some mean value. They have been sufficient to induce trends in stock size and (by inference) to result in variations in fishing intensity. It is known that, as petrale sole declined in abundance, the relative attractiveness of fisheries for other species increased partly for that reason and partly because of improved markets for the other species. There is little doubt that substantial year to year variations have occurred in the amount of "effective" fishing effort, but because of the tenuous nature of the assumptions attending calculations of this sort, it is impossible to say whether "effective" fishing effort has been with or without trend during the study period. Certainly, the observed (recorded) fishing effort of Canadian vessels has been subject to trends and this may well have resulted in trends in fishing intensity on petrale sole specifically. While the "steady-state" models can show the best utilization of any given number of recruits whether or not these vary from year to year, with or without trends, the inconclusiveness of information on fishing intensity demands a cautious approach to the subject of yield per recruitment.

2. Choice of Population Model

In the sections of this report which have provided estimates of the various population parameters, we have attempted to conform with current trends in standardization of notation to permit ease of comparison with observations on other species in other parts of the world. However, in the application of some of these parameters to a model for estimation of equilibrium yield, the method of Ricker (1945; 1958) has been employed, though the Jones (1957) modification of the model proposed by Beverton and Holt (1957) would have served equally well. The former model yields essentially the same results as would be expected from the latter, since amongst the various assumptions is that of a constant mortality rate with age. While this appears to be satisfied for the intermediate ages of petrale sole, it may not be true for the youngest and oldest age groups. Although no attempt is made here to explore these possibilities or their effects on yield estimates, the need for such consideration is acknowledged and for that purpose the Ricker model possesses decided advantage.

The Ricker model has been employed in estimation of equilibrium yield from the southern stock of petrale sole (Area 3C). Table 61 provides an example of the calculations where a given weight (1000 units) of female recruits enters at age III (length 249 mm), and are subjected to an instantaneous rate of natural mortality (M) of 0.05 and an instantaneous rate of fishing (F) of 0.05. Note that the life span has been divided into $\frac{1}{2}$-year intervals and that it has been assumed that growth in length is linear between one completed year and the next. The length at $\frac{1}{2}$-year intervals is then converted to weight from the length–weight formula (p.94), and instantaneous rate of growth (g) is obtained from the difference in the natural logarithms of these weights. To fit the actual observations it would have been better to treat growth by four quarters of the year since most of the growth of petrale sole occurs in the second and third quarters (April–June and July–September) of the "petrale sole year." However, since the within year changes in growth rate are not very great, use of $\frac{1}{2}$-yearly rather than quarterly divisions will not produce markedly different results in the yield calculations.

It has also been assumed that F and M are constant throughout the life span in the fishery and that these mortalities operate uniformly by $\frac{1}{2}$-year intervals. Thus, half the mortality is assigned to each interval. Of course, nothing is known of the seasonal pattern of M, but it is known that fishing mortality is seasonal, occurring mainly in the 6-month period May–October or, like growth, in the second and third quarters of the "petrale sole year."

TABLE 61. Example of a computation of equilibrium yield of petrale sole for a rate of fishing (p) of 0.025 applied during each of two halves of the calendar year, and for an instantaneous rate of natural mortality (q) equal to 0.025 in each half of the year. New yield is the equilibrium yield from the stock when the age groups fished include those above the line in question. This is obtained by multiplying reduced yield by the ratio of stock size in column 13 to stock size in column 8. (See Ricker, 1958, p. 212, and Chatwin, 1958, p. 845, for complete details of method.) Ages in column I.

Age	Length	*g*	*q*	*p*	*g-q-p*	Factor	Stock	Mean wt	Yield	*g-q*	Factor	Stock	Reduced yield	New yield	Age of entry
years	*mm*						*lb*	*lb*	*lb*			*lb*	*lb*	*lb*	*years*
3.0	249						1000					1000			
		.332	.025	.025	+.282	1.3258		1163	29.1	+.307	1.3593				
3.5	275						1326					1359			
		.292	.025	.025	.242	1.2738		1508	37.7	.267	1.3060				
4.0	300						1689					1775	2840.0	2985	4.0
		.238	.025	.025	.188	1.2068		1864	46.6	.215	1.2399				
4.5	322						2038					2201			
		.211	.025	.025	.161	1.1747		2216	55.4	.186	1.2044				
5.0	343						2394					2651	2738.0	3032	5.0
		.181	.025	.025	.131	1.1400		2562	64.0	.156	1.1688				
5.5	362						2729					3098			
		.163	.025	.025	.113	1.1196		2892	72.3	.138	1.1480				
6.0	380						3055					3556	2601.7	3028	6.0
		.138	.025	.025	.088	1.0920		3196	79.9	.115	1.1218				
6.5	396						3336					3989			
		.133	.025	.025	.083	1.0865		3480	87.0	.108	1.1140				
7.0	412						3624					4444	2434.8	2986	7.0
		.104	.025	.025	.054	1.0555		3724	93.1	.079	1.0822				
7.5	425						3825					4809			
		.101	.025	.025	.051	1.0523		3925	98.1	.076	1.0790				
8.0	438						4025					5189	2243.6	2892	8.0
18.0	558						3335					7087			
		.018	.025	.025	−.032	.9685		3282	82.0	−.007	.9930				
18.5	561						3230					7037			
		.012	.025	.025	−.038	.9627		3170	79.2	−.013	.9871				
19.0	563						3110					6946			
								Total	2906.8						

Estimates of equilibrium yield have been obtained for various combinations of mortality rates and ages of entry in conjunction with data on the growth of both sexes. Yields were computed for each sex separately (beginning with equal weights of each sex at age III) and then combined into a single model. The various calculations for the Ricker model were facilitated by use of an IBM computer.

It will be recalled from p. 129 that two possibilities were to be explored concerning the mortality rates of male and female petrale sole. These were: Case 1, where M for males and females is 0.25 and 0.20, respectively, thus implying that most of the sex difference in Z is due to F; and Case 2, where M is 0.20 for females and 0.45 for males, implying that all of the sex difference in total mortality rate is due to, M, and that F is the same for each sex.

3. Results

(a) Case 1 — Large difference in F by sex

We may examine yield in three ways: first with fishing mortality rate constant and size at entry variable (Fig. 47a); secondly, with size at entry constant and fishing rate variable (Fig. 47b); and thirdly, a composite of these two situations which employs the yield-isopleth presentation (Fig. 48).

In Fig. 47a, the fixed fishing rate is that observed (under the stated assumption of natural mortality rate) for the 1940–43 year-classes, namely 0.25 for females and 0.45 for males. This shows that the yield expected from 1000 lb of recruitment has a maximum of 3320 lb at a size of retention (l_m) of 32 cm. The present size of entry is estimated as 35 cm, with a corresponding yield of 3250 lb. Thus a reduction in the size of entry to 32 cm would, in theory, result in a small (2%) increase in yield.

Figure 47b, in which size at retention is constant at 35 cm, shows that there is no maximum in the yield curve, at least over the practical range of fishing rates explored. At F = 0.25 for females and 0.45 for males (rates based on observations of the 1940–43 year-classes) the yield is 3250 lb. Doubling the fishing rate (0.50 for females and 0.90 for males) raises the yield by 9% to 3550 lb.

Figure 48 shows the steady state yield from any combination of F and l_m values. The point P represents the value of F and l_m depicted by the 1940–43 year-classes. The horizontal transect through point P is represented by Fig. 47a and the vertical transect by Fig. 47b. Point P lies slightly above the "eumetric fishing curve," the curve which defines for a given fishing intensity the value of l_m that must be used to produce the greatest yield with that particular intensity (Beverton and Holt, 1957, p. 373). For the stock to be fished eumetrically at the "present" fishing intensity it would be necessary to reduce l_m to about 32 cm, or to fish at some very much higher intensity if l_m remains unchanged.

These conclusions presuppose that growth parameters remain unchanged in spite of changes in stock density. It has already been noted (p. 108) that changes in growth occurred during the study period, but that it is not certain whether they arose from environmental variation or from variations in stock density.

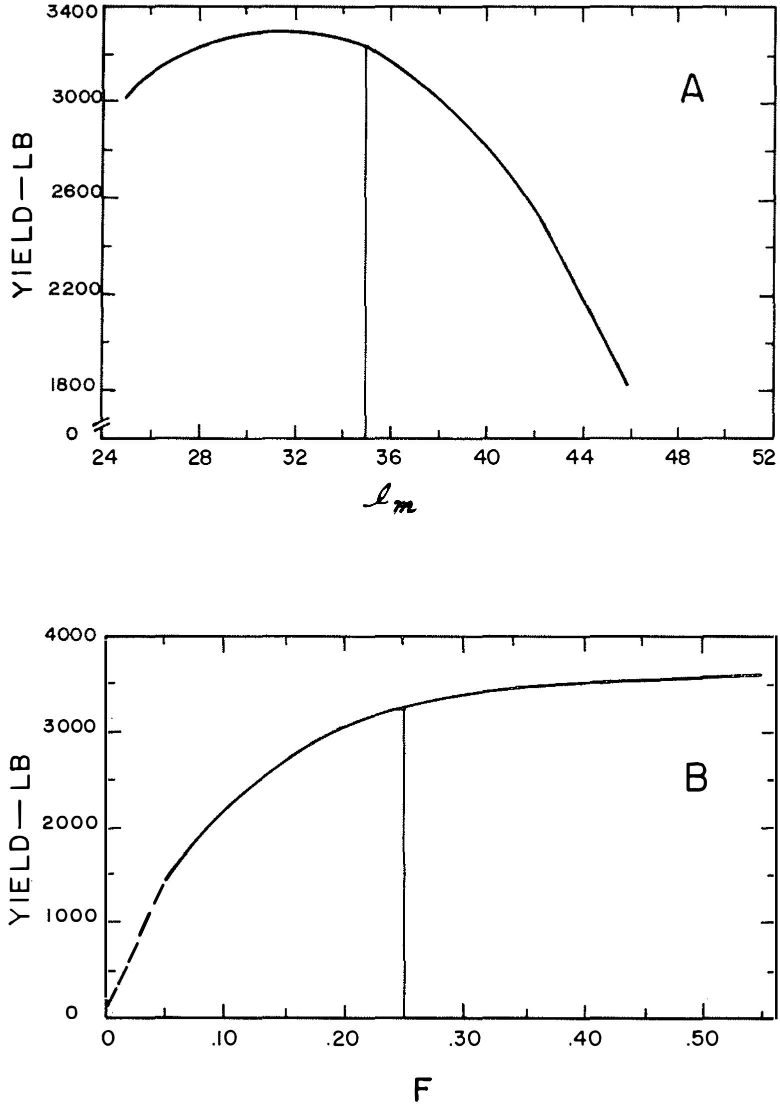


FIG. 47. Curves of yield per recruitment (Case 1): (A) Yield when F is fixed (= 0.25 for females and 0.45 for males) and l_m (length at market retention) is variable; (B) Yield when l_m is fixed (= 35 cm) and F is variable.

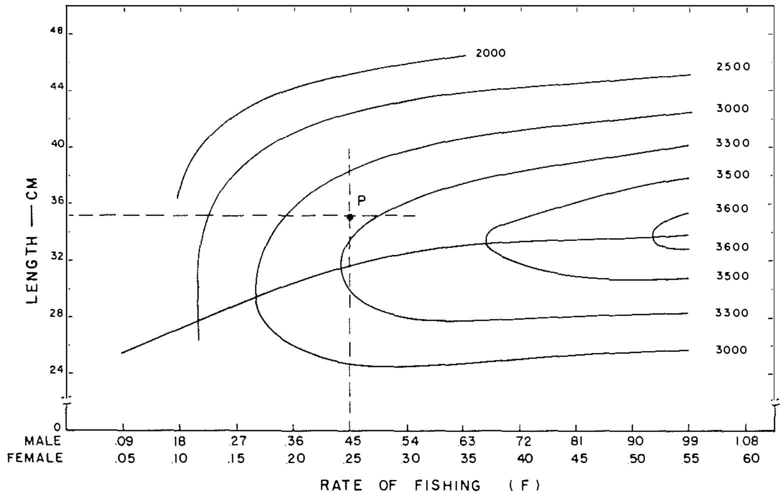


FIG. 48. Yield isopleth diagram (Case 1).

(b) CASE 2 — NO DIFFERENCE IN F BY SEX

Following the same procedures as used in Case 1 we now examine the other possibility, namely, that F for the two sexes is the same (the difference in Z being entirely the consequence of a difference in M). Figure 49a shows the yield for various values of l_m, where F is held constant (F = 0.25). For the "present" size at retention (35 cm) the yield is 2500 lb as compared with maximum value of 2650 lb at a size of retention of 29 cm, which represents an increase of 6%.

When size of entry is held constant and F is variable (Fig. 49b), we note again that there is no maximum in the yield curve within the range of F values which have been used. If F is raised from 0.25 to 0.50, the expected yield is increased from 2500 lb to 2800 lb (a 12% increase).

In the yield-isopleth presentation (Fig. 50) we find once again that the point P lies above the eumetric fishing curve.

Beverton and Holt (1964) have developed a short-cut procedure for estimating yield per recruitment, given the ratio of l_m to L_∞; F to Z and M to K. Using estimates of these parameters, as previously given for both sexes of petrale sole, we reach essentially the same conclusion concerning the position of point P, regardless of the underlying assumption that there is a simple cubic relationship between weight and length.

