A CONTRIBUTION TO THE BIOLOGY OF THUNNUS THYNNUS (LINNAEUS, 1758), IN CONCEPTION BAY, NEWFOUNDLAND

M. J. A. BUTLER

A CONTRIBUTION TO THE BIOLOGY OF *THUNNUS THYNNUS* (LINNAEUS, 1758), IN CONCEPTION BAY, NEWFOUNDLAND

by

M. J. A. Butler

B.Sc., University of London (Queen Mary College), 1964

A Thesis
Submitted in Partial Fulfilment of the Requirements
for the Degree of Master of Science in the
Department of Biology
Memorial University of Newfoundland

March, 1969

"We are dealing with the natures of a specially remarkable species."

Gaius Plinius Secundus

(Pliny the Elder) A.D. 23-79

ABSTRACT

This thesis was based on the results of a two year study of the bluefin tuna of Conception Bay. The program was inaugurated in 1965 under the auspices of the Department of Biology, Memorial University of Newfoundland.

The bluefin was considered in terms of its morphology, taxonomy, and meristic characteristics, the latter in comparison with other areas of the Atlantic and Pacific.

The life history of the western Atlantic bluefin was described in relation to its distribution, feeding migration, schooling behaviour and reproduction. The importance of a comprehensive tagging program was emphasised. Erythrocyte analysis was suggested as a means of sex determination. The age, length and weight inter-relationships were computed for 11, 12 and 13 year old bluefin, the age groups predominantly present in Newfoundland waters. Stomach contents were analysed quantatatively and qualitatively. Related studies included the analysis of stomach parasites and the determination of the major feeding period(s). The hydrographic and meteorological conditions prevalent during the fishing season were considered in relation to bluefin behaviour, distribution and catch success. Methods were suggested to predict the time of arrival of the bluefin in Conception Bay and the total annual catch. A log-sheet was prepared specifically for the bluefin sport-fishery of Conception Bay, to satisfy both biological and commercial requirements.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACKNOWLEDGEMENTS

The author would like to express his gratitude to his supervisor, Dr. C. W. Andrews, Professor of Biology, Memorial University, for this opportunity to study the bluefin, and for his invaluable support and advice throughout the project. Dr. F.A. Aldrich, the Director of the Marine Sciences Research Laboratory of Memorial University and former Head of the Department of Biology, consistently provided encouragement and assistance which was much appreciated. I wish to thank Dr. C.W. Andrews, Dr. T. McKenny and Dr. W. Threlfall, of the Department of Biology and Dr. A. May of the Fisheries Research Board of Canada, St. John's, who reviewed the manuscript, or sections of it, and made many helpful suggestions. To Dr. G. Moskovits and Dr. D.H. Steele, of the Department of Biology, my thanks for the loan of equipment and for much valuable advice.

I am indebted to Memorial University of Newfoundland for providing the necessary financial assistance throughout the two-year period of my residency at the University.

The Newfoundland and Labrador Tourist Development Division, Department of Economic Development, at that time under the Directorship of Mr. O.L. Vardy, supported the project financially. Miss M.F. Godden, the Assistant Director, made available all her efficiently tabulated statistics of bluefin landings and together with Mr. E.P. Henley, formerly the Associate Director, now Director, provided so much additional help that it is difficult to adequately acknowledge. To these Directors and their staff, my sincere appreciation.

I wish to thank all members of the Newfoundland Tuna Fishing Association, particularly Mrs. M Williams (President), Mr. E. Hillyard (Vice President) and Mr. R. Rowe (Secretary for their invaluable cooperation and assistance. Also, my thanks to the tuna boat captains and crew, all of whom willingly and patiently supported the project.

To Dr. W. Templeman and Mr. A.M. Fleming and their staff at the St. John's Biological Station of the Fisheries Research Board of Canada, I am indebted for many helpful suggestions and assistance. The loan of equipment and the use of their library was also much appreciated.

Dr. W. Threlfall, Miss E. Brown and Mr. F. Smith, of the Department of Biology, kindly assisted in the iddntification of stomach parasites.

Thanks are also due to Mr. F.J. Mather III of the Woods Hole Oceanographic Institution, Massachusetts, for his helpful comments and suggestions and also to Dr. E. Cohen of the Roswell Park Memorial Institute, Buffalo, New York, for efforts to determine the sex of bluefin by a technique involving blood analysis.

I wish to acknowledge the many hours of work devoted to the project by Mr. W. Gordon and his staff of the Technical Services, Memorial University. Much of the apparatus used in the study could not have been built or operated without their specialized skills and advice.

Appreciation is expressed to Mr. B. O'Brien, Manager of Arctic Fisheries, Ltd. of Dildo and to Mr. Bidgood, owner of Bidgoods Ltd. of Petty Harbour and their respective staffs for their cooperation in the removal and preserving of the bluefin stomachs, gonads and vertebrae in spite of the inconvenience and time involved.

I would particularly like to thank my two assistants, Mr. L. Brecken of Memorial University, who carried out much of the unpleasant stomach content analysis and preparation of vertebrae, and Master W. Chaytor of Long Pond, Manuels, my deputy on the tuna wharf. Their assistance was invaluable to this project.

The following persons, fellow students at Memorial University, made important contributions to the project by assisting in the collection or preparation of material and data or providing transport: Messrs. R. Gray, J. Percy, R. Riewe, D. Barnes, C.C. Lu, F. Pollett, T. Kan, W. Wiseman, G. Barbour, R. Scaplen, S. Naidu, H. Mercer, and Misses L. Inkpen and B. Gosse. To all of them and to those I might inadvertently have not included, my appreciation.

I wish to thank the Science Assistants of the Department of Biology, Messrs. C.H. Rowe, M.J. Mercer, L. Moores and R. Meade for their assistance and good humour.

Captain W. Weyland and his crew on the "Marilyn Marie" and Mr. R. Bernal, captain of the "Bluefin" were both helpful and interested in the project, for which the author is most grateful.

I wish to thank Mr. D.C. Barter (Bursar) and Mr. R.F. Furlong (Purchasing Officer) of Memorial University for their help in arranging the use of a University half-ton truck by the author. Over four thousand miles were travelled during the course of the 1966 bluefin season.

Thanks are due to Mr. M. Jones of the Mathematics Department of Memorial University who assisted in the tabulation of meteorological data, some of which had been kindly provided by Mr. F. Rowe of the St. John's Meteorological Office.

I wish to thank Messrs. Tucker and Thorpe and their families of St. Phillips, Conception Bay, for permission to set up apparatus on their land, the loan of their boat and assistance in the maintenance of a thermograph.

My appreciation to the secretarial staff of the Department of Biology, Miss L. Sullivan, Miss P. Bradbrook and Mrs. G. Woodland for the typing of numerous data sheets associated with the project.

Also I wish to thank the staff of the University Library for their help and forbearance.

Finally and especially, I wish to thank my wife, Noreen, for her patient and valuable assistance during many hours of field and laboratory work and the typing of seemingly endless manuscripts.

INTRODUCTION

The bluefin tuna, Thunnus thynnus (Linnaeus, 1758), has been a topic of scientific, literary and culinary interest for many centuries. The earliest reference to a study of age and growth of tuna has been traced to observation by Greek fishermen about 2000 years ago, and recorded in Aristotle's "Historia Animalium" (Bell, 1964). Pliny, in the first century A.D., states that the multitude of bluefin which met the fleet of Alexander on one occasion was so vast that only by advancing in battle line was it able to cut its way through the school (Mowbray, L., in Fishing the Atlantic by Farrington, S.K., Jr., 1949). The first known cookery book, that of Apicius (first century A.D.) explains how to cook tuna in imperial Roman style: Bake it and cover it with herbs, onions, vinegar, honey and "liquamen", the latter made of small fish soaked for months in brine (Flower and Rosenbaum, 1958).

In the 20th century (A.D.), the world tuna fisheries (Tunas, Bonitos and Skipjacks) are rapidly expanding and since 1945 have approximately doubled every decade, with some 1,045,000 metric tons being landed in 1962 (McKenzie, 1965). This quantity is less than 3% of the world total catch of fish, which was nearly 46,000,000 metric tons (live weight) in 1963 (FAO Yearbook of Fishery Statistics, 1963, Vol. 16, Rome, 1964). However, in monetary terms the tunas are one of the most valuable groups of fish caught. Chapman (1962) has predicted that the world tuna catch will reach about

1,500,000 metric tons in 1970. To achieve this figure, new or partially developed tuna resources, such as those in the North West Atlantic, must be developed because some existing tuna fisheries have already exceeded or are close to their maximum sustainable yield (McKenzie, 1965). During the period of 1954 to 1963, the bluefin comprised 10.8% of the world landings of tuna (Tunas, Bonitos and Skipjacks), with annual catches exceeding 100,000 metric tons since 1960 (FAO Yearbook of Fishery Statistics, 1963, Vol. 16, Rome, 1964).

The commercial tuna catch (mainly bluefin) of the Canadian Atlantic Provinces is comparatively small, with landings in the 1953-1962 period varying from 40-100 metric tons annually (FAO Yearbook of Fishery Statistics, 1963, Vol. 16, Rome, 1964). Practically all commercial fishing for bluefin on the Canadian east coast is located in Lunenburg County, Nova Scotia, where traps (madragues), harpoons and long lines are commonly used. The conversion of the swordfish fishery from harpoons to longlines in 1962 increased the incidental catch of tuna. In 1963 and 1964 the landings of bluefin increased rapidly to 318 and 565 metric tons respectively, mainly as a result of the introduction of two ninety foot purse seiners (Blue Water and Green Water), operating from Campobello, New Brunswick (Hamre, Lozano, Rodriguez-Roda and Tiews, 1966 and Tibbo, 1967). For a detailed review of the North West Atlantic tunas, bonitos and their fishery, see

McKenzie (1965).

In addition to commercial fisheries, bluefin sport-fishing is of increasing economic value. According to Louis Mowbray (quoted in Farrington, S.K., Jr., 1949:204), the financial gain derived from the promotion of game fishing has probably a greater distribution throughout a community than that derived from purely commercial operations. In the Maritimes, bluefin sport fisheries are carried out in Cape Breton, Halifax and Yarmouth Counties of Nova Scotia, but of particular renown is the Soldier's Rip off Wedgeport. The first of many International Cup Matches was held there in 1937 between teams representing the British Empire and the United States and was a regular event until 1958. In later years the large bluefin appeared to have moved to other areas, notably Conception Bay, Newfoundland (Figure I). In 1956, the Newfoundland Tourist Development Office purchased two tuna boats and engaged experienced Nova Scotian guides in an effort to develop bluefin fishing as a sporting attraction. The success of this venture is clearly apparent from the catch statistics (Appendix I) and the fleet of thirty privately owned tuna charter boats which fished Conception Bay in 1967. Bonavista Bay and in particular Notre Dame Bay are also proving to be successful fishing areas. Numerous National and club tournaments which attract the world's most experienced deep sea anglers, are held annually in Conception Bay. The vice-president of the Newfoundland Tuna Association, Mr. E. Hillyard, was selected as a member

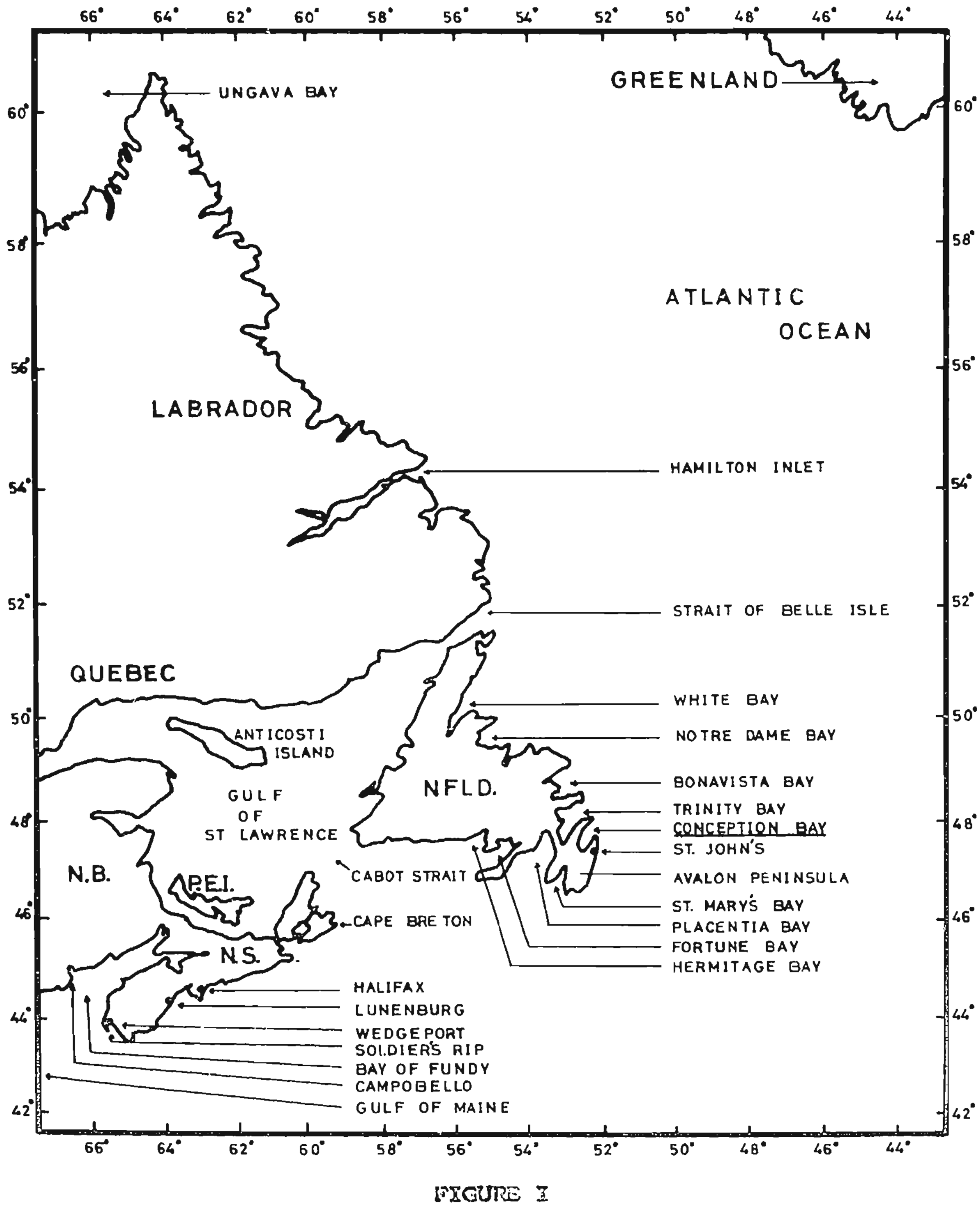


FIGURE I

THE CENTRES OF BLUEFIN SPORT FISHING IN THE ATLANTIC PROVINCES OF CANADA of the Canadian national team which competed in the 1967 International Cup Match (re-established since 1965) held at Wedgeport. The Provincial Government of Newfoundland has offered 1000 dollars for a tuna weighing 1000 pounds or more. To date the reward has not been claimed although bluefin of that size are undoubtedly present in Newfoundland waters during the fishing season (mid-June to mid-October). A note in the Western Star of August 31, 1917, is of interest:

> "Yesterday we were shown part of a 1000 pound tuna caught by A.B. Harding at Bonne Bay as reported in our last week's issue. Mr. Harding is to be congratulated on his enterprise in the introduction of this new sport on the west coast of Newfoundland."
>
> "Our coastal waters abound with the elusive tuna and we have frequently wondered that such exquisite sport which they afford had not been previously participated in by some of our local or visiting sportsmen."

A bluefin research project centered on Conception Bay was inaugurated in 1965 by the Department of Biology of the Memorial University of Newfoundland, and with the financial support of the Department of Economic Development, Provincial Government of Newfoundland. The project was revised and considerably expanded in 1966 by the author, under the supervision of Dr. C.W. Andrews, Professor of Biology, and forms the basis of this thesis.

For the duration of the 1966 bluefin season the author was appointed by the provincial government as the wharf supervisor at Long Pond, Manuels, 16 miles from St. John's and the centre of tuna boat operations in Conception Bay (Figure 2.) This ap-

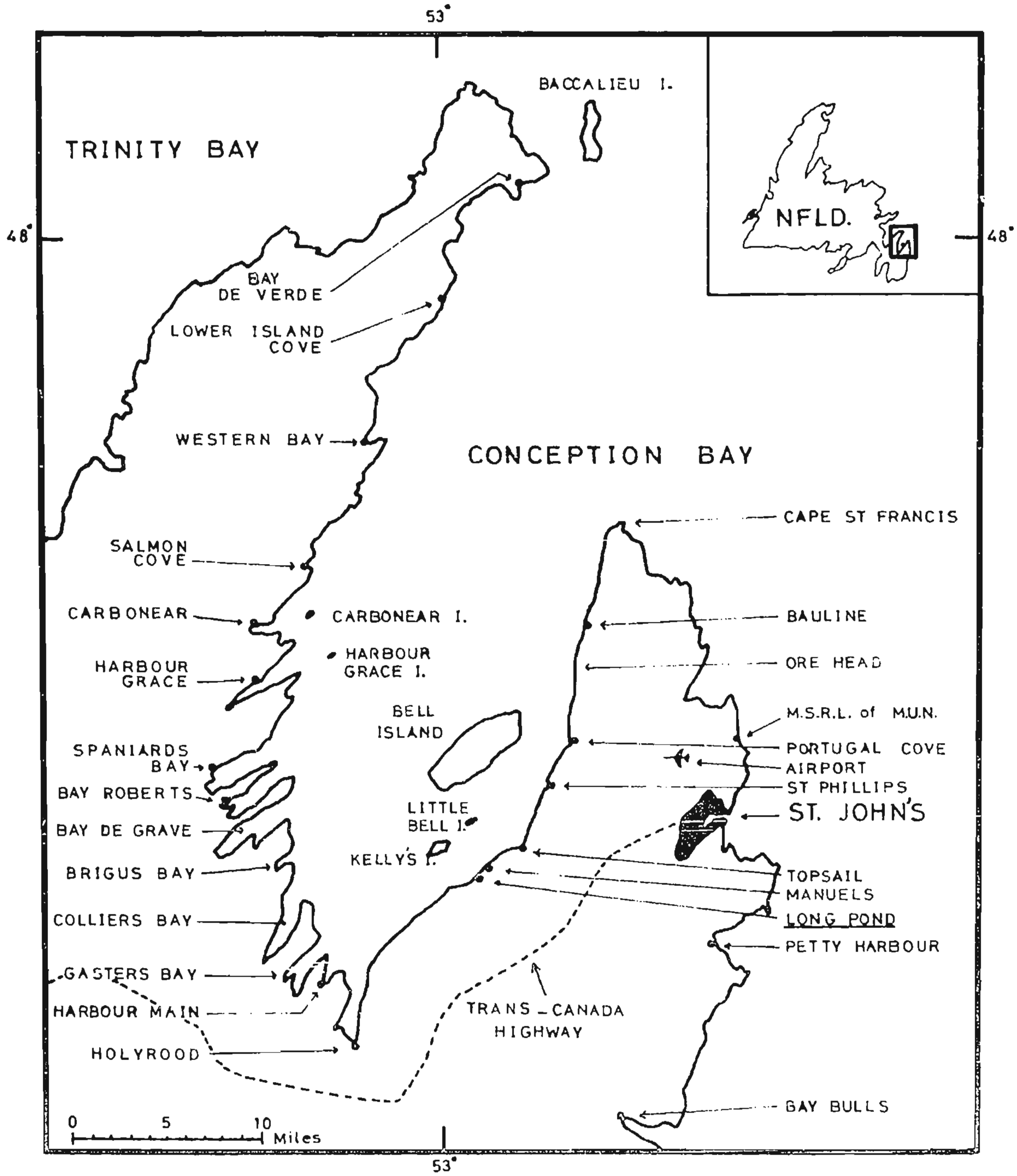


FIGURE 2

CONCEPTION BAY AND ENVIRONS

pointment considerably aided the collection of data and the necessary liaison with members of the Newfoundland Tuna Fishing Association. All morphometric and meristic measurements and counts were made of each bluefin after its official weighing-in on the wharf and each was tagged for later identification. Blood samples were taken when required. The official log-sheets, from which a great deal of valuable data were obtained, were collected from the boat crews as regularly as possible. Obvious discrepancies were immediately clarified in consultation with the relevant crew. On the completion of the day's operations, the catch was collected by truck and transported to Arctic Fisheries Ltd., of Dildo, Trinity Bay or to Bidgoods Ltd., of Petty Harbour. In most instances, the stomach, gonads and a vertebra of each fish (identified by the tag attached at Long Pond Wharf) were placed in a plastic bag by the factory staff and kept in cold storage. These specimens were collected by the author and preserved in 5-10% formalin within a plastic lined 10 ft. x 4 ft. x 3 ft. water-proofed box.

Hydrographic surveys of Conception Bay were made on two chartered in-shore fishing vessels. In addition, water temperature and meteorological data from the Conception Bay area were recorded throughout the bluefin season. This information was correlated, where possible, with the presence or absence of bluefin and their behaviour.

SECTION I

DESCRIPTION

Morphology

The bluefin has a robust, completely scaled, fusiform body about one fourth to one sixth as deep as it is long (Figure 3). From the shoulder region, marked by a corselet of large scales, the compressed body tapers anteriorly to a pointed snout and posteriorly to a slender caudal peduncle which bears a strong median longitudinal keel on either side. The triangular first dorsal fin, composed of 13 or 14 spines, tapers backwards from the first spine. The posterior margin is slightly concave and is almost confluent with the second dorsal fin. The second dorsal fin (about 13 rays) and anal fin (12 rays) which are similar in appearance, are posteriorly deeply concave and taper to sharply pointed apices. There are usually 9 or 10 dorsal finlets and 8 or 9 anal finlets. The lunate caudal fin is inflexible with sharply pointed lobes. The scimitar-shaped pectoral fins are inserted approximately level with the eyes. The pelvic fins are of moderate size and are inserted below the pectoral origin. The pectoral and pelvic fins can be flattened into shallow depressions and the first dorsal fin can be folded completely into a groove, thus considerably reducing locomotory resistance. (Ehrenbaum, 1936; Bigelow and Schroeder, 1953; Tiews, 1962; McKenzie, 1965; Tibbo, 1967).

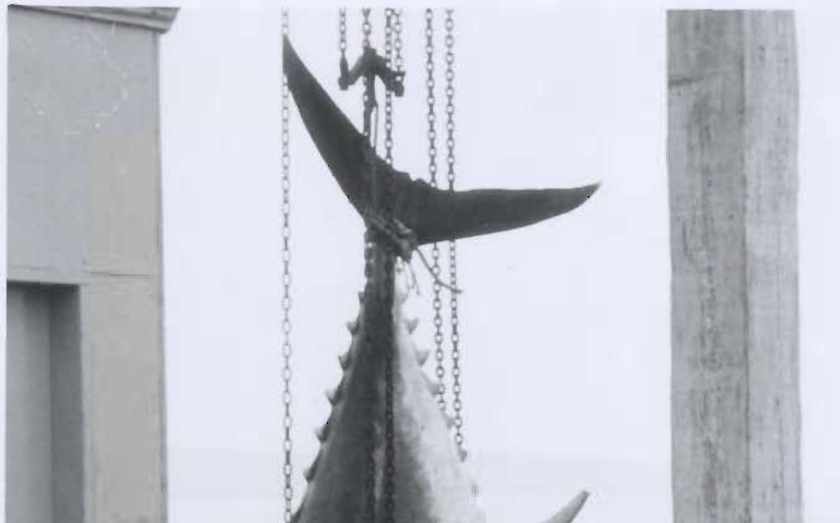


FIGURE 3

THE BLUEFIN TUNA, THUNNUS THYNNUS (LINNAEUS)

Size

The bluefin, the largest member of the family Scombridae, is considered to reach a maximum weight of 1600 pounds (Bigelow and Schroeder, 1953) to 2000 pounds (McKenzie, 1965). The probable length at this weight would be 14 feet (427 cm) and the age 20 years or more.

The most common sizes in the western North Atlantic (McKenzie, 1965: Tibbo, 1967), and specifically in the Newfoundland area, are 400-600 pounds ("giants") and 50-150 pounds ("jumpers"). However, all other weight categories have been caught or observed in Conception Bay, except the very young (less than 50 pounds).

Since the introduction of bluefin sport fishing in Conception Bay in 1956, the maximum and minimum individual catch weights have been as indicated in Table I.

Table I

The Maximum and Minimum Catch Weights, Conception Bay, 1956-66

Year	Heaviest (pounds)	Lightest (pounds)
1956	765 (unofficial world record for 1956)	620
1957	871 (world record for 1957)	502
1958	797 (world record for 1958)	529
1959	737	218
1960	784	274
1961	834	72
1962	724	395
1963	686	368

The Maximum and Minimum Catch Weights, Conception Bay, 1956-66

Year	Heaviest (pounds)	Lightest (pounds)
1964	790	355
1965	732	347
1966	725	336

The present world record bluefin, taken on rod and reel, weighed 977 pounds and was caught in St. Ann's Bay, Nova Scotia on September 4, 1950. In this category of game fishing the maximum breaking strain of the fishing line is 130 pounds, as stipulated by the International Game Fish Association.

According to newspaper reports, a 1600 pound bluefin was harpooned in the Gulf of Portland, Maine, (Crane, 1936). Sella (1931) refers to a tuna of about 1500 pounds which was apparently caught off Narragansett Pier, Rhode Island, in the late 19th century.

Sella (1932) stated that in the Mediterranean the bluefin reaches a weight of 380 pounds, but weights as high as 1595 pounds have been recorded in the eastern Mediterranean (Heldt, 1938), and Akyüz and Artüz (1957) refer to a 924 pound tuna landed at Istanbul. However, in the western Mediterranean and off the California coast, bluefin are reportedly smaller (Bigelow and Schroeder, 1953).

Colour

The following description of the colour of the bluefin is based on accounts by Nichols (1922); Bigelow and Schroeder (1953); Ehrenbaum (1936); Crane (1936); Mather III (1959); Tiews (1962); McKenzie (1965); Tibbo (1967) and on the author's observations. It is rather more of an approximation as the colouration of the bluefin varies considerably and the hues are often very subtle.

Body: The adult living bluefin is dorsally a dark metallic blue with a green-grey sheen. The cheeks are silvery and the sides below the lateral line are silvery-grey, merging into a white belly. In small individuals there are conspicuous white vertical bars and spots along the sides, these gradually disappear with age.

Fins: The first and second dorsal fins are grey-black; the dorsal and anal finlets are yellow with dark borders: the pectoral and ventral fins are grey-black above and silvery-grey below; the anal fin is silvery-grey and the caudal fin is dark grey-blue.

The colours fade and change rapidly after death and exposure to air. In addition, the depth that a tuna has been inhabiting influences the colour. Ehrenbaum (1924) and Arena (1959) suggest that the darker tunas have recently emerged from great depths while the light coloured fish have been swimming in superficial layers for sufficient time to adapt to the increased light radiation.

Transient vertical bars observed on recently caught southern bluefin *Thunnus maccoyii*, (Serventy, 1956), may have been initiated by food stimuli (Magnuson, 1962).

Distinguishing Features

In addition to colour, the following easily observed characteristics are peculiar to *T. thynnus* and may be used to identify the species:

1. The pectoral fin is shorter than in any other tuna, and only extends to the posterior margin of the first dorsal.

2. The posterior margin of the first dorsal is only slightly concave in comparison to the other tuna species.

3. The vent is round in contrast to the oval vent of the Bigeye (*Thunnus obesus*) and the Yellowfin (*Thunnus albacares*).

4. The first gill arch has a total of 31-43 gill rakers, the highest number encountered in the genus *Thunnus*.

5. Ventrally, the three liver lobes are striated and are distinctly separated by clefts.

As well as these characteristics, other less apparent distinguishing features are discussed by Watson (1962) and Gibbs and Collette (1966).

SECTION II

SYSTEMATICS AND NOMENCLATURE

Taxonomy

The most recent systematic interpretation of the suprageneric relationship of tunas and mackerel-like fishes by Gibbs and Collette (1966) places all of these fishes in the family Scombridae, hence substantiating the views of Regan (1909), Starks (1910), Fraser-Brunner (1950) and Collette and Gibbs (1962). Alternative interpretations have been proposed by Kishinouye (1915, 1917, 1923), Takahashi (1924, 1926) and Berg (1955).

Within the family Scombridae two subfamilies are tentatively recognised (Collette and Gibbs, 1962:1):

> ".... the Gasterochismatinae (which may perhaps have to be split off as a separate family) and the Scombrinae. Within the latter there are two major groups of genera, the more primitive ones (Scomber to Acanthocybium) which lack a bony caudal keel and have a caudal notch and the more advanced (Gymnosarda to Thunnus) which have a bony caudal keel and lack a caudal notch. Both these groups can be further split into smaller groups of genera: Scomber (about two species) and Rastrelliger (one or two species); Scomberomorus (nine to fifteen species) and the monotypic Grammatorcynus and Acanthocybium; Gymnosarda (one or two species) and the monotypic Orcynopsis; Sarda (two to five species); Auxis (probably two species); Euthynnus (two to five species); and the monotypic Allothunnus; and Thunnus (six species)".

Ten generic names and thirty-seven specific names have been variously applied to the seven nominal species (Table 2) in the genus Thunnus based on external morphological and internal anatomical characters (Gibbs and Collette, 1966).

Table 2 The Seven Nominal Species in the Genus *Thunnus*

1.	*Thunnus thynnus*	the bluefin tuna: cosmopolitan.
2.	*Thunnus alalunga* (*Germo* Jordan)	the albacore tuna: cosmopolitan.
3.	*Thunnus obesus* (*Parathunnus*)	the bigeye tuna: cosmopolitan.
4.	*Thunnus albacares* (*Neothunnus* Kishinouye)	the yellowfin tuna: cosmopolitan.
5.	*Thunnus atlanticus*	the blackfin tuna: western Atlantic.
6.	*Thunnus tonggol* (*Kishinoella* Jordan and Hubbs)	the longtail tuna: Indo-western Pacific.
7.	*Thunnus maccoyii*	the southern bluefin tuna: South Pacific and Indian Oceans and north west Australia.

Other authors recognise alternative genera or subgenera (in parentheses above) on the basis of meristic and/or morphological considerations (Jordan and Evermann, 1926; Godsil and Byers, 1944; Godsil, 1954; Fraser-Brunner, 1950; Rivas, 1961). However, according to Rivas (1951), deSylva (1955), Iwai, Nakamura and Matsubara (1965) and Gibbs and Collette (1966), the subdivision of *Thunnus* into genera or subgenera is an arbitrary matter and also obscures the close relationship among the species.

In relation to species interpretation, Ginsberg (1953) and Godsil and Holmberg (1950) propose that the various bluefin (*Thunnus thynnus*) populations should be differentiated at the specific level: *Thunnus thynnus*, eastern Atlantic; *Thunnus secundodorsalis* (Storer), western Atlantic; *Thunnus saliens* (Jordan and Evermann), eastern

Pacific; <u>Thunnus maccoyii</u> (Castelnau), Australian bluefin. Serventy (1956) disagrees and suggests that bluefin comprise six isolated populations within a single world wide species. Jones and Silas (1960) and Collette and Gibbs (1962) agree with this interpretation but propose that a distinction be made between an Atlantic subspecies (<u>Thunnus thynnus thynnus</u>) and an Indo-Pacific subspecies (<u>Thunnus thynnus orientalis</u>). However, Gibbs and Collette (1966) recognize (reluctantly) <u>Thunnus maccoyii</u> as a separate species based on the position of the first ventrally directed parapophysis (on the 9th vertebra in <u>Thunnus maccoyii</u>, as opposed to the 10th in <u>Thunnus thynnus</u>) and the colour of the fleshy caudal keels (yellow in <u>Thunnus maccoyii</u>, dark in <u>Thunnus thynnus</u>).

Within the Atlantic subspecies bluefin of the eastern and western Atlantic possess minor meristic differences and probably represent distinct breeding populations at the racial or subspecific level (Rivas, 1954b). Mather is in agreement and states that, "morphometric and meristic comparisons between samples from the two areas (Western and Eastern Atlantic) have failed to show significant differences or complete similarity", (Mather III, 1962b:8). The discovery of spawning grounds in the western Atlantic also suggests the independence of the western and eastern Atlantic populations (Rivas, 1954a).

Thus, the Atlantic bluefin tuna may be classified as follows:

Phylum	Vertebrata
Subphylum	Craniata

Superclass	Gnathostomata
Series	Pisces
Class	Osteichthyes
Subclass	Teleostei
Order	Percomorphida
Suborder	Scombroidea
Family	Scombridae
Subfamily	Scombrinae
Genus	Thunnus South, 1845
Species	Thunnus thynnus (Linnaeus), 1758
Subspecies	Thunnus thynnus thynnus

For a detailed survey of this subject see Gibbs and Collette (1966).

Meristic Characters

Gibbs and Collette (1966) found the number of gill rakers to be the only meristic character valuable in separating species of Thunnus. The Thunnus thynnus-maccoyii complex has the greatest number of gill rakers in the genus (31-43), and its three members can be distinguished by their means and modes respectively: Atlantic 38.9 (39), Pacific 35.9 (35), Thunnus maccoyii 33.7 (34).

The author counted the first arch gill rakers of 150 "giant" bluefin caught in Conception Bay. To facilitate the count it was necessary to enlarge the opercular opening dorsally by means of a hack-saw (See Appendix 2). The results, in comparison with those of other workers, are presented in Tables 3 and 4.

Table 3 Upper and Lower Gill Raker Counts of Atlantic Bluefin

Upper Gill Raker Counts (Left Side)			Lower Gill Raker Counts (Left Side)		
No. of Gill Rakers	Other Workers* West Atlantic	Author	No. of Gill Rakers	Other Workers* West Atlantic	Author
9	1	-	21	-	-
10	3	-	22	-	-
11	7	5	23	-	2
12	50	27	24	26	7
13	130	72	25	78	56
14	55	44	26	98	57
15	7	2	27	43	26
16	-	-	28	8	2
	n = 253	n = 150		n = 253	n = 150
	$\bar{x}$ = 12.97	$\bar{x}$ = 13.07		$\bar{x}$ = 25.72	$\bar{x}$ = 25.69

* Crane, 1936; Rivas, 1955; Mather, 1959; Mather, 1959 counts by Dr. R.H. Gibbs, Jr., et al

Table 4 **Total Gill Raker Counts (Left Side) of Atlantic Bluefin**

No. of Gill Rakers	West[1] Atlantic	East Atlantic[2] South Africa	Author Conception Bay
34	3	-	1
35	2	4	1
36	12	8	4
37	32	40	16
38	63	88	43
39	102	105	44
40	40	74	23
41	29	36	16
42	4	7	2
43	1	4	-
	n = 288	n = 366	n = 150
	$\bar{x}$ = 38.8	$\bar{x}$ = 38.9	$\bar{x}$ = 38.76

1 Gibbs and Collette, original data; Ginsburg, 1953; Godsil and Holmberg, 1950; Mather, 1962a.

2 Gibbs and Collette, original data; Robins, 1957; Talbot, 1964; Tiews, 1962.

A statistical comparison of the author's and other workers' data showed no significant differences.

Tiews (1957) analysed the frequency of combinations of gill rakers on the lower and upper limb of the first gill arch in 232 North Sea bluefin. The author similarly analysed 150 Conception Bay bluefin (Table 5). The Conception Bay results, in contrast to the North Sea data, indicate a greater percentage of bluefin having the two most common gill raker combinations 25 + 13 and 26 + 13. The asymmetry referred to by Tiews (1957) between right and left sides of the first gill arch of North Sea bluefin is most evident in the Conception Bay results in which the two most common combinations are in fact reversed. Six combinations referred to by Tiews (1957) were not encountered by the author and five combinations present in the Conception Bay results were not present in the North Sea results.

Although this comparison reveals considerable disparity between the North Sea and Conception Bay results, the small number of bluefin analysed limits any meaningful taxonomic conclusions, particularly as consideration of other indices strongly suggests a single Atlantic species. However, further data of this nature may provide a distinction at the racial or sub-racial level.

Table 5 — Frequency of Combination of Gill Rakers on the Lower and Upper Limb of the First Gill Arch in 232 North Sea Bluefin (Tiews, 1957) and 150 Conception Bay Bluefin

Combination No.	Lower Limb No.	Upper Limb No.	Sum	Left Side (%) North Sea	Left Side (%) C. Bay	Right Side (%) North Sea	Right Side (%) C. Bay
1	25	13	38	18.1	21.3	16.9	18.0
2	26	13	39	16.0	19.3	16.5	25.3
3	26	14	40	15.4	11.3	14.2	8.7
4	25	14	39	10.7	7.3	12.4	4.0
5	24	13	37	7.8	2.7	7.8	3.0
6	27	14	41	5.6	10.0	6.9	4.7
7	25	12	37	3.9	7.3	5.2	10.7
8	27	13	40	3.8	3.3	5.5	6.0
9	24	12	36	3.6	1.3	0.9	2.0
10	24	14	38	3.0	0.0	3.8	0.0
11	26	12	38	3.0	6.7	2.2	7.3
12	23	13	36	2.2	0.7	0.9	0.0
13	26	15	41	1.3	0.0	1.3	0.0
14	27	15	42	1.3	0.7	1.7	0.6
15	25	11	36	0.9	0.7	0.0	1.3
16	25	15	40	0.9	0.7	0.9	0.6
17	27	12	39	0.9	2.7	0.4	3.0
18	22	13	35	0.4	0.0	0.0	0.0
19	23	12	35	0.4	0.0	0.4	0.0
20	27	11	38	0.4	0.7	0.0	0.0
21	28	13	41	0.4	0.7	0.4	0.0
22	24	11	35	0.0	0.7	0.9	0.0
23	24	15	39	0.0	0.0	0.4	0.0
24	27	16	43	0.0	0.0	0.4	0.0
25	23	11	34	0.0	0.7	0.0	0.0
26	26	11	37	0.0	0.7	0.0	1.3
27	28	14	42	0.0	0.7	0.0	1.3
28	29	13	42	0.0	0.0	0.0	0.6
29	29	14	43	0.0	0.0	0.0	0.6

Nomenclature

Sintesis and Bellon (1954) and Rosa (1950) provided the following list of valid scientific synonyms for *Thunnus thynnus* (Linnaeus), 1758:

1.	Zunnos Aristoteles	
2.	Orcynos Oppianos	
3.	Melandrys Ateneo	
4.	*Scomber pinnulis* Artech	1738
5.	*Scomber thynnus* Linnaeus (original description)	1758
6.	*Thynnus thynnus* Cuvier	1817
7.	*Thynnus mediterraneus* Risso	1826
8.	*Thynnus vulgaris* Cuvier and Valenciennes	1831
9.	*Thunnus brachypterus* Cuvier and Valenciennes	1831
10.	*Thunnus brevipinnis* (?) Cuvier and Valenciennes	1831
11.	*Thynnus coretta* Cuvier and Valenciennes	1831
12.	*Thunnus vulgaris* South	1845
13.	*Thynnus brachypterus* Rosenhauer	1856
14.	*Thynnus alalonga* Machado	1857
15.	*Orcynus thynnus* Lutken	1880
16.	*Orcynus thynnus* Jordan and Gilbert	1882
17.	*Albacora thynnus* Dressler and Fester	1889
18.	*Thunnus thynnus* Jordan and Evermann	1896
19.	*Thunnus coretta* Jordan and Evermann	1926
20.	*Thunnus saliens* (?) Jordan and Evermann	1926
21.	*Thunnus subulatus* Jordan and Evermann	1926
22.	*Thunnus (T.) thynnus* Fraser-Brunner	1950

In addition, *T. thynnus* (L.) has the following English language standard common names:

1. Bluefin tuna
2. Tunny

The species is also known by a number of English vernacular names (Rosa, 1950):

1. Bluefin tuna
2. Horse mackerel
3. Bluefin tunny
4. Tuna
5. Great albacore
6. Leaping tuna
7. Giant tuna
8. Great tuna
9. Common tunny
10. Short-finned tuna

SECTION III

DISTRIBUTION AND MOVEMENT

Horizontal Distribution

The distribution of the bluefin tuna is cosmopolitan in sub-tropical and temperate water, extending into the tropics in winter and as far as the Arctic circle in summer (Mather III, 1962d). In the western Atlantic *T. thynnus thynnus* is found from southern Labrador, along the American seaboard, to Brazil and Argentina in the south; i.e. approximately from 30 degrees S. to 55 degrees N. In the eastern Atlantic this species is found in Icelandic waters (Leim and Scott, 1966) and from the northern coast of the U.S.S.R. (Murmansk) along the European coast, throughout the Mediterranean and the Black Sea and south to Cape Town; i.e. approximately from 30 degrees S. to 70 degrees N. (Rosa, 1950; McKenzie, 1965). Bluefin reported in the tropical and subtropical mid-Atlantic (McKenzie, 1965), may contribute a third Atlantic population or belong to the western or eastern Atlantic stocks (Figure 4).

Leim and Scott (1966:292) describe the Canadian distribution of the bluefin:

> "The most northerly record is from Hamilton Inlet, Labrador, (Backus, 1957). It is reported more frequently from Dildo, Trinity Bay, Newfoundland; also taken off the east coast of the Avalon Peninsula (Anon., 1932). It occurs sparingly in the Gulf of St. Lawrence at Anticosti (Schmitt, 1904); Bonne Bay, Newfoundland (Bigelow and Schroeder, 1953); at Gaspé and Chaleur Bay (Cox, 1896; Stafford, 1912); in the outer estuary of the Miramichi (McKenzie, 1959); and at Malpeque Bay, P.E.I.

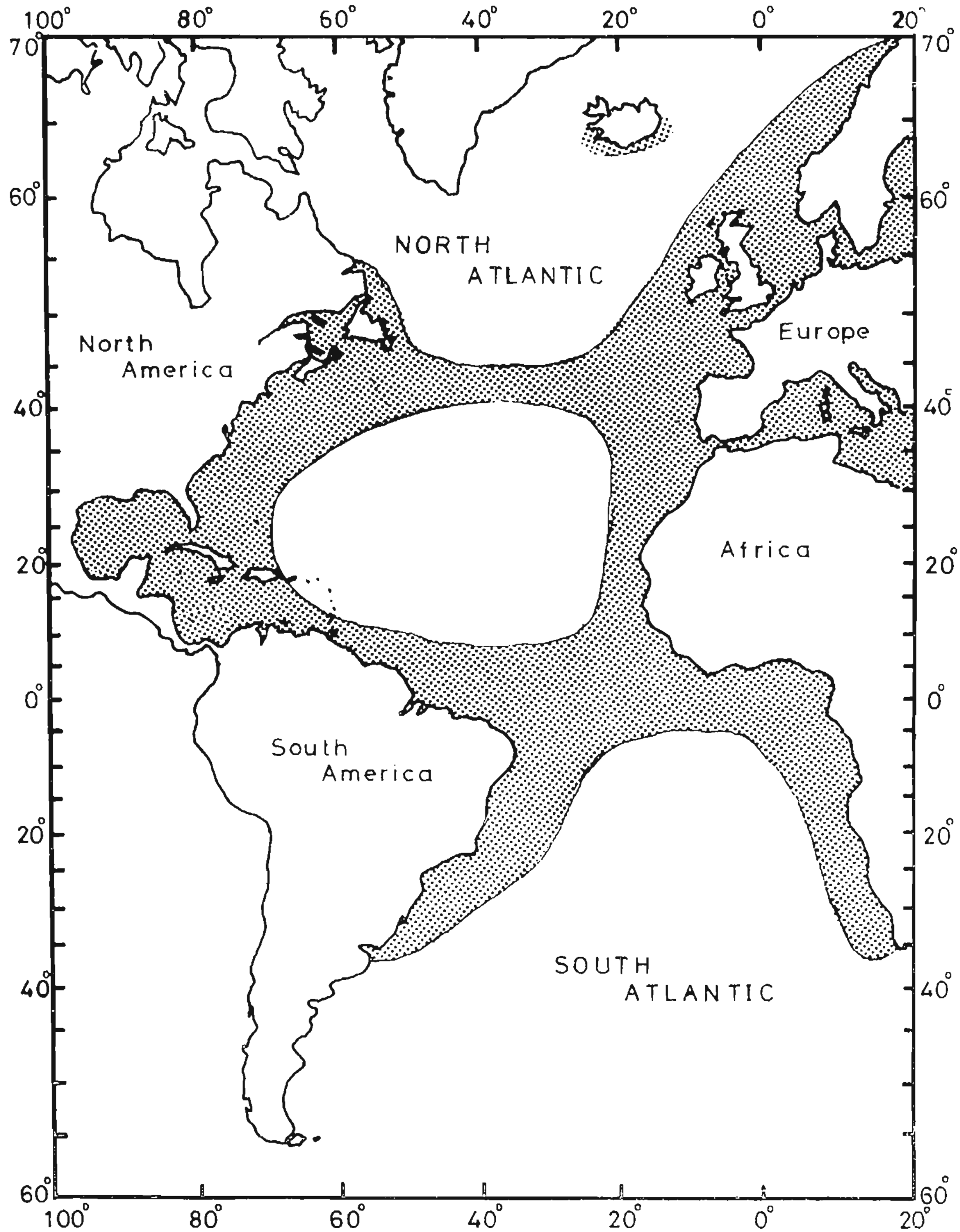


FIGURE 4

THE APPROXIMATE LIMITS OF BLUEFIN DISTRIBUTION
IN THE ATLANTIC OCEAN

(Stafford, 1912). Reported from Cape Breton and at Canso, N.S. (Cornish, 1907); it occurs more frequently in St. Margaret's Bay, N.S., and along the shores from Liverpool to Yarmouth, N.S. Occasionally in the Bay of Fundy, usually on the Nova Scotian side; infrequently in Passamaquoddy Bay (Huntsman, 1922); found at Grand Manan (Scattergood, 1952)."

According to Williamson (1962), there are no reports of bluefin being sighted in offshore Newfoundland waters or on the banks.

Vertical Distribution

The vertical movement of the bluefin is probably related to temperature considerations, food availability and perhaps light (Bigelow and Schroeder, 1953). Many more observations have been made on the vertical distribution of the eastern Atlantic bluefin because of their long established commercial importance, particularly in the Mediterranean. Pavesi (1889) considered the bluefin to be an abyssal dweller in the winter and a surface dweller in the spring (when spawning). Roule (1924) classified the tuna as bathpelagic. In Turkish waters, bluefin are reported at depths between 24-45 metres (Iyigüngör, 1957), and in Mediterranean madragues (traps) at depths of 10-15 metres (Arena, 1959). During their northern feeding migration bluefin are caught by North Sea hook-and-line fishermen at depths of 20-25 metres (Tiews, 1957). According to Tiews, bluefin are usually above the thermocline, although sometimes they go below when feeding on bottom-living fish. Norwegian purse seiners only operate when bluefin have been reported at the surface (Hamre, 1961). Investigations on the depth range of tagged bluefin based on pressure marks on the Lea hydrostatic fish tag, indicate that the bluefin stock feeding off the Norwegian coast during the summer does not go below 250 metres, whereas the stock seems to have a deeper range during the winter (Hamre, 1965).

On the basis of commercial fishing results for the western Atlantic and Pacific oceans, the vertical range of bluefin is considered to be at least from 0-150 metres (Blackburn, 1965) or 0-200 metres (McKenzie, 1965).

Within the western Atlantic population there appears to be a seasonal variation in the vertical distribution; from 30-200 metres in the winter (except for small individuals) and from 0-200 metres in the spring and summer. In the Gulf of Maine, during the bluefin's northerly feeding migration, the shallow summer thermocline (17-30 metres) probably restricts the bluefin's vertical range (Murray, 1953), but farther offshore the tuna are usually at depths of 80-90 metres (Crane, 1936). In the Havana region of the warm Gulf Stream, "giants" are caught by longlines at depths of 100-200 metres (Rivas, 1953).

Tiews (1962) suggests the possibility of a correlation between the vertical depth distribution of the bluefin and the range of light intensity to which they seem to react (70-450 foot candles); i.e. under maximum natural illumination (summer, noon), 70-450 foot candles corresponds to a depth of approximately 90-140 metres in clearest ocean water and 45-75 metres in average ocean water.

Vertical distribution of all species of tuna larvae in the tropical Pacific appears to be limited to surface waters above 50 metres (Matsumoto, 1958). However, Strasburg (1960) did obtain yellowfin and skipjack larvae between 70-130 metres although in far less quantities than in the upper layers (0-60 metres). The results of Nakamura and Matsumoto (1966) working on the same species were inconclusive, but did not conflict with those of Strasburg (1960). The western Atlantic bluefin larvae are probably distributed similarly, i.e. the majority being in the upper 50 metres of water.

Patterns of Migration

The information contained in this subsection was compiled from the observations and research of the following authors: Crane, 1936; Farrington, 1949; Bigelow and Schroeder, 1953; Rivas, 1954(a), 1954(b) and 1955; Migdalski, 1958; Mather, 1962(b); Squire, 1962(a); Tiews, 1962; Williamson, 1962; McKenzie, 1963; and Tibbo, 1967. The author has made his own deductions where appropriate.

The bluefin changes its habitat seasonally and at various stages in its life cycle. The western Atlantic population can conveniently be divided into 3 or 4 (if "very small" are being considered) basic size categories, each of which has a distinct distributional pattern (Figure 5). However, these zones may overlap, particularly during the summer when the bluefin

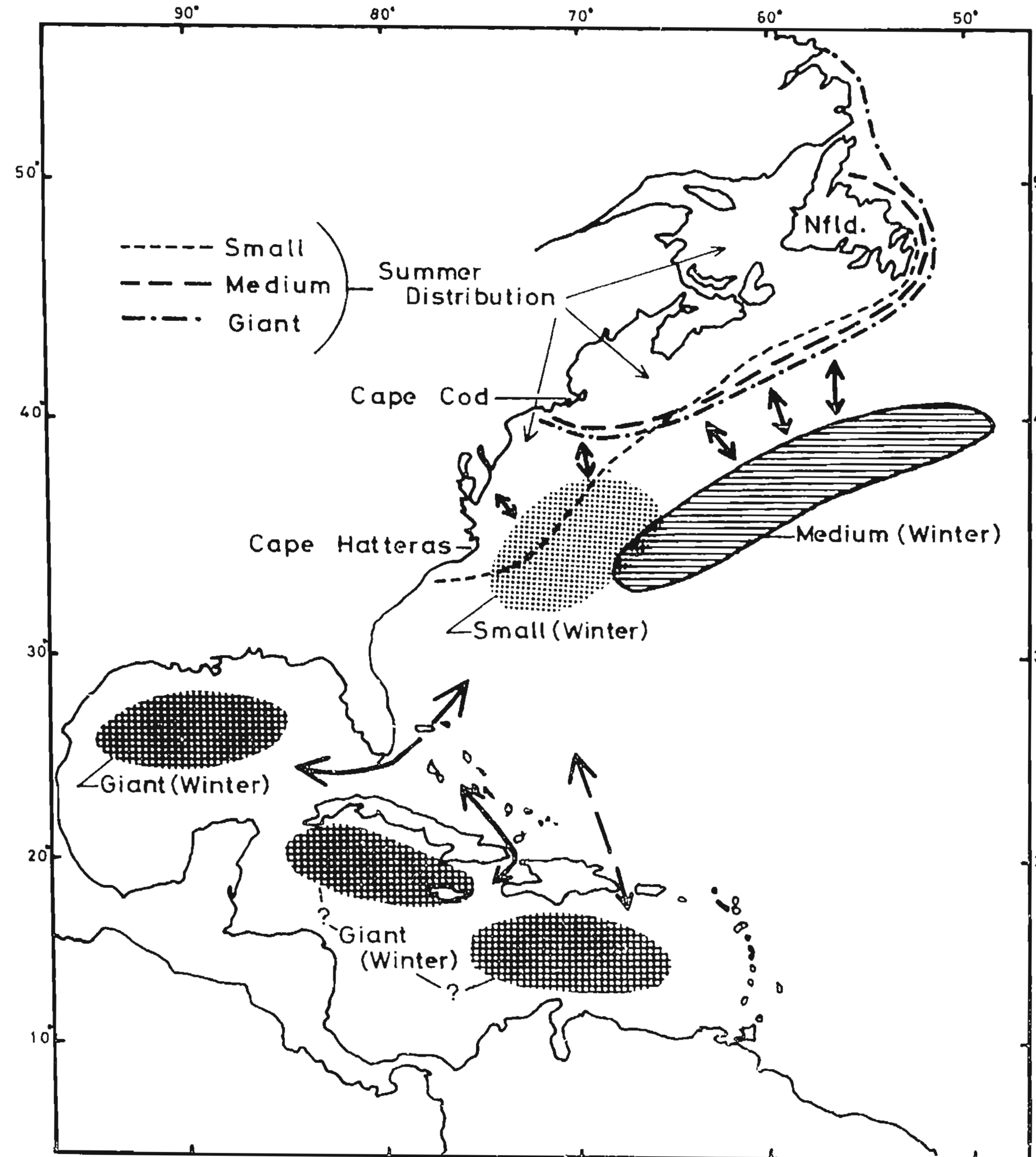


FIGURE 5

THE APPROXIMATE DISTRIBUTION AND MIGRATION ROUTES OF BLUEFIN IN THE WESTERN NORTH ATLANTIC, ACCORDING TO AGE AND SEASON population is most concentrated. The size categories are as follows:

1. "Very Small" - less than 5 pounds, less than one year old
2. "Small" - 5-69 pounds, 1-4 years old
3. "Medium" - 70-269 pounds, 4-9 years old
4. "Giant" or "Large" - 270 pounds and over, 9 years old and older

The distributional pattern can also be divided in relation to season (Figure 5).

1. January to April - Wintering period (lowest water temperature). Bluefin are absent from the shelf north of Cape Hatteras in this period.
2. May to June - Migration period (to north or west).
3. July to October - Summer inshore feeding period (highest water temperature). Southern and oceanic areas virtually devoid of bluefin over 5 pounds.
4. November to December - Migration period (to south or east).

"VERY SMALL": In general, bluefin appear to spawn over wide areas and for a considerable period of time in the western Atlantic. In spite of this, little is known about the "very small" tuna. Young bluefin (2 months old and approximately 25 cm in fork length) observed in the Straits of Florida are probably the result of May spawning in the same area, as they tend to remain in the vicinity of the spawning grounds at least for two months according to European information. They remain in the Straits of Florida until early in August and are then absent until November, which suggests a migration to northern waters and a return in the autumn.

Juveniles (less than 8 cm long) have been collected near the edge of the Continental Shelf off the middle Atlantic states late in July (progeny of "medium" spawners?). They probably move offshore into the warm Gulf Stream and Sargasso Sea or migrate south in the fall. Unlike the "small" and "medium", the "very small" (and "giants") are often found south of 36 degrees N. during the winter period.

"SMALL": The "small" bluefin are normally the second size category to arrive in northern waters (after the "giants"), and during the season of maximum water temperature are most abundant in inshore waters from Cape Cod to the southwestward, but may extend as far north as Newfoundland. In the wintering period they are found inshore as far south as Cape Hatteras or 36 degrees N. in offshore waters, but as with all size categories, the eastern margin of their winter habitat has not been accurately defined.

"MEDIUM": In June, "medium" bluefin in a ripe or nearly ripe condition have been caught along the edge of the Shelf and toward the Gulf Stream off southern New England and the banks. Hook rates indicate that the medium bluefin school-up on the northern edge of the Gulf Stream, which is part of their wintering area, prior to migrating to the inshore feeding grounds (May-June). The "medium" bluefin are normally the last to arrive (July-August) and the last to leave (October-December) the northern feeding grounds. In company with the "giants" they are mainly distributed from eastern Long Island to the northeast, including Nova Scotian, Newfoundland and Labrador coastal waters. Heavy catches are taken in the South Channel area, 40-50 miles east of Chatham, Massachusetts, in late summer and early fall. It is believed that bluefin use this route to enter and leave the Gulf of Maine at the beginning and end of the summer feeding period. During November and December the "medium" (and a few "small") again appear to school-up, but at this time along the 1000 fathom contour off southern New England, Long Island and New Jersey. This concentration is in preparation for the migration to their wintering area which extends, as in the case of "small" bluefin, as far south as Cape Hatteras or 36 degrees N. in offshore waters.

"GIANTS": From May to early June schools of "giants" migrate through the Straits of Florida in a northeast direction. During this period they are rarely observed to be "pushing" or "milling", though occasionally "smashing" (see Page 50). They travel just below the surface at an average speed of 3.5-4 knots and appear to remain east of the Gulf Stream to a point north of Cape Hatteras (Figure 6). Time of day does not appear to have any effect on the fish movements in the Florida Strait/Bahama region, but fairly strong northerly winds cause them to move more slowly (3 knots). "Giant" tuna feed little or not at all during the exhausting spawning season, hence it is unlikely that they would be capable of increasing their migratory speed in response to the hunger drive, and according to the evidence they do not.

"Giant" bluefin arrive in the Cat Cay area in the middle of

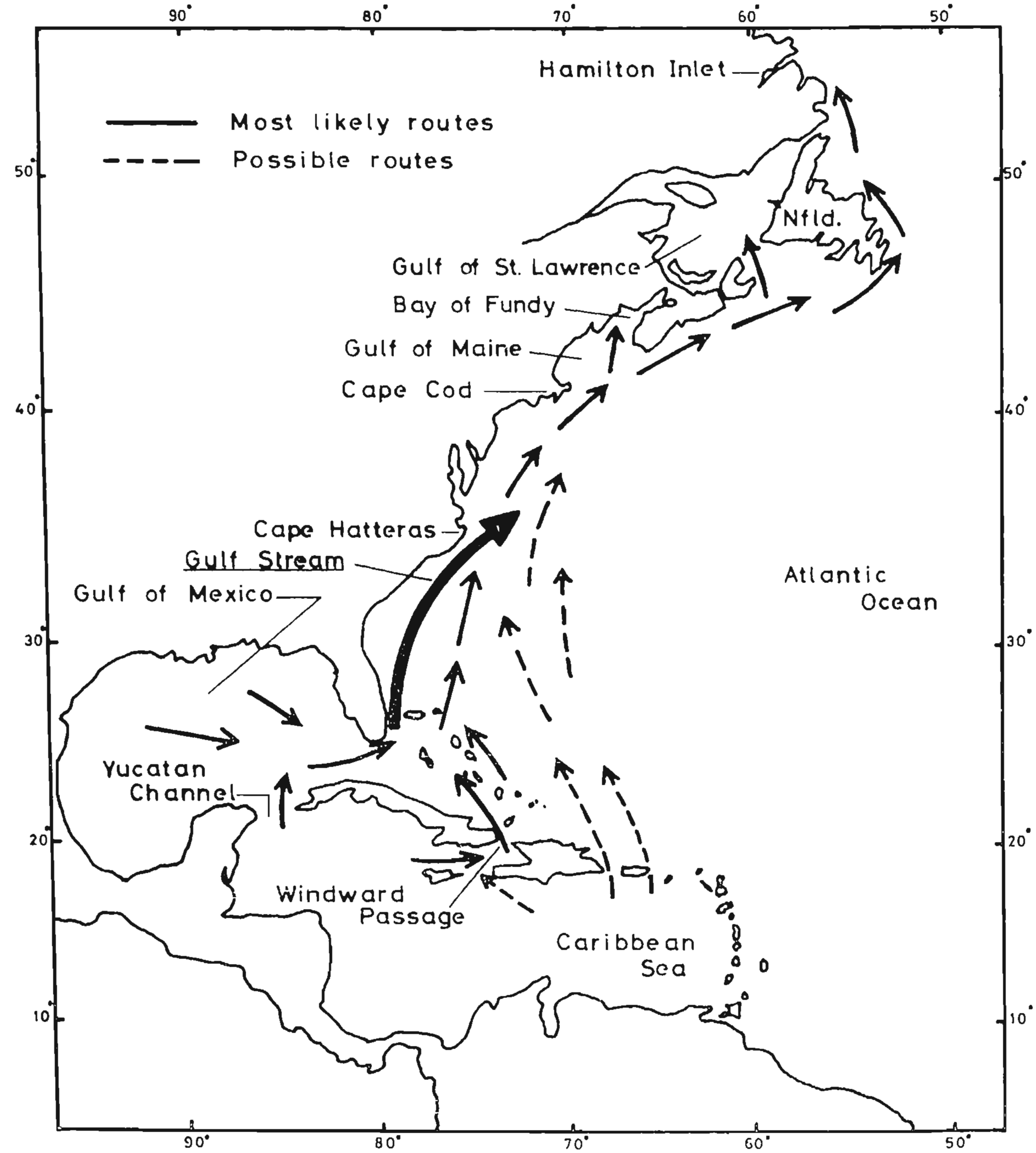


FIGURE 6

THE PRESUMED MIGRATORY ROUTES OF GIANT BLUEFIN IN THE WESTERN NORTH ATLANTIC

May and approximately two weeks later are the first to arrive in Cape Cod inshore waters, a distance of 1,150 miles. The speed of migration must, therefore, be similar to that observed in the Straits of Florida, 84 miles per day (3.5 knots). "Giant" bluefin have never been captured or seen between the Straits of Florida and northern waters. This may be attributed to lack of exploration or to the fact that the bluefin are travelling at depth, a habit of tuna when in deep water. They gradually migrate north from Cape Cod into the Gulf of Maine (rarely into the Bay of Fundy), along the Nova Scotian Shelf and into the Gulf of St. Lawrence. In July they reach Newfoundland waters approximately 4-6 weeks after their arrival in Cape Cod. Assuming a minimum distance from Cape Cod to Conception Bay of 1000 miles, the speed of migration appears to be reduced to a foraging pace (20-40 miles per day).

During this feeding period in the North West Atlantic, "giant" bluefin tend to concentrate (and provide good fishing) in the "Mud-Hole" of New York harbour, the Rhode Island-Block Island area, Cape Cod Bay, the northern edge of Stellwagen Bank, Ipswick and Cascot Bays, Trinity Ledge, the Tusket Islands (Wedgeport), St. Margaret's Bay, Conception Bay, Bonavista Bay and Notre Dame Bay. During the period of minimum water temperature (January to April), the "giants" may be found over practically all of the bluefin wintering area which probably is delimited by the edge of the Continental Shelf in the west and a postulated eastern border running from the southeastern corner of the Grand Bank to Puerto Rico and including the Gulf of Mexico and the northern Caribbean. Concentrations of the "giants" have been found in the northern Gulf of Mexico and the Windward Passage. The spring migration through the Straits of Florida is probably composed of these bluefin, with the Windward Passage fish arriving in the Straits via the Old Bahama and Santaren Channels (Figure 7, Page 56).

The eastern Atlantic pattern is basically similar and differs only in dates and sizes of fish landed in certain parts of the cycle, which is further evidence for a resident bluefin population in both the eastern and western Atlantic (Mather III, 1962b).

Tagging

The tagging of fish, and the subsequent recovery of tagged fish, is the only sure way of proving migratory routes. It also provides accurate growth data, verification of ageing techniques, and is the quickest and most positive way of identifying the stocks and estimating the effects of the fishing effort on them.

Bluefin were first tagged (unsuccessfully) by Sella (1929) in the eastern Atlantic. He also assembled considerable information on movements of the tuna by studying the origin of hooks found attached to some of the bluefin, i.e. hooks of a certain design were known to be peculiar to specific areas of the European coast, hence indicating previous location of the captured bluefin and its probable migration route to the point of recapture. Russell (1934) similarly worked on the origin of hooks. The Norwegian

Institute of Marine Research carried out the first successful European tagging programme in 1958.

Westman and Neville (1942) were the first to successfully tag bluefin in the western Atlantic. They tagged 23 fish near Long Island, New York, two of which were recovered in the same area two months later.

Experiments in marking tunas have been in progress at the Woods Hole Oceanographic Institution since 1951. Small scale experiments with marked hooks and opercular tags carried out from 1951-1953 were unsuccessful (Mather III, 1960). Type G dorsal loop tags (Wilson, 1953) were used in New England waters in 1954. Two reports, including one return, were obtained. In the same year the Cooperative Game Fish Tagging Program was introduced under the direction of F.J. Mather III. To facilitate the tagging of large tuna, particularly by non-scientific personnel, F.J. Mather III, designed the first dart and streamer tag, type A (Mather III, 1960). In subsequent years "dart tags" have been used almost exclusively and have undergone various modifications: A type B dart tag, made of mass produced components reduced the cost. It also incorporated a smaller head to reduce the possibility of injuring small fish. A type C dart tag was introduced in 1958. It utilized the same head but had a more conspicuous yellow streamer. Because of reports of higher recovery rates obtained by plastic-headed dart tags (Floy Tag and Manufacturing Company, Seattle, Washington) used in the Pacific (Yamashita and

Waldron, 1958) and in the eastern Atlantic (Hamre, 1959), they were introduced in the western Atlantic in 1959 as the type D dart tag, in conjunction with the successful type C yellow streamers. A type E dart tag with a large double-barbed nylon dart and thicker streamer was introduced in 1960 for use on large fish, over 150 pounds (Mather III, 1963).

The number of bluefin tagged and returned during the first ten years of the Cooperative Game Fish Tagging Program's existence is indicated in Table 6.

Table 6 The Number of Tagged (Cooperative Game Fish Tagging Program) and Returned Bluefin in the Years 1954-1964

Year	No. Tagged	No. Returned
1954	190	1
1955	229	0
1956	99	0
1957	38	0
1958	38	0
1959	149	4
1960	232	0
1961	186	2
1962	129	6
1963	222	19
1964	571	104

Results

1. Trans-Atlantic Migrations

Two small bluefin tagged off Martha's Vineyard, Massachusetts, in 1954 and recaptured in the Bay of Biscay five years later provided the first proof of trans-Atlantic migrations (Mather III, 1960), although this migration was anticipated by Sella (1931).

Two "giant" bluefin released in the spring of 1961 off Cat Cay, Bahamas, were recaptured less than four months later off Bergen, Norway. They had thus travelled at least 4,200 nautical miles at an average speed of 35 nautical miles per day, probably assisted by the North Atlantic Drift and the Gulf Stream. They were extremely slender on recapture in comparison with the well-fed bluefin normally taken in the autumn. These "long-tailed bluefin" are apparently not uncommon in Norwegian late-season catches (Mather III, 1962c).

In contrast, two bluefin tagged in June 1960 off Cat Cay, Bahamas, were recaptured and were in a well-fed condition two years later off Norway (Bergen and Narvik) indicating that they had participated in the summer feeding in European waters and therefore had crossed the Atlantic in an earlier season.

Another bluefin tagged in June 1962 off Cat Cay, Bahamas, was recaptured off Bergen a mere 50 days later having travelled at an average speed of more than 80 nautical miles per day. Thus, of the 77 tuna tagged off Cat Cay between 1960-1962, five trans-Atlantic recaptures were reported (more than 6%), indicating that a large fraction of the "giant" bluefin passing the Bahamas in those years migrated to Norwegian waters, rather than to the northwestern Atlantic coastal waters (Mather III, Cooperative Game Fish Tagging Program, Nov. 9, 1962). The reverse countercurrent migration from the eastern to the western Atlantic has not yet been demonstrated but in the North Pacific where the current patterns are similar to those of the North Atlantic such a migration has been reported: Three bluefin tagged off California were recaptured in Japanese waters (Orange and Fink, 1963; Anon., 1964). Much more tagging will be required to determine the degree of eastern and western movement.