4. CONCLUSIONS

From the point of view of the relation of point P to the eumetric fishing curve, it is apparently immaterial which of the two assumptions concerning natural mortality rate (Case 1 or 2) is used. Both lead to the conclusion that the approach

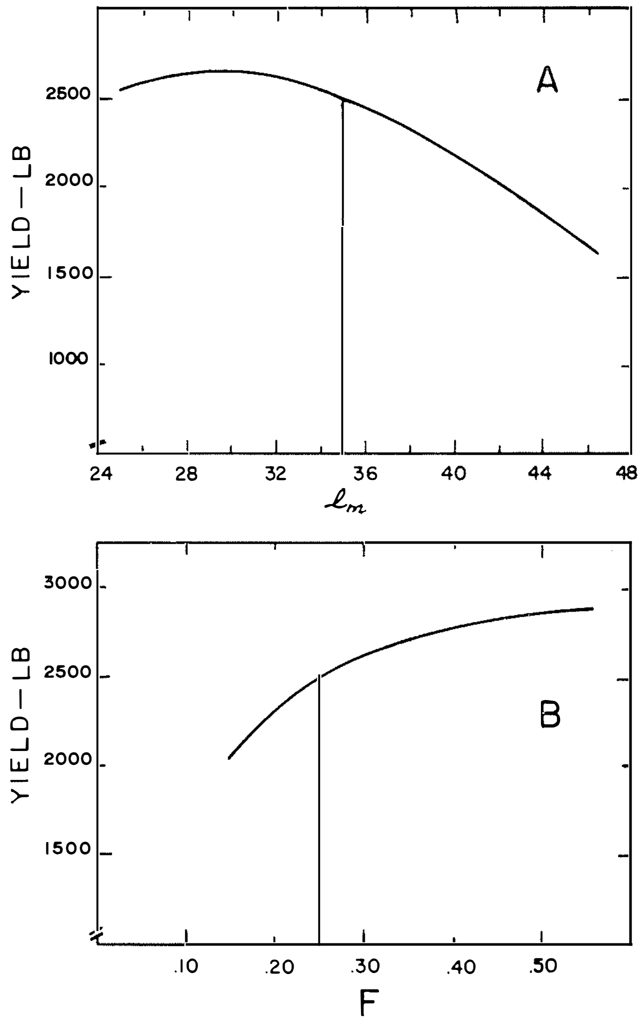


FIG. 49. Curves of yield per recruitment (Case 2): (A) Yield when F is fixed (= 0.25 for both sexes) and l_m (length at market retention) is variable; (B) Yield when l_m is fixed (= 35 cm) and F is variable.

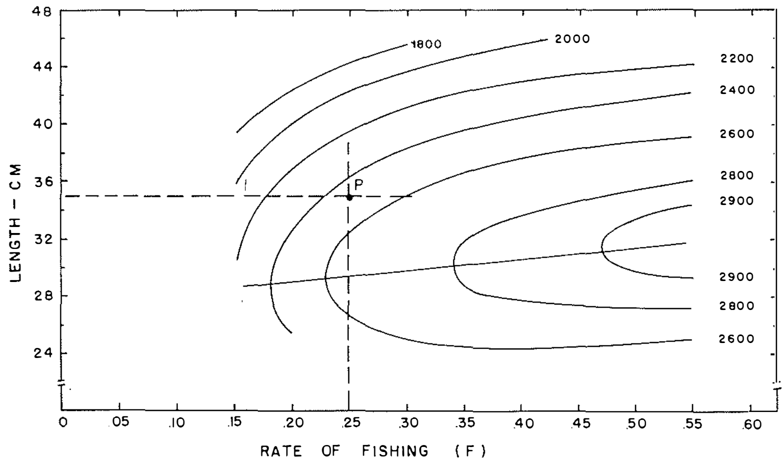


FIG. 50. Yield isopleth diagram (Case 2).

to a state of eumetric fishing may be through a reduction in l_m alone, through an increased fishing intensity, or a combination of these. If it is true that a state of underfishing existed during the period when the 1940–43 year-classes were supporting the fishery, then we are led to the further conclusion that factors other than fishing have played a more important role than has the amount of fishing in the dynamics of the British Columbia petrale sole stocks.

These conclusions, of course, apply to a steady state and assume among other things that recruitment is constant, or if variable, only moderately so and without trend. Clearly such a condition has not prevailed during the recorded history of the petrale sole fishery. There have indeed been substantial variations in recruitment, the causes of which require examination before we consider implications from the standpoint of fishery regulation.

Chapter XIII

FACTORS INFLUENCING RECRUITMENT

In Chapter VI, we observed that over the long term there have been substantial variations in the size of year-classes supporting the petrale sole fishery in British Columbia waters. Year-classes of 1940–43 appeared to be stronger than those of the late 1930s and preceded a series of progressively weaker year-classes through 1949. More recent year-classes have shown a reverse trend, with the 1958 year-class appearing to be about as strong as those of 1942 and 1943.

Generally speaking, oscillations in fish populations, aside from those generated by variable amounts of fishing, can be traced to variations in recruitment which in turn may stem from one or a combination of two main causes. They may be related directly or indirectly to the size of the juvenile and/or adult (spawning) population or, on the other hand, to factors which are independent of variations in the size of these populations (fluctuations in the biological or physical properties of the environment).

Beverton and Holt (1957, p. 44–60) state that general indications from the behaviour of many marine species are that there is no marked relationship between the abundance of spawners and the number of subsequent recruits, within the range of population size for which data are available. They subscribe to the view that, given the full population range, an asymptotic curve is probably the most generally useful method at the present time of representing the relationship between egg-production and recruitment. On the other hand, Ricker (1954, 1958) considers that the possibility of a dome-shaped recruitment curve is perhaps more common than is generally believed, though the dome may often be broad or flat.

As far as the petrale sole is concerned, it is impossible as yet to say which of these hypotheses is most likely to apply. Data pertaining to the southern stock are illustrated in Fig. 51. Estimated brood strengths of the 1939–58 year-classes (from Table 41) are plotted against average catch per unit of effort (index of "parent stock" size) for the same series of years.[33] Probably, a straight line would fit the sets of points no better than either an asymptotic or a dome-shaped curve. The suggestion that the 1939–43 data represent the descending (right-hand limb)

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[33]Catch per effort data are from Table 26 for 1945 and onwards. For the years 1939–44 some liberties have been taken with Cleaver's (1949) Fig. 16, which shows average catch per trip of sole and flounder from April to September in each year. These data have been translated to average catch per day fished per trip and then scaled to catch per hour by a factor relating catch per day to catch per hour in the Canadian fishery. The resulting calculations used as a measure of change in parent stock size between 1939 and 1944, are nothing more than rough approximations, for they involve not only the assumption that the catch per day/catch per hour ratio was the same in the Washington and Canadian fleets but also that the catch of "sole and flounder" was comprised mainly of petrale sole.

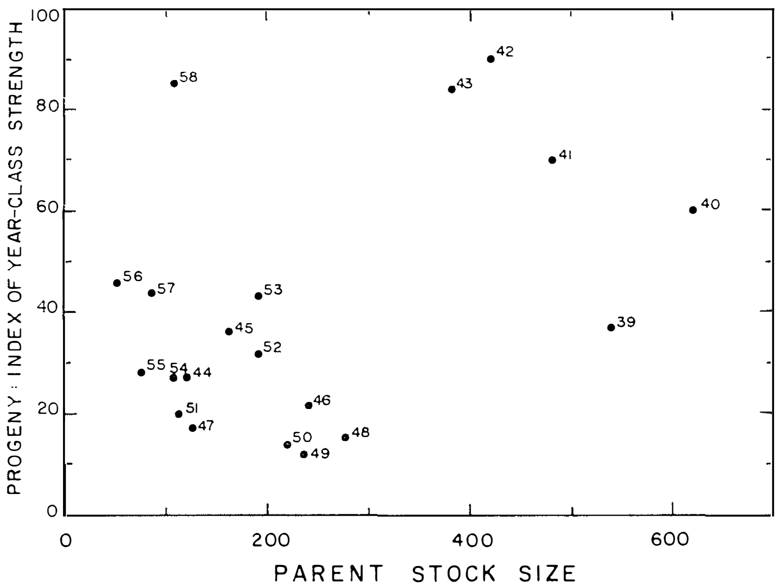

FIG. 51. Stock–recruitment relationship in petrale sole.

portion of a dome-shaped curve merits little support. The upward trend in the strengths of year-classes 1939–43 was associated in those years with an apparent reduction in size of the southern stock through fishing. The same upward trend in year-class strength must have occurred in the northern stock (see p. 107) but in the absence of a fishery. If the northern stock was in a state of primitive equilibrium prior to the inception of fishing (1944), the trend in strengths of the 1939–43 year-classes has to be attributed to some factor other than present stock density.

For present purposes it will be presumed that variations in strength of petrale sole year-classes are independent of parent stock density, within the range of densities for which information is available.

1. The Critical Stage

It is generally accepted that amongst marine fishes the size of a year-class is determined in early life, perhaps at some critical stage in larval development. High mortality presumably would occur if, at the time of yolk-sac exhaustion, the environment failed to provide the larvae with suitable kinds and amounts of food. Amongst flatfishes, the process of metamorphosis (transition from a pelagic to a side-swimming, bottom-dwelling existence) may itself in some way be of critical importance to survival. During the pelagic egg and larval stage the young are vulnerable not only to predation by larger planktonic feeding fishes and invertebrates but also to the vicissitudes of the physical environment. Water currents and temperature may influence respectively the direction and duration of drift and hence determine the proportion of young which will be swept into areas where depths and substrate are suitable for development. Whatever, the cause, whether it be biological or physical factors, or complex combinations of both, the fate of a year-class is most likely determined during the pelagic stage.

Concerning the petrale sole, relatively little is known about its early life history, or of the factors which govern survival. However, some facts are fairly well established. For instance, we know that the petrale sole spawns in relatively deep water (ca. 200 fath) and in fairly well defined localities along the North American coast. Alverson and Chatwin (1957, p. 960) concluded from periodic sampling on the Estevan Deep that spawning commences as early as January and probably terminates in April. While they suggest that the latter part of March marks the peak of spawning, their sampling was not sufficiently frequent to establish this with certainty even for the single year of study. Probably the peak of spawning varies from year to year within the months of February–March. Thus, the critical stage presumably occurs during the late winter months.

2. Transport Mechanism

Studies conducted by the Fisheries Research Board of Canada indicate that the newly fertilized egg of the petrale sole has a specific gravity of about 1.0247. From this information and knowledge of the salinity–temperature structure, and hence density structure off the Vancouver Island coast, we may draw the following inferences about the drift of petrale sole eggs: (i) Water overlying the continental slope during the winter months at all depths has a specific gravity greater than that of the petrale sole egg. Hence, there will be a tendency for the eggs to rise from the spawning grounds. (ii) At that particular time of year off the British Columbia coast, winds are predominantly from a southerly direction. Their effect is to produce a northwesterly and inshore convergence, which in cross-section is characterized by a downward slope of the isotherms and isohalines towards shore. Likewise, bands of equal density (isopycnals) slope downwards (Fig. 52). Thus, it is possible that as the eggs of the petrale sole are carried northward and inshore they sink to intermediate depths on the shelf. The presence of low density sea water at innermost stations along the coast presumably would act as a barrier to shoreward transport of the eggs, and would explain the absence of juvenile petrale sole in the inshore (near inter-tidal) zone. It will be recalled from Chapter XI that juvenile petrale sole seemed to be restricted in their distribution to intermediate depths on the continental shelf.

3. Variability of Survival

It is rather unlikely that a single factor, whether it be physical or biological, determines the degree of success of survival of a year-class, and even less likely that such a factor operates with the same effectiveness every year. In any case there are severe practical limitations to the number and kinds of events in the sea that can be monitored with sufficient continuity to permit a search for causal connections. The only hope then is that some easy-to-measure physical or chemical

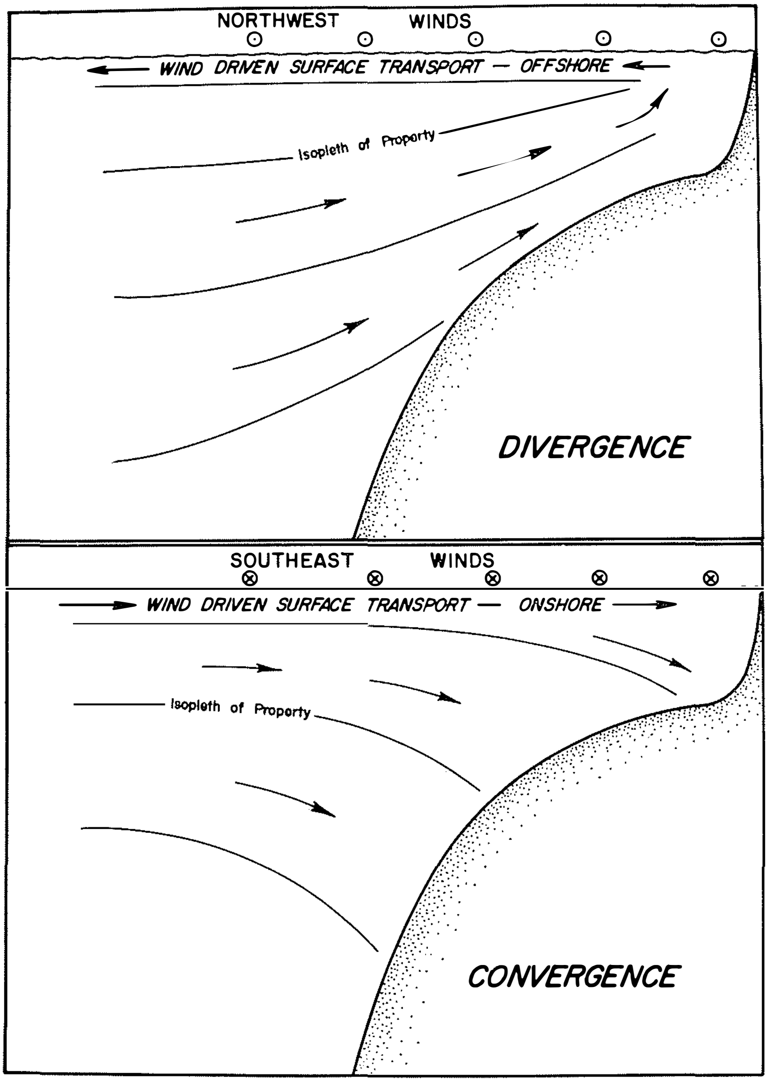

FIG. 52. Conditions of divergence and convergence in British Columbia waters (from Lane, 1963).

property is related, if not directly, then indirectly to the critical factors which determine the success of survival. Ketchen (1956a) drew attention to evidence of long-term trends in sea surface temperature along the British Columbia coast and suggested that they may have a bearing either directly or indirectly on fluctuations in certain groundfish stocks including petrale sole.