2. Western Atlantic Migrations

In general the number of returns is still too small to be of conclusive statistical significance (Mather III, Cooperative Game Fish Tagging Program, Dec., 1963). However, tag returns in conjunction with fishing results and exploratory surveys (reports of the M/V Delaware Cruises, Comm. Fish. Rev., 19(5): 28-29, 19(8): 27-29, 1957; 20(7): 35-36, 1958; 21(4): 46-47; 21(7): 40-41, 1959) have indicated the probable location of the various size groups at different times of the year (see previous sub-section). The need to tag a larger sample in future years is obvious.

3. Fishing Mortality

An overall 18% tag return in 1964 confirmed the very high fishing mortality suggested by the 1963 results. This drastic increase is due almost entirely to the growth of the seine fishery. The concentration of the entire northwestern Atlantic stock on the continental shelf in summer makes them highly vulnerable to this technique of exploitation. As many as seven age groups are fished by seiners, a fact which, in conjunction with the high rate of bluefin attrition indicated by tag returns, indicates that the northwestern Atlantic bluefin resource cannot stand unrestricted exploitation (Mather III, Cooperative Game Fish Tagging Program, July, 1965).

4. Growth

Reliable size information is scarce because of the difficulty of obtaining accurate data at both the time of tagging and at the time of recapture. Length and weight data can only be estimated when taggingbluefin caught by rod and reel sport fishermen, because of the difficulties of dealing with such large, powerful fish.

A total of 177 bluefin have been tagged and released in Conception Bay, Newfoundland, the majority by W.K. Carpenter of Fort Lauderdale, Florida, President of the International Game Fish Association. No returns have been reported (Table 7).

Table 7 — The Number of Bluefin Tagged in Conception Bay in the Years 1962-1966

Year	No. Tagged
1962	3
1963	3
1964	62
1965	60
1966	49
Total:	177

Speed and Endurance

A fish's swimming style is a function both of its shape and of its inner structural plan.

> "In free-swimming species the body approximates the theoretically perfect streamlined form in which the greatest cross section is located close to thirty-six percent of the length back from the anterior tip (the entering wedge), and the contours sweep back gently in the tail race." (Lagler, Bardach and Miller, 1962:52).

The bluefin, conforming to these specifications, is one of the swiftest and widest ranging fish in the sea, being hydrodynamically equipped for speed and endurance. According to Kawada, Tawara and Yoshimuta (1958), the bluefin's speed varies from one to ten knots but is normally about five knots. However, this species is capable of bursts of great speed. Harlan Major is reported to have clocked a fifty pound bluefin at 44 knots, using a special speed-measuring device attached to a roller on his rod (Anon., 1967). Frictional resistance is reduced by the streamlined contours of the body, the smooth skin surface and its construction, i.e. oily tissue sandwiched between layers of connective tissue which possibly act as a "turbulence damper."

The body muscles comprise nearly three-quarters of the weight of the bluefin and are arranged so as to transmit most of their pull to the slim caudal peduncle and hence to the inflexible, lunate tail-fin which provides virtually all of the thrust, i.e. there are no waves of flexure moving down the body as in many fishes. The high aspect ratio (fin span: fin area) of the tail-fin reduces drag and is partly responsible for massive thrust potential (Marshall, 1965). In addition, large articulating processes on the closely but not rigidly interlocked vertebrae are thought to be associated with the bluefin's speed (Yapp, 1965).

The endurance of the bluefin is associated not only with its heavily muscled body and its shape but also with its ability to remove and conserve energy-releasing oxygen from its environment. A litre of well aerated water contains no more than 10 cc. of oxygen; to compensate for this relative shortage of oxygen, the bluefin has a sophisticated respiratory system. The most important adaptations are:

1. The mouth and gill chambers remain open during the relatively long pauses between successive inspirations, hence maintaining a continuous flow of water over the gills and thus enabling a more thorough removal of dissolved oxygen (Marshall, 1965). If bluefin are prevented from swimming freely they die from lack of oxygen.

2. The large surface area of the gills promotes gaseous exchange (Marshall, 1965).

3. A large powerful heart weighing relatively nearly twice as much as that of the Atlantic marlin (Krummholz, 1959), facilitates gaseous exchange and distribution.

4. The high percentage of red muscle fibres in the myotomes contain the oxygen retaining pigment myoglobin (Marshall, 1965).

5. The provision of a swim bladder and buoyant oils reduces the amount of energy which would otherwise be required to counter the bluefin's tendency to sink (Marshall, 1965).

The above phenomena are all associated with the ability of a 15-year-old bluefin to travel an estimated one million miles since its birth. They also help to explain the large sizes attained by bluefin, as the maximum growth of fishes is likely to be limited more by the oxygen-catching capacities of their gills than by surface area of alimentary tract that is available for the absorption of digested food stuffs (Fry, 1957).

Schooling

According to Breder (1959), schooling is characterised by a group (school) of fish swimming together on parallel courses with a relatively fixed distance between each individual and with negligible independence of action. The distance between individuals is evidently maintained by a process of attraction and repulsion, the attraction mediated by vision, and the repulsion by water movement, sound, odour and taste in addition to vision (Breder, 1954). Marshall (1965) suggests that the lateral line organs and the production of swimming disturbances of similar frequency by like-sized fishes may also aid the schooling process.

As will be apparent from the description of their migratory habits, the bluefin is a pelagic marine schooling fish, as are all scombrids other than the wahoo (Magnuson, 1962), and one of the greatest oceanic wanderers. The number of these allelomemetic creatures in a school tends to vary inversely with the size of the individuals (Scaccini, 1959; Crane, 1936; Arena, 1959; Mather III, 1962b; Bigelow and Schroeder, 1953; Tibbo, 1967). Schools of large or "giant" bluefin (270 pounds and over, 9 years old or older) rarely exceed 100 individuals and usually number 6 to 10 fish. In contrast, schools of "medium" bluefin (70-269 pounds, 4-9 years old) may number 1000 or more individuals and "small" bluefin (5-69 pounds, 1-4 years old) may include several thousand members (Mather III, 1962b; Bigelow and Schroeder, 1953; Tibbo, 1967). The very large fish are usually solitary (Crane, 1936). The integrity of size of a school's members may be related to swimming speed (Brock, 1954), i.e. small fishes will not be able to keep pace with larger and faster moving individuals. Tiews (1962) suggests that the combined influence of temperature and salinity (density) is responsible for this segregation.

Schools of different (inter-school) but uniform (intra-school) sized fish may live together (Scaccini, 1959) and, if an individual school is composed of mixed sizes, the smaller fish frequently swim above the larger ones. These stratified schools, particularly relevant to the medium sized and the smaller bluefin, may extend over a much greater area than is indicated on the surface (Mather III, 1962b). Tunas of similar size but of different species may school together, e.g. bluefin and skipjack (Katsuwonus pelamis) in northern waters or bluefin and blackfin (Thunnus atlanticus) in southern waters (Mather III, 1962b).

Schools of surface swimming bluefin in the northwestern Atlantic exhibit three common behaviour patterns (Murray, 1955; Mather III, 1962b; McKenzie, 1965; Tibbo, 1967).

1. PUSHING: This occurs when a school is swimming in the same direction (3-8 knots) and near the surface (often finning, i.e. showing upper caudal lobe, second dorsal fin and occasionally the first dorsal if a directional change is involved) and creating a frontal wave (See Appendix 2).

2. MILLING (Breezing): The school remains almost stationary but the individual fish moves at random causing a surface ripple.

3. SMASHING: This pattern, which lasts 30 seconds or more, occurs when the fish are feeding ravenously and creating a great deal of turbulence.

Surface swimming bluefin are noted for their habit of jumping, either singly or in schools, and as observed in Conception Bay may do so whether pushing, milling or smashing. They normally re-enter the water head first but larger tuna may belly-flop (Mather III, 1962b; Bigelow and Schroeder, 1953).

Tuna probably disperse in absolute darkness although moonlight can be expected to provide enough light for schooling (Magnuson, 1962).

The advantages of schooling appear to be fourfold:

1. Propagation of the species, i.e. a school is a potential stock of breeding fish even if it never meets other schools of its own state of maturity.

2. Protection against predation. Brock and Riffenburgh (1960:317) treated the problem mathematically and summarised their findings as follows:

> "..... the frequency of detection of prey by a predator is an inverse function of the number of schooled or grouped prey. The quantity of fish that any predator can consume on any single encounter with a school of prey has some average limit, and once school size exceeds this quantity, further increases in school size reduce the frequency of predator-prey encounters without necessarily changing the quantity of prey consumed on the occasion of each encounter, which in turn may reduce the rate of consumption of a prey species by a predator."

It should be noted that although the bluefin is considered a predatory species, for much of its life span it is a prey species also. In Newfoundland waters bluefin are preyed upon by killer whales (Orcinus orca). Other predators include a cetacean called "Blackfish", (Mather, 1962b), the swordfish (Xiphias gladius) and the toothed whales (Phocaena communis and Globicephalus melas), (Frade and Vilela, 1960). When bluefin attain sizes sufficient to render them largely immune to predation the schools formed are less stable than for younger and smaller fish (Brock and Riffenburgh, 1960).

3. Sette (1950) suggested that schooling of predators may also assist in the capture of prey. Olson (1964), by reference to the Koopman Theory of Search (Koopman, 1956), showed this to be due to the increase in swept path achieved by a school. Thus in the sea, where sight ranges are short, schooling is advantageous to both prey and predator.

4. Groups of fishes (schools) appear to feed more readily, learn more quickly and possess a better memory than isolated individuals of the same species (Marshall, 1965).

SECTION IV

REPRODUCTION AND POPULATION STRUCTURE

Spawning and Fecundity

The sex of the bluefin has only been determined successfully by gonadectomy or, in the case of young fish, by histological examination (Vilela, 1960). Depending on environmental conditions and food supply, the eastern Atlantic bluefin reaches maturity at the age of 2-4 years (Sella, 1929; Le Gall, 1954: Frade and Vilela, 1960) and the western Atlantic fish at the age of 4-5 years (60-90 pounds), (Williamson, 1962).

Bluefin are considered to spawn fractionally during one period of the year (Sanzo, 1910; Frade and Manacas, 1933; Vilela, 1960; Rivas, 1954b), although they have rarely been observed mating. It is believed that individual pairs roll around and touch their ventral surfaces, at which point the eggs and milt are released (Heldt, 1932; Sella, 1911). This operation is considered to occur at depths of 8-10 metres in shallow or deep water (Heldt, 1932). A report of the courtship and mating of another tuna, the Pacific bonito, is in basic agreement with this description (Manar, 1965:11):

> "After a brief courtship, the male and female leave the school. The female swims in a tight circle as she extrudes the eggs. The male follows her exuding milt. The process is brief, lasting 1 or 2 minutes."

Bluefin fecundity has been little studied and the results of these few studies are conflicting. Frade (1950) reports an eastern Atlantic bluefin, approximately six years old, bearing a calculated total of 9,360,000 eggs. Williamson (1962) states that a 600 pound tuna (approximately 13 years old) will produce about 1,000,000 eggs and according to McKenzie (1965), large females may produce up to 1,000,000 eggs. The externally fertilized eggs of the western Atlantic bluefin are spherical and translucent and are covered by a thin smooth membrane. Their diameter ranges from 0.7 - 1.1 mm in contrast to 1.0 - 1.12 mm for Mediterranean-bluefin eggs, a phenomenon which is explained by the higher temperature (6 degrees - 8 degrees C) of the western Atlantic sqawning grounds (Rivas, 1954a).

According to work carried out in the Mediterranean (the breeding ground of the eastern Atlantic population), the bluefin developes a high degree of sensitivity to salinity and temperature during the reproductive season. The eastern and western Atlantic populations are probably analogous in this respect, although the preferred temperature (and salinity?) values appear to differ. Breeding fish seek the warmer and most saline waters (Roule, 1924) and spawn at the time of maximal increase in temperature (Sella, 1931). In addition, the surface temperature and salinity requirements of the small tuna (23 degrees - 25 degrees C and 38.2 - 38.5‰) differ from those of large tuna (18 degrees - 22 degrees C and 37.2 - 37.8‰), (Sella, 1931), with an overall average temperature of about 20 degrees C (Roule, 1924). In comparison, the surface temperature of the western Atlantic spawning grounds (Straits of Florida) range from 24.9 degrees - 29.5 degrees C (Rivas, 1954a).

Knowledge of the eastern Atlantic spawning grounds and breeding season is considerably more extensive than of the western Atlantic. Rivas (1954a:303) reports:

> "The known European bluefin spawning grounds comprise mainly the central Mediterranean (Roule, 1924) and the breeding season extends from late April through about the middle of July (Roule, 1924; Heldt, 1926; Sanzo, 1929). The ripening of the gonads begins about late April and early May in various parts of the Mediterranean (Roule, 1924). At this time, the fish school in great numbers and form shoals composed sometimes of several thousand individuals which then travel to the spawning grounds where they arrive during the last two weeks of May. Sexual maturation is now completed and the actual spawning takes place during the months of June and early July."

Possible spawning grounds and/or breeding grounds for the western Atlantic bluefin have been a subject for much speculation (Sella, 1931; Heldt, 1931; Westman and Neville, 1942; Mowbray, 1949). However, Rivas (1954a) was the first to provide evidence to indicate a spawning ground in the Straits of Florida. "Giant" tuna caught off Bimini and Cat Cay in May and June have probably spawned (according to evidence based on gonad condition) south of this region, possibly as early as April and early May (Bullis and Mather III, 1956). Spawning in the Bimini area does not appear to begin until early May nor to extend beyond the middle of June. The latter observation is based on disappearance of the adults at this time and on the growth rate of the young bluefin (Rivas, 1954a).

Krumholz (1959) provided additional evidence when he determined the sex of 7 bluefin caught between May 19-23, 1956, near

Cat Cay. All were "giants", their sizes ranging from 223.5 - 254 cm and 361 - 562 pounds. The ovaries of the two females indicated recent spawning. The testes of all the males contained mature sperm and their condition indicated that they had already spawned or were about to do so at the time of capture. Further examination of adult gonads and the analysis of the stomachs of predacious fishes (eg. Coryphaena) for juveniles, has shown the full extent of this spawning area to be from Cuba along the eastern edge of the Florida current to the western edge of the Bahamas. The most active spawning appears to occur in May, from Riding Rocks to Bimini, along the western edge of the Great Bahamas Bank (Rivas, 1954b), (See Figure 7). Only large individuals (300-700 pounds) have been observed in this spawning zone, hence mature fish below 300 pounds must spawn independently (Rivas, 1954b). Larger tuna (over 700 pounds) are thought to spawn far to the south in the warm waters of the Gulf of Mexico and Caribbean in late April to early June. The medium-sized fish (less than 300 pounds) probably spawn from late May to early July farther to the north in the warm Gulf Stream and Sargasso fringe, between Florida and New England (Mather III, 1962b; Williamson; 1962). Thus, the larger the tuna the farther south it spawns and at an earlier time in the year (McKenzie, 1965).

Larval Stages

The larvae of Thunnus species are very difficult to separate.

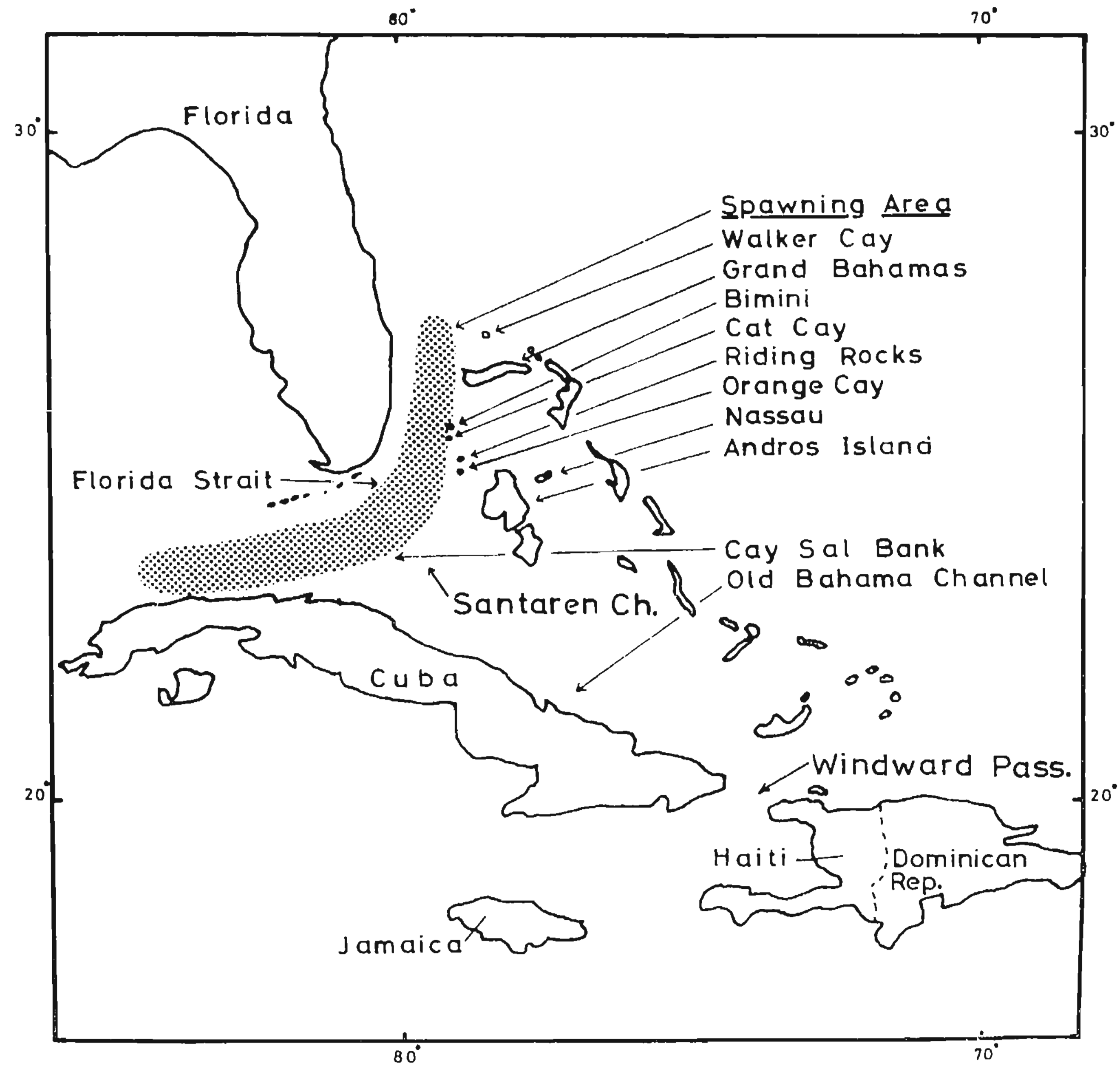


FIGURE 7

A SPAWNING AREA (STRAITS OF FLORIDA) OF WESTERN ATLANTIC BLUEFIN

They are characterised by the preopercular spinescence, the number of vertebrae (39), and the black pigmentation of the first dorsal fin (Rivas, 1951). Embryonic and juvenile life has been studied mainly in the eastern Atlantic population (Ehrenbaum, 1924; Sanzo, 1932; Dieuziede, 1951; Morovic, 1961; Scaccini, 1965; Dieuziede and Roland, 1955).

Information concerning the diet of larvae and juvenile tuna is limited to eastern Atlantic populations, in the Mediterranean (Oren, Ben-Tuvia and Gottlieb 1959):

Larvae (Less than one year old): Decapod crustaceans and euphausids (28%); amphipods (28%); fish (20%); cephalopods (18%); stomatopods (2%); heteropods (1%); tunicates (1%).

Juvenile tuna: Fish larvae (including bluefin): young clupeids e.g. *Sardinia pilchardus*.

Sex Ratio

During the Bahama bluefin tuna season, in May 1952, 1953 and 1954, the gonads of 95 individuals ranging from 199.7 - 255 cm (fork length) and from 297 - 746 pounds in weight, were examined at Cat Cay (Rivas, 1954a). The females outnumbered the males by at least 2:1.

Year	Month	Total No. Examined	Number & Percent Males	Number & Percent Females
1952	May	35	10(29%)	25(71%)
1953	May	31	8(26%)	23(74%)
1954	May	29	11(38%)	18(62%)
		95	29(31%)	66(69%)

Bullis and Mather III (1956) examined 13 bluefin from the northern Caribbean Sea, the ratio in favour of the females increased to 3:1. The fish ranged from 209 - 245 cm, with most of them near 255 cm (fork length) or about 470 pounds in weight.

Years	Month	Total No. Examined	Number & Percent Males	Females
1955	April	13	3(23%)	10(77%)

Krummholz (1959) determined the sex ratio of 7 bluefin caught near Bimini (Bahamas) between May 19 -23, 1956. Their sizes ranged from 223.5 - 254 cm (total length) and from 361 - 562 pounds.

Years	Month	Total No. Examined	Number & Percent Males	Females
1956	May	7	5(71%)	2(29%)

Because of the limited number examined the ratio in favour of the males cannot be considered significant.

However, in the northern feeding grounds, the sex ratio appears to alter radically. Crane (1936) studied 30 bluefin caught off Portland, Maine. Their sizes ranged from 104 - 246 cm (standard length) and from 65 - 800 pounds. All of the fish were males and five of the largest (700 pounds and over) had broadly distended sperm ducts and spent testes. In the other 25 bluefin the sperm ducts were slender and the testes were far from being in a breeding condition.

Year	Month	Total No. Examined	Number & Percent Males	Females
1936	July	30	30(100%)	0(0%)

Rivas (1954a) examined 9 "giant" tuna from Wedgeport, Nova

Scotia, their sizes ranging from 205.9 - 253.4 cm (fork length) and from 380 - 701 pounds. All were male.

	Year	Month	Total No. Examined	Number & Percent Male	Female
	1952	Oct. 3	9	7(78%)	0(0%)
and	1953	Aug. 7-10		2 unidentified (22%)	

The results of the sex ration determinations in the Caribbean and in the Bahamas are substantiated by the findings of European workers in the analogous region of the eastern Atlantic (the Mediterranean and Iberian Atlantic). Frade (1950) found in 1933 and 1934 that from a total of 8,988 bluefin analysed, 57% were female and 43% were male. The sex ratio of fish going to (May - June) or coming from (July - August) the central Mediterranean spawning grounds is considered to be constant and of 787 bluefin investigated from 1958 - 1960, approximately 38% were males and 62% were females (Vilela, 1960). Of a total of 1,111 bluefin caught on the Portuguese coast from 1958 - 1961, 36.9% were males and 63.1% were females (Vilela and Monteiro, 1961). Rodriguez-Roda (1960) analysed 607 tuna caught off the south Atlantic coast of Spain during the years 1956 - 1958. He found that 64.5% were female and 35.5% were male.

CONCEPTION BAY

Sex Determination

Materials and Methods

1. Gonadectomy

The author examined the gonads of 106 bluefin caught in Conception Bay from July 20 - September 19, 1966. Their sizes varied from 211 - 254 cm (fork length) and from 336 - 695 pounds. The males were readily distinguished from the females by sectioning the gonads. The spent male testis was triangular in cross section with a small duct and blood vessels running along the margin of the organ (Figure 8A). In contrast, the ovary of the spent female was round in cross section and its diameter was considerably larger than that of a testis from a bluefin of similar length. The ovary tended to be flabby, partly due to the large cavity along its length (Figure 8B).

2. Erythrocyte Analysis.

Differentiation of male from female avian erythrocytes was demonstrated by the use of lysin present in the lectin extract of chestnut, Aesculus hippocastnum, (Cohen, no date). Male cells were more readily lysed than female cells, confirming a similar observation by Borel (1962). Dr. Cohen (Roswell Park Memorial Institute) the author of the above mentioned paper, kindly analysed samples of blood from Conception Bay tuna in an attempt to similarly differentiate the sexes.

The bluefin blood was obtained as follows: Each fish was suspended by its caudal fin and an anterior-ventral incision made with a knife. Blood was initially allowed to flow freely to avoid possible contamination with residual surface water.

A

B

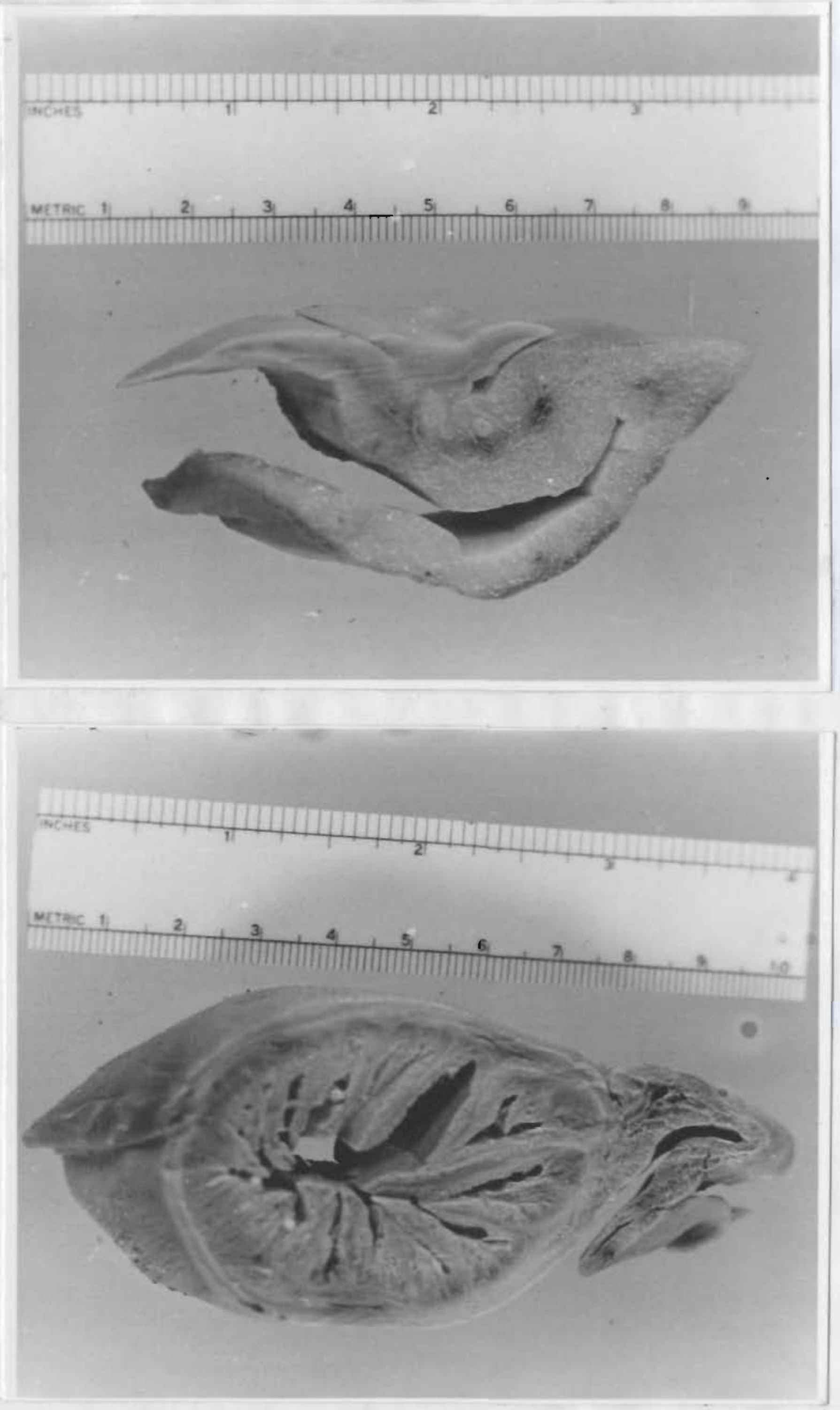


FIGURE 8

A MALE (A) AND A FEMALE (B) BLUEFIN GONAD IN TRANSVERSE SECTIONS.

Approximately 20 cc of blood was then collected in a glass, screw top vial. The vial was appropriately labelled and stored at 5 degrees C prior to express air transport in insulated containers to the Roswell Park Memorial Institute, Buffalo, New York. All of the samples arrived in a partially hemolysed condition so preventing reliable analysis. The addition of appropriate quantities of Heparin Sodium by the author did not overcome this problem. Future samples will be collected according to the methods recommended by Fujino (1967), and hopefully from fresh specimens. The blood samples taken in 1966 were obtained from bluefin which had been dead for as many as nine hours.

Results

When the data were considered by monthly intervals it was apparent that the males outnumbered the females by a ratio as high as 3:1 and by an overall average ratio of slightly less than 2:1.

Year	Month	Total No. Examined	Number & Percent Male	Number & Percent Female
1966	July	68	38 (56%)	30 (44%)
1966	Aug.	28	22 (79%)	6 (21%)
1966	Sept.	10	7 (70%)	3 (30%)
		106	67 (63%)	39 (37%)

According to these results there appears to be a reversal of the sex ratio when considering the western Atlantic bluefin in its southern habitat (May) and in its northern feeding grounds (July - October.

To date the author has been unable to find any data concerning the sex ratio of the eastern Atlantic bluefin during their feeding period in the Norwegian and North Sea, i.e. areas analogous to Newfoundland waters. The Conception Bay results, therefore, cannot be substantiated by comparison with northern European determinations. In addition, because of the inadequate sampling period (1966 season only) and the limited number of sex-determined bluefin (106) it would be unwise to speculate as to possible reasons for the indicated sex ratio reversal. However, the selectivity (if any) of rod and line fishing at the various stages of the bluefin life cycle should be considered.

SECTION V

AGE AND GROWTH

As noted in the "Introduction," the earliest reference to a study of age and growth of tunas (probably bluefin) has been traced to observations by Greek fishermen about 2000 years ago (Bell, 1964), but only in the last decade has much effort been directed towards this phase of tuna research. Three major reviews have been published in this period, Hayashi (1958) on Pacific tuna stocks, Bell (1964) on world tuna stocks (including bluefin) and Shomura (1966), also on Pacific tuna stocks. Hamre (1962) reviewed the methods used and results obtained in estimating vital statistics of tuna populations. The ageing techniques are common to all tuna species: rings on hard parts, progression of modal sizes in length-frequency distributions, and tagging. Tiews (1960) developed a new technique separating year-classes of large tuna by means of their eye diameters. None, however, are very precise. The results achieved by one technique are therefore verified by comparison with the results obtained using other methods.

Rings on Hard Parts

As the bluefin undertake an annual feeding migration from warm Caribbean waters to cold Newfoundland areas they experience radical environmental and physiological changes. The formation of distinct growth rings is usually associated with such phenomena. It is assumed that the rings are formed once a year, probably during the winter or early spring (Mather III and Schuck, 1960) and therefore indicate the age of the fish. The rings are thus called annuli. In contrast, the Pacific albacore remains throughout its life span in a tropical environment and ageing via ring counts has proved impossible (Otsu and Uchida, 1959).

Scales and vertebrae are the hard parts normally utilised, rather than the otoliths which are milky white throughout in the bluefin and consequently are unreadable (Williamson, 1962). Other bony structures, such as fin spines, can probably be used as, according to Heincke (1905), there is a complete correspondence in the sequence of growth lines in the various bones and scales of an individual fish. Scale reading has proved to be unsatisfactory for bluefin older than 7 years according to Westman and Gilbert (1941) or over 50 pounds according to Mather III and Schuck (1960), because the scales become thick and unreadable. However, annuli formation on vertebrae can be used for age determination in bluefin of all year-classes (Westman and Gilbert, 1941), although difficulties in reading the annuli and avoiding subjective judgements increase with their number, particularly in fish over ten years old. Vertebral-ring age determinations of Atlantic bluefin have been conducted by a number of authors: Sella (1929), Hamre (1958), Vilela (1960), Rodriguez-Roda (1960) and Mather III and Schuck (1960).

<u>Length-Frequency Analysis</u>

This technique involves following the seasonal progression of the dominant bluefin length groups: Westman and Gilbert (1941), Westman and Neville (1942), Rivas (1954a), Tiews (1957), Hamre (1958), Lühmann (1959), Mather III and Schuck (1960) and Williamson (1962). It is particularly appropriate for species such as bluefin which spawn over a short season and grow rapidly, hence accentuating the modal groups.

A problem which indirectly affects the ageing of Conception Bay bluefin is whether or not fish forming the first modal group appearing in length distributions are young of the year. Mather III and Schuck (1960), working on bluefin taken in the vicinity of Cape Cod, concluded that the first modal group (average fork length = 38.0 cm) were in fact the young of the year (0 - year olds). They based their conclusion on the lack of annuli on the scales and vertebrae of fish of that size, and the lack of any evidence that tuna in a smaller size group exist. This is in agreement with the work of Sella (1929), Westman and Gilbert (1941), Westman and Neville (1942) and Rivas (1954a). In general, age and growth data for western Atlantic "giant" bluefin, particularly above the age of ten years, is sparse.

CONCEPTION BAY

The bluefin caught in Conception Bay are normally the "giants" and are rarely less than ten years old, hence vertebral ring counts and the analysis of length-frequencies, rather than scale readings, are the common methods of age determination.

Materials and Methods

The standard procedure for a vertebral ring count is to remove a section from the backbone, preferably in the region of the anus where the vertebrae are largest. However, the 1966 Conception Bay tuna catch was commercially utilised (fish being headed, gutted and deep frozen whole) and the author was, for the most part, able to obtain samples of the smaller anterior vertebrae only. The vertebrae were separated and the soft tissue attached to them was removed. They were then preserved in 10% formalin and after suitable treatment the concave centra were inspected. The annuli were marked by depressions and colour variations, which were accentuated by direct or indirect light, staining, or when soaked in water or dried (Figure 9A). Wax (parawax) and modelling clay (permoplast) casts were used to verify some of the results (Figure 9B). Galtsoff stain (Galtsoff, 1952) proved effective but was time consuming and was used for only 12 of the vertebrae. According to Galtsoff, the stain operates on the following principles: Alizarin Red S (anthraquinone group) was shown to be a specific stain for bone (Lippman, 1935) and Hollister (1934) noted its affinity to calcium phosphate. The intensity of the staining is related to the concentration of the calcium phosphate in the bone. This concentration varies uniformly with the season in the case of bluefin, hence accentuating growth rings.