There are various ways in which water temperature may be critical to survival of a year-class. Beyond certain limits it may operate as a lethal factor, or may control the production of the right kinds and amount of food required by the pelagic larvae. Furthermore, water temperature at time of spawning and during the subsequent egg and larval period presumably would dictate the rate of development and hence the duration of the critical stage, if any, or at least the overall duration of the pelagic stage. Thus, timing and duration may determine the degree of success with which the larvae are transported to suitable rearing areas.

On the other hand, water temperature may in itself have no bearing on survival but rather may be associated with some other factor in the environment. Ketchen (1956b, p. 687) pointed out that water temperature, while it might determine survival of lemon (English) sole year-classes in Hecate Strait through its effect on the length of the pelagic stage, may be significant only to the extent that it reflects changes in wind-induced currents. Some support for the latter hypothesis was subsequently provided in Eber and Sette's (1959) analysis of geostrophic wind components in the northeastern Pacific, which demonstrated significant correlation between paired values of wind indices and sea temperature in northern Hecate Strait.

4. The Petrale Sole and its Environment

The same line of reasoning was followed concerning possible factors affecting survival of petrale sole, namely, that temperature (i) either acts indirectly by governing food supply or by controlling the duration of the pelagic stage or, (ii) is related to brood strength only because it is a function of the direction and velocity of wind-induced currents.

Daily surface seawater temperatures are recorded by lighthouse keepers along the British Columbia coast and published by the Pacific Oceanographic Group (Hollister, 1964). Mean temperatures for the months of January through March from two stations on the west coast of Vancouver Island (Amphitrite Point and Kains Island) have been averaged and paired with the estimates of strength of the 1939–58 year-classes as given in Table 26. A correlation (r) of +0.535 was found which was statistically significant at the 5% level but not at the 1% level. This and other correlation coefficients obtained from various combinations of water temperature data are shown in Table 62. Correlations involving February–April temperature data are significant at the 1% level (see Fig. 53).

It might be argued that variations in surface temperature of the sea bear little resemblance to those at subsurface layers, where perhaps the larvae spend most of their pelagic stage. However, at the time of year we are considering (late winter months) waters of the continental shelf are essentially isothermal. Thus, we find close resemblance between mean monthly temperature at the surface, as recorded at Amphitrite Point lighthouse and mean monthly temperature at a depth of 44 m (ca. 23 fath) as recorded at the Swiftsure Lightship (see Fig. 54; locations given in Fig. 55).

TABLE 62. Correlation between strengths of year-classes (1939–58, inclusive) and sea surface temperature as recorded at Amphitrite lighthouse (A) and Kains Island lighthouse (K) on the west coast of Vancouver Island. (d.f. = 18; 5% and 1% levels of significance 0.444 and 0.561, respectively).

Average sea surface temperature		Correlation coefficient
Months	Locality	r
Jan.–Mar.	A+K	0.535
Jan.–Mar.	A	0.462
Jan.–Mar.	K	0.558
Feb.–Apr.	A+K	0.648
Feb.–Apr.	A	0.642
Feb.–Apr.	K	0.652

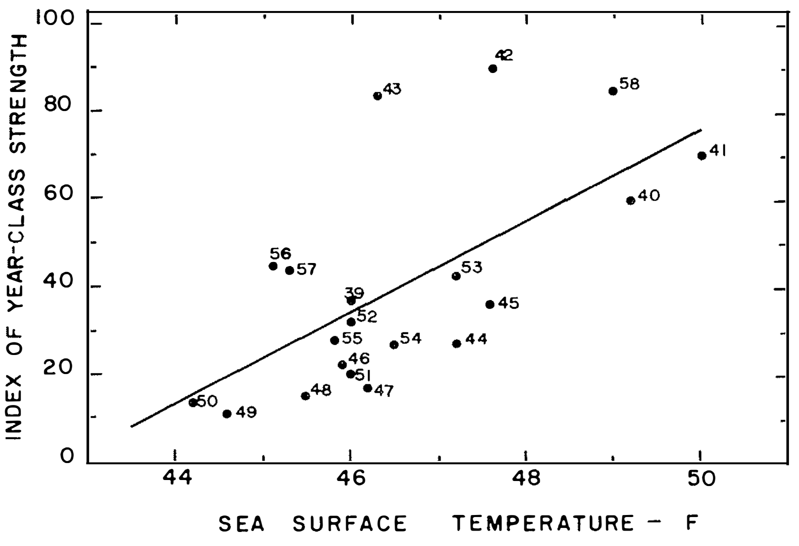

FIG. 53. Relationship of petrale sole year-class strength to February–April mean sea surface temperature as recorded at Amphitrite Point and Kains Island lighthouses.

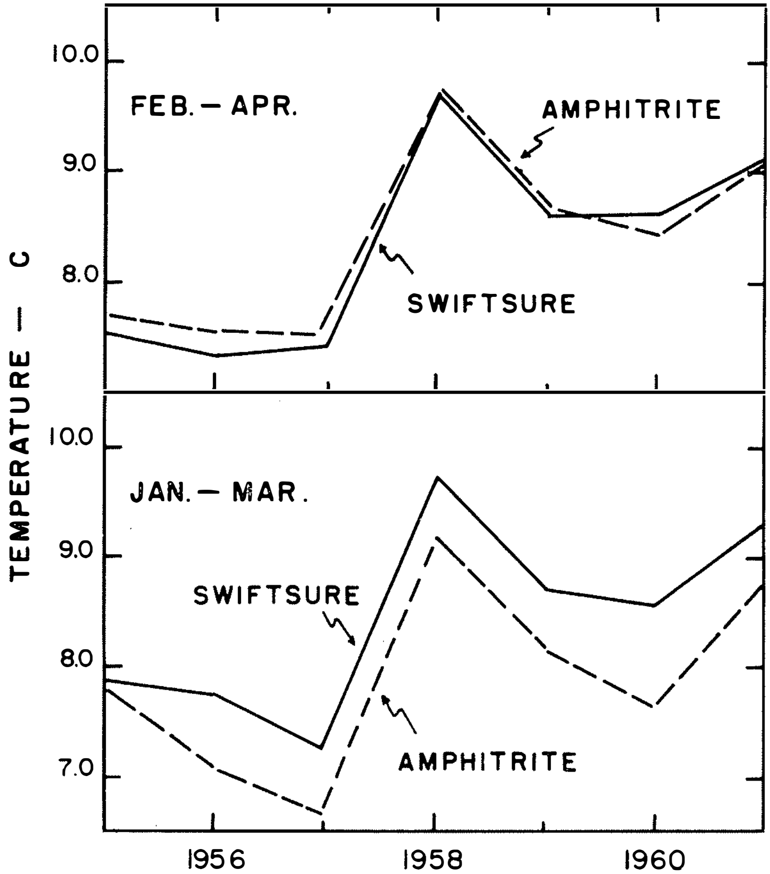

FIG. 54. Comparison of January–March and February–April mean sea surface temperature at Amphitrite lighthouse with mean temperatures at depth of 140–150 ft (ca. 42–45 m) as recorded at the Swiftsure lightship.

Much has already been said about the dangers of hasty interpretation of correlation coefficients (Fisher, 1950; Gulland, 1953; Ketchen, 1956b; Bell and Pruter, 1958; and others). Briefly, in the absence of antecedent knowledge of the actual factors which determine success of survival of a year-class, there is no assurance that, in the present instance, water temperature, or any phenomenon correlated with it has a causative connection. Even the significance of the correlation is open to question, since the intensity of search for correlation (number of trials) is not adequately accounted for in the analysis.

Accordingly, we must look upon the apparent correlation between year-class strength and water temperature only to the extent that it provides us with a working hypothesis, a base from which (i) to predict strengths of future year-classes and hence test the validity of the correlation and (ii) to narrow the field of possible factors affecting survival and thus expedite direct investigation.

The petrale sole offers a good example of the complexity which attends the search for cause and effect relationships. While we observe a positive correlation between year-class strength and water temperature, we also find a relationship between water temperature and wind, thus implying that the velocity and/or direction of ocean currents may be involved. It follows from knowledge that the surface circulation of the ocean is driven primarily by the winds, that variations in the winds will cause changes in the surface ocean currents. Wind force and its direction also influences the amount of vertical mixing and the intensity of upwelling which in turn affect the physical and chemical properties of the seawater and change the amounts and kinds of food organisms. Except for the summer months, winds along the British Columbia coast are predominantly from a southerly direction. According to Doe (1955), the currents are weak and variable. The principal direction of flow is from south to north, being stronger in the winter months than in the summer months, and about twice as strong in the surface layers as at a depth of 300 m (164 fath).

Eber and Sette (1959) have used charts of monthly mean atmospheric pressure at sea level for inference of oscillations in the major wind systems of the Pacific Ocean, and for further inferences as to the movements and properties of water masses. Geostrophic wind was computed from pressure differences across 36 pairs of geographically fixed points in portions of the wind system which appeared

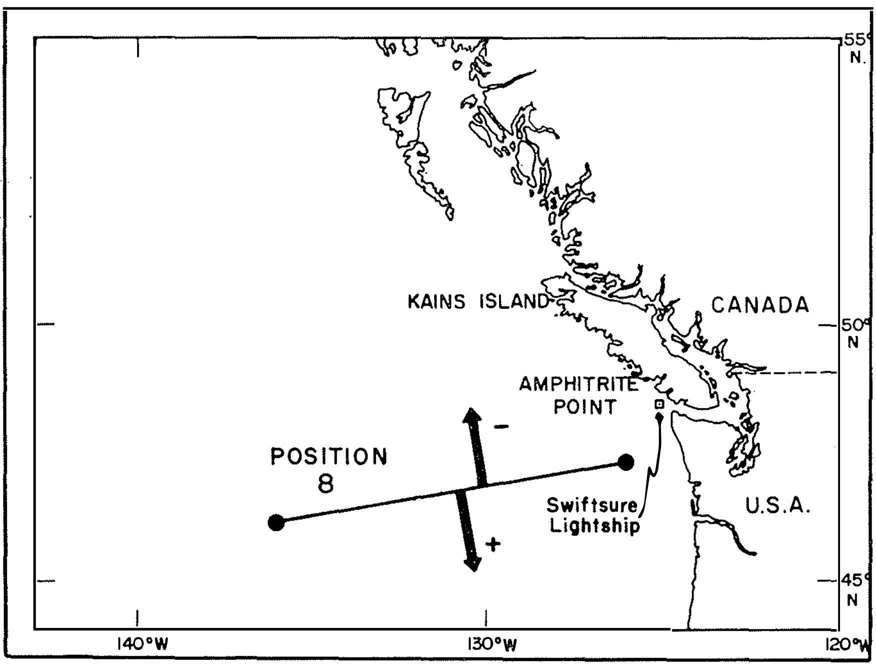

FIG. 55. Location of Position 8 used by Eber and Sette (1959) computing atmospheric pressure gradients in relation to Amphitrite Point, Kains Island, and Swiftsure lightship.

to be most effective in driving the surface circulation of the Pacific.[34] From this network one pair of points defining Position 8 has been selected and this is shown in Fig. 55. At this position positive pressure differences represent northerly winds and negative differences represent southerly winds.

As indicated by the long term (1926–57) average picture, monthly mean pressure differences are positive in the late spring and summer, and negative during the remainder of the year (Fig. 56). Variations in the southerly winds in winter-time presumably would result in variations in the intensity of the northward moving current off British Columbia.

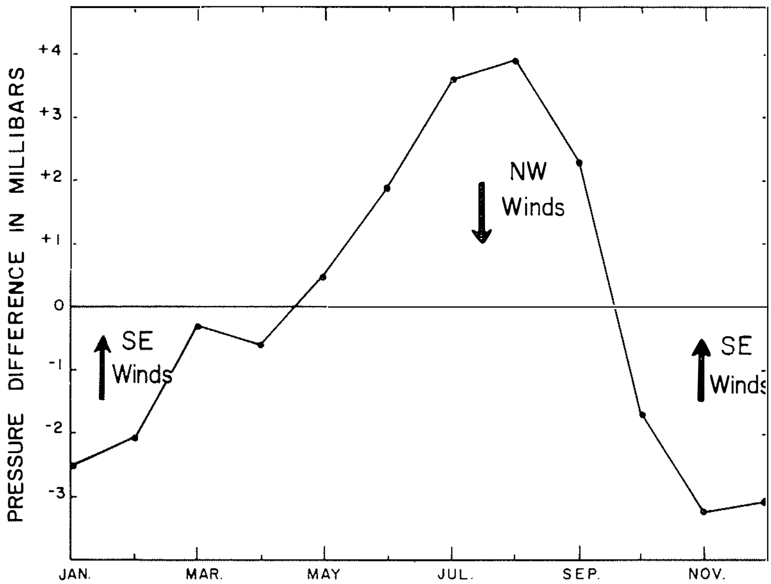

FIG. 56. Long-term (1926–63) monthly mean atmospheric pressure differences at Position 8.

In Fig. 57, pressure differences at Position 8 for the months of January through March are compared with the average sea surface temperature between Amphitrite Point and Kains Island for the same period of the year. Years of relatively high temperature tend to correspond with years of above average negative pressure differences (see Fig. 58). The correlation coefficient is –0.612 and is significant at the 1% level. For a later period, February through April, the coefficient is -0.350 and this is not significant at the 5% level.

[34]Eber and Sette used geostrophic wind because it more nearly approximates the direction of induced water movement than would the actual observed winds; and pressure differences are considered to be more reliable than the wind observations.

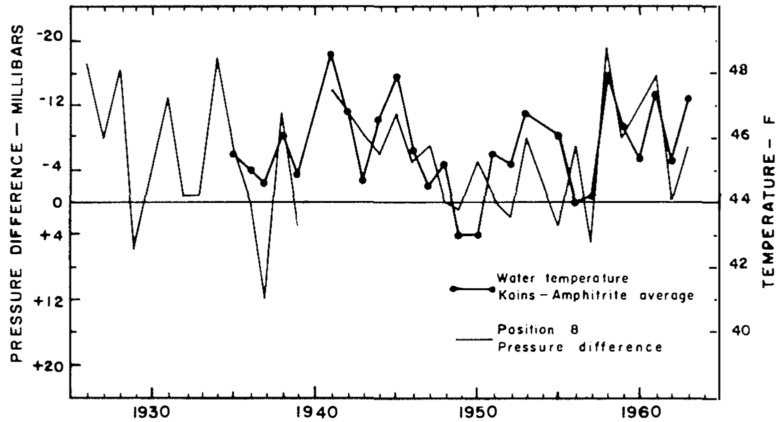

FIG. 57. Long-term (1926–63) atmospheric pressure difference at Position 8 (January–March average) compared with January–March average sea surface temperature registered at Amphitrite Point and Kains Island lighthouses.

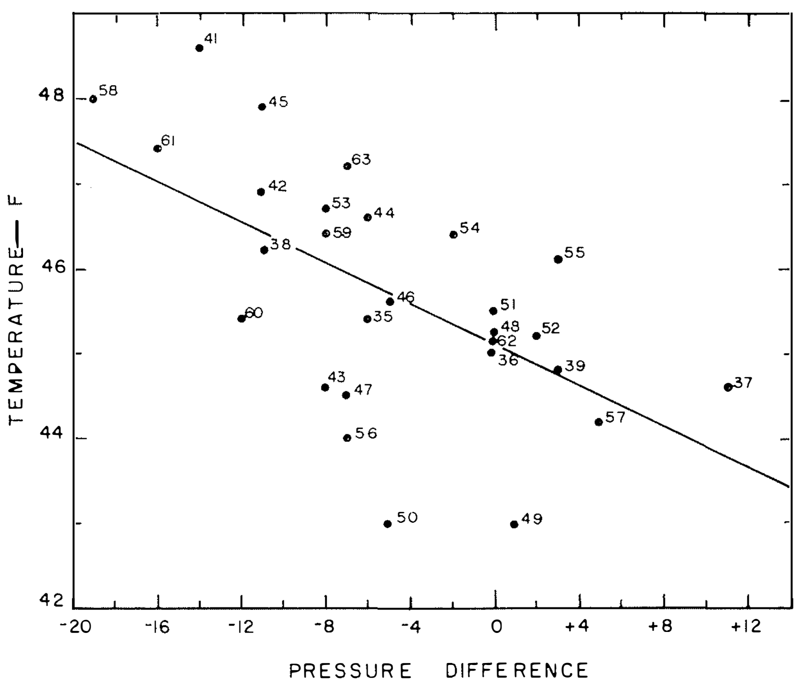

FIG. 58. Regression of sea surface temperature (Amphitrite–Kains Is.) on atmospheric pressure difference at Position 8 (January–March).

Similarly, if we compare year-class strength with the January–March pressure difference (Fig. 59) we find a correlation of -0.631 (significant at the 1% level); while use of February–April pressure differences yields a coefficient of -0.440 which is not significant at the 5% level.

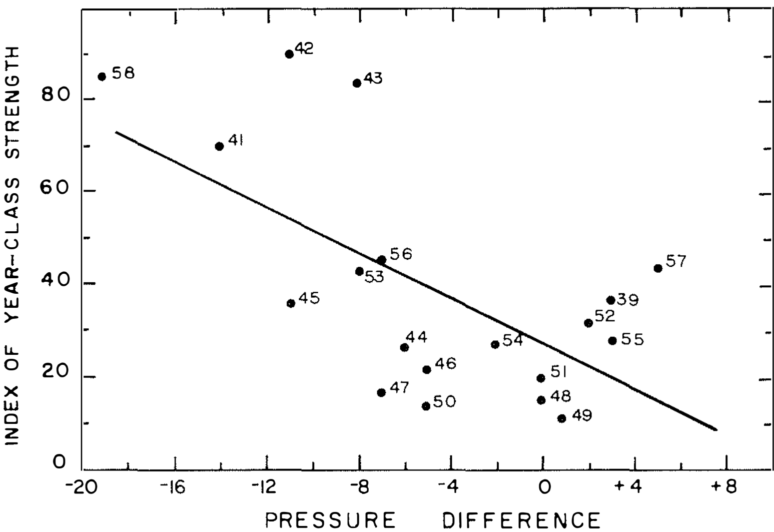

FIG. 59. Regression of year-class strength index on atmospheric pressure difference at Position 8.

5. HYPOTHESES REGARDING SURVIVAL

With certain combinations of surface water temperature data it is possible to obtain statistically significant positive correlations with petrale sole year-class strength. Likewise, certain combinations of geostrophic wind data are correlated (negatively) with year-class strength, and with water temperature. If these correlations are real, and not just the product of fortuitous combination, then several possible hypotheses may be proposed regarding factors influencing survival of petrale sole during the pelagic stage.

(a) If temperature per se is the critical factor, then it may affect survival through (i) its influence on the duration of the pelagic stage (when temperature is relatively high the pelagic stage is of relatively short duration), (ii) its influence on the production of the right kinds and quantities of plankton.

(b) The negative relationship between year-class strength and wind (positive pressure differences across Position 8) implies that wind-induced currents are the important factor. Strong year-classes are associated with weak positive pressure differences (i.e. strong negative differences — southerly winds — which would tend to enhance the northward and shoreward drift of eggs and larvae and hence may assure transport of greater numbers to suitable nursery areas). Another possibility is that predominant southerly winds bring a different water mass in contact with the continental slope and shelf, thus providing a "better" supply of food for the larvae.

c) Other possibilities involve various combinations of mechanisms suggested above. For example, perhaps production of large year-classes depends on rapid growth through some critical period in the pelagic stage, coupled with a pronounced transport from the spawning area to the intermediate depths on the continental shelf.

6. Prediction of Petrale Sole Abundance

It would take many years and an unrealistically large expenditure of funds to track down and monitor the particular environmental factor or set of factors which determine the size of a petrale sole year-class. Even so, there is no assurance of a successful solution. However, as long as it is possible to find some environmental indicator, albeit merely associated with the factors directly governing success or failure of a year-class, a basis is then available for prediction of future events. Such presumably would be of value either to the fishing industry, to management, or to both.

In consideration of the fluctuations in strength of petrale sole year-classes of 1938–58, questions come to mind concerning their interpretation. Were the year-classes of say 1940–43 of above "normal" strength or were they merely average? Was their great strength only created by a subsequent succession of "abnormally" poor year-classes? Clearly, accumulation of several more decades of data would be required to establish the "norm," or at least establish the period of long-term oscillations.

The petrale sole is a species which appears to favour warmer waters of the north temperate region (the south boreal zone according to Rass's (1959) classification). Its primeval centre of abundance presumably was off the United States coast south of latitude 48°N. Results of extensive surveys conducted in recent years suggest that the northern limit of its commercial range (concentration in commercially attractive quantities) is Hecate Strait. It is not unreasonable to suppose that near the extreme limits of a species range its existence is more tenuous than near the centre because of more frequent encounters with unfavourable environmental conditions (such as low temperature or an associated factor). Several strong year-classes of petrale sole were produced in the early 1940s, and apparently again in 1958. These successful events perhaps were more the exception than the rule in the first half of this century. From evidence of long-term temperature trends in British Columbia waters (Tully, 1950; Ketchen, 1956a) it is apparent that the early 1940s marked the maximum advance of temperatures since at least as early as 1915 (judged from daily seawater observations at Departure Bay, B.C., which, for more recent years appear to conform generally with those from stations along the open coast of the province). Thus the large stocks of petrale sole available to the trawl fishery during the middle to late 1940s may have been just a fortunate coincidence — a situation similar to that suggested by Royce et al. (1959) in a study of the yellowtail flounder population of New England.

Following a sharp recession in temperatures during the late forties and early fifties, we have seen (Fig. 57) that in the years 1958–64, there has been a return to the relatively warm conditions of the early forties, and as exemplified by the 1958 year-class, a return to stronger year-classes of petrale sole. Whether there will be enough "good" years to promote a sustained improvement in recruitment to the stock cannot be stated at the present time, but the next few years should provide a test of the temperature relationship. Isolated strong year-classes unless they are of strength greater than anything observed so far would be of transient benefit.

Chapter XIV

REGULATION OF THE PETRALE SOLE FISHERY

It is appropriate at this concluding state to review certain of the biological observations on petrale sole, particularly those which have a bearing on the question of fisheries regulation and hence on the long-term prospects for maintenance of an economically attractive enterprise. In the first place, we observed that the trawl fishery along the North American coast takes place on a number of stocks of petrale sole which are not completely distinguishable from one another. Tagging suggests some overlapping of adjacent stocks and alternating seasonal movements northward and southward along the coast as well as between deep and shallow water, and in some places between territorial and international waters. Thus, from an administrative standpoint the definition of regulatory areas presents some difficulty.

The fishery itself is not distinct because the petrale sole is caught in varying proportions with several other species. In summer its associations may be with Pacific cod, lingcod, English sole, dogfish, and rock sole, while in winter (because of its seasonal bathymetric movements) the associations are more with deep water species as Pacific Ocean perch and Dover sole.

To add to this complexity we find that the two "stocks" in waters adjacent to British Columbia have been subject to substantial fluctuations in recruitment of a secular rather than random nature. There is little or no basis for concluding that variations in recruitment are related to changes in the density of the parent stock. Rather, they appear to be density independent and governed by factors in the environment which presumably influence survival during the pelagic stage of the life history.

Simple population models which assume equilibrium conditions suggest that a slightly greater yield could be obtained from a given recruitment by reducing the size at entry into the commercial catch, by more intensive fishing, or both.

1. The Question of Optimum Fishing

As pointed out by Beverton and Holt (1957, p. 378) conservation and economic management cannot be regarded as two separate and independent functions of fisheries regulation. Such regulation should have as its general objective the adjustment of biological, economic, and social factors ". . . .so that in each particular case the best balance is achieved between the benefits on the one hand to the producer, in the form of profit to the fishing industry and a good living for fishermen, and on the other to the consumer as a large and steady supply of fish at a reasonable price." Beverton and Holt call the best balance a state of optimum fishing.

It will be recalled that neither of the eumetric yield curves for petrale sole (Fig. 48 and 50) had a maximum, but ascended continuously to an asymptotic value at least over the range of F values used. Beverton and Holt (1957) consider it to be a working generalization that for single species fisheries as $F \rightarrow \infty$ the eumetric yield curve tends asymptotically to a limit which is the greatest possible yield obtainable from the population. In their words: "It means that there is no biological criterion that can be used as a guide to where it would be best for a fishery to operate. Thus, the maximum possible yield, i.e. the asymptote of the eumetric yield curve, can be attained only with an infinitely high fishing intensity and hence at a correspondingly high cost; it is therefore a totally unreal objective for regulation — not for any biological reason but on purely economic grounds."

The optimum, expressed in economic terms is then the point where the difference between total value of the catch and the total cost of operation is a maximum. In the case of the Pacific coast trawl fishery where vessels tend to be individually owned and operated, the above difference, namely the total profit, is not as significant as the profit to each owner, the average of which is the total profit divided by the number of vessels.