A total of 87 vertebrae were examined by the author on three occasions. The age was accepted only if a minimum of two out of

A

B

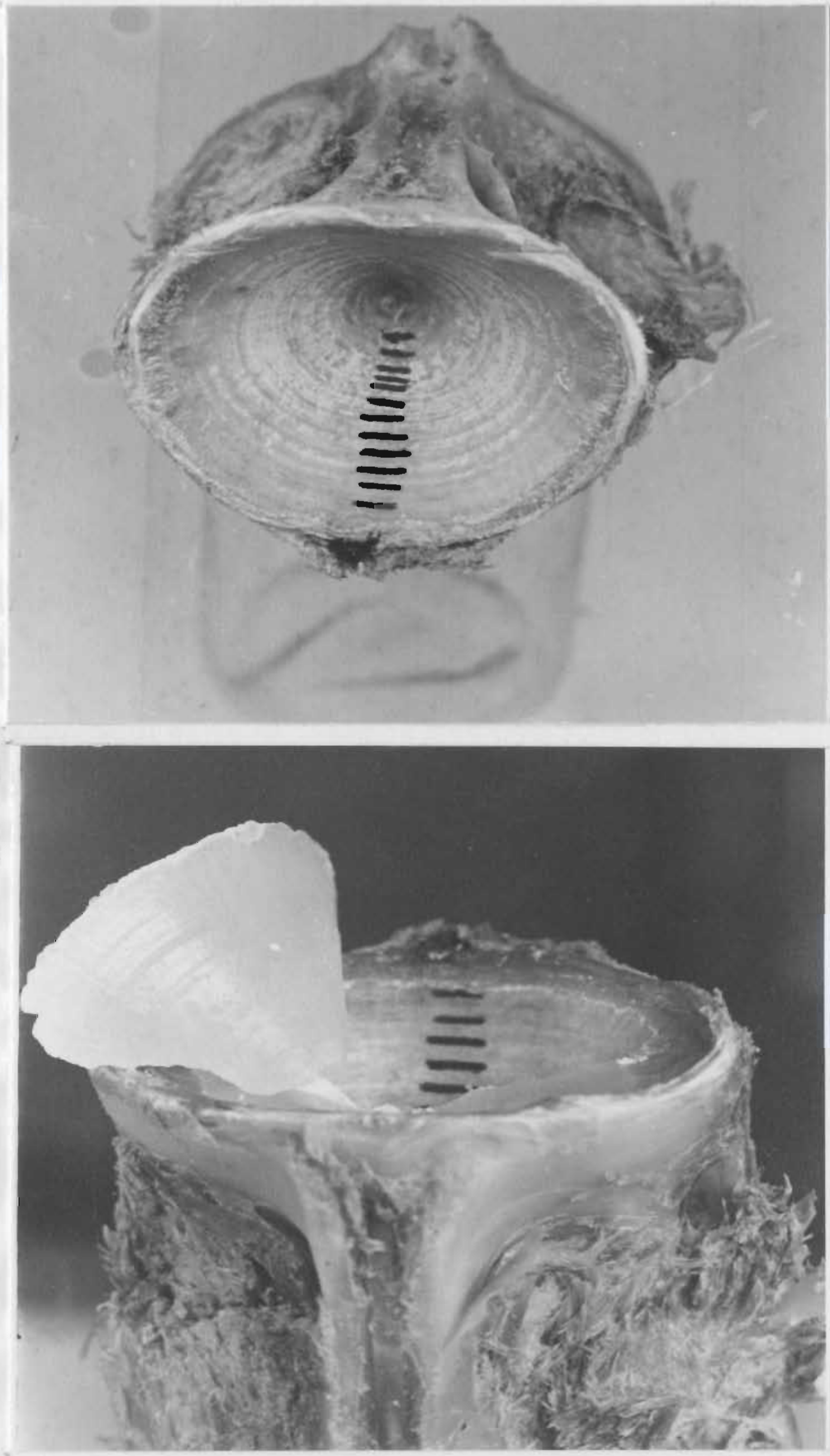


FIGURE 9

A DRIED VERTEBRA (UNSTAINED) FROM A 12 YEAR OLD BLUEFIN, WITH DEPRESSIONS (ANNULI) INDICATED (A); AND A BLUEFIN VERTEBRA WITH ITS ASSOCIATED PARAWAX CAST (B) the three readings were in agreement, if not the vertebra was discarded.

Morphometric measurements were made with the aid of large and small calipers and a flexible steel rule. The associated data sheet and measurement techniques are illustrated in Appendix 2. All fork length measurements referred to in this thesis are straight as opposed to curved (flank) measurements, unless otherwise stated (Figure 21, page 93).

Results

Vertebral Ring Counts

Of the 87 vertebrae examined, 24 were discarded because of unreliable readings and a further 21 because their centra were partially destroyed during removal from the fish or their subsequent preparation. The results of the examination of those remaining are recorded in Table 8. The majority of the Conception Bay bluefin catch (1966) would appear to be 11, 12 and 13 years old.

Table 8 — The Fork Lengths (cm) of Bluefin Tuna Caught in Conception Bay (1966), For Each Number of Annuli (years)

10	11	12	13	14
218	218	219	236	251.5
	218	228	240	
	220	231.5	241	
	222	231.5	241	
	222.5	233	244	
	223.5	234	244	

Table 8 Cont'd.

	10	11	12	13	14
		224	234	246	
		227	235	247	
		227	235	250	
		228	236	251	
		231	236		
		234	236.5		
			237		
			237		
			238		
			240		
			241		
Average Fork Length	218.0	224.51	234.2	244.0	251.5
No. of Specimens	1	12	17	10	1

Analysis of Length Frequencies

The results are presented in Figure 10. The fork lengths represented by the modes (224 - 225 cm, 234 - 235 cm, 246 - 247 cm) closely approximate the values determined for the ages 11, 12 and 13 years by the vertebral ring count method (Table 8). The results are also similar to the estimations of Mather III and Schuck (1960), and Williamson (1962) for bluefin caught in the north western Atlantic (Table 9).

Table 9 The Average Fork Length of North West Atlantic Bluefin Aged 10 - 14 Years

Age	Mather III and Schuck	Williamson	Present Study
10	209.4	206.8	(218.0)
11	224.5	221.4	224.5
12	233.7	233.5	234.2
13	243.3	245.7	244.0
14	248.0	255.4	(251.5)

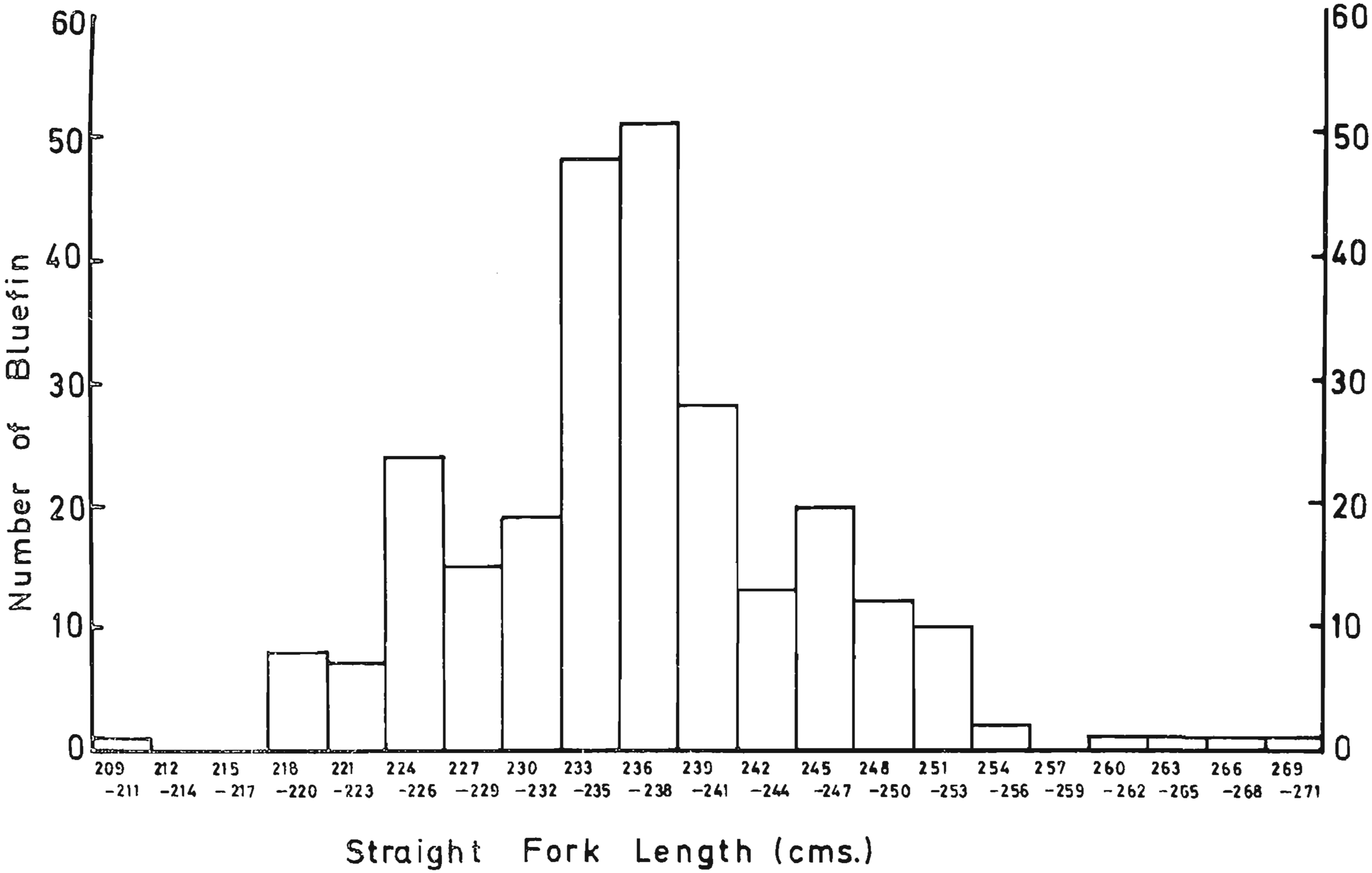


FIGURE 10

THE FORK LENGTH DISTRIBUTION OF 260 BLUEFIN CAUGHT IN CONCEPTION BAY, 1966

Note:

1. From Mather III and Schuck (1960:42), Table 2. Average fork lengths of bluefin tuna taken in the vicinity of Cape Cod. Age from readings of annuli on vertebrae.

2. Williamson (1962:10). Flank lengths (inches) that can be expected in the first two weeks of August in the north western Atlantic. Converted to fork lengths (cm) by the author, using the following conversion factor from Mather III and Schuck (1960:43):

fork length (cm) = flank length (inches) x 2.54 x 0.958

3. Parentheses indicate that only one specimen was examined.

To verify the above results a technique involving probability paper was used to extract the component groups of the polymodal frequency distribution. This method, described by Harding (1949) and extended by Cassie (1950), involves the fitting of a normal curve (either graphically or arithmetically) by means of its exposed flank (the part which does not overlap with its neighbour). Once the first curve has been so eliminated the flank of the next becomes exposed and the process may be repeated. The use of probability paper provides a linear transformation which allows the overlapping flanks to be more readily detected (Figure 11). The inflection points were considered to be at cumulative frequencies of 3.5%, 20.0%, 77.0% and 94.0%. The points of intercept between the linearly transformed data and the line of 50% cumulative frequency represent the size frequency modes: 225 cm, 235 cm, and 245 cm (11, 12 and 13 year old bluefin respectively). The

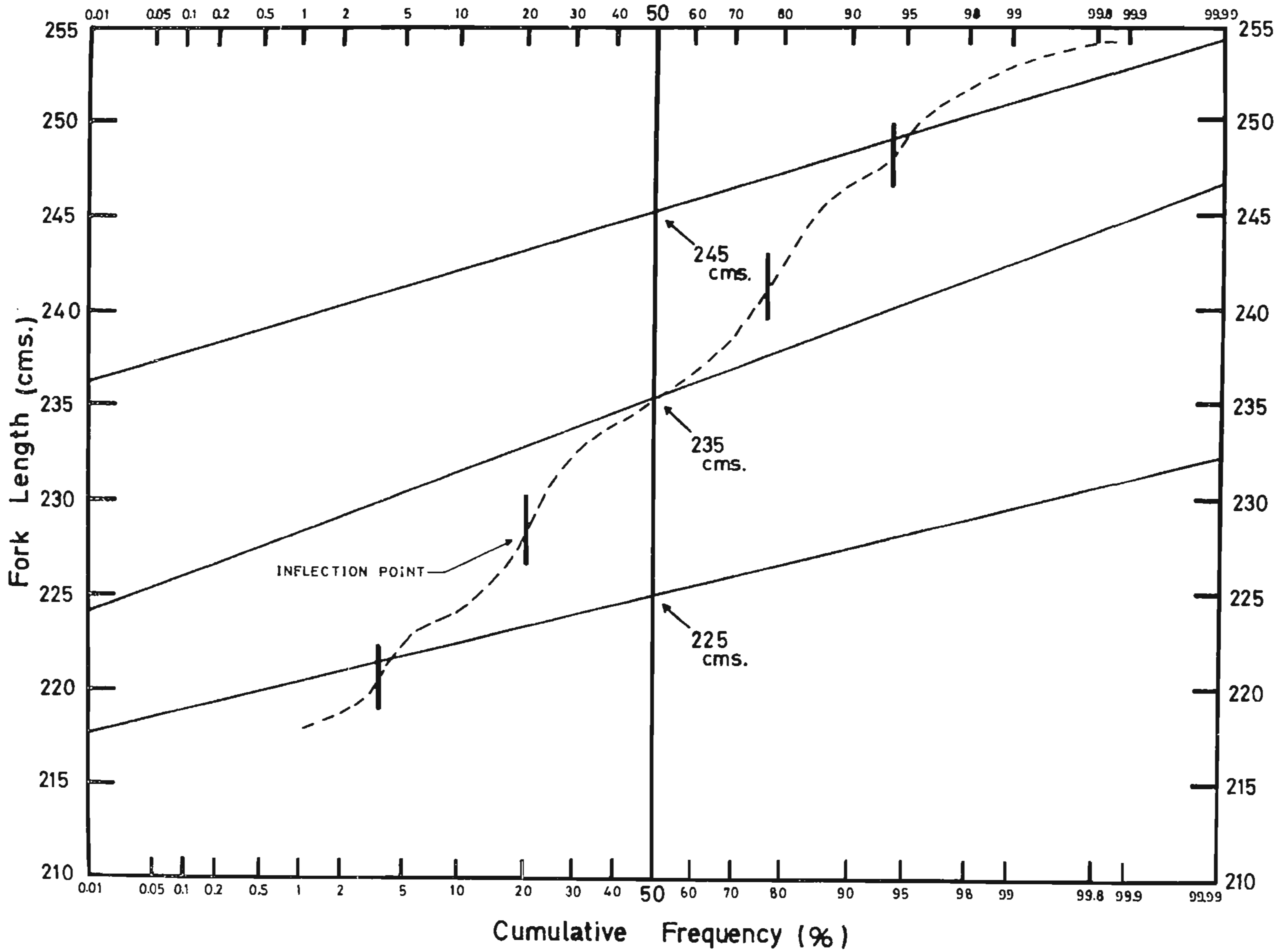


FIGURE 11

THE CUMULATIVE PERCENTAGE LENGTH DISTRIBUTION OF
257 BLUEFIN CAUGHT IN CONCEPTION BAY, 1966

technical procedures were explained by Cassie who also emphasised the value of such a technique (Cassie, 1954:522).

> "... The simple and rapid precaution of plotting on probability paper sometimes reveals unsuspected features in even the most apparently simple distributions."

Although the author was unable to reveal any unsuspected features, the size frequency modes so determined do substantiate the results obtained by the previously discussed techniques.

Age - Length Relationship

All fishes apparently exhibit an initial period of increasingly rapid absolute increase in length increment followed by a decrease (Ricker, 1958). The increasing phase is seldom seen as it occurs very early in life, usually before the end of the first year. In the case of the bluefin, the rate of decrease in length increments is so slow as to make the age-length relationship effectively linear for the restricted size range of bluefin caught in Conception Bay, i.e. mainly 11, 12 and 13 year olds, with a minority of younger or older fish. The biological effectiveness of Von Bertalanffy's decaying exponential growth curve (Von Bertalanffy, 1934, 1938) was recently demonstrated when applied to Pacific tuna species (Shomura, 1966). Application of this growth curve to fishes followed from the demonstration of its effectiveness by Beverton and Holt (1957). However, because of the limited age-span (3 years out of a possible total of 20+ years) of the Conception Bay bluefin the results derived by this technique would have been of doubtful biological importance.

Because of the stated complications, the age-length relationship of Conception Bay tuna is presented in its simplest graphical form (Figure 12). Figure 13 is adapted from Williamson (1962) based on the work of Mather III and Schuck (1960), and incorporates a considerably larger range of ages.

The value of l∞ (asymptotic length) may be calculated by fitting the following equation to the Walford plot:

$$l_{t+I} = l\infty \; (I-k) + kl_t$$

This describes a straight line between values of l_{t+I} and l_t with slope K and Y-axis intercept of l∞ (I-k), where

l_t = length at age t

l_{t+I} = length at age t+I

l∞ = theoretical maximum attainable length (asymptotic length).

The value of l∞ was calculated as 356 cm. It may be estimated less precisely as the point of the plot of l_{t+I} against l_t where $l_{t+I} = l_t$, i.e. the point of interception of the "Walford line" and the 45 degree diagonal (Figure 14).

The above procedure was developed empirically by Ford (1933) and Walford (1946) and represents each years' growth increment as less than the previous year's by the fraction (I-k) of the latter, starting from an hypothetical initial size of l∞ (I-k) at true age zero (Ricker, 1958:194).

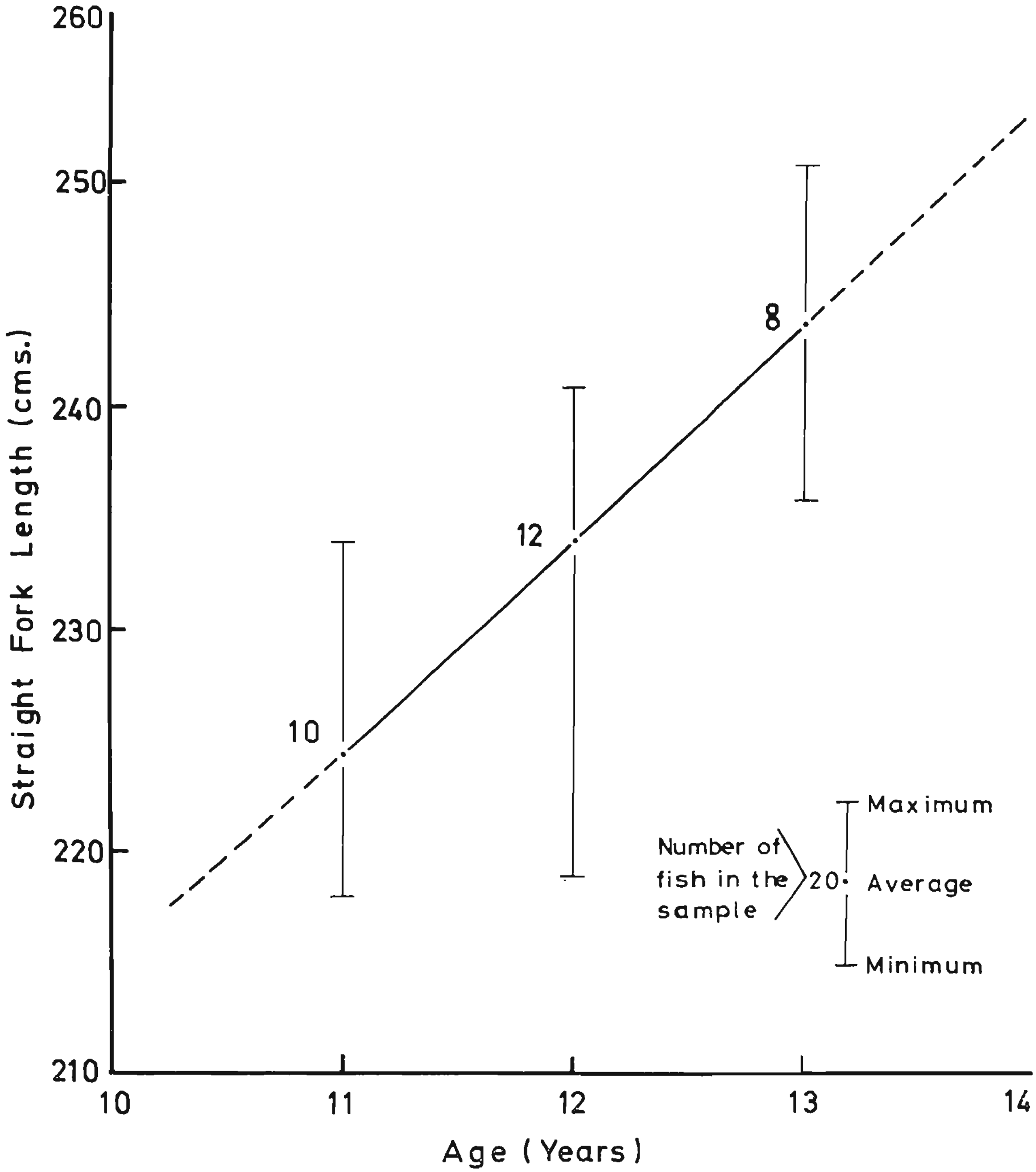


FIGURE 12

THE AGE-LENGTH RELATIONSHIP OF 30 BLUEFIN CAUGHT IN CONCEPTION BAY, JULY - SEPTEMBER, 1966

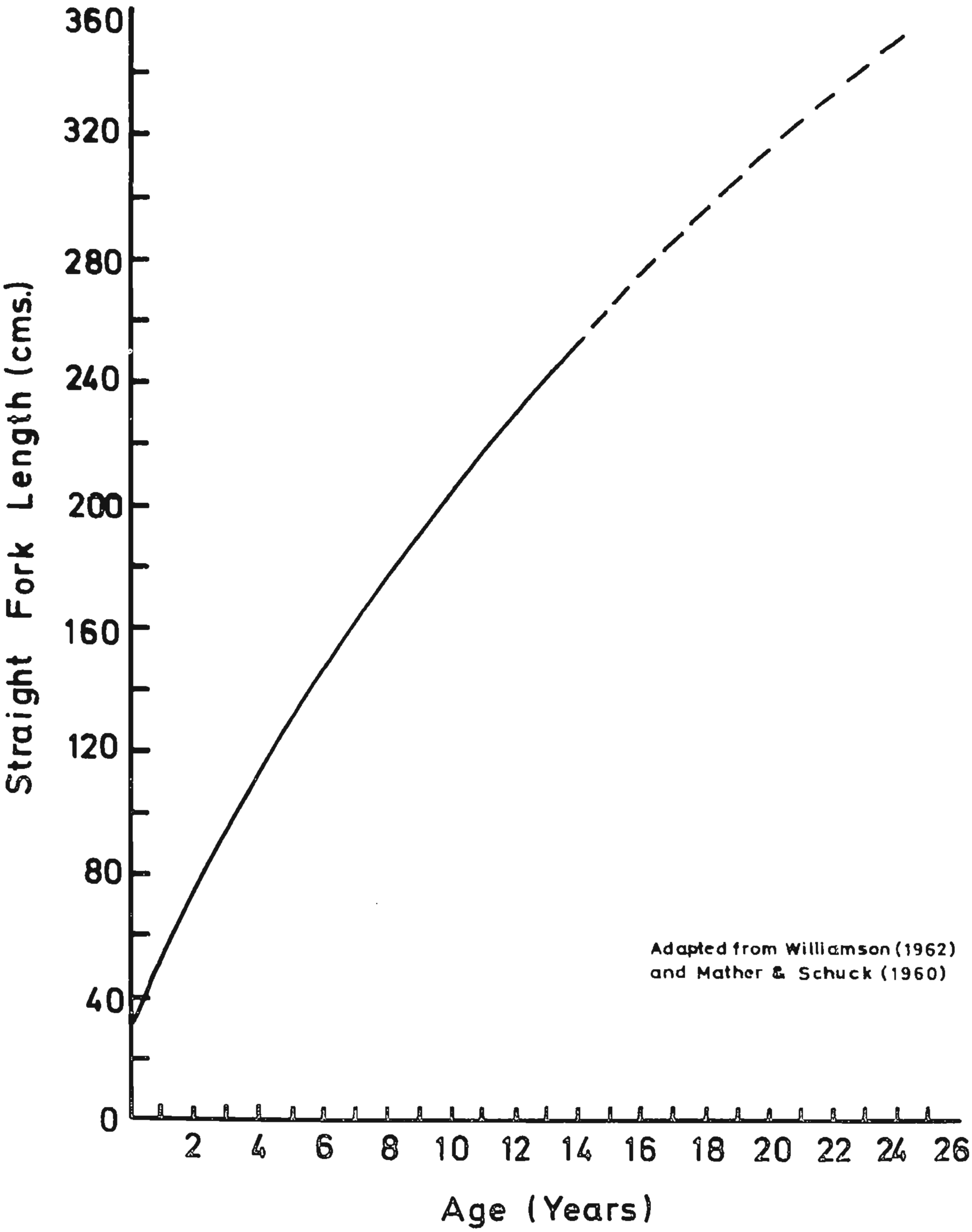


FIGURE 13

THE AGE-LENGTH RELATIONSHIP
OF BLUEFIN DURING AUGUST

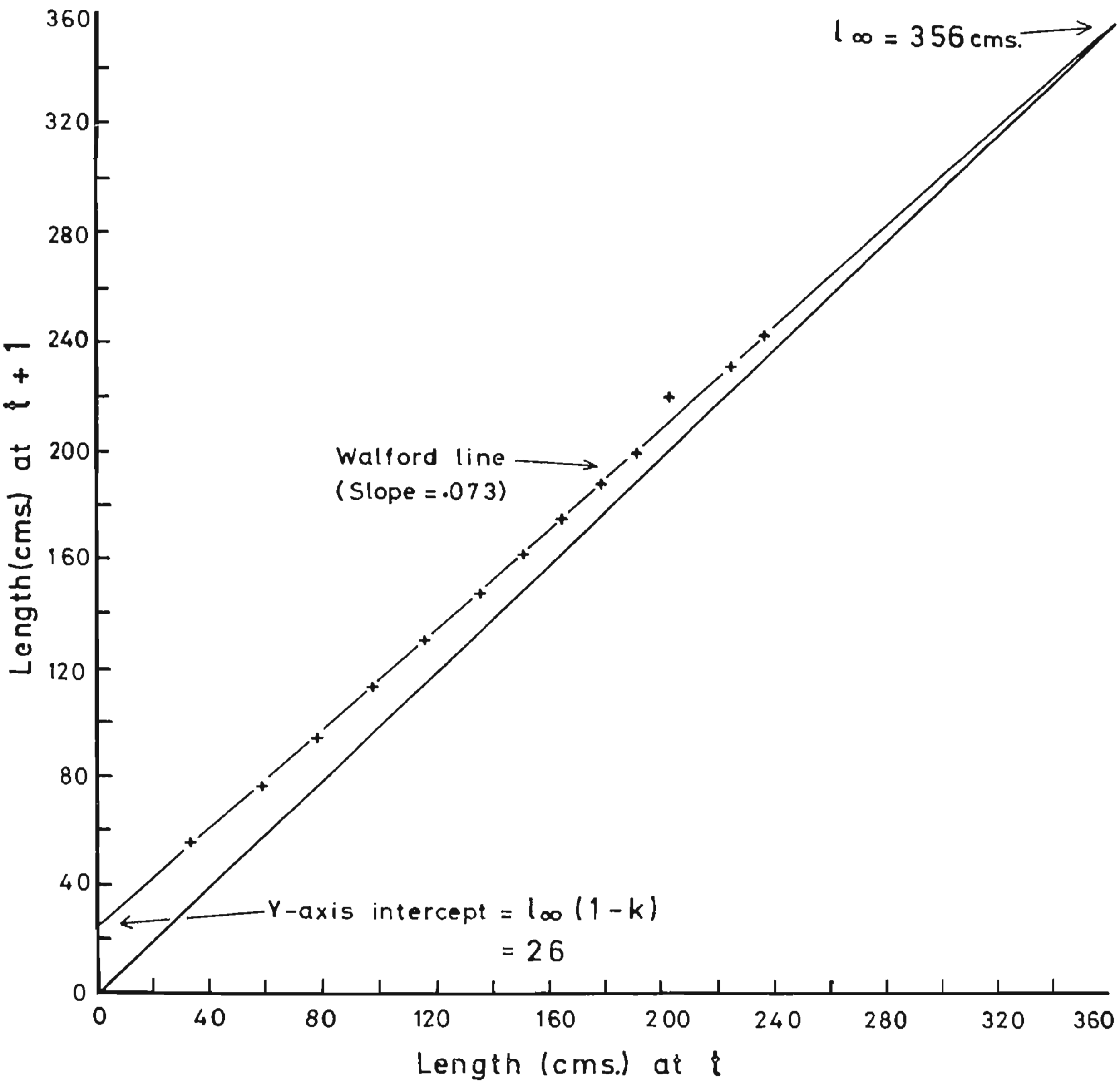


FIGURE 14

A WALFORD PLOT INDICATING THE PROBABLE MAXIMUM FORK LENGTH ATTAINED BY BLUEFIN

The value of 356 cm for maximum fork length appears to be a reasonable result when the suggested maximum weight (1500 - 2000 pounds) and maximum age (20+ years) are considered as extrapolated values on the age-length and age-weight graphs, Figures 13 and 16, respectively. Also, the substitution of 356 cm in the length-weight relationship results in a calculated maximum weight of 1550 pounds.

Age-Weight Relationship

Bluefin increase their weight faster than any other fish in Newfoundland waters (Williamson, 1962). Various computations for the age-weight relationship of the Conception Bay catch (1966) are presented in Table 10 and Figure 15. It should be noted that the weight values are only averages and, because the bluefin increase their weight by approximately 1-2 pounds per day during the northern feeding season, the variations are considerable. In addition, the author's age determinations were, of necessity, indirectly computed from the length-frequency analysis unless otherwise noted (see footnotes to Table 10). Figure 16 is the estimated growth curve for bluefin aged 1 - 14 years, based on data adapted by Williamson (1962) from the investigations of Mather III and Schuck (1960).

Table 10 The Age-Weight Relationship of the Conception Bay Bluefin Catch (1966).