To pursue this question further in the light of present knowledge would not be realistic, for we are dealing with an extremely complicated fishery based not only on petrale sole but also on lingcod, Pacific cod, turbot, Dover sole, and Pacific Ocean perch, the dynamics of which are little understood. From what we know of the growth and mortality of cod (Ketchen, 1961; 1964), lingcod (Chatwin, 1958) and ocean perch (Alverson and Westrheim, 1961) it is quite evident that their individual requirements for regulation would be different. They vary in abundance relative to one another and in market demand; they are exploited by two fleets (Canadian and United States) which apparently operate under different value–cost structures. Thus, for the present at least, it is out of the question to construct composite value–cost curves which would have any practical meaning.

As an alternative, however, it is instructive to consider further the possible effects and complications of a change in fishing practice or regulations, as if we were dealing with petrale sole as a single species fishery.

As mentioned above, we lack the information to identify the point of optimum fishing. In a single species fishery, however, we would know that the optimum lies somewhere on the eumetric fishing curves of Fig. 48 and 50. Thus, by manipulation of either size at retention or fishing intensity, we know the direction which point P must shift in order to approach more closely the condition of optimum fishing.

(a) CHANGE IN MINIMUM SIZE LIMIT

It is not inconceivable that the present value of F corresponds with that generated by the optimum fishing intensity, and all that needs to be done to reach the optimum point on the eumetric fishing curve is to reduce the market retention size, l_m. The resulting increase in yield (2% or 6% depending on our choice of models) is perhaps too small to be worthwhile; indeed, it may well be within the limits of error in the estimated value of l_m. In any event, realization of an increased yield would depend on several factors: (i) that smaller sizes of petrale sole are actually fully available to the fishery (it will be recalled from Chapter XI that we could not be sure of the true recruitment ogive), (ii) that relative yield of fillet (wt of fillet ÷ wt of whole fish) is no less for small fish than for large ones, and (iii) that the landings of small fish would be acceptable to the market without penalty on price for reason of higher filleting cost. For example, if the smaller sizes of fish are undesirable, the industry might feel obliged to establish a price differential between small and large fish. At present, there is no separation into size categories (such as we find in the fisheries for say halibut and sablefish). Thus, while we might anticipate a slightly greater yield in weight by reduction of the minimum size limit, yield in value might not show a proportional increase; it might even be less if the establishment of size categories resulted in lower unit price for small to medium sizes of fish than that now commanded in the absence of size discrimination.

(b) CHANGE IN FISHING INTENSITY

Now let us consider the converse situation where l_m is fixed and F is below the point corresponding to optimum fishing intensity. The magnitude of F is a function of the cost of generating it and may, as noted by Beverton and Holt, be changed by (i) a change in the total number of fishing vessels, (ii) a change in the time spent fishing each year or, (iii) by change in the fishing power of each vessel.

There is, however, still another possibility. According to the population models we could expect an increase in yield of 12–18% if F were increased to an unrealistically high level. Such a prediction assumes that the fishery remains essentially an inshore one during the spring, summer, and autumn months, and hence the cost of fishing would likewise be unrealistically high. However, it is quite possible that for a small increase in cost a proportionately large increase in yield could be achieved if unrestricted fishing were permitted on the spawning grounds during the winter months. This would occur as a result of a seasonal change in the vulnerability[35] of mature petrale sole, which in its effect is the same as proposition (iii) above. In the winter months (January through March, particularly) vulnerability is substantially greater than that on the inshore (summer) grounds because the fish gather in relatively dense shoals. Alverson and Chatwin (1957, p. 958) noted that in March 1954 large landings of petrale sole were made by vessels which had fished in the Estevan Deep, one being 90,000 lb, the product of 2½ days fishing. Catch rate for the vessel making that particular landing was in excess of 2000 lb/hr, as compared with contemporary summertime inshore catch/hr of 100–200 lb. Such catch rates in deep water were not uncommon in other years up to 1957. To the extent that this "easily" acquired increase in

[35]Following Ricker's (1958) definition: vulnerability is the fraction of a portion of a stock (in this case the mature portion of the stock) which is caught by a defined unit of fishing effort actually used.

yield would lead to optimum fishing, there appears to be some advantage to the exploitation of petrale sole on the spawning grounds. The consequences of this, however, deserve further consideration.

2. Consequences of a Spawning Ground Fishery

There are two ways in which fishing on a spawning stock could have an adverse effect on yield, one, the relatively immediate effect of a pair of values of F and l_m which results in overfishing in respect to yield per given recruitment, and the other, a long-term effect of a reduction of the spawning stock to a size which is critical with respect to production of recruits.

(a) Immediate effects

With a markedly greater vulnerability during the spawning season than at other times of the year, the usefulness of the population models for prediction of the effects of changes in fishing mortality rate is severely diminished. The fishing intensity (effective fishing effort) which generates an F of say 0.2 on the inshore grounds during summer months is far greater (perhaps 10–20 times greater) than the intensity required to generate the same value of F on the spawning grounds. Thus, it is likely that only a very small increase in fishing intensity on the spawning grounds would be sufficient to achieve a yield which approximates the maximum expected from a given recruitment.

In any event, heavy removals from the spawning grounds in winter might have a detrimental effect on fishing success for petrale sole in the following spring and summer months in shallower water. As yet, this has not been demonstrated.[36] The possibility remains that significant segments of the stocks in British Columbia waters are available to the fishery during the spawning season but unavailable to the inshore fishery in the summer.

Granted that a spawning ground fishery would permit a greater sustained annual yield of petrale sole, it would be necessary to contend with economic, sociological, and perhaps international political considerations. From the economic standpoint it is a difficult matter to determine whether it would be better to fish for petrale sole with high efficiency during a short span of weeks in winter, or with relatively low efficiency but in a way that permitted a continuing supply over a protracted period of months at some other time of year. Certainly, the latter is preferred by the fresh fish trade.

The practice of fishing mainly during the period of spawning is not without precedent in British Columbia waters. If it were not for fishing during the period of spawning concentrations, it is doubtful that the degree of utilization would be as high as it is in the Hecate Strait fisheries for Pacific cod and butter sole or the Strait of Georgia fisheries for Pacific cod and English sole.

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[36]In 1957, when more than 2.5 million lb of petrale sole were removed from the Estevan Deep (a figure at least double the then prevailing annual yield from the inshore fishery on the northern stock), it was expected that the succeeding inshore fishery would be virtually nonexistent. However, fishing success appeared to be no worse than in adjacent years.

In consequence of an unrestricted and intensive fishery on the spawning populations, it is inevitable that there would be a marked and perhaps undesirable redistribution of yield among fleets and vessels. For example, there might be reduced catch by fishermen who for one reason or another operate only during the times of year when petrale sole are available in inshore waters. At present this would involve all of the Canadian fleet and perhaps some vessels in the United States fleet. It is rather obvious that operators of such vessels would not take kindly to removal of the present restrictions. Presumably, there would also be objections from buyers whose market depends on an orderly supply of fresh fish in good condition.

(b) LONG-TERM EFFECTS

We turn now to the long-term or delayed effects of increased fishing which is now possible on highly vulnerable spawning concentrations. A potential danger, but one that has rarely if ever been convincingly demonstrated for a marine species, is the possibility that a large or even a moderate increase in fishing intensity would so reduce the adult stock that its size would then become a determining factor in the abundance of offspring. It is virtually impossible to prove or disprove such effects with information at hand. Heavy fishing by United States vessels took place in 1957 on the Estevan spawning ground (Table 18). If most of the catch consisted of fish which had yet to spawn, then it is possible that the remaining stock was smaller than the critical size for reproduction. As the 1957 year-class is still in the early stages of recruitment to the northern stock, consideration of the effect that the fishery on the parent stock had on that year-class must be deferred. However, it is doubtful that an effect clearly distinguishable from environmental influence will be demonstrable, unless of course some scheme can be devised to permit repeated testing in future.

The Canadian and United States trawl fishery in the northeastern Pacific, broadly speaking, is restricted by costs of operation which are high relative to those in other parts of the world. Thus, the threshold between economic and uneconomic fishing, as expressed in dollars per unit of effort is relatively high. Likewise, the cost of shore labour is high and is manifest in the relatively high minimum market size not only on petrale sole but also on Pacific cod, English sole, rock sole, and other species. Thus, it follows that at the extreme stage of overfishing where cost of fishing equals or exceeds the value of the catch, the abundance as well as the average size of fish remaining to support the stock would be larger than in low cost areas. In other words, before the stock could be reduced to the point where its size determined the number of recruits, economic factors would intervene to make the fishery unattractive, and these factors would be expressed at a relatively early stage in the reduction of the stock by fishing.

Available evidence on the plaice stock of the North Sea suggests that despite considerable overfishing, there is "... no indication that the large changes in abundance of mature plaice during the last 50 years have had any clearly-defined influence on recruitment" (Beverton and Holt, 1957, p. 270). Indeed, for no species of marine fish has irrefutable evidence been advanced in support of such a relationship. Thus, precedent offers no guidance in development of a policy for protection of a spawning stock.

As mentioned above, there are several fisheries in British Columbia waters which occur primarily during or just before the spawning season. Possibly there are others in United States waters: e.g. the winter fishery for English sole off the northern Washington coast. Yet in none of these situations is it apparent that the fishery has been responsible for a reduction in recruitment. In light of this evidence, one might presume that unrestricted (winter) fishing on the petrale sole spawning grounds would have no measurable effect on recruitment. Yet all of the above examples (including plaice) are of species characterized by a relatively early age at maturity occurring close to the age of recruitment to the fishery. In other words, at least some of the fish reach maturity before they are fully vulnerable to capture. In contrast, the petrale sole reaches maturity at rather an advanced age (ref. p. 99), apparently several years after having become fully vulnerable to capture. By that time the fish are of such size as to rule out practical application of a mesh regulation to ease the pressure on those age groups which are close to first maturity.[37] Thus, the lack of prospect for beneficial results from mesh regulation, coupled with the petrale sole's tendency to concentrate in small areas at time of spawning and also to be available over a long span of months at other times of the year, makes that species potentially more vulnerable to the effects of intensive fishing than others. This perhaps is the only biologically-based argument for continued prohibition of fishing on the spawning concentrations. There is, however, no proof that the spawning stock could be reduced under the present economic structure to the critical size as far as recruitment is concerned, nor assurance that the effect could be distinguished from the large natural variations in the size of year-classes.

The original agreement to restrict petrale sole fishing was largely based on the fact that abundance on the inshore grounds of British Columbia had declined sharply between 1948 and 1956. Discovery of the Estevan Deep spawning ground in 1953 (and the presence there of inshore-tagged fish) attracted considerable attention. Before agreement was reached to restrict fishing in that region as well as in the other "deeps" along the Washington coast,[38] the catch from the Estevan Deep had risen to 2.8 million lb by the end of the winter of 1956–57. Apparently, the regulation came into effect before "deeps" off Washington (Cape Flattery,

[37]To have any savings effect for mature females the mesh size would have to be more than 6 inches (15.2 cm). Undoubtedly, this would lead to undesirably large escapement of other species of narrower body proportions, such as English sole and Dover sole, and to excessive gilling of dogfish and rockfish.

[38]In April of 1957, the first conference on Co-ordination of Fishery Regulations between Canada and the United States was held in Seattle. Among other things, it was agreed that fishing for petrale sole during the period January–April would be prohibited. The agreement applied to British Columbia, Washington, and Oregon. California was not involved except to the extent that action was to be taken by that state to prevent use of California ports by Washington and Oregon vessels as a means of evading the regulation. Further details are given in Appendix 2.

Willapa Deep, Gray's Harbour Deep) were brought into significant production. More recently, spawning grounds have been encountered off Hecata Head in Oregon. Several "deeps" off California have produced substantial amounts of petrale sole since their discovery in 1948, 1953, and 1957.

In recent years Oregon fishermen have voiced increasing opposition to the winter closure, claiming that the petrale sole stock(s) in waters adjacent to Oregon are not in danger of overfishing, that the winter closure on petrale sole makes fishing for other species unprofitable, and that few Oregon fishermen are interested in fishing as far north as Vancouver Island and the Estevan Deep. In short, industry in Oregon wants to be placed on the same footing as in California, where no winter closure is in force.

Certainly, on the basis of results of the 1960 tagging off Hecata Head, Oregon (p. 37) it appears that few of the petrale sole which spawn in that region move northward into waters adjacent to British Columbia (the extent to which spawning off Oregon contributes recruits to the latter region is, of course, unknown). This may be sufficient evidence to warrant release of Oregon fishermen from the obligation to restrict winter fishing for petrale sole (in waters south of the Columbia River estuary). However, the need for such action depends on additional considerations not the least of which is the question of whether the fishery in that region is already at the optimum intensity, without the need for additional removals from spawning grounds; but this matter is beyond the scope of the present discussion. What is of critical concern is the question whether continued prohibition of fishing on spawning grounds off Washington and British Columbia is consistent with the objective of optimum fishing, not just with respect to petrale sole but to the entire complex of species which contribute to the groundfish fishery. As should be amply clear, no answer is available from past experience.