	Weight (pounds)					
Age (years)	A[1]	B[2]	C[3]	D[4]	E[5]	F[6]
1	-	-	-	-	-	-
2	-	-	-	-	-	-

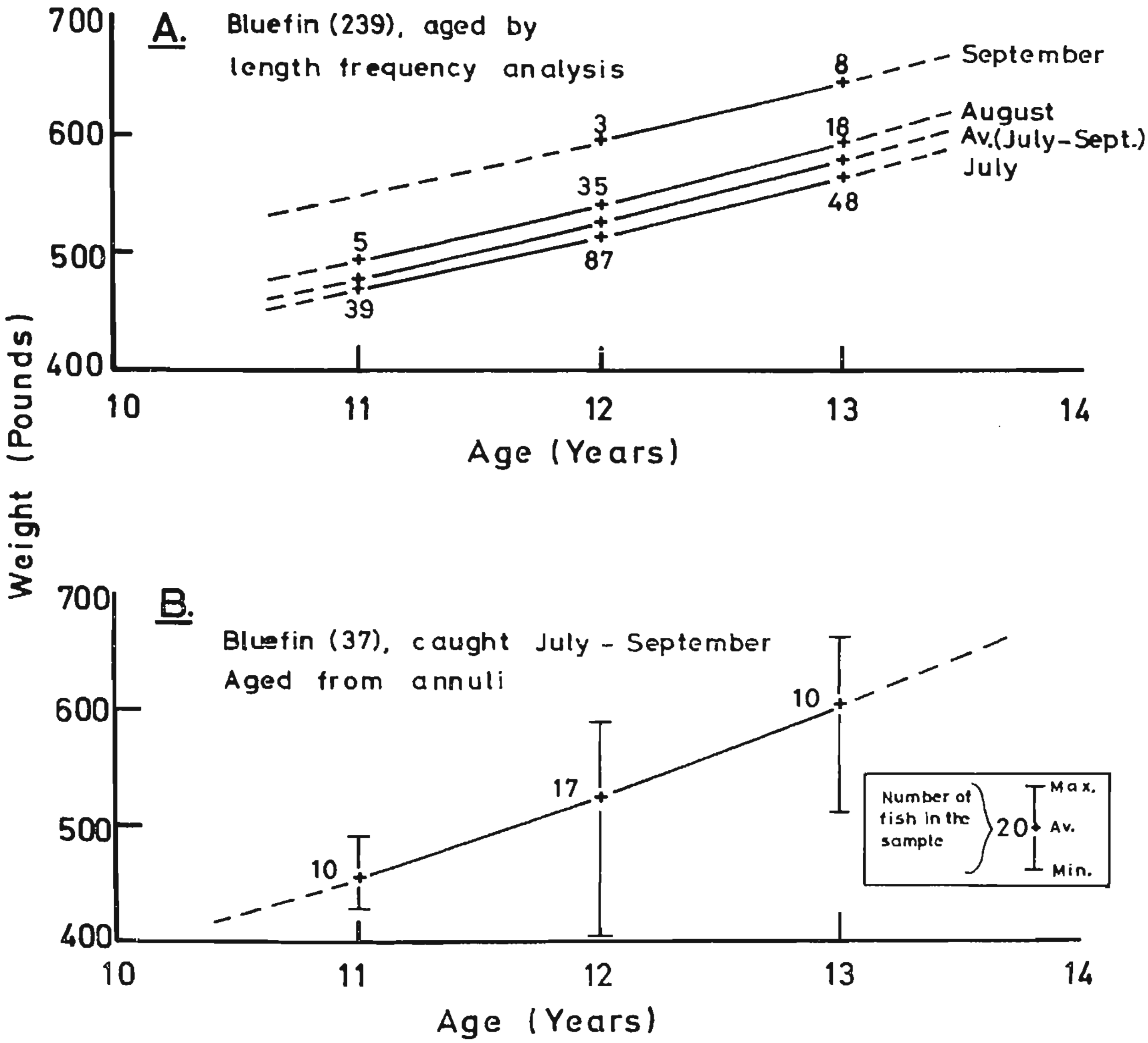


FIGURE 15

THE AGE-WEIGHT RELATIONSHIP OF BLUEFIN CAUGHT IN CONCEPTION BAY, JULY - SEPTEMBER, 1966

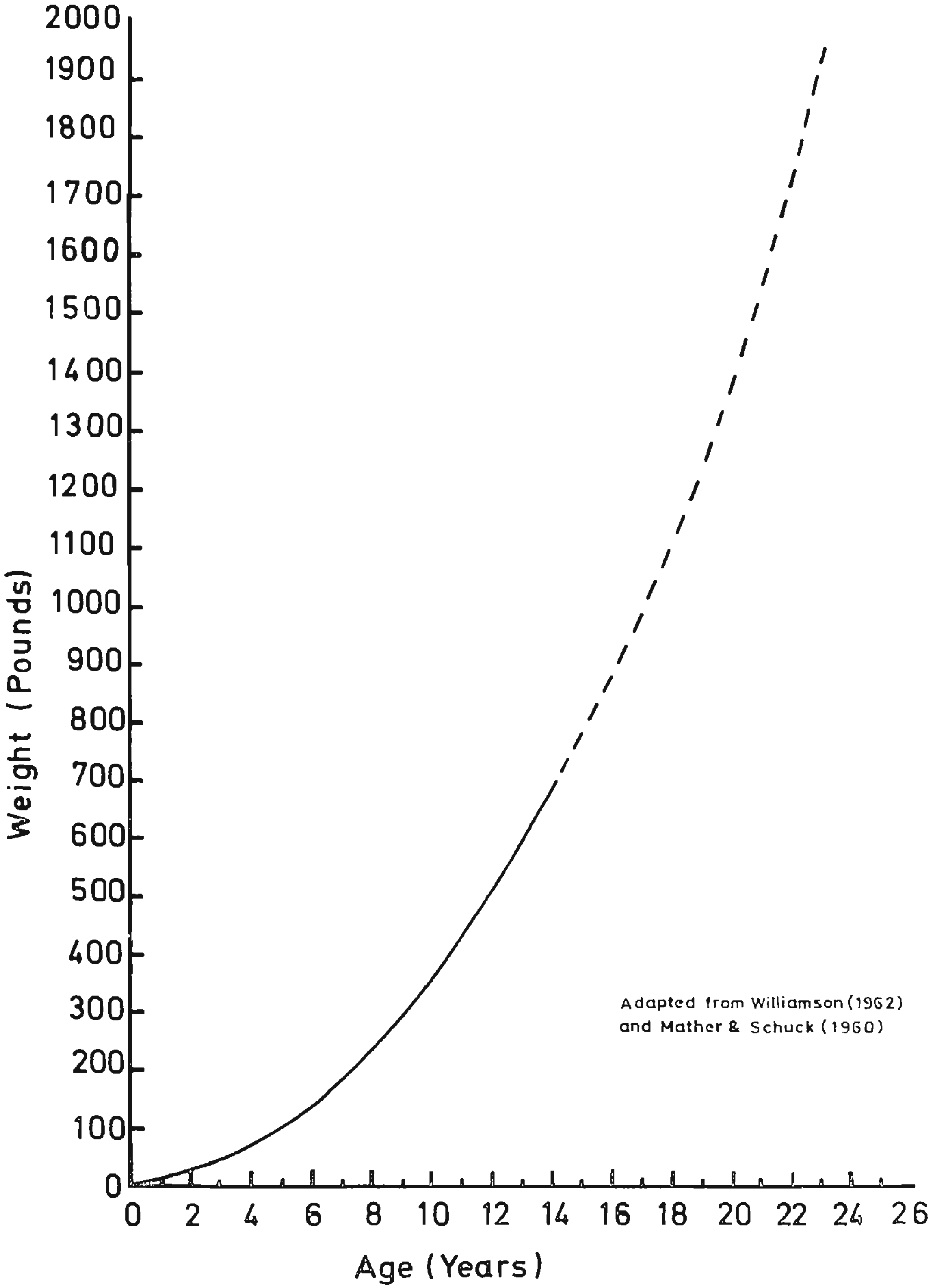


FIGURE 16

THE AGE-WEIGHT RELATIONSHIP
OF BLUEFIN DURING AUGUST

Table 10 Cont'd.

Age	A[1]	B[2]	C[3]	D[4]	E[5]	F[6]
3	-	-	-	-	-	-
4	-	-	-	-	-	-
5	100	-	-	-	-	-
6	140	-	-	-	-	-
7	185	-	-	-	-	-
8	240	-	-	-	-	-
9	300	-	-	-	-	-
10	360	-	-	-	-	-
11	430	455	477	475	494	470
12	510	526	525	516	543	600
13	600	591	584	569	597	650
14	690	-	-	-	-	-

Footnotes to Table 10:

1. Values that can be expected in Newfoundland waters in the first two weeks of August. Williamson (1962) adapted from Mather III and Schuck (1960).

2. Mean values for 39 bluefin caught during the period July to September, 1966, and aged by annuli determinations.

3. Mean values for 240 bluefin caught during the period July to September, 1966, i.e. average of columns D, E, and F. The ages were determined approximately from the fork length frequency analysis, i.e. 11 years (219 - 228cm), 12 years (229 - 238 cm) and 13 years (239 - 248 cm).

4. Mean values for 174 bluefin caught during the month of July (1966). Ages were determined as in section 3 above.

5. Mean values for 54 bluefin caught during the month of August (1966). Ages were determined as in section 3 above.

6. Mean values for 12 bluefin caught during the month of September (1966). Ages were determined as in section 3 above. Only one 11 year old bluefin was caught during this month.

Length-Weight Relationship

The length-weight relationship was determined by the standard least squares regression method for the 237 bluefin caught from July to September (Conception Bay, 1966). The result:

$$\log W = 2.50 \log L - 3.20$$

$$\text{or } W = .0016 \times L^{2.5}$$

is presented in Figure 17.

Increase in Weight During the Northern Feeding Season

According to Rivas (1955), the western Atlantic bluefin ("giants") increase their weight by approximately 7.5% per month (July - September) in the feeding grounds off New England and Nova Scotia. Using the technique adopted by Rivas (1955), the author analysed the weight distribution and weight increase of 1260 bluefin caught in Conception Bay from July to September, 1957 - 1966, (Table 11). The weight increase so determined ranged from 8.5% - 10% per month. This result is approximately in agreement with the determination of Bahr (1952) for North Sea "giants" but is considerably in excess of the determination of Tiews (1957) and Lühmann (1959), both of whom worked on similar sized bluefin in the same eastern Atlantic area.

The author further analysed the increase in weight with time of the three major age groups. The ages of the bluefin were derived from their fork lengths, i.e. 11 year olds (219 - 228 cm), 12 year olds (229 - 238 cm), and 13 year olds (239 - 248).

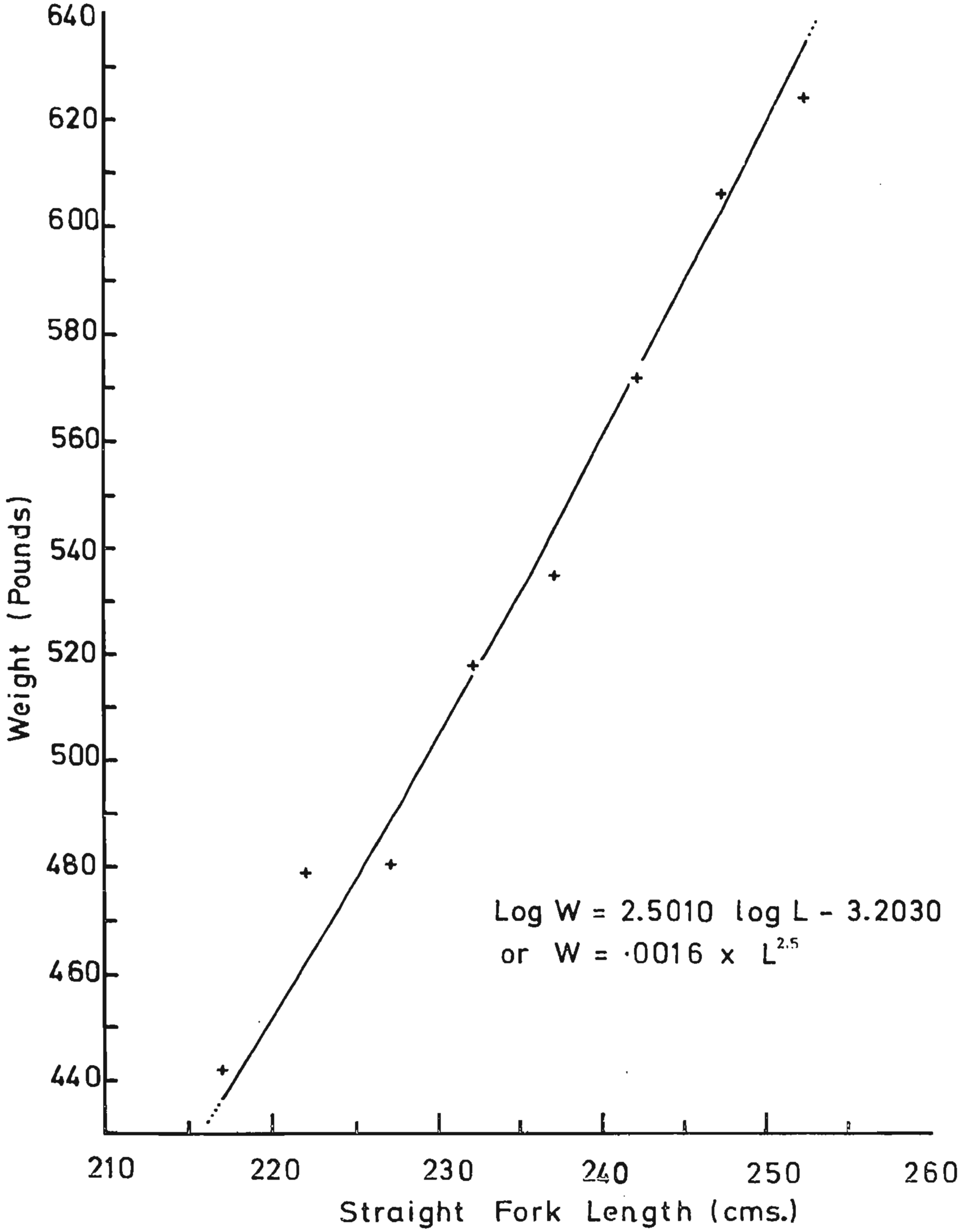


FIGURE 17

THE FORK LENGTH--WEIGHT RELATIONSHIP OF
257 BLUEFIN CAUGHT IN CONCEPTION BAY,
JULY - SEPTEMBER, 1966

650 699	700 749	750 799	800 849	850 899
		JULY		
-	-	-	-	-
-	-	-	-	-
-	-	-	-	-
-	-	-	-	-
-	-	-	-	-
-	-	-	-	-
-	-	-	-	-
-	-	-	-	-
1	-	-	-	-
6	3	-	-	-
7	3	-	-	-
		AUGUST		
1	1	-	-	1
1	-	-	-	-
-	-	-	-	-
2	1	-	-	-
1	-	-	-	-
1	-	-	-	-
4	-	-	-	-
8	4	-	-	-
8	4	-	-	-
4	-	-	-	-
30	10	-	-	1
		SEPTEMBER		
-	-	-	-	-
-	-	1	-	-
-	1	-	-	-
1	-	2	-	-
6	3	1	1	-
1	1	-	-	-
3	-	-	-	-
13	8	3	-	-
6	1	-	-	-
8	-	-	-	-
38	14	7	1	-

Table 11 Weight Frequency Distribution (Pounds) of 1260 Giant Bluefin from Conception Bay, July - September 1957 - 1966, Showing the Mean Weight Increase During the Season.

Year	Mean Weight	200 249	250 299	300 349	350 399	400 449	450 499	500 549	550 599	600 649
JULY										
1957	-	-	-	-	-	-	-	-	-	-
1958	600	-	-	-	-	-	-	-	-	-
1959	-	-	-	-	-	-	-	-	-	-
1960	-	-	-	-	-	-	-	-	-	-
1961	-	-	-	-	-	-	-	-	-	-
1962	-	-	-	-	-	-	-	-	-	-
1963	548	-	-	-	-	-	4	5	6	3
1964	458	-	-	-	2	2	1	1	-	1
1965	504	-	-	-	1	5	10	11	7	-
1966	524	-	-	1	2	12	59	78	48	20
Mean (1957-66)	527	-	-	1	5	19	74	95	61	25
Mean (1963-66)	495									
AUGUST										
1957	622	-	-	-	-	-	-	1	5	1
1958	588	-	-	-	-	-	-	1	3	-
1959	553	-	-	-	-	1	-	-	2	1
1960	600	-	1	-	-	-	-	-	2	2
1961	489	-	-	1	10	22	33	22	12	10
1962	508	-	-	-	1	6	7	12	6	4
1963	496	-	-	-	12	21	55	52	29	12
1964	555	-	-	-	1	3	24	44	34	25
1965	563	-	-	1	1	5	16	35	34	34
1966	557	-	-	-	-	-	7	18	24	7
Mean (1957-66)	553	-	1	2	25	78	142	185	151	96
Mean (1963-66)	558									
SEPTEMBER										
1957	-	-	-	-	-	-	-	-	-	-
1958	663	-	-	-	-	-	-	-	-	-
1959	559	1	-	-	-	1	-	-	2	1
1960	739	-	-	-	-	-	-	-	-	-
1961	649	-	-	-	-	1	-	1	5	3
1962	625	-	-	-	-	-	-	-	3	1
1963	528	-	-	-	-	10	5	9	11	3
1964	597	-	-	-	-	1	5	22	27	27
1965	591	-	-	-	-	-	-	12	15	12
1966	633	-	-	-	-	-	1	-	3	6
Mean (1957-66)	620	1	-	-	-	13	11	45	66	53
Mean (1963-66)	607									

Theoretically the weight-time relation should consist of a number of sigmoid curves, but because of the restricted time period studied (July - September) only part of the curve is apparent (Figure 18). The curves of the type $W = kt^n$, were fitted by eye because of the large standard errors obtained by statistical methods. A consideration of the weight and length data in relation to time, suggests the following hypotheses:

1. The largest individuals of a specific age class arrived first in Conception Bay because of their faster swimming speed, hence reducing the initial (calculated) rate of weight increase.

2. The smallest individuals of a specific age class arrived in the latter half of August, hence reducing the (calculated) rate of weight increase.

3. The mid-August period provided the highest surface water temperature enabling larger individuals of an age group to exploit rich feeding grounds in colder waters to the north of Conception Bay.

4. Maximum feeding usually occurs only when the temperature is in the middle of the preferred range. Thus the latter half of August could have been too warm.

5. The rate of weight increase was restored as the water temperature declined to the preferred range in late August and September.

6. The rate of weight increase in late September and October (not shown) would probably be accentuated by the temporary

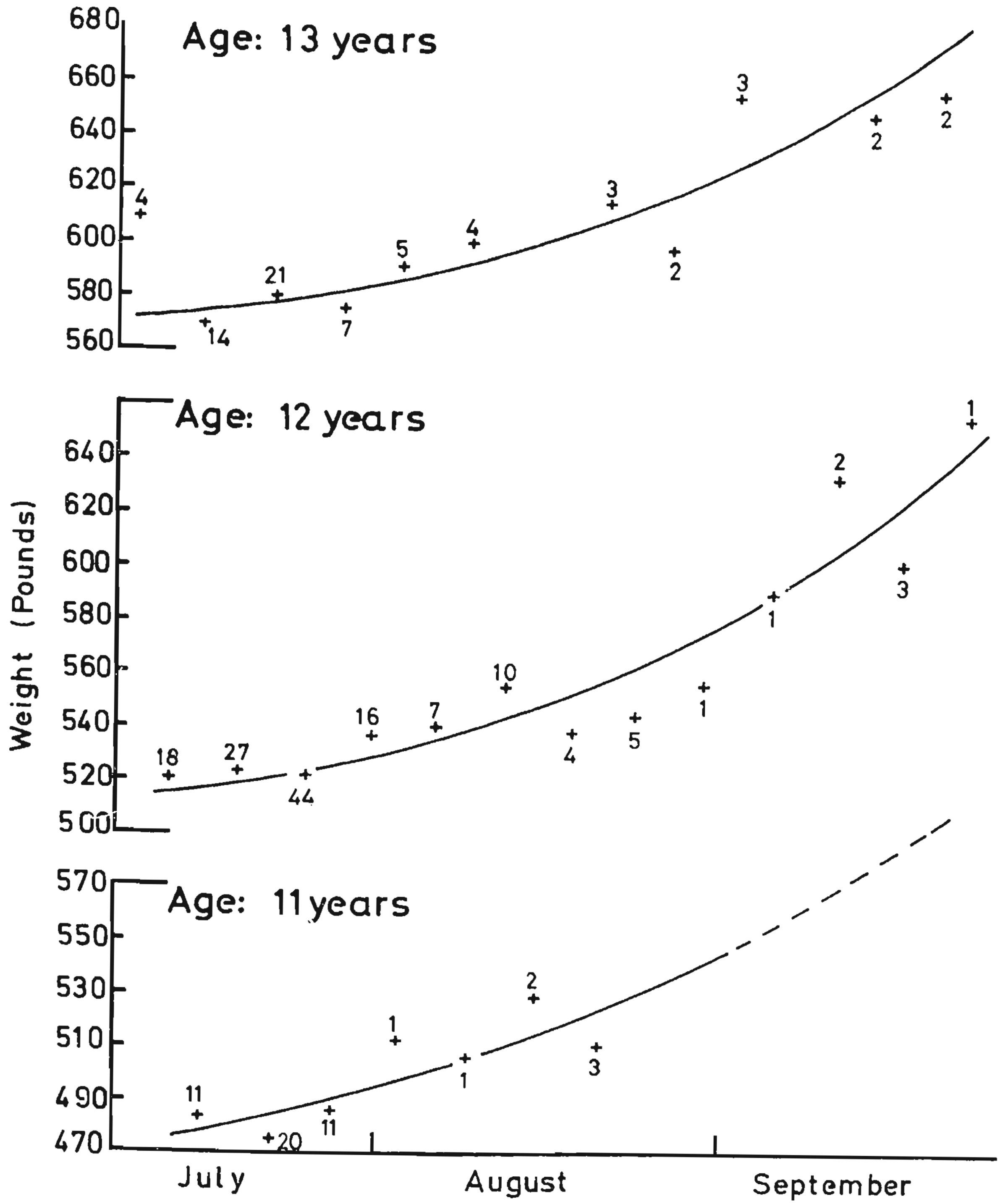


FIGURE 18

THE INCREASE IN WEIGHT WITH TIME FOR 11-13 YEAR OLD BLUEFIN CAUGHT IN CONCEPTION BAY, JULY - SEPTEMBER, 1966

The number of tuna represented by each point is indicated. Curves fitted by eye.

return of the larger bluefin of an age group from waters farther north, prior to their migration south (October - November) to their wintering grounds. The smaller bluefin of an age group will tend to leave Conception Bay first because of their limited cold tolerance as compared with the larger fish.

Evaluation of Figure 18, indicates an average weight increase of 100 - 150 pounds in a 3-month feeding period for 11 - 13 year old fish. This is in agreement with Williamson (1962) who suggested that a 12 year old bluefin increased its weight by approximately 180 pounds in about a 4-month period and that 80 pounds of this weight would be lost again during the winter and the spawning season when little food is eaten. According to Williamson (1962), the bluefin's nutritional reserves take the form of oil which is stored in the muscles and fat which comprises the bulk of a subdermal blubber tissue (64% fat).

The author's estimate of an average weight increase of 8.5% - 10% per month would appear to be substantiated.

Increase in Growth and Depth During the Northern Feeding Season

Because of insufficient data only 12 year old bluefin were considered (Figures 19 and 20). The curves were fitted by eye for the reasons indicated in the previous section. The results indicate a girth and depth increase of approximately 15 cm and 5 cm respectively during the three month feeding period of July - September, 1966.

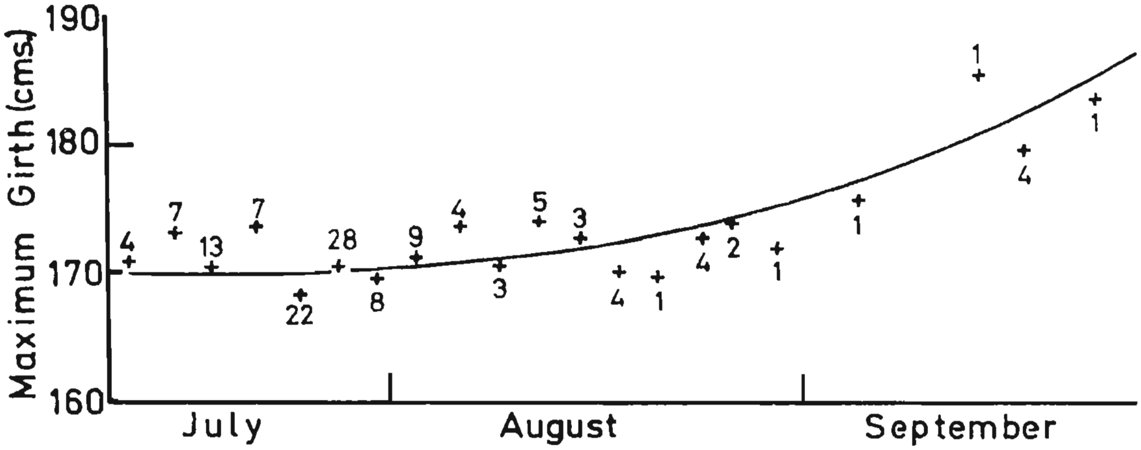


FIGURE 19

THE INCREASE IN GIRTH WITH TIME FOR 12 YEAR OLD BLUEFIN CAUGHT IN CONCEPTION BAY, JULY - SEPTEMBER, 1966

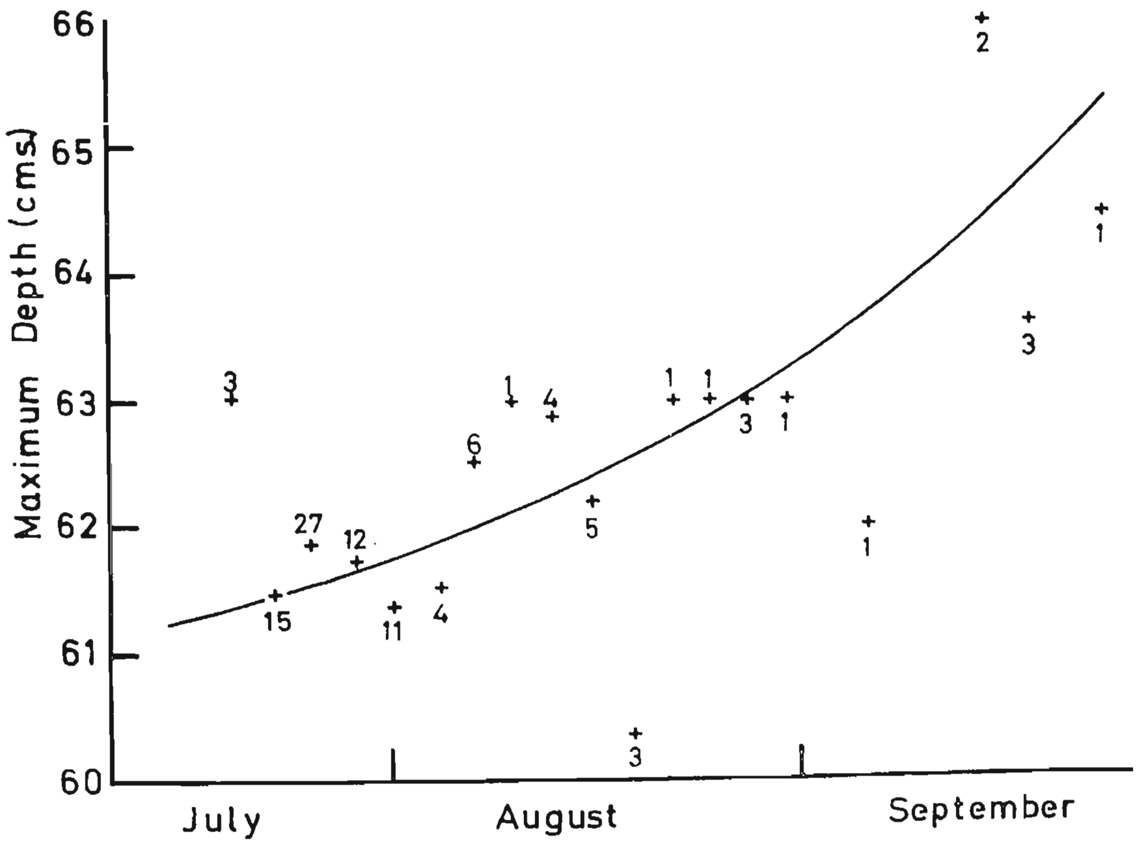


FIGURE 20

THE INCREASE IN DEPTH WITH TIME FOR 12 YEAR OLD BLUEFIN CAUGHT IN CONCEPTION BAY, JULY - SEPTEMBER, 1966

The number of tuna represented by each point (Figures 19 & 20) is indicated. Curves fitted by eye.

Relative Growth

The changes in body proportion during the growth of eastern Atlantic bluefin have been described by Heldt (1927), Frade (1931), Aricò and Genovese (1953) and Genovese (1956). Tiews (1962, 3:11) summarised their results as follows:

1. Body depth decreases relatively with fork length. The decrease is linear to length. This is also true for the head length and the distance from the tip of snout to the insertion point of the ventral fins.

2. Eye diameter decreases relatively with head length, but with increasing length at a decreasing rate.

3. Distance of eye from snout, measured along the body surface, increases relatively with head length, but with increasing length at decreasing rate.

4. Length of pectoral fin decreases relatively with fork length, but with increasing length at a decreasing rate. This is also true for the distance from tip of snout to the insertion point of the anal fin.

5. Distance from tip of the snout to the insertion point of the first and second dorsal fins decreases relatively with fork length, but in specimens above 200 cm at a lesser rate than for those between 100 - 200 cm.

The direct morphometric comparison of eastern with western Atlantic bluefin is complicated by the variation in measuring procedures adopted by the various authors. However, as the western and eastern Atlantic bluefin populations are considered to differ at the racial level at most (Mather III, 1962a), the above changes in body proportions are probably common to both, although a comparison between individual indices might have revealed slight differences.

Because of allometric development of certain proportions the bluefin, and tunas in general, usually differ greatly in appearance at different sizes. However, according to Gibbs and Collette (1966), the relative lengths of body parts per se has limited value in species identification of tunas and has been responsible for many misconceptions. Mather III (1962a) studied the relative growth of northwestern Atlantic tuna as a means of identifying the various species but in conjunction with meristic data. In the case of the bluefin the range of fork lengths varied from 20 - 270 cm. The results indicated that the head and anterior portion of the body became relatively shorter with growth. In contrast, the posterior part of the body, the second dorsal, the anal and the caudal fins become relatively longer. The ventral fins and the first dorsal remain relatively unchanged whereas the pectoral fin attains its maximum relative size in the medium sized bluefin.

The author studied the relative growth of 187 "giant" bluefin (aged 10 - 14 years) with fork lengths varying only from 215 - 254 cm (Table 12).

Table 12 **The Fork Length Distribution of 187 Bluefin Used for Relative Growth Studies**

Fork Length (cm)	No. of Bluefin
215 - 219	4
220 - 224	12
225 - 229	26
230 - 234	35
235 - 239	59
240 - 244	24
245 - 249	18
250 - 254	9

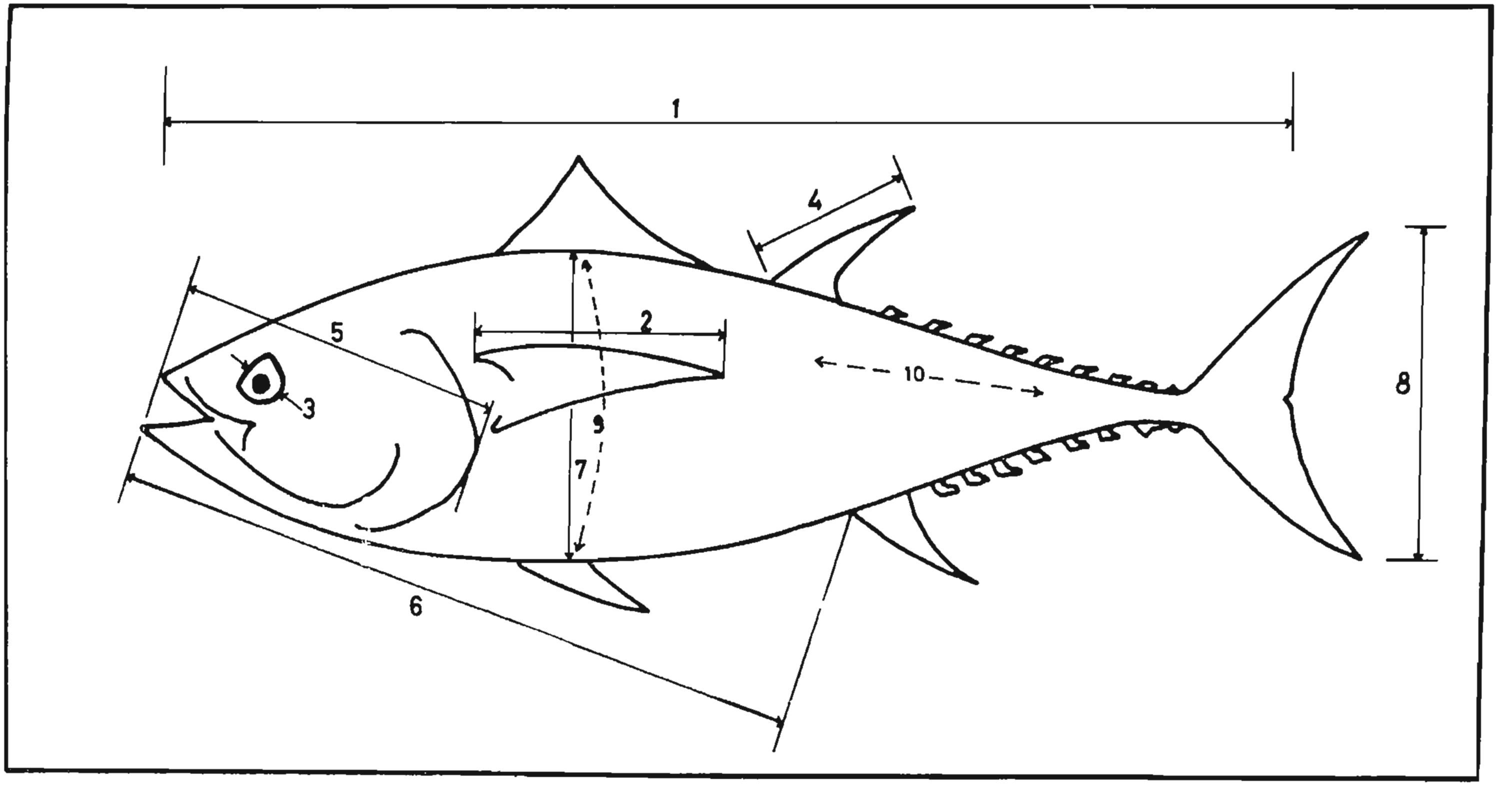
To facilitate comparison the measurements used were those adopted by Mather III (1962a) which were based on the work of Marr and Schaefer (1949, Figure 21). The "curves" were fitted by the method of least squares.

Results

The results are presented in Figures 22 and 23. Because of the limited size range examined, it proved difficult to detect isometric or allometric trends. However, there appears to be a slight decrease in length of all parameters relative to an increase in fork length, or head length in the case of the pectoral fins.

FIGURE 21

THE METHODOLOGY USED IN TAKING MORPHOMETRIC MEASUREMENTS
NOTE THAT CALIPERS ARE USED FOR MEASUREMENTS 1-8
AND A FLEXIBLE RULE FOR MEASUREMENTS 9-10



1. Fork Length: Snout of upper jaw to fork of tail.
2. Length of Pectoral Fin: From most anterior visible point of insertion to tip with fin laid flat along body.
3. Maximum diameter of Iris: measured to edge between yellow or bluish iris and surrounding dark tissue.
4. Length of Second Dorsal Fin: from end of groove of first dorsal fin to tip of second dorsal fin.
5. Length of Head: from snout of upper jaw to most distant point on edge of opercle.
6. Snout to Insertion of Anal Fin: From snout of upper jaw.
7. Maximum Depth.
8. Spread of Caudal.
9. Maximum Girth
10. Flank Length: measured along flank from snout of upper jaw to fork of tail.