3. Future Outlook

The fact that a number of species in addition to petrale sole support the trawl fishery of British Columbia waters severely limits the possibility that the fishery for each of the important species can be regulated so as to achieve in each case the level of optimum fishing. Obviously, some compromise would be necessary. Within Area 3C (our principal study area) it will be recalled that in any 1 year during the past decade the petrale sole has never predominated in the catch. It has ranked anywhere from second to fourth by weight and has averaged about 15% of the annual total production. With the possible exception of lingcod, the several species which at least occasionally exceed petrale sole in landed weight, also apparently exceed petrale sole in abundance, but command a lower unit price (Pacific cod, turbot, Dover sole, Pacific ocean perch). Preliminary evidence on growth and mortality suggests that the Pacific cod could withstand much more intensive fishing (Ketchen, 1961 and 1964). The same no doubt applies to turbot, Dover sole, and perhaps to Pacific ocean perch, but the yield of lingcod may already be at or near the optimum. In the presence of under utilized species, it may be more economical to divert some fishing effort to such species rather than attempting to approach more closely the optimum yield from petrale sole or any other species singly.

In a species complex it seems inevitable, however, that over the long-term the species whose critical size[39] most exceeds the mean selection size of the gear in use must be sacrificed (overfished) in order to obtain the optimum yield from the resource as a whole. This is particularly true if the species in question is one that is in strong market demand. In this regard the petrale sole is probably the species most susceptible to overfishing.

In international waters where vessels of more than one nation are engaged in the exploitation of a resource, optimum fishing conditions to one nation may not be the same as those to another because of different national economies (different costs of fishing, market interests, etc.). Such is apparent even in the relatively similar economies of the Canadian and United States trawl fisheries in the Pacific, where considerable complexity is created by (i) different fishing intensities of fleets of the two nations, (ii) possibly different gear selectivity and culling practices, (iii) exploitation of different segments of the same population, and (iv) different relative value of the various species exploited. Ideally, such factors must be taken into consideration in framing of international agreements. Beverton and Holt (1957, p. 415) consider that the only satisfactory solution to the problem of regulating an international fishery lies in each nation's contributing to the regulation as a whole, and further that there be "equivalence" based on equality of initial sacrifice and of final benefit resulting from the regulatory measures.

In practise, however, it seems improbable that such a solution would find ready acceptance if the Canadian and United States fishery reached a state where joint broad conservation measures were necessary. Equality of final benefit would seem to require arrangement of national quotas, otherwise inequality would not take long to appear, unless the economic opportunities were identical in the two or more countries involved. As an example, in the North American halibut fishery of the northeastern Pacific, one of the few cases of international regulation of a purely marine fishery, the benefits to Canada and the United States have not been equally divided. Only the former country has profited (by increased catch through greater fishing effort) from the restoration of the stocks to the present relatively high level of sustainable yield. Possibly a system of national quotas would have been better if equality of benefit had been decreed at the time the halibut treaty was negotiated. No doubt there would be practical difficulties in such an agreement, but they would be small in comparison with those encountered in multiple species fisheries.

[39]Following Ricker's (1958) definition: the average size of the fish in a year-class at the time when the instantaneous rate of natural mortality equals the instantaneous rate of growth in weight for the year-class as a whole.

In multiple species fisheries it is unrealistic to consider catch quotas, closed seasons or closed areas for a particular species as practical measures of regulation. Even in well defined bodies within territorial limits, to say nothing of international waters, such measures are apt to have serious drawbacks (Forrester and Ketchen, 1963). Closed seasons and closed areas in one way or another restrict the efficiency of the fishery for species which are not in need of regulation. Accidental or incidental catches of the particular species requiring regulation which are made during a closed season or, say, after an agreed quota has been reached, may be difficult if not impossible to avoid. Complete ban on retention of such catches would lead to needless wastage if dead or dying fish are returned to the sea, or perhaps to falsification of catch statistics if retained covertly. Of course, if large amounts of dead or dying fish are returned to the sea the catch statistics become falsified anyway, but quite unintentionally, for the dead fish which should have been recorded as catch now become inseparably identified with natural mortality. To the extent that such practice greatly distorts the estimated parameters of fishing mortality, natural mortality, and perhaps of recruitment, the scientific basis for assessing the condition of a fishery is seriously weakened.

An alternative which avoids the problems created by a regulation which is aimed at maintenance of the stock of one particular species, is to regulate the total annual production from some specified ecological system. This has some appeal if it is true that before long the world population will have reached a level where quantity rather than quality of animal protein is the main consideration. Above a certain base level of man's entry as a competitor in the food chain, whether it starts with, say, the exploitation of euphausiids or with the forage fishes such as herring and sand lance, the actual composition of the annual yield would be of secondary importance. By that time, species high in the food chain (halibut, lingcod, sablefish, and petrale sole) presumably would have been reduced to a position of negligible importance. Such a prospect is unattractive and is perhaps rather distant, but certainly it would be accelerated by entry of other nations into that part of the North Pacific which, by fortune of geography, has been the exclusive preserve of the Canadian and United States fishing industries for more than half a century (at least, this was the situation until 1963).

It is, however, unnecessary to look beyond the immediate future to appreciate the difficulties of regulating the trawl fisheries in the Pacific which are pursued by North American nationals alone. Indeed, as we have pointed out, even the unrealistic proposition of treating the petrale sole as if it alone supports the fishery, creates problems of regulation which are of almost insurmountable difficulty.

On this rather gloomy note we turn finally to consideration of some of the lessons learned from the study of the population dynamics of the petrale sole and of some of the requirements in future research.

4. Research Programs Past and Future

Among various lessons to be learned from past studies on petrale sole, the most obvious is that where international fisheries are involved, research programs must be developed on a closely coordinated international basis. We have seen how lack of detailed information of the distribution of fishing effort (by area, season, and depth) handicaps the interpretation of tag returns and hence the definition of stocks. Likewise, it handicaps evaluation of effective fishing effort — effort directed towards capture of a particular species and standardized with sufficient accuracy that full account can be taken of long-term changes in gear efficiency. The problem of obtaining a reliable measure of relative abundance from information on catch per unit of effort is of enormous complexity in multiple species fisheries. It grows worse as newer and better electronic devices are developed to detect and differentiate species of fish and hence reduce the time of searching. Yet, unless the methods of collecting catch statistics keep pace with these developments and are sensitive to the multitude of other distorting influences, the usefulness of the research program either as a monitoring device or as a source of information basic to fishery regulation is seriously limited.

Despite extensive taggings of petrale sole along the Pacific coast of North America, there remain a number of questions regarding the discreteness of stocks which require early solution, particularly if winter closures are to be maintained as a conservation measure off one part of the coast but not off another. Synoptic taggings in adjacent areas likely would yield useful information, but it should be recognized that since tag recaptures depend on the existence of a fishery, the present winter closure affects adversely the interpretation of results.

Carefully designed tagging projects are needed to test the validity of the estimates of natural and fishing mortality rates used in this report. Despite the fact that sampling of petrale sole catches for age composition began at or near the inception of the British Columbia fishery, wholly reliable information on mortality rates in the primitive state were not forthcoming for reasons of unstable recruitment and possibly unrepresentative sampling by the early fishing fleets. To the extent that natural mortality rate is a function of stock density, the primitive natural mortality rate may be higher than that in the presence of a fishery. In any event, it is essential to know whether the rates as used in this report satisfactorily represent present-day conditions.

Of necessity, the subject of the growth rate of petrale sole in this report has been treated rather superficially. More and better information is required on the growth of juvenile fish, and a more searching investigation is required of the apparent trends in length-for-age of adults to determine whether these are reflections of density-dependence, environmental influence, or weakness in the technique of sampling.

We believe that the research on petrale sole has provided convincing evidence that variations in recruitment have been every bit as important as the fishery (if not more so) in determining the abundance of petrale sole off British Columbia after the initial fishery on the primitive stocks. It is unlikely that the effect of these variations could have been correctly diagnosed if the fishery had not been intensively sampled during the past 2 decades. This should be sufficient warning of the dangers involved in assessing the condition of a fishery purely on the basis of catch and effort statistics.

It is evident from research on petrale sole as well as on other groundfish of the northeastern Pacific that if reasonable advances are to be made in the understanding of causes of variations in recruitment, more refined methods of measuring variations in size of broods and of their parent stocks must be developed; that more and better information must be obtained on the early life histories of species contributing to the fishery and on the biological and physical factors which affect survival. We should then be in a better position to determine the kind of information required from the physical oceanographic programs for effective monitoring of the environment. If accurate long-range forecasting of abundance is ever to become a reality, as much attention must be given to this aspect of population control as is conventionally given to the effects of fishing.

Chapter XV

SUMMARY

The petrale sole or "brill" is the most highly valued of flatfishes contributing to the Canadian and United States ottertrawl fishery in the northeast Pacific Ocean. The principal fishing grounds extend from southern California to northern British Columbia, where annual production has varied from a high of 21.6 million lb in 1948 to a low of 7.3 million lb in 1956. Adjacent to British Columbia, the fishery began in a small way in the middle 1930s and expanded rapidly during and immediately after World War II. Canadian production reached a peak of 7.7 million lb in 1948 and then declined to 0.6 million lb in 1956. A slight recovery occurred in subsequent years to a level of about 1 million lb. Throughout its history, the Canadian fishery for petrale sole has remained essentially an inshore (continental shelf) operation, occurring mainly in the spring–autumn months. The United States (Washington) fishery began in waters off the Vancouver Island coast, reaching a peak of 6.0 million lb there in 1943. Production in the succeeding 4 years was maintained at a slightly lower level, only by expansion of fishing into waters off northern British Columbia. Total catch reached 6.2 million lb in 1948 and declined thereafter, but not to the same degree as the Canadian fishery. Development of markets for deep-water species of rockfish led to the discovery of spawning or prespawning concentrations of petrale sole in winter months and in relatively deep water (200 fath). Exploitation of these concentrations tended to offset declining production from the traditional inshore grounds until 1957, when international agreement was achieved to restrict fishing of petrale sole during the winter months.

Results of extensive tagging conducted along the Pacific coast of Canada and the United States indicate that there is relatively little mixing of petrale sole which occur on the inshore (summer) grounds, for the bulk of recaptures are made in the area of tagging even when initial recaptures are discounted. There is, however, a seasonal north–south migration associated with spawning which complicates geographical definition of stocks and hence the interpretation of catch statistics. While there is some degree of overlap of stocks, it appears practical in consideration of Canadian waters to identify two stocks: (i) a southern stock which inhabits shelf waters in summer months off southwestern Vancouver Island (Statistical Area 3C) and which migrates to spawning grounds in deep water of Area 3C and other grounds farther to the south off the coast of Washington (Areas 3B, 3A, and part of Area 2D defining the "Willapa Deep" spawning ground); (ii) a northern stock which in summer inhabits shelf waters of northern Vancouver Island (Area 3D), Queen Charlotte Sound (Areas 5A and 5B) and Hecate Strait (Areas 5C and 5D) and which migrates southward in winter to the "Estevan Deep" spawning

ground off Vancouver Island. A possibility remains that there are more or less separate units of the northern stock and that there are still undiscovered spawning grounds to the north of the Estevan Deep.

Reconstructed history of removals by the fishery on the southern stock indicates that greatest yield occurred in 1943, 6–8 years after commencement of fishing. Total catch as well as relative abundance (catch per effort) declined between 1943 and 1947, recovered briefly during 1948 and 1949, and then entered an irregular decline through 1955–56. A modest recovery occurred in subsequent years, but catch and abundance have been much below levels achieved in 1948 and earlier.

A much more spectacular sequence of events occurred during the early stages of the fishery on the northern stock which began in Queen Charlotte Sound in 1944 and spread into Hecate Strait by 1948. In the latter year, total catch rose to 10.7 million lb and catch per effort was higher than in any of the preceding years. In the succeeding 12 years, catch on the inshore grounds fell to less than 1 million lb. In 1953, however, United States vessels began fishing in the "Estevan Deep" and in 1957, just prior to the international agreement to restrict fishing, production from that spawning ground rose to 2.7 million lb.

Sampling of commercial landings of petrale sole at Canadian ports revealed a decline in average size and age of fish in the southern stock between 1944 and 1947, thus confirming and extending observations made by Cleaver (1949) on the Washington fishery between 1942 and 1944. Beginning in 1948, however, average size and age increased noticeably and reached a maximum in 1953. Thereafter, another decline set in, which has continued to the present but as yet has not reached a level as low as that observed in 1947. A similar pattern of events, identical in timing, occurred in the northern stock.

The increase in average size and age from 1948 to 1953 occurred at a time when landings and catch per effort in both the southern and northern stocks were in a decline, thus pointing to a downward trend in recruitment and this was confirmed by estimates of year-class strength. Year-classes of 1940–43, inclusive, appeared to be exceptionally strong in comparison with those which preceded and followed. They accounted for the resurgence of fishing success in the southern area and dominated in catches during the short but spectacular fishery on the northern stock in the late 1940s. Year-classes of 1944 through 1949 were successively weaker than those of 1940–43 and this accounted for the rise in average size of fish in catches between 1948 and 1953. This general trend was reversed beginning in 1954 as stronger year-classes once again entered the fishery. Early indications are that the 1958 year-class is as strong or stronger than those of the early 1940s.

Growth of petrale sole, as determined by otolith readings, indicates that the von Bertalanffy growth constant, K, is 0.160 for males and 0.167 for females, while the corresponding values of L_∞, the asymptotic length, are 49.0 cm and

58.6 cm, respectively. Observed values of length-for-age among female fish agree well with predicted values from the von Bertalanffy growth equation over the full range of ages, while those of males conform only from age IV onwards.