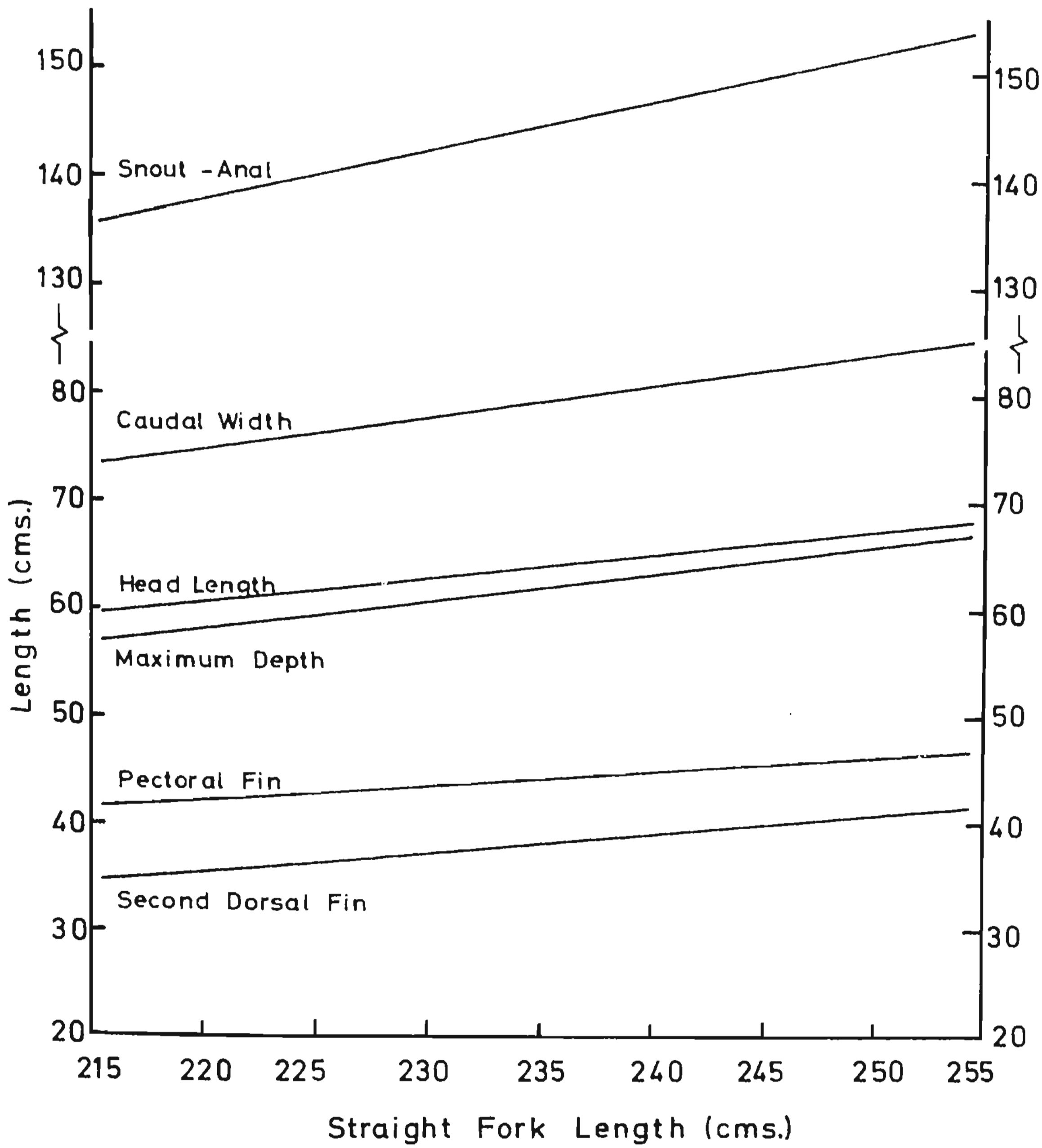


FIGURE 22

THE GROWTH IN LENGTH OF APPENDAGES AND REGIONS OF THE BLUEFIN RELATIVE TO THE FORK LENGTH

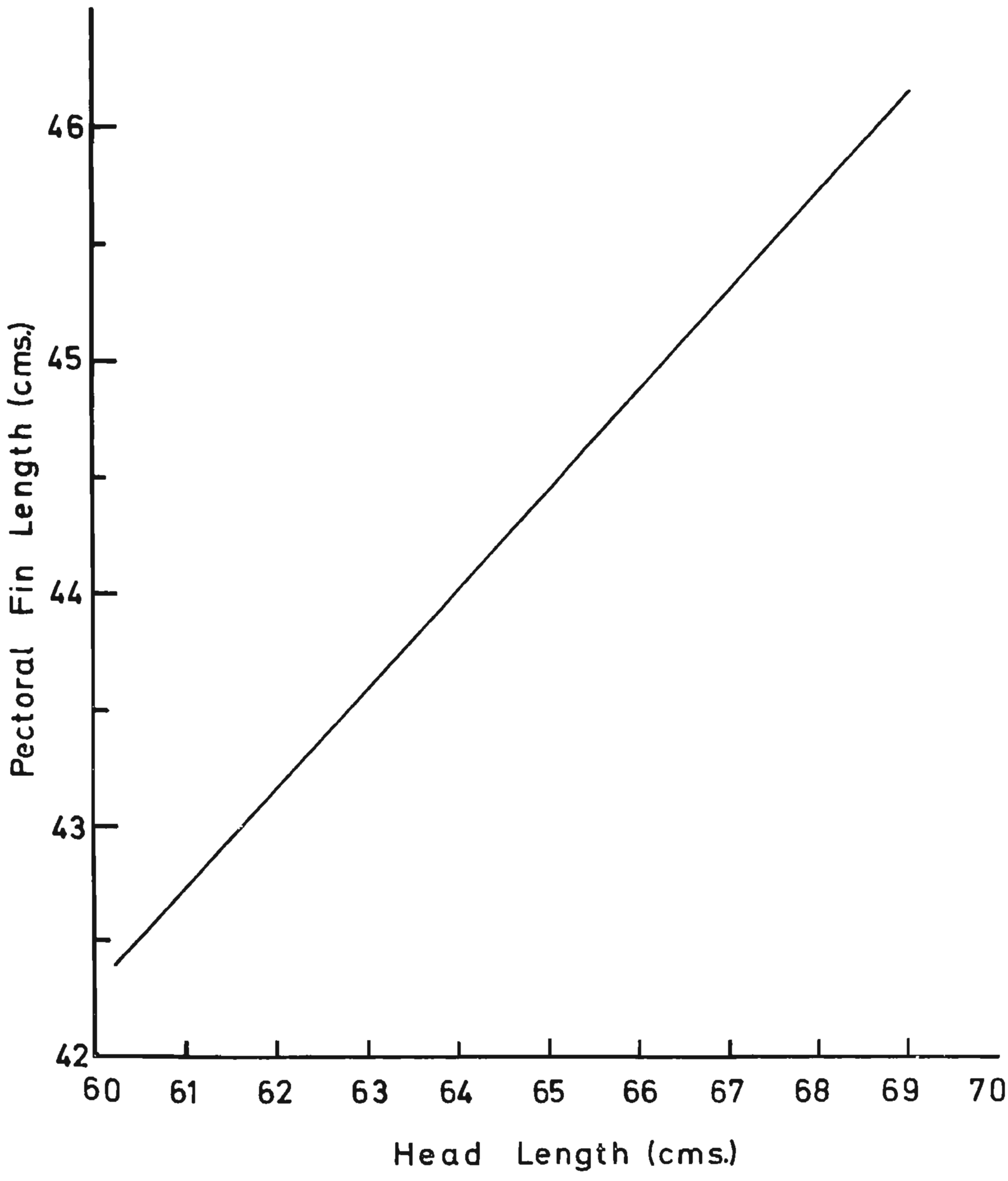


FIGURE 23

THE GROWTH IN LENGTH OF THE PECTORAL FINS RELATIVE TO THE HEAD LENGTH

SECTION VI

FOOD AND FEEDING BEHAVIOUR

Stomach Contents

De Sylva (1956) analysed the stomach contents of bluefin taken near Cat Cay, Bahamas. They contained freshly digested squids, squid beaks, and the radulae of bottom-dwelling snails. He lists squids, flying fishes, sardines, herring and krill as preferred food items.

Krummholz (1959) analysed the stomach contents of seven ripe Bahama bluefin in May, 1956 and identified 560 larval *Diodon hystrix* (porcupine fish), 90 *Pyrosoma atlantica gigantea* (salps), 5 axial skeletons of small eel-like fish, 4 portunid crabs, 1 octopus beak and a single plant leaf. He notes the absence of any of the finned fishes (other than the porcupine fish) such as herring, mackerel or mullet. When bluefin are in full sexual maturity they refuse to eat, but progressively reacquire this capacity in relation to the fractional delivery of their sexual products (Genovese, 1962). According to Roule (1924), this may be due to "stomach upset" caused by the pressure of ripe gonads on the digestive organs.

Bigelow and Schroeder (1953) state that in the Gulf of Maine (Part of the northern feeding grounds) the principal food of the bluefin consists of menhaden, mackerel and herring. They also list dogfish, squid and the smaller schooling fishes as supplementary food items. In addition to the surface dwelling forms already mentioned, Tibbo (1967) includes deep living fishes such as barricudinas, which occur down to about 100 fathoms, and lantern fish. Crane (1936) analysed the stomach contents of 34 bluefin caught in the Gulf of Maine in July, 1936 (Table 13). Five stomachs were completely empty and almost all of the food in the other 29 was in an advanced stage of digestion.

Table 13 The Stomach Contents of 34 Bluefin Caught in the Gulf of Maine (Crane, 1936)

Food Items	No. of Stomachs in which they occurred
1. *Merluccius bilinearis* (silver hake) from 1 to 38 fish in a single stomach, each measuring from 8 to 13 inches in length. In most of the tunas the food consisted entirely of this species.	26
2. Seaweed. In stomachs containing little other food: only one or two fronds were found in each stomach.	4
3. Squids. One or two in a stomach, alone or with shrimps.	3
4. *Meganyctiphanes norvegica* (krill). Numerous, all adults.	2
5. Clupeid. 215 mm.	1
6. Clupeids. Different from above, three ca 75 mm.	1

Table 13 Cont'd

Food Items	No. of Stomachs in which they occurred
7. *Sebastes marinus* (redfish). Four, 53 to 117 mm.	1
8. *Tylosaurus marinus*. One, 135 mm.	1

CONCEPTION BAY

Materials and Methods

The author examined 112 stomachs of bluefin caught between July 20 and September 19, 1966 in Conception Bay, Newfoundland. Many of the stomachs were in an advanced stage of digestion because the time interval between capture and removal and freezing of the organs varied from 6 to 15 hours (occasionally as long as 24 hours). This probably also explains the high percentage (28%) of stomachs found to contain 5 ml or less of food.

The stomachs, which had been preserved in 5 - 10% formalin, were cut open by a longitudinal incision. The contents were placed into a narrow gauge sieve and a hose was used to remove material trapped in the internal corrugations of the stomach wall and also to disperse the digested material (liquid) in the sieve. Counts and measurements were then made of all organisms present, if identifiable. The contents were then placed in muslin bags and their combined and individual volumes were measured by means of water displacement in graduated cylinders of various sizes (10 ml - 1000 ml). The volume of bulky contents was measured with the aid of a 5 gallon tank; displaced water was carried by a rubber hose (with tap) into a 1000 ml graduated cylinder. Volume measurements were made to the nearest ml, but errors of up to 5 ml are to be expected because of the problem of removing residual water from the stomach contents. Parasite samples (and other organisms where necessary) were removed for positive identification at a later date.

The reporting of results follows the approach used by Reintjes and King (1953), King and Ikehara (1956) and Iversen (1962), which considers the number of organisms (where possible), the frequency of their occurrence, and their individual and aggregate total volumes.

Statistical tests of the significance were not made as it is likely that the aforementioned variates are not distributed normally and that the means are correlated with the variances or standard deviations. Transformation of data would therefore be necessary before meaningful tests of significance could be applied (King and Ikehara, 1956). In addition, it appears that the stomachs of the larger bluefin contain more food than those of the smaller bluefin, but the larger fish eat less per pound of body weight (Figure 24). The great variability of the data reduces the opportunity of demonstrating statistically significant differences.

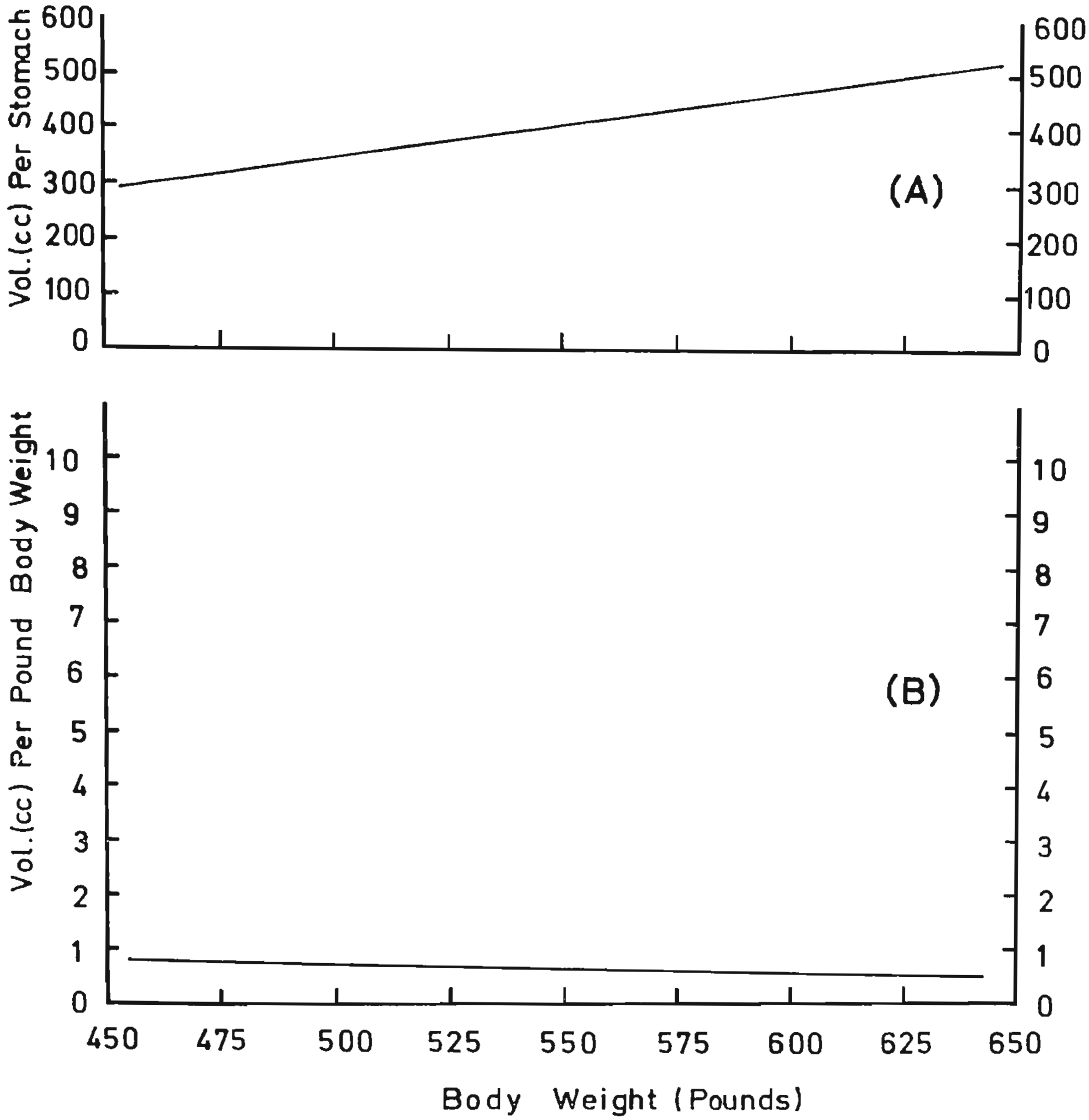


FIGURE 24

REGRESSIONS OF (A) FOOD VOLUME PER STOMACH AND (B) FOOD VOLUME PER UNIT BODY WEIGHT ON TOTAL BODY WEIGHT FOR 112 BLUEFIN CAUGHT IN CONCEPTION BAY, 1966

However, these trends appear to be common to yellowfin (*Neothunnus macropterus*) and bigeye (*Parathunnus sibi*), (King and Ikehara, 1956) and to albacore (*Thunnus germo*), (Iversen, 1962). The parameters therefore do not appear to be independent, hence the assumption underlying the common tests of significance would be violated.

Results

The contents of the 112 bluefin stomachs, tabulated according to the number and percentage of stomachs in which they occurred, are recorded in Table 14.

Table 14 The Stomach Contents of 112 Bluefin Caught in Conception Bay, 1966

Food Items		No. and % of Stomachs in which occurred.	
1.	Empty (other than parasites)	10	8.9%
2.	5 cc or less (including parasites)	31	27.6%
3.	*Illex illecebrosus* and possibly *Gonatus fabricii* (squid)	90	80.3%
4.	*Mallotus villosus* (capelin)	42	37.5%
5.	Unidentified fish/invertebrates	13	11.6%
6.	Gadidae, probably *Gadus morhua* (cod) and *Microgadus tomcod* (tomcod)	10	8.9%
7.	*Mugil cephalus* (mullet). Bait	6	5.3%
8.	*Clupea harengus* (herring)	4	3.5%
9.	*Scomberesox saurus* (needlefish, billfish, skipper or saury).	4	3.5%
10.	Feather	2	1.7%
11.	Decapod limb (chela?)	1	0.8%
12.	Kelp	1	0.8%

A detailed quantitative and qualitative list of the recorded food organisms and stomach parasites may be found in Appendix 3.

In spite of the variety of food utilised by the Conception Bay bluefin, only two items were of primary importance, the squid and the capelin. Figures 25 and 26 show the percentage of occurrence (percentage occurrence) and the comparative importance by volume (percentage volume) of the food items obtained during the feeding period, July 20 - September 19, 1966. A high result for either or both of these parameters indicates the relative importance of the food-species in question to the diet of the bluefin.

The squid rank highest in percentage occurrence (80%) and second in percentage volume (25%). Williamson (1962) noted their importance. The capelin, in contrast, rank second in percentage occurrence (37%) and highest in percentage volume (65%), indicating that they are only occasionally utilised, but in great bulk. The Gadidae, herring and needlefish appear to be of secondary importance.

The percentage occurrence and percentage volume of the individual food items were also grouped by month; July, 72 tuna; August, 30 tuna; September, 10 tuna, in order to determine the possible food succession (Figures 27 and 28). The results of this grouping were as follows:

Squid: There appears to be an increase in percentage occurrence from 78% - 80% - 100%, for the months of July, August and September,

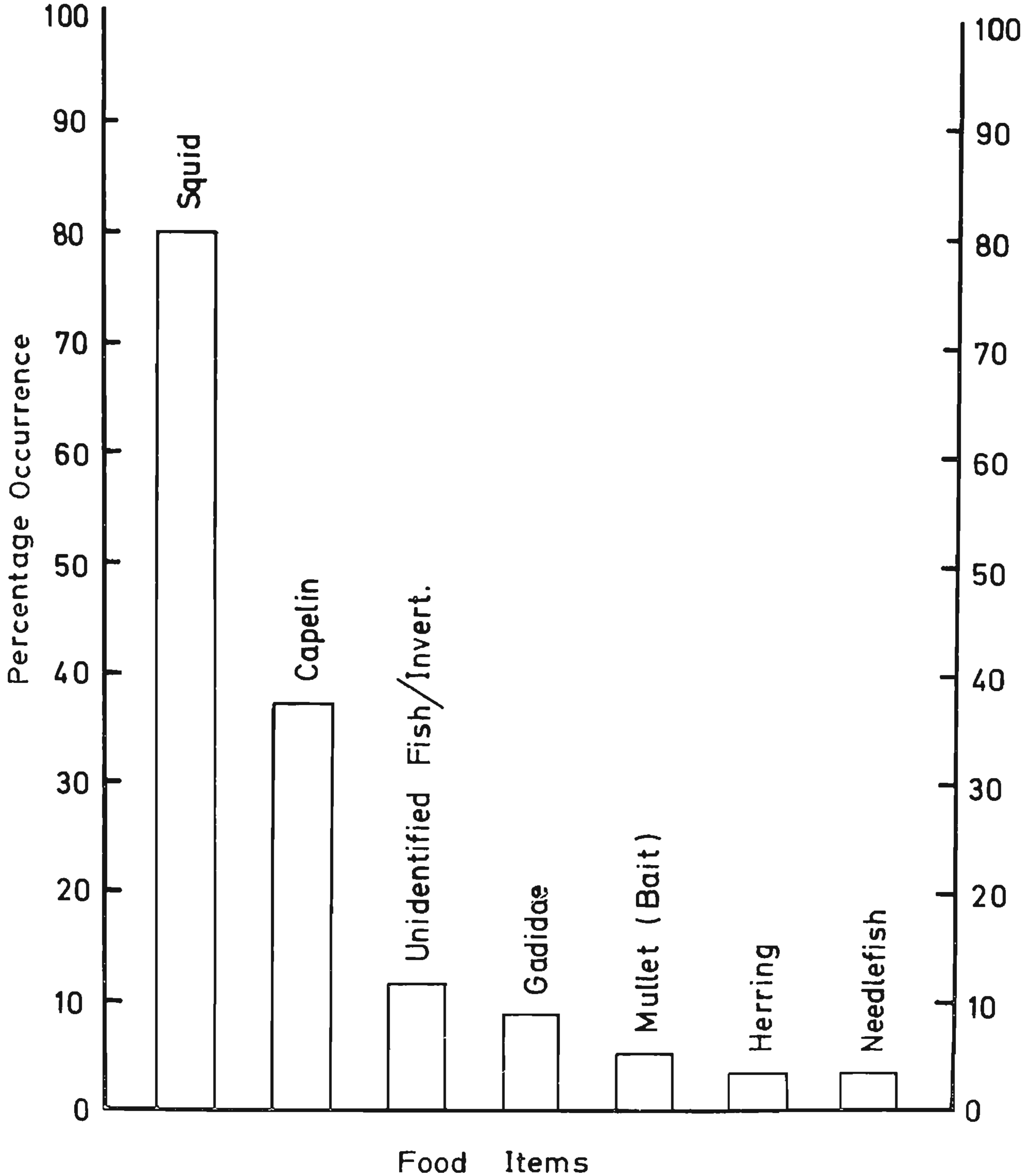


FIGURE 25

THE PERCENTAGE OCCURRENCE OF MAJOR FOOD ITEMS IN THE BLUEFIN DIET, CONCEPTION BAY, 1966

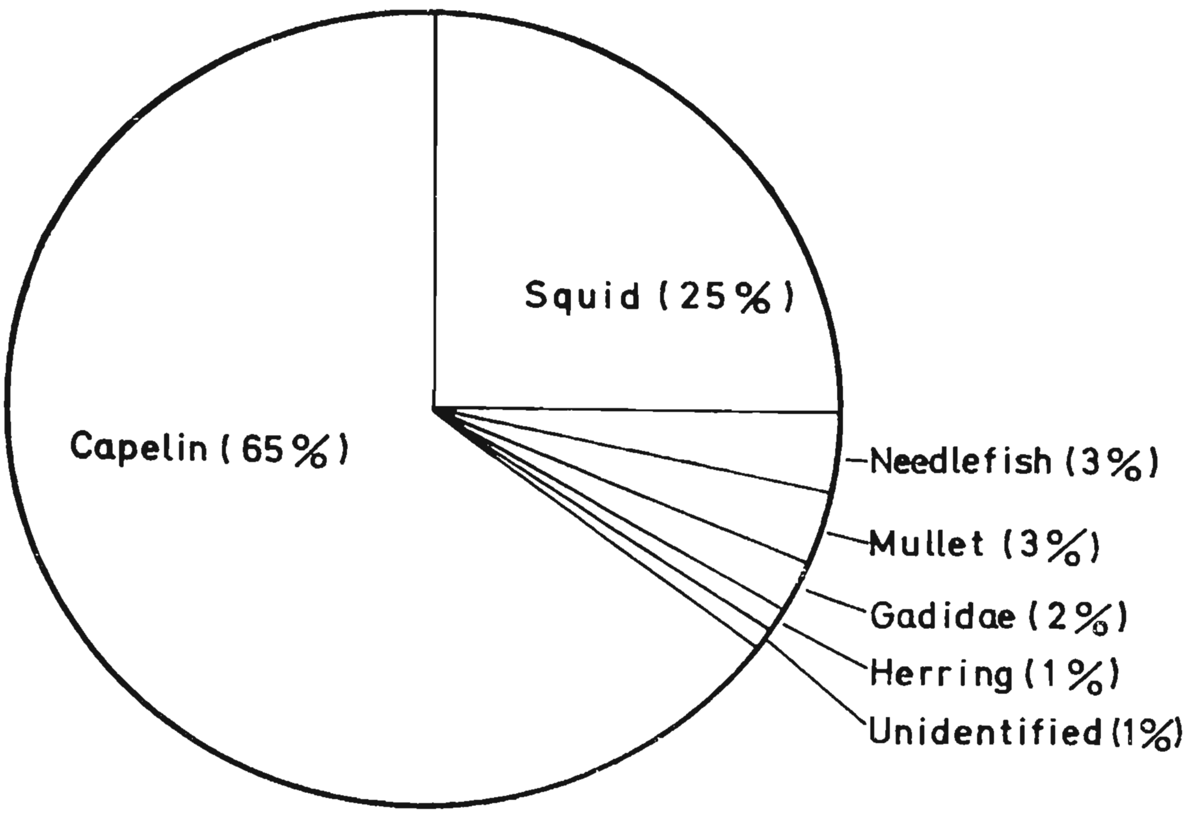


FIGURE 26

THE COMPARATIVE IMPORTANCE IN VOLUME OF MAJOR FOOD ITEMS IN THE BLUEFIN DIET, CONCEPTION BAY, 1966

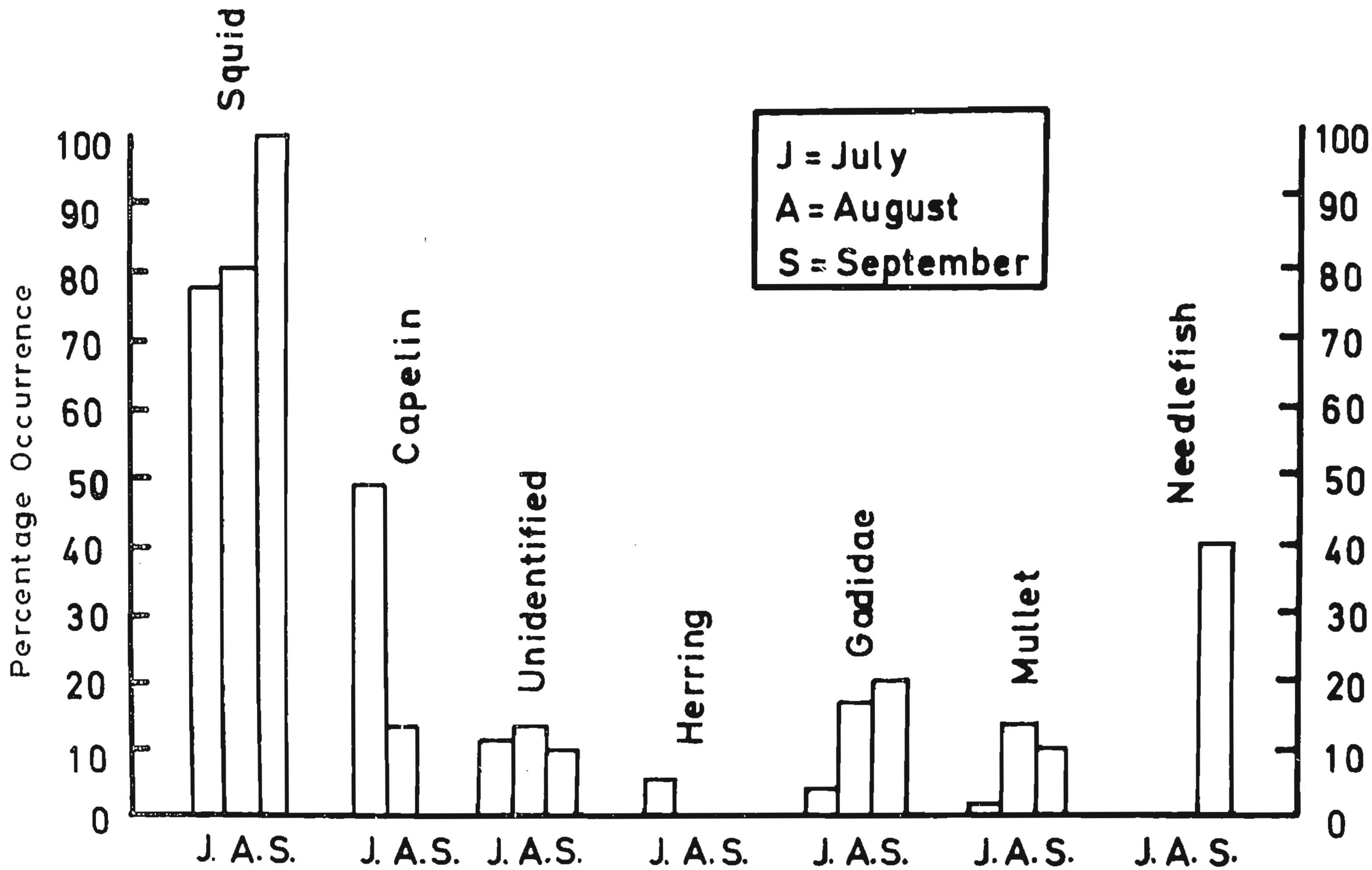


FIGURE 27

THE PERCENTAGE OCCURRENCE OF MAJOR FOOD ITEMS IN THE BLUEFIN DIET FOR THE MONTHS OF JULY, AUGUST AND SEPTEMBER, 1966, IN CONCEPTION BAY

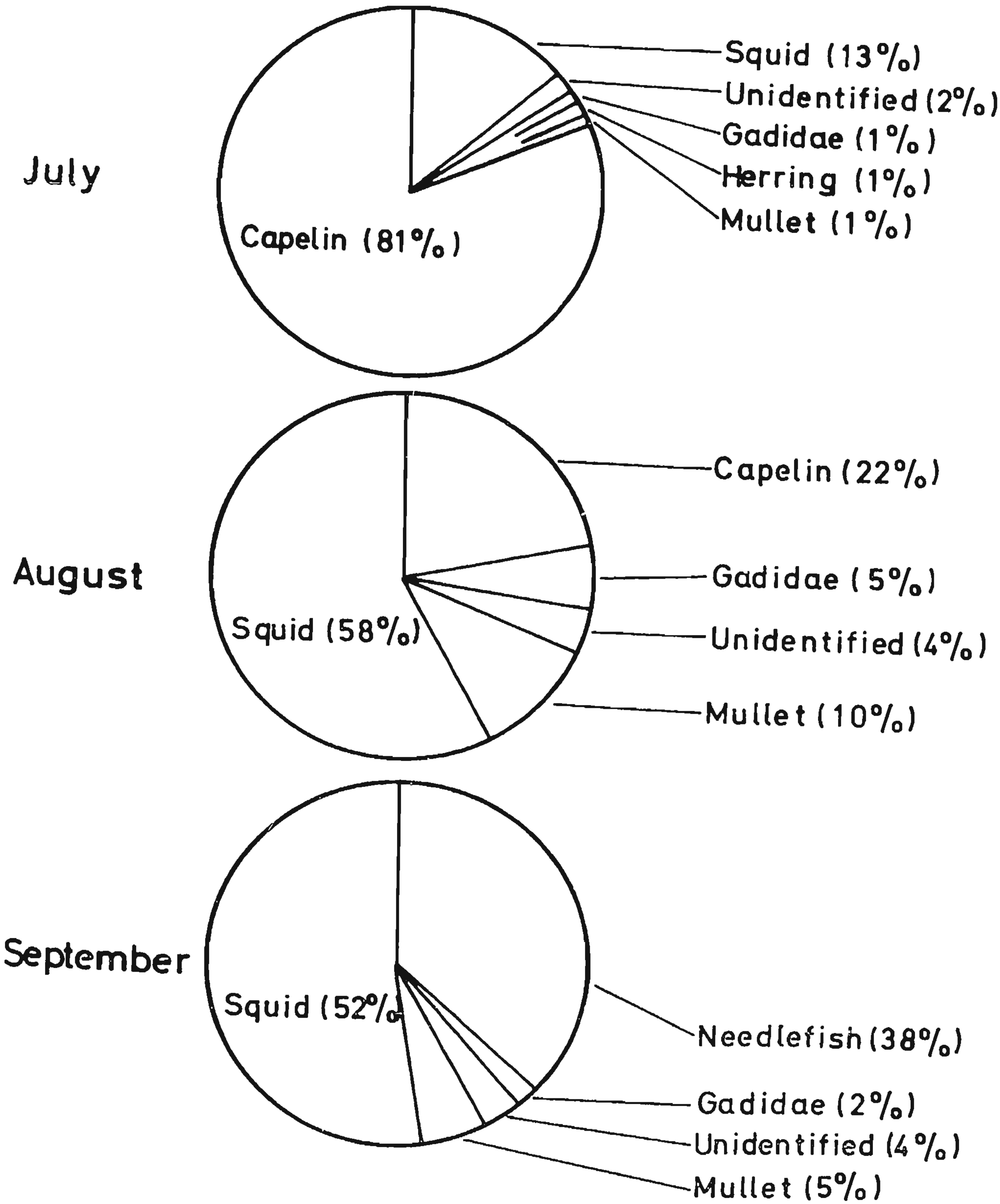


FIGURE 28

THE COMPARATIVE IMPORTANCE IN VOLUME OF THE MAJOR FOOD ITEMS IN THE BLUEFIN DIET FOR THE MONTHS OF JULY, AUGUST AND SEPTEMBER, 1966, IN CONCEPTION BAY respectively. Their percentage volume is low in July (13%) but increases in August (58%) followed by a slight decline in September (51%).