Over the longterm, there have been small changes in growth rate, the causes of which are uncertain. The fact that average size at each age among the strong year-classes (1940–43) was below average while that of relatively weak year-classes (1947–50) was above average suggests that growth rate is to some extent density-dependent. However, it is also possible that observed changes are related to conditions in the physical environment, for the strong year-classes progressed through the fishery at a time when water temperature appeared to be below average. Another reason for questioning the likelihood of density-dependence is that the principal organisms in the diet of the petrale sole (euphausiids, sand lance, and herring) are also important contributors to the diet of other demersal and pelagic fishes, which greatly exceed the petrale sole in total abundance.

In Canadian waters about 50% of male and female petrale sole are mature by the time they reach a length of 38 cm and 44 cm, respectively. These lengths are achieved at corresponding ages of VII and VIII years. Progressing southward to California, it appears that petrale sole mature at a smaller size. Whether or not age is correspondingly lower is unknown.

Mortality rates of petrale sole have been calculated from data on age composition and catch per effort. "Best" estimates of the instantaneous total mortality rate Z based on observed performance of the strong 1940–43 year-classes are 0.70 for males and 0.45 for females. Expressed on an annual basis these rates are 50% and 36%, respectively. More recent year-classes appear to exhibit lower total mortality rates than those of the 1940–43 year-classes. This may reflect decreased fishing pressure resulting from diversion of fishermen's interest to other species of groundfish which are more abundant than petrale sole. However, the possibility cannot be ignored that present day estimates of petrale sole abundance may be biased upward by unaccounted for changes in gear efficiency and hence may have resulted in overestimation of survival rate.

Estimates of instantaneous natural mortality rate (M) have been obtained from primitive age composition. Two possibilities emerged: one, that M for males is slightly greater than that for females, being 0.25 as compared with 0.20; the other, that M for males is 0.45 and for females 0.20. Acceptance of the first of these possibilities leads to the conclusion that the instantaneous rate of fishing mortality (F) on the 1940–43 year-classes was 0.70–0.25 or 0.45 for males and 0.45–0.20 or 0.25 for females. The second possibility assumes that most of the differential in Z between males and females is due to a differential in M, whence F is 0.25 for both sexes. Support for the former set of F values is difficult to find in available information on the degree to which the Canadian fishery is likely to generate a differential mortality on the two sexes. There remains the possibility that F for males is greater because that sex is more vulnerable to the United States fishery at the time of year (late fall, early winter) for which there is no information on sex composition of the catches. Preference is therefore given to the conclusion that the differential in Z is due largely to a differential in M, although both possibilities are incorporated in subsequent consideration of theoretical population models.

In examination of the pattern of recruitment to the fishery, results of small-meshed trawl surveys at various depths on the continental shelf and slope adjacent to Canada suggest that petrale sole enter the area where commercial fishing is in progress at least as early as age I, but there is insufficient evidence to say at which age this recruitment is complete or reaches the half-way mark. The 50% recruitment length is assumed to be between 32 and 34 cm (corresponding to an age of IV+ years).

In theory, the 50% retention length of fish exposed to trawl nets with cod-end mesh size of 4 inches is 22.2 cm (corresponding to an age of II+ years). It is believed, however, that in actual fact relatively few fish are vulnerable to capture at that size. The picture is further complicated by the fact that up to a certain size petrale sole are culled at sea. The 50% length at retention for market appears to be around 35 cm (corresponding to an age of V+ years).

Theoretical yields from a given amount of recruitment have been computed from a simple Ricker-type population model embodying information on growth rate of petrale sole, various estimates of fishing mortality, natural mortality, and size at retention for market. Models which take into account the two different possibilities concerning the relative magnitude of F and M in male fish yield similar results, viz. both suggest that in order to achieve a state of eumetric fishing, size at retention for market should be reduced, leaving F unchanged, or F should be increased greatly if retention size is left unchanged. Expected increase in yield is only 2–12%, depending on choice of model and choice of parameters to be adjusted. This conclusion, however, is based on the assumption that equilibrium conditions have prevailed during the period of study.

Investigation of the causes of variable recruitment suggests that factors independent of parent stock density are involved, namely, variations in environmental conditions at the time of the pelagic stage. Statistically significant correlations have been obtained between year-class strength and surface water temperatures in late winter months as well as between year-class strength and geostrophic wind indices. Several hypotheses emerge: (i) that water temperature is itself the critical factor, controlling duration of the pelagic stage of the petrale sole or controlling the production of planktonic food organisms available to the larval fish; (ii) that, as strong year-classes are associated with strong southerly winds, it is possible that such winds enhance the northward and inshore drift of eggs and larvae and hence assure transport of greater numbers to suitable rearing areas; (iii) through the combined effects of water temperature, speed and direction of water transport, strong year-classes result from rapid growth through some critical period in the pelagic stage and rapid transport inshore from the spawning areas.

In any event, it is apparent that the petrale sole, being close to the northern limit of its commercial range in waters adjacent to Canada, has not in the period of recorded history achieved a steady state insofar as recruitment is concerned.

In light of the evidence of underfishing as deduced from yield per recruitment models and evidence of substantial variations in recruitment, one is led to the conclusion that the environment has been a more important influence on petrale sole abundance than the fishery, at least during the past decade. The fishery probably was the dominant factor in changes in abundance during the initial stages of exploitation of the southern and northern stocks.

The fact that the petrale sole is but one of a number of species exploited more or less simultaneously by the ottertrawl fishery poses a difficult problem from the standpoint of regulation. While it seems theoretically possible to achieve a state of eumetric fishing for petrale sole by manipulation of such parameters as size at retention for market and fishing intensity, it is impossible to determine the point of optimum fishing without reference to the other species. It is obvious that regulation of the trawl fishery to obtain the optimum yield would involve a compromise weighted to the relative values of the contributing species.

Even if we consider an hypothetic situation in which petrale sole is the exclusive object of fishing, regulation with the view to achieving the optimum is confronted by serious difficulties. In the first place, the predictive value of the yield per recruitment model is limited because the underlying assumption of an equilibrium condition cannot be satisfied. Furthermore, the model, based as it is on observations of the inshore (summer) fishery, fails to take account of seasonal differences in vulnerability of petrale sole. Unrestricted fishing intensity, or even a moderate increase, on deepwater (winter) spawning concentrations, coupled with the prevailing intensity inshore, might generate a fishing mortality rate which greatly exceeds the optimum. In any event, it would lead to a sharp change in the conduct of the fishery, since the effects of fishing on spawning concentrations presumably would have an adverse impact on the inshore fishery. Whether or not the resulting reorganization of the fishery would be a "good" or a "bad" thing would depend on economic and sociological considerations — to say nothing of the essential consideration that the petrale sole must be treated not as an independent entity but as an integral part of a large and complex ecological community.

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APPENDICES I–VII

APPENDIX I

Scientific and Common Names of Species Mentioned in this Bulletin.

Common commercial name		Common name (American Fisheries Society list)	Scientific name
Canada	United States		
Brill	Petrale sole	Petrale sole	*Eopsetta jordani*
Lemon sole	English sole	English sole	*Parophrys vetulus*
Rock sole	Rock sole	Rock sole	*Lepidopsetta bilineata*
Flounder	Flounder	Starry flounder	*Platichthys stellatus*
Butter sole	Bellingham sole	Butter sole	*Isopsetta isolepis*
Turbot	Turbot	Arrowtooth flounder	*Atheresthes stomias*
Halibut	Halibut	Pacific halibut	*Hippoglossus stenolepis*
Dover sole	Dover sole	Dover sole	*Microstomus pacificus*
Grey cod	True cod	Pacific cod	*Gadus macrocephalus*
Ocean perch	Ocean perch	Pacific ocean perch	*Sebastodes alutus*
Blackcod	Blackcod	Sablefish	*Anoplopoma fimbria*
Dogfish	Dogfish	Spiny dogfish	*Squalus suckleyi*[a]
Herring	Herring	Herring	*Clupea pallasii*
Sandlance	Sandlance	Arctic sandlance	*Ammodytes hexapterus*
Bigeye or whiting	Pollock	Walleye pollock	*Theragra chalcogrammus*
Lingcod	Lingcod	Lingcod	*Ophiodon elongatus*
Hake	Hake	Pacific hake	*Merluccius productus*

[a]American Fisheries Society list of common and scientific names (1960) gives *S. suckleyi* as synonymous with *S. acanthias*.

APPENDIX II

Agreement Between Canada and the United States to Restrict Winter Fishing for Petrale Sole.

Representatives of Canada and the United States met in Seattle, Washington in February 1957, to discuss coordination of specific fisheries regulations for the Pacific area pertaining to offshore salmon net fishing, salmon troll fishing, and trawl fishing for petrale sole and sablefish (Anon. 1957a). The United States Delegation outlined certain recent developments in the otter-trawl fishery (apparent decline in success of the inshore fishery for petrale sole and rapid development of a fishery on spawning fish in deep water) which, in their view, demonstrated the necessity for a number of restrictions, among which was a closed season on petrale sole.

The Conference agreed on the establishment of a uniform closed season for petrale sole extending from December 20 to April 15 of the following year, to become effective in the winter of 1957–58. To accompany this regulation was a permissible tolerance, a maximum incidental catch of 3000 lb of petrale sole per trip, not to exceed two trips per month, applying uniformly to Oregon, Washington, and British Columbia. California was to take such action as necessary to prevent the use of California ports for the purpose of evading regulations applicable in the northern areas. These regulations were implemented by the two countries in 1957.

At the second Conference on Co-ordination of Fisheries Regulations held at Vancouver, B.C. in April 1959, an ad hoc committee on trawl fishery regulations (Trawl Fishery Committee) was appointed to review, among other things, regulations which had been agreed upon at the first Conference. The Canadian Delegation reported no change from the original agreement and, incidentally, no change in the practise of Canadian fishery to fish only during the spring to autumn months in relatively shallow water. The United States Delegation advised that the 3000 lb limit not to exceed two trips per month had been found too restrictive and thus had made some changes. In Washington State the regulation was amended to permit trawl fishermen to land incidental catches of petrale sole of 3000 lb or not more than 8% of the total catch of any one trip. This change was made with the understanding that fishermen would avoid areas of spawning concentrations of petrale sole during the December 20 to April 15 period. Oregon likewise found the original agreed regulation to be too restrictive and in the winter of 1958–59 abolished the two-trip limit of incidental landings during the closed period. However, the 3000 lb limit per trip was retained. While it appeared that the amended regulation in Washington and Oregon had been no less effective in discouraging fishing on spawning concentrations of petrale sole, difficulties were encountered in enforcement.

In December 1961, the Trawl Fishery Committee approved a recommendation to change the period of winter closure to January 1 to March 31, inclusive. This was adopted by Oregon, but Washington proclaimed December 23 to March 31 as the closed period, and in March 1962, abolished the 8% tolerance limit and reverted to the 3000 lb tolerance limit as maintained by Oregon and British Columbia.

Late in 1962, as a further step to improve enforcement and minimize the restrictiveness of the regulation and yet still provide protection of spawning fish, the Trawl Fishery Committee approved a change in the tolerance limit from 3000 lb to 6000 lb. This was subsequently approved by Washington and Oregon, but British Columbia retained the original limit.

More recently there have been increasing objections to the regulation, particularly on the part of Oregon fishermen who consider that it places them at a potential disadvantage respecting fishing off the southern Oregon coast where the petrale sole grounds are within the range of the California fleet, which is not involved in the regulations. Furthermore, they consider that stocks which spawn off Oregon are not in need of the same restrictive regulations as those farther to the north, off Washington and British Columbia.

The need for a better understanding of stock divisions along the Pacific coast was recognized by the Trawl Fishery Committee. Largely in response to its recommendations, the various research agencies have intensified efforts to tag petrale sole in waters from Oregon northward to the Vancouver Island coast.

APPENDIX III

Estimation of Washington Catch of Petrale Sole by Area in the Years 1939–47, Inclusive.

During the period of investigation covered by Cleaver (1949), namely, 1939–45, the fishery for petrale sole took place largely from April to September, inclusive. For these months (and years) Cleaver provides estimates of the distribution of fishing effort (his Table 10), which have been consolidated into statistical areas and reproduced in the following tabulation (the figures are percentages of total recorded effort).

If we assume that catch of petrale sole in each area is proportional to the total fishing effort, then we can estimate from the total production of petrale sole (as given in column 11 of Table 18) the percentage taken in each area. This was the method used in proportioning the catch for 1939–43 in Table 18. The above-mentioned assumption probably holds fairly well for the years 1939–42,

Year	Statistical Area				
	3A	3B	3C	3D	5A–5D
1939	...	35.5	64.5	...	...
1940	...	38.9	61.0	...	...
1941	...	33.5	66.5	...	...
1942	...	36.7	63.4	...	...
1943	4.7	19.7	75.4	...	...
1944	...	12.0	61.5	12.3	14.3
1945	0.7	17.1	28.8	10.0	43.3

since most of the fishing effort apparently was directed to the capture of petrale sole. In 1943 and 1944, however, there was a heavy fishery for dogfish, pursued to the exclusion of other species. As this took place mainly in Area 3C, the calculated catches of petrale sole from this area in 1943 and 1944 probably err on the high side.