Capelin: The percentage occurrence is at a maximum in July (49%) but decreases markedly in August (13%) and September (0%). The percentage volume parallels the trend with 81% in July, 22% in August and 0% in September.

Needlefish: These fish are only present in September; their percentage occurrence is 40% and their percentage volume is 38%.

Herring: They appear to be utilised only in July, with a 5% percentage occurrence and a 1% percentage volume.

Gadidae: These show a monthly increase in percentage occurrence (4% - 17% - 20%), but a percentage volume peak in August (5%) as opposed to 1% in July and 2% in September.

Thus the squid are the major source of food throughout the feeding period in Conception Bay, ranking first in percentage occurrence and first in percentage volume, other than in July which is dominated by capelin. The needlefish are second only to squid in both percentage occurrence and percentage volume in September. All other food items appear to be of secondary importance, as has been previously indicated.

Feeding habit studies of the western Atlantic bluefin therefore indicate that the fish is an opportunistic feeder, taking whatever prey is available within broad food categories. This is particularly evident in Conception Bay where the time of maximum concentration of a specific prey is clearly correlated with the maximum percentage of occurrence and percentage volume of that organism in the bluefins diet. The capelin, for instance, moves inshore to spawn in Newfoundland waters in late June to mid-July (Templeman, 1948), a period in which their major contribution to the bluefin's diet is indicated by their percentage volume (81%) and their percentage occurrence (49%). The squid (Illex illecebrosus) migrates inshore from the "Banks", possibly in pursuit of the capelin and reaches the eastern coast of Newfoundland by late June. Its occurrence inshore may also be partly dependent on the local weather conditions. The largest concentrations occur at the traditional squid-jigging grounds, such as Holyrood (South Conception Bay), where it arrives earliest (June) in the season and remains latest (November), (Squires, 1957). The bluefin, a climax predator, in turn pursues the squid which has a minimum monthly percentage occurrence and percentage volume in the bluefin diet of 78% and 13% respectively.

The needlefish is a periodic visitor to the Gulf of Maine and Nova Scotia from the warmer offshore or southern waters and may be caught from mid-June to October or November (Bigelow and Schroeder, 1953). Environmental conditions permitting, it occasionally migrates as far north as eastern Newfoundland and, in 1966, it was observed in Conception Bay for the first two weeks in September. This correlates with its high percentage occurrence and percentage volume in the stomachs of bluefin for the period from September 1st to 17th only.

From this information it is clear that bluefin have a varied diet and that the selected foods consist of animals that are locally abundant and which may be either pelagic or demersal.

Stomach Parasites

Tiews (1962) includes two intestinal parasites, Hirudinella clavata (Menzies, 1791) and Contracaecum (Thynnascaris) legendrei (Dollfus, 1933) in a list of thirteen parasites found in Thunnus thynnus L. However, literature on stomach parasites of bluefin appears to be limited.

The author analysed 112 bluefin stomachs and four species and one class of parasites were identified (Table 15). The percentage infection by each species was also recorded.

Table 15 The Stomach Parasites of Bluefin Caught in Conception Bay, and Their Percentage Infection

Class	Species	Percentage Infection
1. Nematoda:	Contracaecum (Thynnascaris) legendrei (Dollfus, 1933)	71%
2. Trematoda:	Hirudinella (Fasciola) clavata (Menzies, 1791)	52%
3. Copepoda:	Lernaeocera branchialis (Linne, 1767)	16%
4. Palaeoacanthocephala:	Bolbosoma thunni (Harada, 1935)	5%
5. Cestoda:	Unidentified (only gravid proglottids present)	.01%

Of the bluefin (71%) parasitised by Contracaecum legendrei, 47% had a light infection (0 - 20 nematodes), 17% had a medium infection (20 - 100 nematodes) and 6% had a heavy infection (100+ nematodes). The nematodes were possibly acquired from capelin, in which a juvenile form of Contracaecum is found. The presence of parasitic copepods coincided in all cases with the presence of cod remains. Lernaeocera adults are commonly found on the gills of cod. The parasites were identified with the aid of studies by Yamaguti (1958-1961) for all classes, Nigrelli and Stunkard (1947) for the trematodes, and Scott and Scott (1913) for the parasitic copepods.

Time of Feeding

Compared to its body weight, the bluefin stomach is small (Krummholz, 1959), and according to Moss (1967) the fish must therefore eat regularly and often to sustain its power. However, according to Tiews (1962), German hook and line fishermen have reported bluefin strikes mainly from sunrise to about 11:00 hours. Turkish hook and line fishermen consider 09:00 - 10:00 hours to be the best fishing time (Iyigüngör, 1957). In contrast, California purse-seine fishermen expect successful bluefin sets in the afternoon but Canadian purse seiners, operating on an experimental basis in the Cape Cod area, have also made successful morning sets (McKenzie, 1965). Farrington in his book, "Fishing the Atlantic", described the bluefin fishing at Cat Cay (Bahamas) as being best in the morning (p. 234). These conflicting reports may perhaps be partially explained by the catch locations being at different stages of the bluefin's feeding migration. In addition, the size of school is pertinent, i.e. fish in small schools are usually most voracious and their activity stimulates even tuna with full stomachs to take the bait (Inoue, 1959; Hotta, Kariya and Ogawa 1959).

In order to examine the daily trend of feeding in Conception Bay, the stomach volumes of 112 bluefin (cc per pound body weight) were plotted by one-hour periods corresponding to successful strike times. Results are shown in Figure 29. It is evident that while feeding takes place throughout the day, the major feeding period is from 11:00 - 15:00 hours. This result is substantiated by the successful strike data (Figure 30), which indicate that 201 (83%) of a total of 230 recorded successful strikes were made between 10:00 and 17:00 hours. The author appreciates that a reduced fishing effort before 09:00 hours and after 19:00 hours has accentuated the mid-day catch and feeding peak but not to the extent of invalidating results. In addition, the suggested bias in fishing effort is compensated, to a certain extent, by some of the fishing boats ceasing operations at the mid-day lunch period.

The results differ markedly from those obtained for skipjack tuna (*Katsuwonus pelamis*), (Uda, 1940) and albacore (*Thunnus germo*), (Iversen, 1962), both of which feed mainly in the early

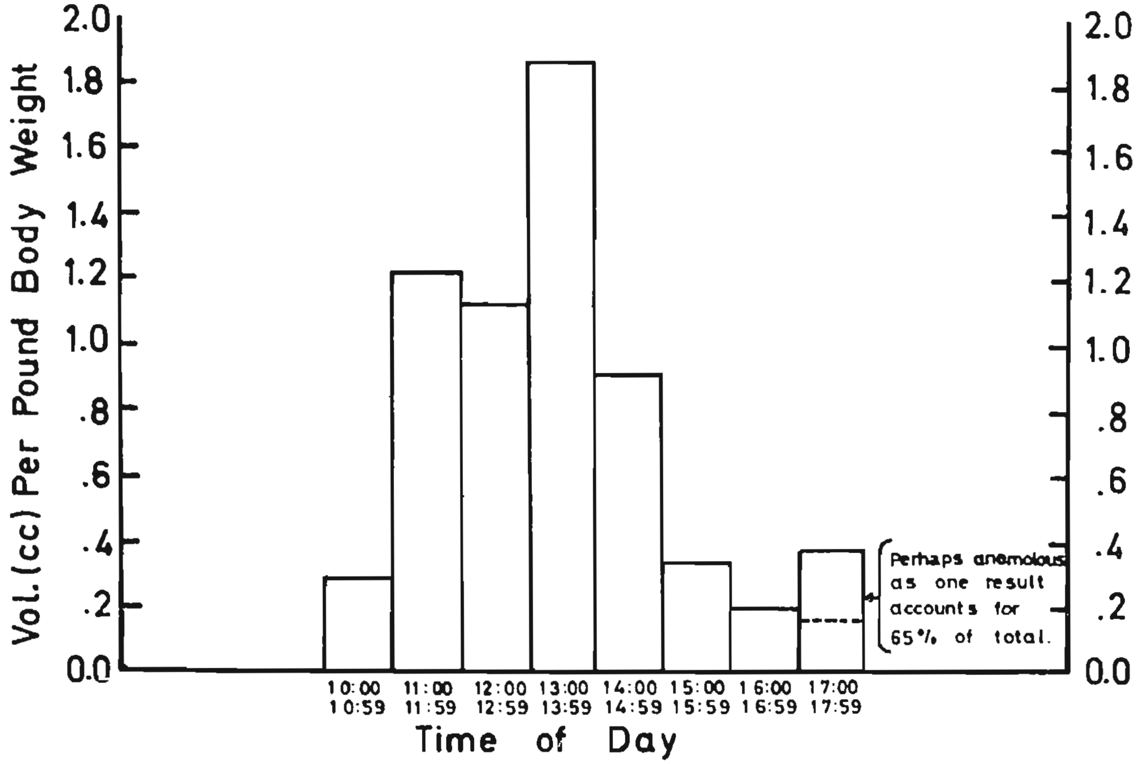


FIGURE 29

THE VARIATION IN STOMACH CONTENT IN RELATION TO THE TIME OF DAY WHEN HOOKED, CONCEPTION BAY, 1966

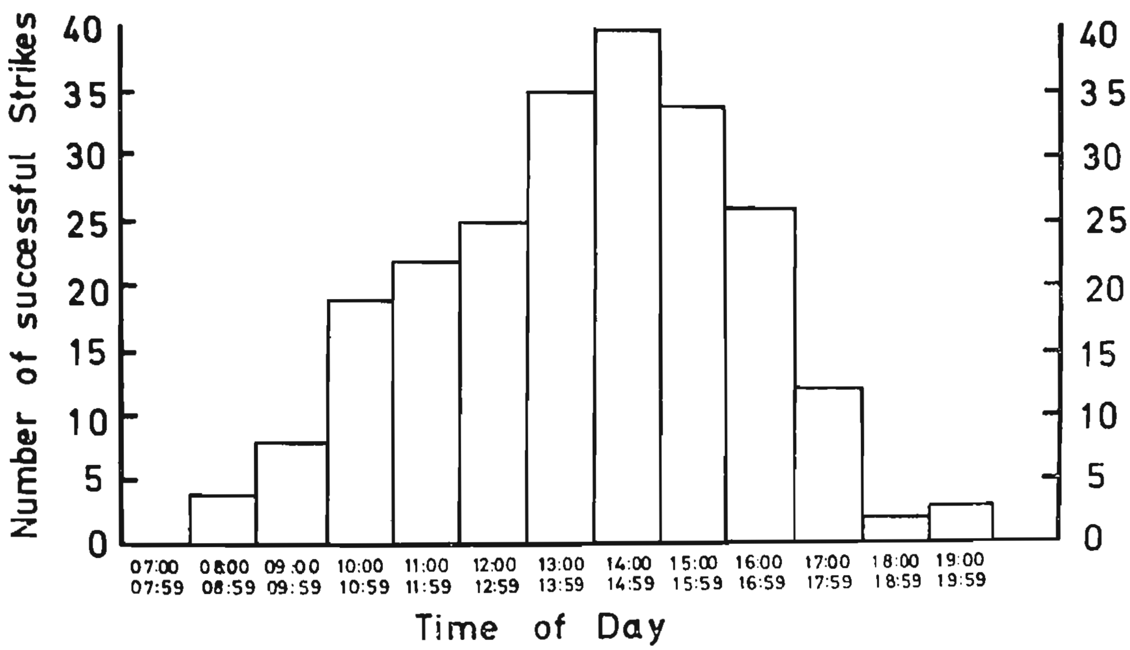


FIGURE 30

THE NUMBER OF SUCCESSFUL STRIKES IN RELATION TO THE TIME OF DAY WHEN HOOKED, CONCEPTION BAY, 1966 morning and again near sunset. Nakamura (M.S.) suggests that this reflects the lessened availability of forage due to the downward daytime migration of zooplankton, the prey of much tuna forage. This does not appear to be relevant to Conception Bay bluefin as their primary forage organisms, Illex illecebrosus are not reported to show a regular diurnal movement with respect to depth and their depth distribution is considered unpredictable in relation to time (Fishermen's reports; Williamson, 1965). The major feeding period does occur, however, during the time of maximum diurnal water temperatures and presumably the time of maximum underwater visibility, both of which may be controlling factors.

It is not known at present whether bluefin feed at night, but according to Watanabe (1958) both bigeye (Thunnus obesus) and yellowfin (Thunnus albacares) do. A histological comparison of the retinas of yellowfin, bigeye, and skipjack (Katsuwonus pelamis) indicated little difference in visual potential but albacore (Thunnus germo) or (Thunnus alalunga) are reported to have at least twice as many cones as the previously mentioned species (Matthews, M.S.) Albacore therefore have the capability for comparatively keener night vision. On the basis of these observations and experiments on other members of the genus Thunnus, it seems reasonable to conclude that bluefin are capable of feeding at night. Experimental night fishing, associated stomach analysis and histological examination of the bluefin retina will be necessary to validate this conclusion.

SECTION VII

WATER TRANSPARENCY AND ITS RELATION TO CATCH SUCCESS

The intensity of light impinging on the sea surface depends on the altitude and azimuth of the sun and the amount of cloud cover. The degree of light penetration into the sea is reduced by surface reflection (increased by wave action) and further attenuated by absorption and scattering, (Blaxter, 1965), due to the presence of dissolved and suspended material. The loss of light energy, through a known distance of water, is commonly expressed as an attenuation length ($\frac{1}{\alpha}$), which is a measure of water clarity, i.e. long attenuation lengths (small values of alpha) are usually found offshore, whereas short attenuation lengths (large values of alpha) are associated with turbid and dirty inshore water (Hester & Taylor, 1965).

The rate of decrease of downward travelling light energy (radiation) can be defined by means of the extinction coefficient (Pettersson, 1936):

$$\mathcal{K}\lambda = 2{\cdot}30\left[\log I_{\lambda,z} - \log I_{\lambda,(z+1)}\right],$$

where $I_{\lambda,z}$ and $I_{\lambda,(z+1)}$ represent the radiation intensities of wave length on horizontal surfaces at depths z and (z + 1) metres. According to Sverdrup et al (1946) the extinction coefficient of a given wave length varies with the locality, depth and time. The maximum penetration in clear oceanic water is in the blue range of the spectrum (400 - 500mμ), whereas in coastal water the maximum penetration is in the green-yellow range (500 - 600 mμ). The composition of the light changes with increasing depth, as the spectrum narrows to the most penetrating wave length (Jerlov, 1951). The marked difference in extinction coefficient and wave length of maximum penetration exhibited by coastal and oceanic waters is commonly attributed to the relative presence of minute suspensoid particles, dominant in oceanic waters, and of "yellow substances" (Kalle, 1938), dominant in coastal waters.

The transparency of water in relation to radiation of different wave lengths can be expressed by means of the percentage amounts of radiation which penetrate a one-metre layer. According to Sverdrup et al (1946), the greatest transparency of the clearest oceanic water is at a wave length of 480mμ(blue) and of coastal water is at a wave length of 530mμ or higher (green-yellow).

No teleosts have been shown <u>not</u> to have colour vision. They are most sensitive to the colour of light predominating in their environment (Blaxter, 1965). According to Borisov and Protasov (1960) bluefin have maximum sensitivities of 555mμ(light adapted) and 505mμ(dark adapted). Thus there is a "Purkinje shift" in the spectral sensitivity of the eye as photopic (cone) vision changes to scotopic (dark) vision. Bluefin would therefore appear to be suited to vision in coastal waters. It is not known whether they change their visual pigment when in their oceanic environment. Other research related to tuna vision has, to date been limited to studies of visual acuity in the skipjack (Katsuwonus pelamis), yellowfin (Thunnus albacares) and the little tunny (Euthynnus affinis), (Nakamura, 1964).

Because of evidence that the tuna visually locate their prey at close range, transparency probably has considerable relevence to catch success or failure (Magnuson, 1962). Murphy (1959) suggested that sight-feeders (such as tuna) might temporarily leave an area due to the available forage being obscured by an increase in phytoplankton density. According to Russell (1936), the opacity of the silt laden waters of the eastern end of the English Channel and the southern North Sea appears to be an effective barrier to bluefin. Iversen (1962) investigated albacore stomach volumes in relation to secchi disc observations and found higher values (stomach volume) in the mid-range of light penetration, approximately 22 metres. Yabe, Yabutu and Ueyanagi (1962) and Laevastu and Rosa (1962) found that secchi disc readings under good or optimum tuna-fishing conditions varied from 15 - 35 metres. In the Mediterranean, Lozano Cabo (1957, 1958) and Arena (1959), unlike Sara (1960), were able to correlate the size of bluefin catch and the water transparency, the optimum being 15 - 16 metres. Iversen (1962) found that the most successful foraging took place in water which represented a compromise between conditions of excellent visibility (reduced amount of tuna forage) and waters of low clarity (heavy standing crops of tuna forage). Land run-off may also be associated with low transparencies. The variation in optimum water transparency, as determined by secchi disc (15 - 35 metres), in relation to tuna catch is probably accentuated by the different fishing techniques utilised, the different hydrographic conditions, and the different visual capabilities of the various tuna species.

According to Hester and Taylor (1965), visibility of an object under water during the day is dependent on its contrast with the background. This is affected by the sun's elevation, cloud cover and depth of the object. The distance over which it can be seen is controlled by water clarity as measured by alpha. For horizontal paths of sight, the contrast between an object and its water background diminishes exponentially with the distance. Thus sighting range depends on the distribution of the light field under water, the water clarity, the position of the object in relation to the fish, and the nature of the observed object. Light or shiny objects, for instance, induce greater feeding response in tuna than dark or dull objects, (Hsiao and Tester, 1955; Shomura, 1955 and Tester et al, 1954), presumably because brighter objects are more visible (Magnuson, 1962) due to their greater contrast with the background. Size and movement are other visual stimuli which similarly influence the intensity of the feeding response in tuna. Thus the mullet, which is commonly used as bluefin bait in Conception Bay, is probably visually stimulating to the tuna because of its silvery sides, and is preferred by the angler because of its resistance to decomposition on the trolled hook. The squid (*Illex illecebrosus*), another popular bluefin bait, although not as bright as the mullet, exhibits a greater movement when trolled because of its trailing tentacles and would probably be visually stimulating also.

Methods of submarine light measurement in addition to secchi disc, include the hydrophotometer (self-contained light source) and the submarine photometer. The latter detects and records, by means of photoelectric cells, the light intensity at the surface and at all depths down to approximately 150 metres. Through the use of filters, observations may be made in specific ranges of the spectrum. The technical problems associated with the construction and operation of such apparatus and the standardized technique proposed by the International Council for the Exploration of the Sea are discussed by Atkins et al (1938).

CONCEPTION BAY

In view of the apparent correlation between catch success and visibility a submarine photometer was constructed with the aid of the Technical Services of Memorial University and the Fisheries Research Board, St. John's, Newfoundland. Because of rapidly changing inshore hydrographic conditions, the photometer was designed to provide a continuous record of the quantity in foot candles, of green light (optimum penetration in coastal waters) reaching a specified depth. The author appreciates that within a limited budget it is impossible to design and construct an apparatus which is capable of compensating for the numerous operational errors involved in the under water measurement of light (see Atkins et al, 1938). However, accepting the foregoing qualifications it was hoped to detect a relationship between the time and frequency of bluefin strikes and the relative transparency of the water. The recording apparatus was anchored in thirty feet of water approximately 600 feet offshore in Holyrood Arm, Conception Bay. This location was chosen because of accessibility for apparatus maintenance and because it appeared to be a major catch area according to previous years' data.

The results were disappointing; insufficient synchronous catch and transparency data were obtained to attempt a correlation (see "Results"). However, the author considered that the comparatively successful functioning of the photometric apparatus warranted the inclusion of this section.

Materials and Methods

The complete photometric apparatus is shown in Figure 31 (A - B).

Electrical Components: Two Rustrak temperature recorders (model 133/135T) were similarly modified to act as surface and subsurface light sensitive recorders respectively. The modifications involved the removal of the thermistor in an arm of the

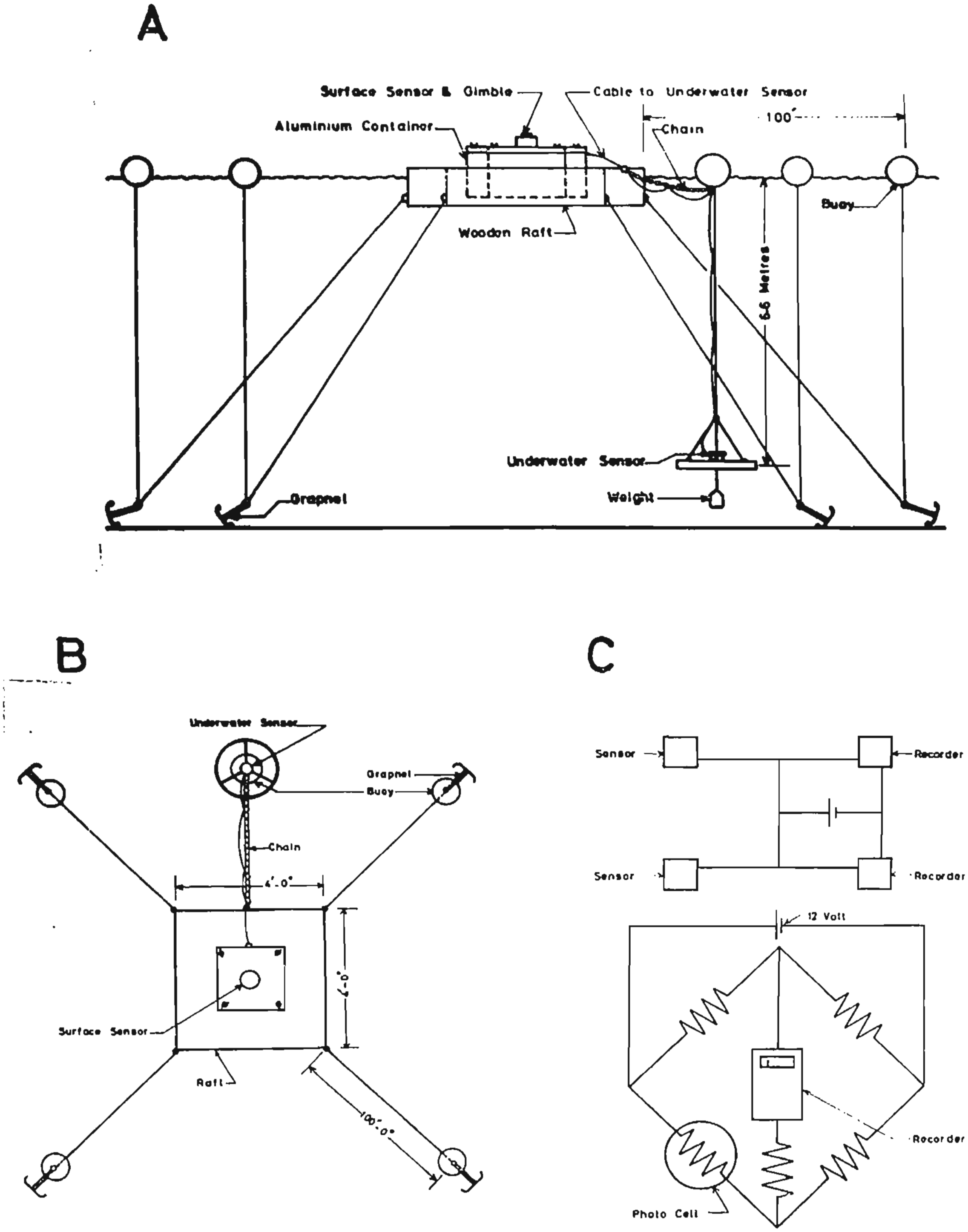


FIGURE 31

THE PHOTOMETRIC APPARATUS OPERATED IN CONCEPTION BAY: SIDE VIEW (A), TOP VIEW (B), AND BRIDGE CIRCUIT (C).

recorder's bridge circuit and its replacement with an RCA photo-conductive cadmium sulphide cell (#4402). In addition, a 20K ohm fixed composition resistor was placed in series with the detecting galvanometer (Figure 31C). A 12 volt wet cell battery provided sufficient power for at least two weeks continuous operation. The recorders were calibrated with a Weston foot-candle meter (model 614), using a 60 watt bulb as the light source. The applied voltage and hence light intensity was controlled by a Variac voltmeter. In both the surface and subsurface recorders, the amplitude of the applied signal (light intensity) was recorded by a stylus on pressure-sensitive chart paper, moving at a rate of one inch per hour. The stylus, striking once per second, thus produced a continuous trace.

Mechanical Components: The two recorders, battery and associated junction box were placed in a water proof but ventilated aluminium container. The lid rested on a rubber gasket and was secured by four hand-tightened bolts. The surface sensor, gimble-mounted to compensate for wave motion, was secured centrally to the lid of the aluminium container (Figure 32A). The subsurface sensor was mounted in a water proof brass structure (Figure 32B) at a depth of 6.6 metres. It was suitably weighted to prevent excessive movement. Both sensors were operated in conjunction with a green Kodak wratten gelatin filter (#58), with a dominant wave length of 540.2mμ, i.e. the region of the spectrum least attenuated by coastal water. Water absorbent material was placed

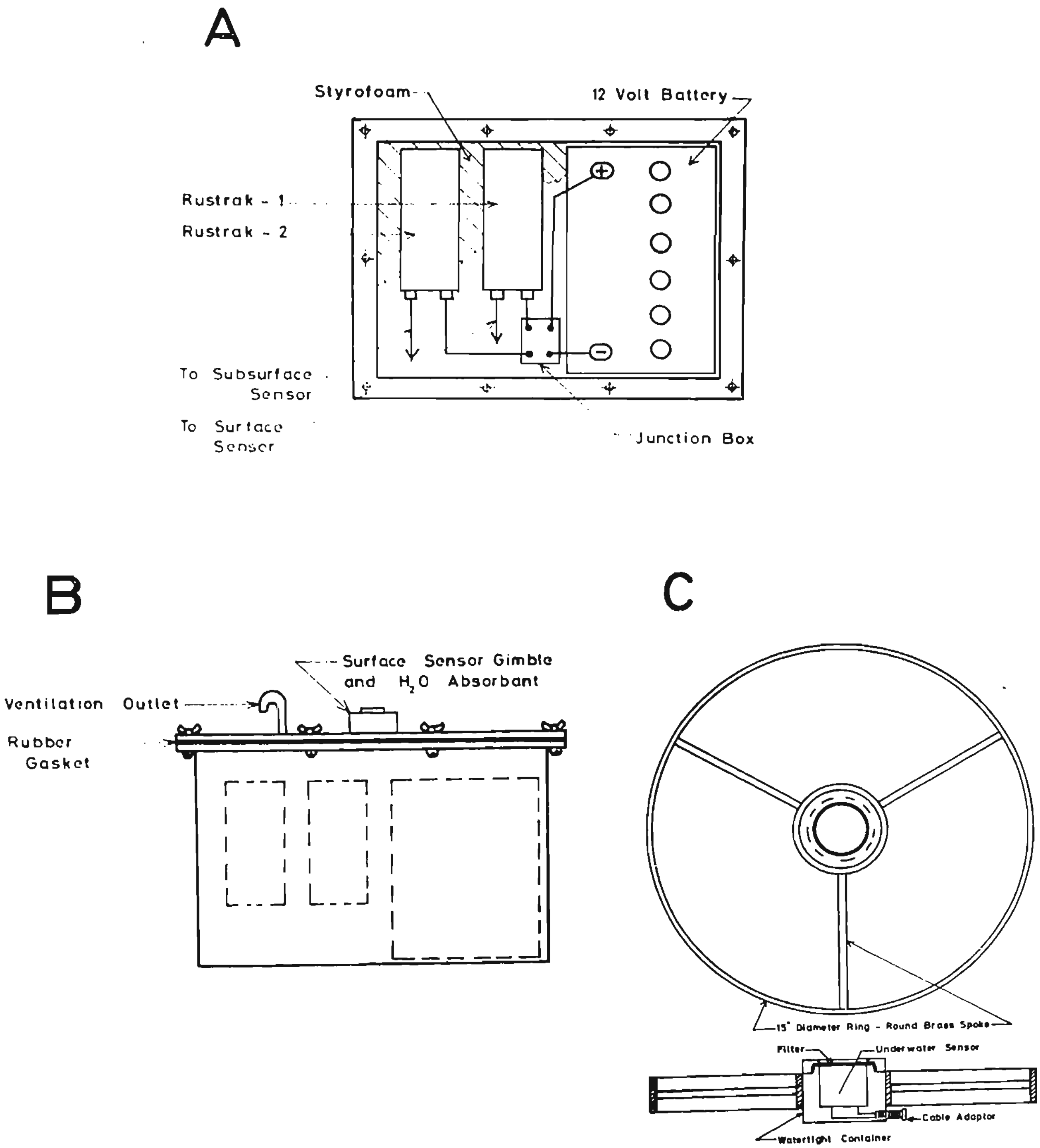


FIGURE 32

THE PHOTOMETRIC APPARATUS OPERATED IN CONCEPTION BAY: ALUMINIUM CONTAINER, SURFACE VIEW (A), SIDE VIEW (B), AND UNDERWATER SENSOR (C).

within the sensor containers to prevent misting.

Flotation and Anchorage: The aluminium container holding the surface sensor was secured in the central recess of a four foot square wooden raft, which was anchored by four grapnels (Figure 31 A - B). A coloured plastic buoy, approximately 100 feet from the raft, marked the position of each grapnel. The under water sensor was suspended from a similar buoy, which was attached to the raft by a chain, at a distance of approximately ten feet. The possible shadowing of the underwater sensor by the raft was thus prevented.

Results

Difficulties in obtaining certain components, particularly Kodak filters of the required specification, delayed the commencement of operations until September 19, 1966. An unforeseen problem then arose; the sea birds defecated on the surface sensor, hence invalidating the recorded data. This problem could not be solved immediately. As a temporary solution, the surface sensor and its recorder were removed from the raft, provided with their own power source, and placed ashore, approximately a quarter of a mile from their original location. An electrical fault caused a further delay but sufficient synchronised surface and submarine light data to permit evaluation of the apparatus were obtained before the final removal (in early November) of the raft and submarine recording equipment because of excessively rough seas. The usable data were analysed by means of a chart viewer with a calibrated scale constructed by the Technical Services of Memorial University. Thus the light intensity at the sea surface and at 6.6 metres, hence the relative transparency, could be compared for any given time of the day. Unfortunately, during this period from September 19th to early November only three bluefin were caught (the last catch of the season was on September 26th) and the majority of the tuna fishing boats ceased operation for the year. Any future operation of the photometric apparatus will require its relocation in a more suitable area, selected on the basis of the 1966 catch results, e.g. the Bauline "hot-spot", and the development of a bird scaring device.

SECTION VIII

CATCH ZONES

CONCEPTION BAY

Materials and Methods

Three hundred and eighty eight (388) bluefin were caught in Newfoundland waters in 1966, the majority in Conception Bay. The estimated strike locations of 234 of these fish were recorded on grid patterned diagrams of Conception Bay (see Section XIII). Because of the experience of the crews and their familiarity with Conception Bay and surrounding features a high degree of accuracy was achieved. Where possible, the locations of the other successful, but not recorded, strikes were verbally obtained from the crews and although not included in the following figures they fully substantiated the trends established from the log-sheet data. This was also true of unsuccessful strikes (pulled hook etc.) data, which proved harder to obtain. The ratio of unsuccessful to successful strikes was generally 2 or 3:1, depending on the proficiency of the fisherman and boat crew.

Results

The strike locations of the 234 bluefin are presented in Figures 33 and 34, in which they have been recorded by weekly intervals. The surface isotherms have been included to indicate the influence of temperature on bluefin distribution. This is particularly marked at the beginning of the season when the bluefin initially penetrate Conception Bay in the region of Cape St.