Cleaver (p. 37) estimated that in April 1944, 1 million lb of petrale sole were removed from the Esperanza ground in Area 3D. Only small amounts of sole were taken on that ground in the following 18 months. Thus, the Area 3D catch in 1944 was probably in excess of 1 million lb. However, on the basis of the percentage of effort expended in that area (12.3%) the calculated catch was only 0.628 million lb. To achieve closer accord with the known facts, therefore, the calculated Area 3D catch has been raised to 1 million lb and the difference has been subtracted proportionately from the calculated catches in other areas.

In 1945, Cleaver adopted an interview system which provided a greater coverage of the fishery. His unpublished records show that 1,938,000 lb (or 35%) of the estimated total landing of petrale sole in that year were accounted for by interview, and identified by area of capture. Prorating the distribution of this catch to the total yields the estimates shown in the first row of the following tabulation. Shown also are the estimates based solely on the distribution of fishing effort (the same technique as that used for earlier years).

	3A	3B	3C	3D	5A	5B	5C	5D
Estimates from:								
1. Sample catch	0.003	0.368	1.223	0.383	1.512	1.678	0.343	0.044
						3.577		
2. Distribution of effort	0.039	0.950	1.600	0.555		2.405		

Presuming that estimates based on the sample catch are reliable, this provides some indication of the magnitude of error which may be involved in the estimates based on effort statistics alone. It is in the direction expected, for in 1945 the fishery had shifted sharply to the northward, and catch of petrale sole per unit of effort on these previously unexploited grounds (Areas 5A and 5B in particular) was no doubt much higher than on the longer fished grounds (Areas 3B and 3C) to the south.

For the years 1946 and 1947, no information is available on the Washington catch by area. Estimates given in Table 18 are merely interpolated (mean) values calculated from the distribution of catch in 1945 (as given above) and that provided by Alverson and Chatwin (1957) for 1948.

APPENDIX IV

MONTHLY LANDINGS OF PETRALE SOLE IN THOUSANDS OF POUNDS BY WASHINGTON AND BRITISH COLUMBIA TRAWLERS OPERATING IN AREA 3C (SOUTHERN VANCOUVER ISLAND).

Year		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1955	Wash.	2.1	8.2	1.5	38.8	148.3	221.2	4.9	4.7	76.1	69.1	0.8	0.3
	B.C.	...	...	...	4.3	34.3	61.8	115.1	17.8	37.4	107.2	1.2	...
	Total	2.1	8.2	1.5	43.1	182.6	283.0	120.0	22.5	113.5	176.3	2.0	0.3
1956	Wash.	...	2.3	0.1	34.6	36.3	100.4	40.8	2.8	99.6	125.5	239.1	190.5
	B.C.	...	0.2	0.4	2.4	13.2	41.6	20.7	20.7	67.9	245.0	3.9	...
	Total	...	2.5	0.5	37.0	49.5	142.0	61.5	23.5	167.5	370.5	243.0	190.5
1957	Wash.	9.0	6.0	0.5	10.0	52.5	227.2	4.2	195.1	221.1	78.6	57.2	5.5
	B.C.	...	...	...	0.5	18.5	51.3	17.8	78.4	286.9	67.9	0.8	...
	Total	9.0	6.0	0.5	10.5	71.0	278.5	22.0	273.5	508.0	146.5	58.0	5.5
1958	Wash.	...	...	5.8	114.5	66.9	18.7	133.5	140.7	271.0	119.7	11.2	51.5
	B.C.	...	...	0.2	0.5	16.6	30.8	45.5	105.8	113.5	94.3	2.8	...
	Total	...	...	6.0	115.0	83.5	49.5	179.0	246.5	384.5	214.0	14.0	51.5
1959	Wash.	1.5	27.5	7.6	125.7	131.6	357.3	256.9	229.5	246.2	366.7	191.2	14.5
	B.C.	...	...	0.4	0.8	15.4	22.7	68.1	48.5	148.3	99.8	4.3	...
	Total	1.5	27.5	8.0	126.5	147.0	380.0	325.0	278.0	394.5	466.5	195.5	14.5

APPENDIX V

Observed Relationship Between Total Length and Mean Weight of Petrale Sole.

Length	Male		Female	
	Number of observations	Mean weight	Number of observations	Mean weight
cm		*oz*		*oz*
21	...	...	1	5.0
22	1	3.0	...	...
23	...	...	...	...
24	3	6.7	...	...
25	6	6.4	3	7.4
26	6	7.4	2	7.5
27	11	8.5	5	8.3
28	14	9.3	5	9.3
29	10	10.4	11	9.8
30	16	11.4	12	10.7
31	20	13.0	9	12.0
32	27	14.4	12	14.2
33	38	16.2	16	16.0
34	52	17.4	15	17.9
35	47	18.9	14	19.7
36	66	20.5	14	21.3
37	76	22.6	25	23.0
38	58	24.6	24	25.1
39	64	26.9	32	27.4
40	53	28.8	35	29.8
41	29	30.4	40	32.3
42	19	32.6	39	35.0
43	12	35.5	35	38.1
44	11	38.2	44	42.1
45	8	42.2	40	45.9
46	3	44.6	36	49.6
47	4	48.5	30	52.5
48	5	52.3	30	55.2
49	...	...	30	58.4
50	...	...	25	62.4
51	...	...	14	68.6
52	...	...	19	74.1
53	...	...	6	79.0
54	...	...	11	80.5
55	...	...	6	84.6
56	...	...	6	88.0
57	...	...	2	92.6
58	...	...	2	101.6
59	...	...	2	112.5
61	...	...	1	129.6
64	...	...	1	126.4

APPENDIX VI

AVERAGE LENGTH (MM) BY AGE OF MALE AND FEMALE PETRALE SOLE CONTAINED IN CANADIAN LANDINGS FROM AREA 3C (SOUTHERN VANCOUVER ISLAND).

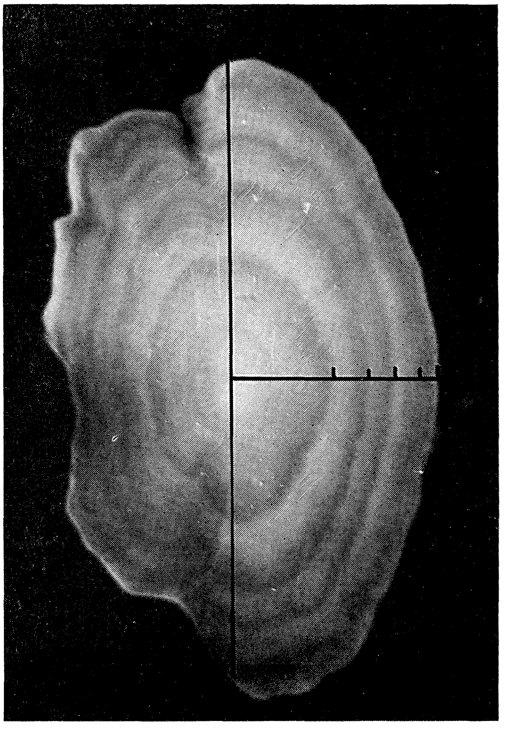
	Year of catch																			
	1944		1945		1946		1947		1948		1949		1950		1951		1952		1953	
Age	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀
III	...	330	...	300	295	290	...	...	...	330	...	310	286	...	294	290	315	...	...	318
IV	350	344	316	319	321	325	323	336	321	333	312	326	323	333	321	328	342	328	361	361
V	360	384	338	359	345	361	339	352	355	373	348	362	343	356	349	366	363	371	368	390
VI	374	407	368	402	360	391	364	381	371	399	368	395	362	381	370	396	382	404	386	417
VII	381	431	387	430	385	423	381	410	387	425	385	420	385	420	387	416	401	434	405	439
VIII	407	442	397	443	398	449	397	434	405	450	397	443	397	442	405	443	412	446	413	455
IX	430	472	411	452	414	467	406	463	416	470	409	451	410	459	414	459	419	462	426	466
X	417	466	427	483	422	482	418	479	425	490	419	481	427	473	426	477	428	475	435	485
XI	450	492	424	500	428	487	435	495	436	503	425	498	441	492	430	483	443	491	447	494
XII	448	513	444	507	443	506	460	510	443	512	433	512	448	504	439	502	440	507	452	508
XIII	480	518	455	523	451	515	460	529	453	520	455	521	457	516	447	513	439	529	464	529
XIV	...	548	475	544	466	534	...	547	463	537	455	533	463	535	465	533	461	530	...	541
XV	...	580	...	544	...	550	...	552	475	548	454	545	477	540	496	541	480	538	480	557
XVI	...	600	...	567	475	568	...	590	...	557	470	555	469	558	435	546	...	568	486	559
XVII	...	570	...	575	...	580	...	580	...	568	...	570	505	558	...	562	470	562	...	557
XVIII	...	575	...	587	...	...	...	620	...	583	...	...	...	572	...	565	...	559	...	597
XIX	...	...	...	590	...	...	...	...	...	...	...	595	...	579	...	569	...	587	...	577
XX	...	...	...	590	...	...	...	...	...	...	...	...	...	...	...	550	...	584	...	560
XXI	...	...	...	...	...	...	...	...	...	...	...	620	...	...	...	573	...	560	...	600
XXII	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	600	...	...

Age	Year of catch																			
	1954		1955		1956		1957		1958		1959		1960		1961		1962		1963	
	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀
III	313	320	310	310	...	...	300	355	320	...	...	...	...	...	...	...	313	314	340	...
IV	344	357	344	348	347	341	359	368	357	365	344	349	335	340	336	346	339	353	355	365
V	375	400	366	388	373	379	378	405	376	395	367	383	355	372	360	376	354	376	372	390
VI	391	430	386	414	384	408	393	430	389	414	383	410	375	396	373	400	373	407	385	412
VII	410	441	400	433	401	424	407	451	403	435	397	430	388	422	390	427	392	430	403	440
VIII	421	465	413	453	412	450	420	473	420	455	409	453	400	435	405	444	408	454	418	456
IX	430	476	428	470	425	470	441	485	425	467	427	478	412	452	424	471	415	472	420	480
X	431	488	433	487	433	483	439	494	431	489	435	494	428	478	430	483	425	491	446	493
XI	445	506	439	498	438	493	445	516	438	494	438	503	427	474	445	495	441	500	456	505
XII	448	514	446	510	452	500	456	515	455	500	447	500	444	494	473	509	465	523	463	520
XIII	462	529	454	533	458	502	461	515	459	516	461	548	453	518	475	530	443	531	465	522
XIV	472	549	444	548	470	522	471	547	456	530	449	537	442	523	...	547	473	540	475	540
XV	490	564	462	556	479	537	452	550	465	545	470	556	...	549	490	562	...	554	...	550
XVI	...	578	430	559	...	554	457	557	...	551	460	564	472	547	...	563	463	557	...	610
XVII	...	573	...	...	480	568	...	554	490	552	500	572	...	557	...	563	...	558	...	605
XVIII	...	583	...	580	...	575	...	602	...	566	...	580	...	589	...	557	...	583	...	575
XIX	...	590	...	580	...	...	490	590	500	584	...	596	...	578	...	590	...	600	...	...
XX	...	...	...	...	...	...	...	600	...	587	...	...	...	540	...	...	...	...	...	580
XXI	...	610	...	605	...	...	...	...	...	594	...	550	...	590	...	...	...	600	...	...
XXII	...	...	...	...	...	...	...	...	...	597	...	...	...	...	...	...	...	...	...	...

APPENDIX VII

Back-calculation of lengths of
petrale sole at ages I–IV.

In the summer of 1956, a sample of otoliths and length measurements was collected from a commercial landing of petrale sole from Area 3C. It consisted of 606 female fish ranging in length from 32 to 65 cm, and 324 male fish ranging from 29 to 51 cm.



The left-hand (blind side) otolith was used for measurement, the radius being determined from the transverse axis, as shown in the accompanying photograph. A mean radius (*mm*) was calculated for each cm category of fish length. The regression of fish length on otolith radius, as determined by least squares, for female petrale sole is expressed by

$$Y = 1.7018 + 1.28093\ X$$

where Y is $\log_{10}$ fish length in cm and X is $\log_{10}$ otolith radius in mm. The corresponding relationship for males is

$$Y = 1.13490 + 1.30387\ X$$

By means of these equations, the mean radii of the first to fifth winter checks were converted to calculated lengths at the completion of ages I through IV. The results are given in the following table along with estimates of the standard deviation and range of fish lengths at each age.

Age in completed years	Number of readings	Mean radius	Calculated mean fish length	Standard deviation from mean	Calculated range of lengths
Female		*mm*	*cm*	*cm*	*cm*
I	511	0.77	10.6	1.85	6.3–15.2
II	536	1.21	18.4	2.52	13.1–25.3
III	454	1.55	25.0	3.29	14.1–32.8
IV	260	1.78	30.9	3.86	22.8–41.7
Male					
I	246	0.79	10.7	1.94	6.4–17.7
II	244	1.25	18.6	2.41	13.4–24.5
III	200	1.64	26.1	2.98	18.7–34.2
IV	88	1.88	31.6	3.17	25.5–38.9

The calculated lengths are, of course, useful only as approximations since they were obtained by extrapolation of the fish length-otolith radius relationship applying to relatively large (old) fish. To corroborate these estimates, additional back calculations are required from fish of smaller size and younger age than those used.