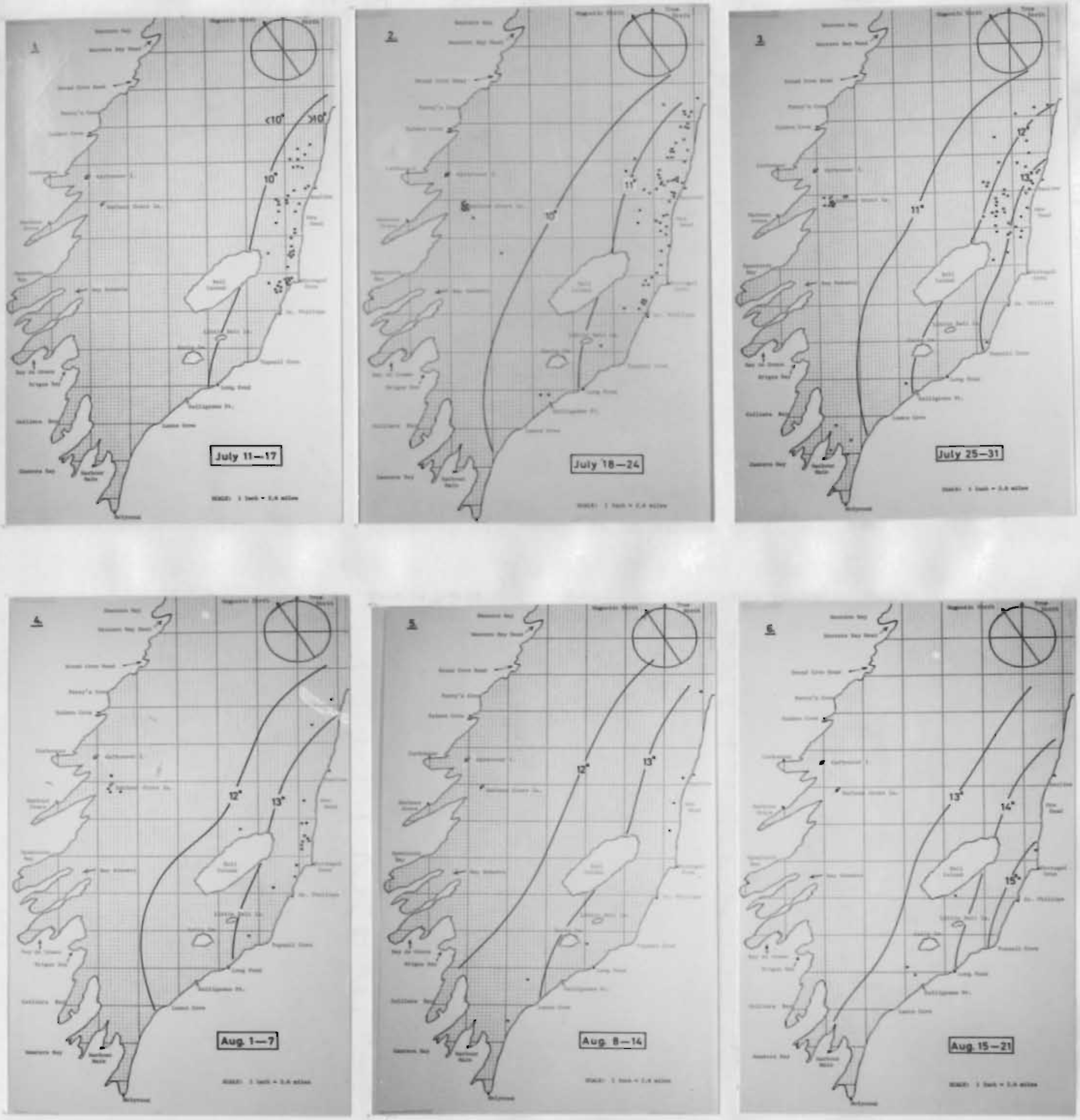


FIGURE 33

THE STRIKE LOCATIONS OF 212 BLUEFIN, RECORDED BY WEEKLY INTERVALS (JULY 11 - AUGUST 21), IN CONJUNCTION WITH THE SURFACE WATER ISOTHERMS, CONCEPTION BAY, 1966.

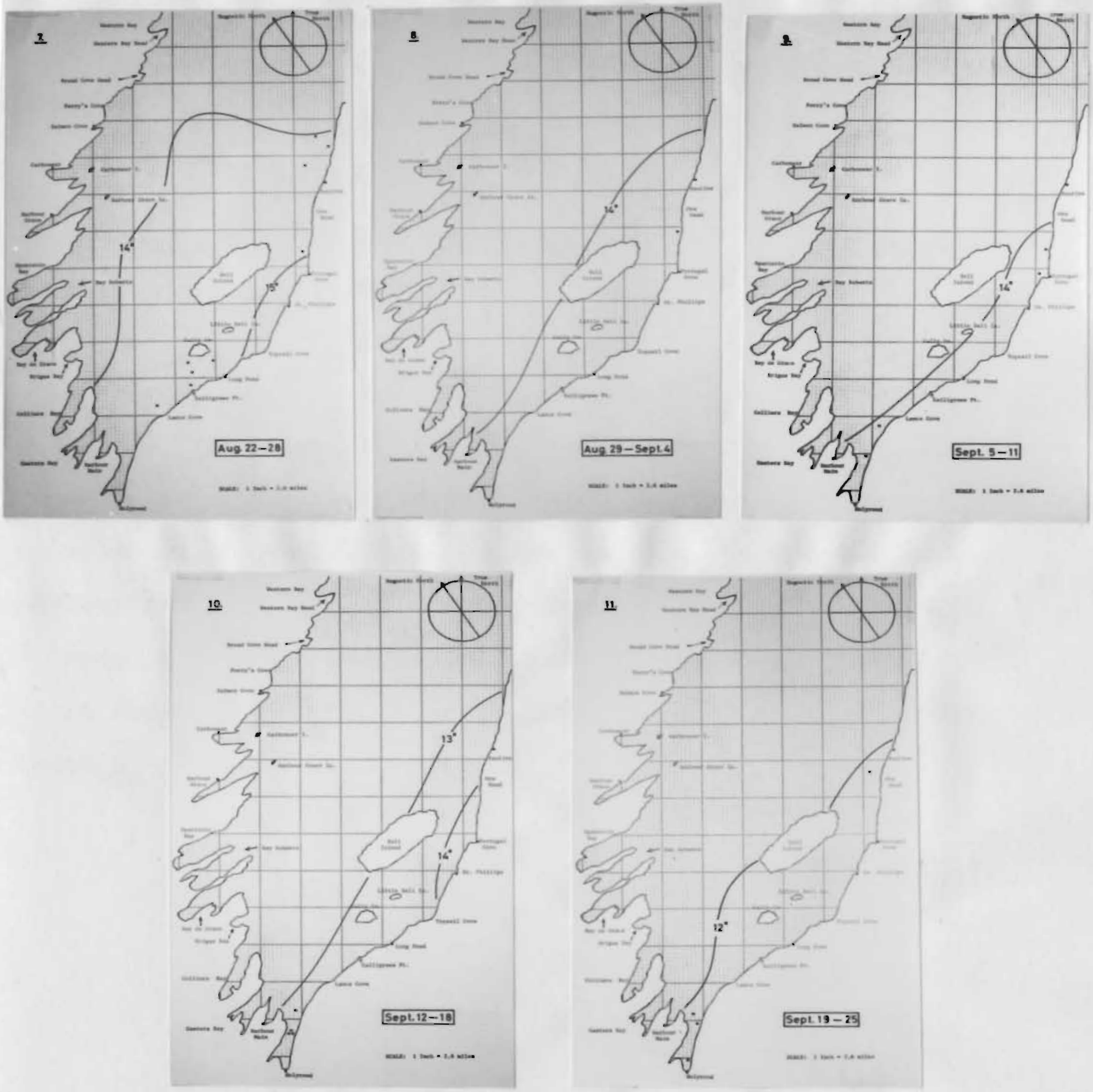


FIGURE 34

THE STRIKE LOCATIONS OF 22 BLUEFIN, RECORDED BY WEEKLY INTERVALS (AUGUST 22 - SEPTEMBER 25), IN CONJUNCTION WITH THE SURFACE WATER ISOTHERMS, CONCEPTION BAY, 1966.

Francis, but during August and September the surface waters of the entire Bay were in excess of the critical 10 degrees C with the resulting dispersion of catch locations. Food availability rather than temperature was probably the major factor influencing the distribution of bluefin during this period.

The total number of recorded bluefin caught in each zone (1 inch square = 6.7 square miles) during the 1966 season is indicated in Figure 35. The Bauline area (182 bluefin) and the Harbour Grace Island area (21 bluefin) were the major "hot spots". The inshore region of shallow banks between St. Phillips and Holyrood was also of importance (33 bluefin), but particularly Holyrood Arm in the last month of the season. The topography and water characteristics of these areas and their possible direct or indirect relationship to bluefin concentrations are discussed in Section X.

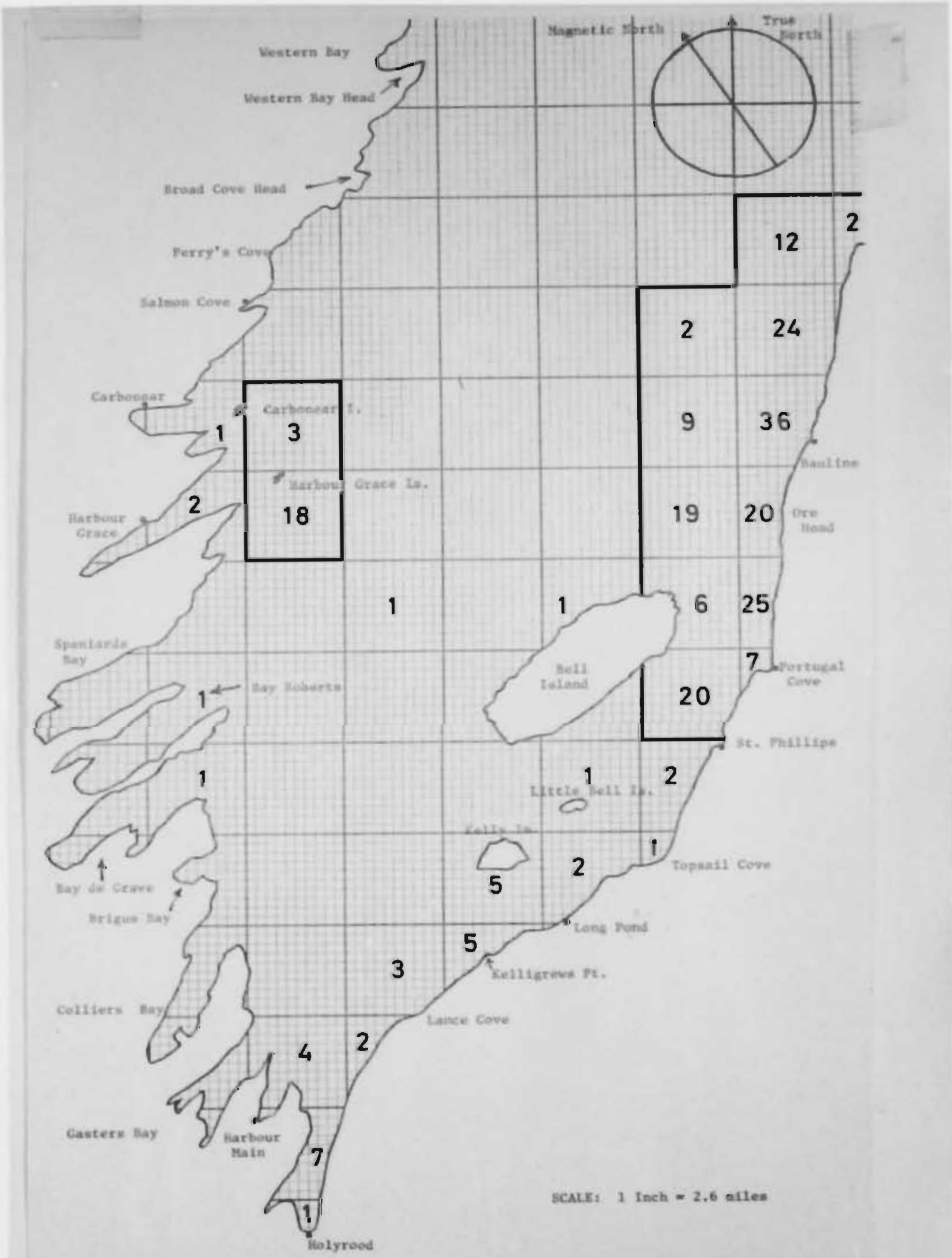


FIGURE 35

THE TOTAL NUMBER OF RECORDED BLUEFIN CAUGHT IN EACH ZONE OF CONCEPTION BAY IN 1966

SECTION IX

HYDROGRAPHY OF THE NORTH WESTERN ATLANTIC

To understand the hydrography of the Newfoundland area and the associated presence (or absence) of bluefin in Conception Bay, it is necessary to consider ocean relationships somewhat remote from the Newfoundland coast. This topic is discussed in considerable detail in view of the influence of hydrographic features and conditions on bluefin behaviour and on the temporal and spatial extent of their annual feeding migration.

Submarine Topography

The submarine topography of the Continental Shelf from Labrador to Cape Cod (Figure 36) is particularly pertinent to oceanographic conditions and to the fisheries as it is the area of confluence of the cold Labrador Current and the warm Gulf Stream. Their mixing provides the characteristic "slope water" which profoundly affects inshore waters by gradual mixing and direct incursion, the extent of which is related to the submarine topography. Water of deep oceanic origin is also able to penetrate inshore regions via three deep channels: the Hudson Strait, the Laurentian Channel and the Fundian Channel (Hachey, 1961).

The bottom deposits of this region follow a definite basic pattern (Shepard, 1948): sand predominates on the banks, mud in the deeper channels and troughs, and rock (or boulders) on inner zones along the shore.

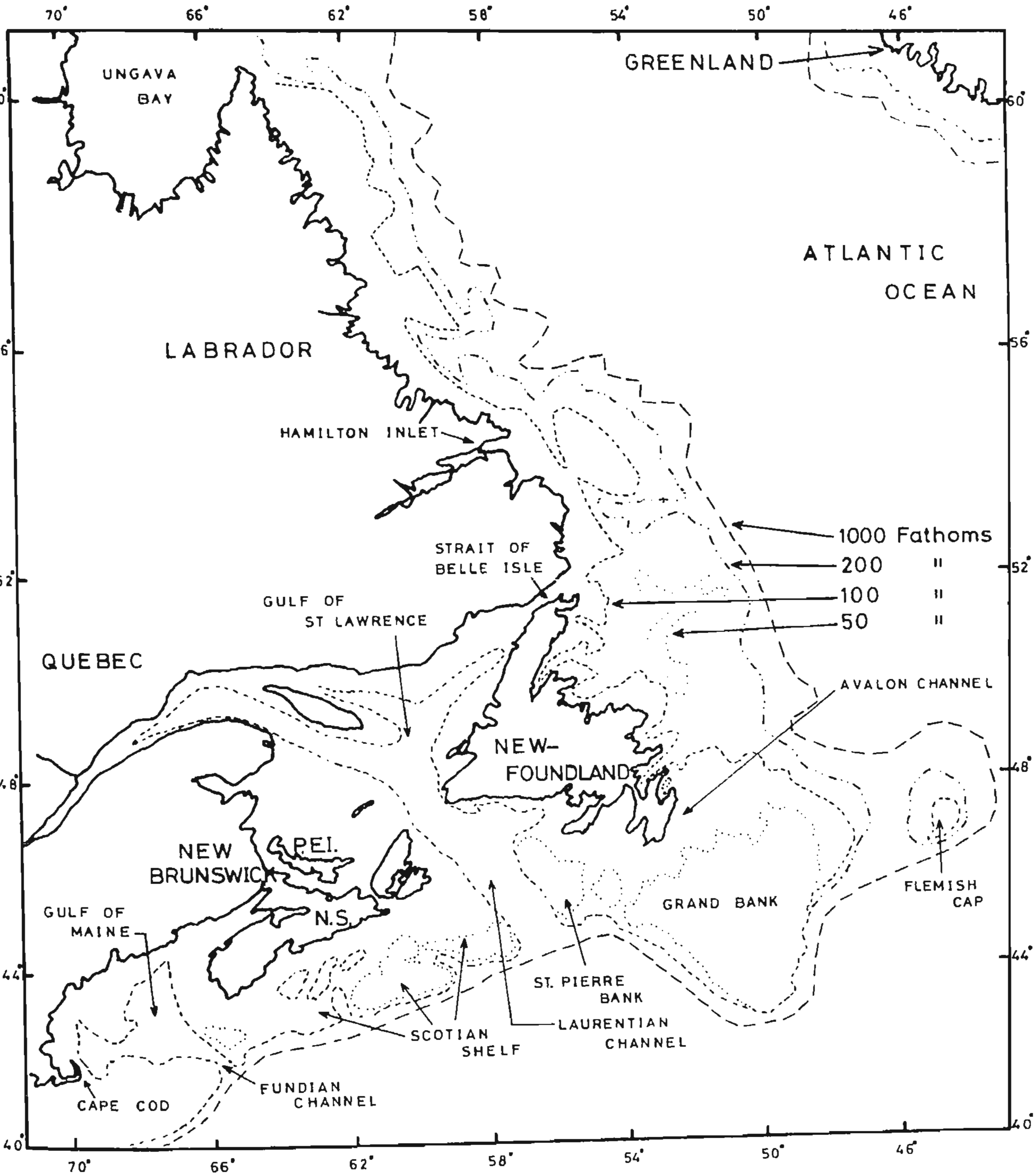


FIGURE 36

THE SUBMARINE TOPOGRAPHY OF THE CANADIAN ATLANTIC REGION

General Circulation

The circulation of waters of the upper layers in the North West Atlantic, dominated by the Gulf Stream System and the Labrador Current, is presented in Figure 37. The current velocities are high (Figure 37) and variable and their axes show considerable horizontal displacement. This results in the adjustment in location and strength of associated water masses with a resulting change in the environment, i.e. temperature, salinity, oxygen and nutrients (Dietrich, 1964).

Gulf Stream

The term "Gulf Stream" is reserved for that part of the Gulf Stream System between Cape Hatteras and the tail of the Grand Bank (Figure 37). It is a narrow channel, of comparatively high salinity water, extending to depths of 900 fathoms and acting as a boundary that prevents the warm water of the Sargasso Sea from overflowing the colder, denser waters on the inshore side. The northern edge of the stream, recognised by its comparatively high temperature, fluctuates between 250 miles (early winter and late summer) and 500 miles (spring and autumn) from the Nova Scotian coast. Within this major fluctuation there may be additional course variations and areas of rapid current flow (Fuglister and Worthington, 1951; Iselin, 1960).

Labrador Current

This current, characterised by its low temperature and low

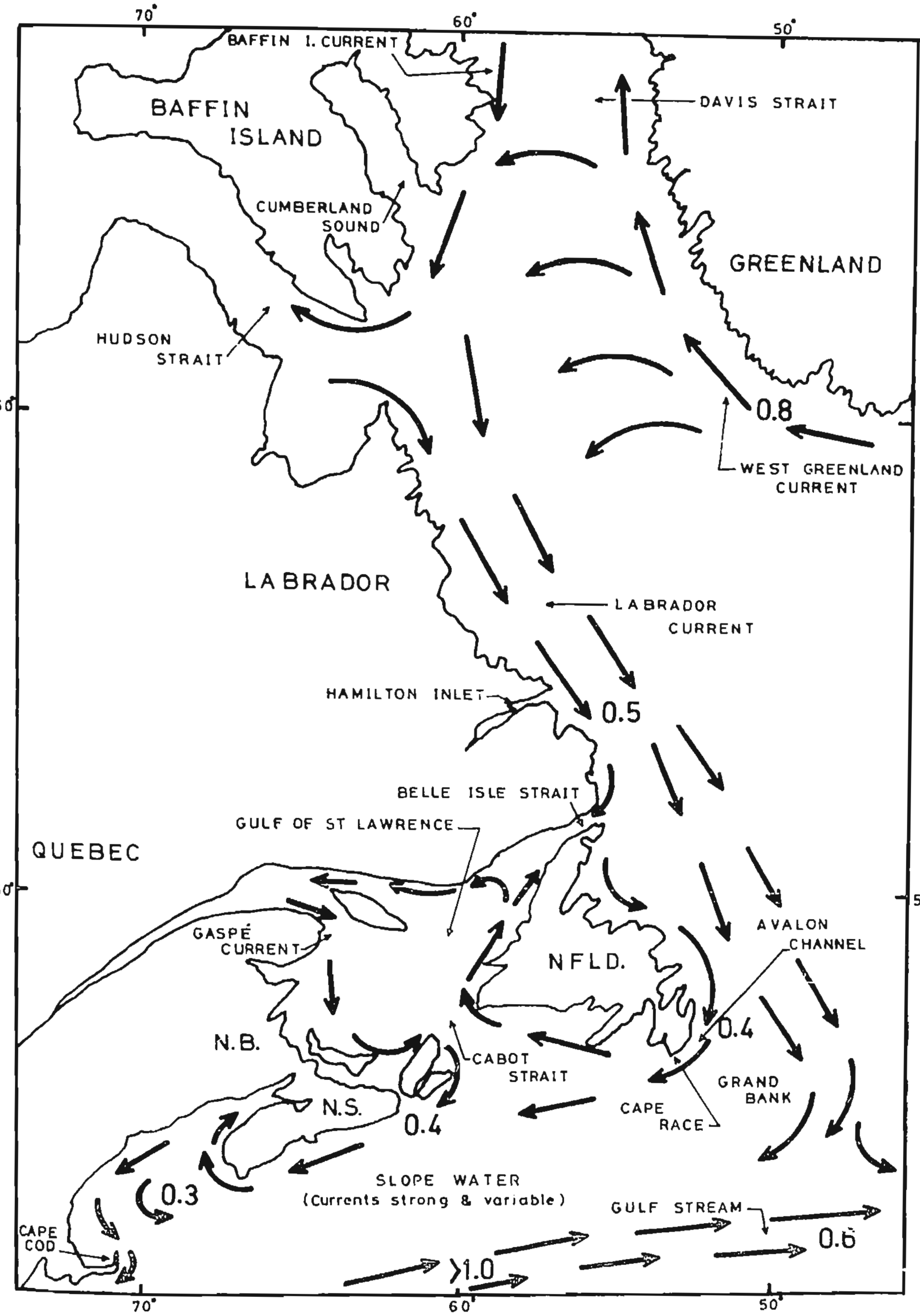


FIGURE 37

THE GENERAL CIRCULATION AND CURRENT VELOCITIES (KNOTS) IN THE NORTH WEST ATLANTIC salinity, is especially relevant to the author's thesis as it dominates the Conception Bay water mass. Iselin (1927) described the Labrador Current as a cold water stream which flows southward over the Continental Shelf inside the comparatively motionless, homogeneous mass of North Atlantic water (Figure 37).

According to Dunbar (1951), three major water masses contribute to the Labrador Current:

1. The Baffin Island Current (Polar origin).

2. The West Greenland Current (Polar origin - East Greenland Current; and Atlantic origin - Irminger Current).

3. Hudson Bay water (Polar origin).

Smith, Soule and Mosby (1937), on the basis of the "Marion" and "General Greene" expeditions, located the origins of the Labrador Current in the Cumberland Sound region, where the Baffin Island Current is joined by significant branches of the West Greenland Current.

The Labrador Current may be divided into an inshore and an offshore stream; the inshore stream confined to the Continental Shelf and containing the greater volume of cold Baffin Island and Hudson Bay water (Average temperature, −0.5 degrees C; average salinity, 33.5‰) and the offshore stream characterised by warmer West Greenland waters (Average temperature, 3.8 degrees C; average salinity, 34.6‰). Both southerly flowing streams follow the Labrador and Newfoundland coastline, under the influence of the earth's rotation which causes the current to turn to the right (Coriolis Force). A branch from the inshore stream passes through the Belle Isle Strait (50 fathoms) into the Gulf of St. Lawrence (Smith, Soule and Mosby, 1937). The major current continues south until it meets the northern face of the Grand Bank where the deeper water is split. A slope branch follows the eastern margin of the Bank, while a colder inner branch penetrates the Avalon Channel between the Grand Bank and the Avalon Peninsula. This inner branch rounds Cape Race, runs westward along the Newfoundland coast and contributes to the Gulf of St. Lawrence water mass via the Cabot Strait (Hachey, 1961). A southern branch is deflected toward the Nova Scotian Banks at right angles to the Laurentian Channel (Bjerkan, 1919). The outer stream of the Labrador Current which flows over and to the east of the Grand Bank splits into easterly and westerly flowing segments and finally confronts the Gulf Stream, resulting in the formation of "slope water". The "tail" (south east margin) of the Grand Bank is considered to be the terminus of the Labrador Current proper. The changing relative strengths of the Labrador Current and the Gulf Stream are little understood and produce complicated changes in the location of their common boundary, as indicated by the course and drift rates of icebergs (Hachey, Hermann and Bailey, 1954).

<u>Horizontal and Vertical Temperature Distribution (Summer)</u>

Most of the major currents in the Newfoundland area are recognisable from the surface temperature distribution (Figure 38A). Spring and summer heating decreases the density of the surface waters, hence throughout the summer there are three layers of water along the Newfoundland coast; an upper warm layer and an intermediate cold layer, both derived from the colder inshore branch of the Labrador Current and a deep warm layer derived from the warmer offshore branch of the Labrador Current (Figure 39). In the coastal area south of Baccalieu Island (mouth of Conception Bay) the water is too shallow (less than 100 fathoms) for this deep warm layer to be present. The thickness of the two upper colder layers which are present varies by as much as 20 fathoms or more from year to year (Templeman, 1966). On the south and western slopes of the Grand Bank, incursions of "slope water" introduce waters of temperatures as high as 10 degrees C (Hachey, 1961).

Horizontal and Vertical Salinity Distribution (Summer)

The surface salinity distribution (Figure 38B) indicates that the waters of the Labrador Current are composed of many tongues and eddies. The salinity of coastal water is generally less than 33.0‰ and of "slope water" as high as 34.5‰. In the Labrador Sea salinities are less than Atlantic water and vary from 34.5‰ - 35.0‰ (Hachey, 1961).

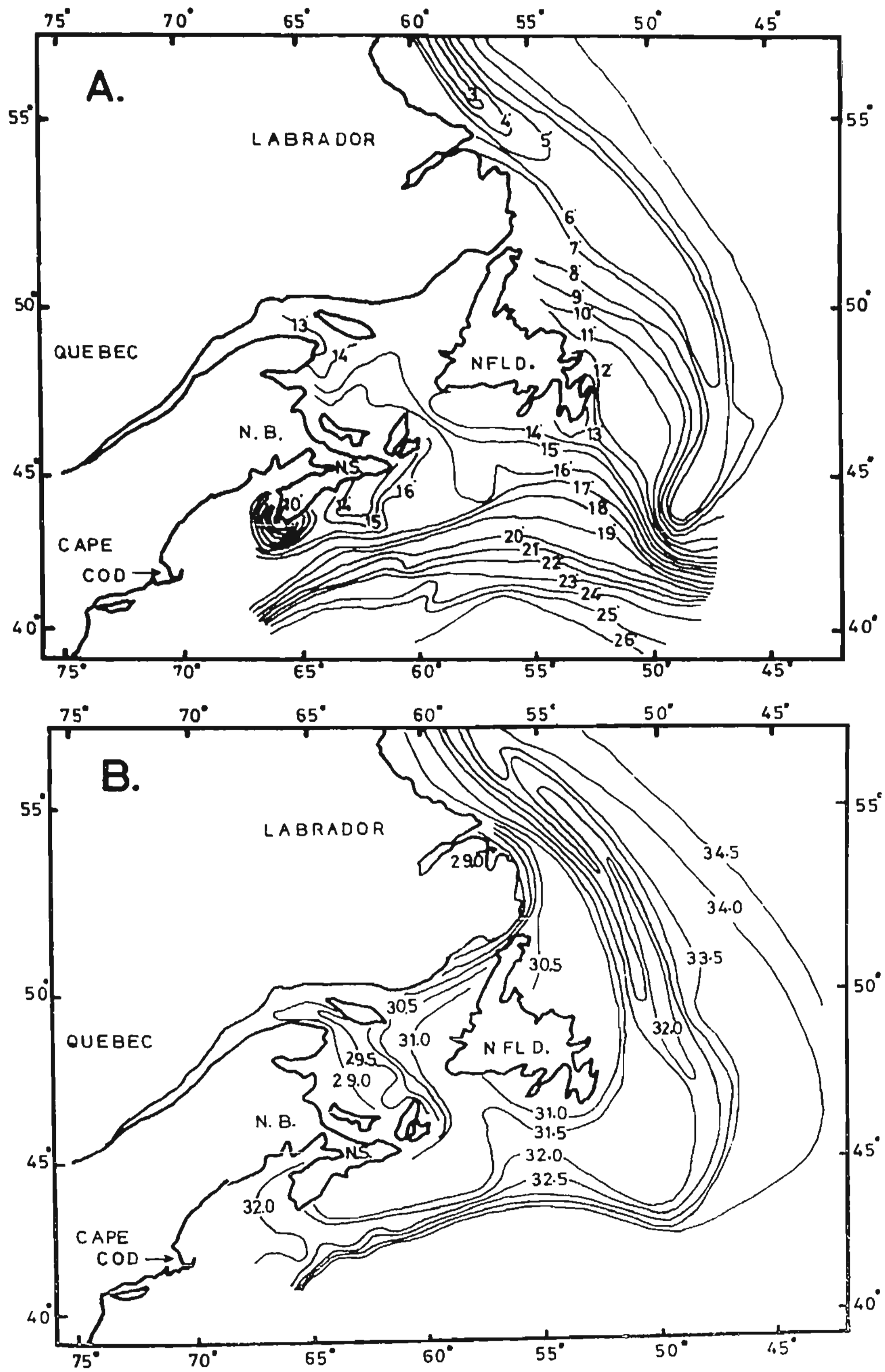


FIGURE 38

GENERALIZED SURFACE WATER TEMPERATURE (°C) DISTRIBUTION (A) AND SALINITY (°/oo) DISTRIBUTION (B) IN THE NEWFOUNDLAND AREA DURING AUGUST

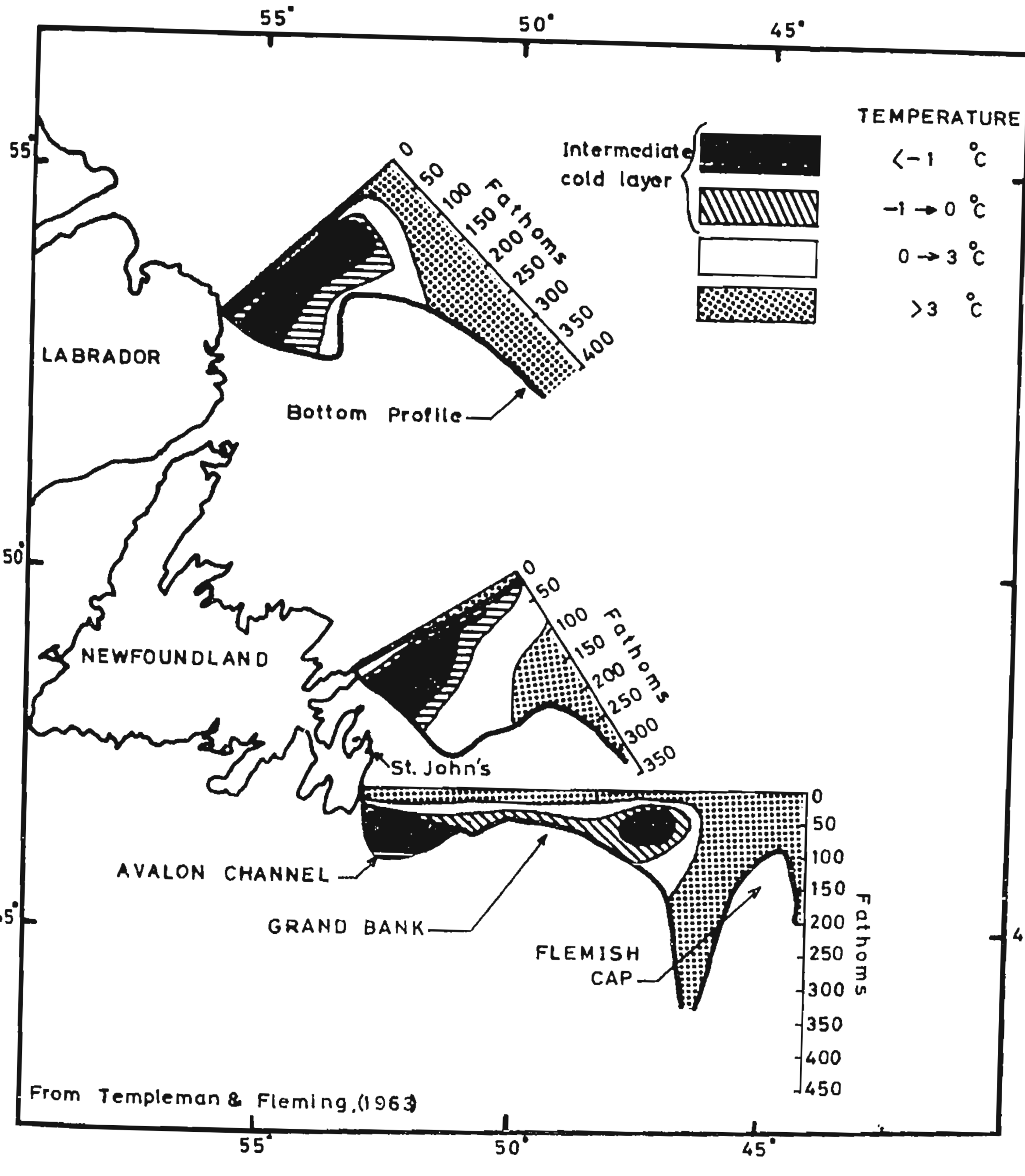


FIGURE 39

GENERALIZED TEMPERATURE SECTIONS, SURFACE TO BOTTOM, IN THE SUMMER OFF THE EAST COAST OF NEWFOUNDLAND

SECTION X

HYDROGRAPHY OF CONCEPTION BAY AND ITS RELATIONSHIP TO BLUEFIN DISTRIBUTION

Submarine Topography

Materials and Methods

Isobaths, at ten fathom intervals, were constructed from a Canadian Hydrographic Service Chart (Scale 1:75000) of Conception Bay (No. 4565). Eleven east-west profiles were then prepared, with the aid of the isobaths, and their scale reduced by means of an Ott planimeter prior to presentation.

Results

The isobaths and profiles of Conception Bay are presented in Figures 40 and 41 respectively. The topography is shown to be characterised by seven major features.

1. A comparatively shallow bay sill of less than 100 fathoms.

2. A primary N.N.E. - S.S.W. trench which bisects the bay to a depth of 160 fathoms.

3. A secondary trench which runs along the eastern margin of the bay, parallel to the primary trench, and extending from the latitude of Bauline to that of St. Phillips. The maximum depth of this trench is 100 fathoms.

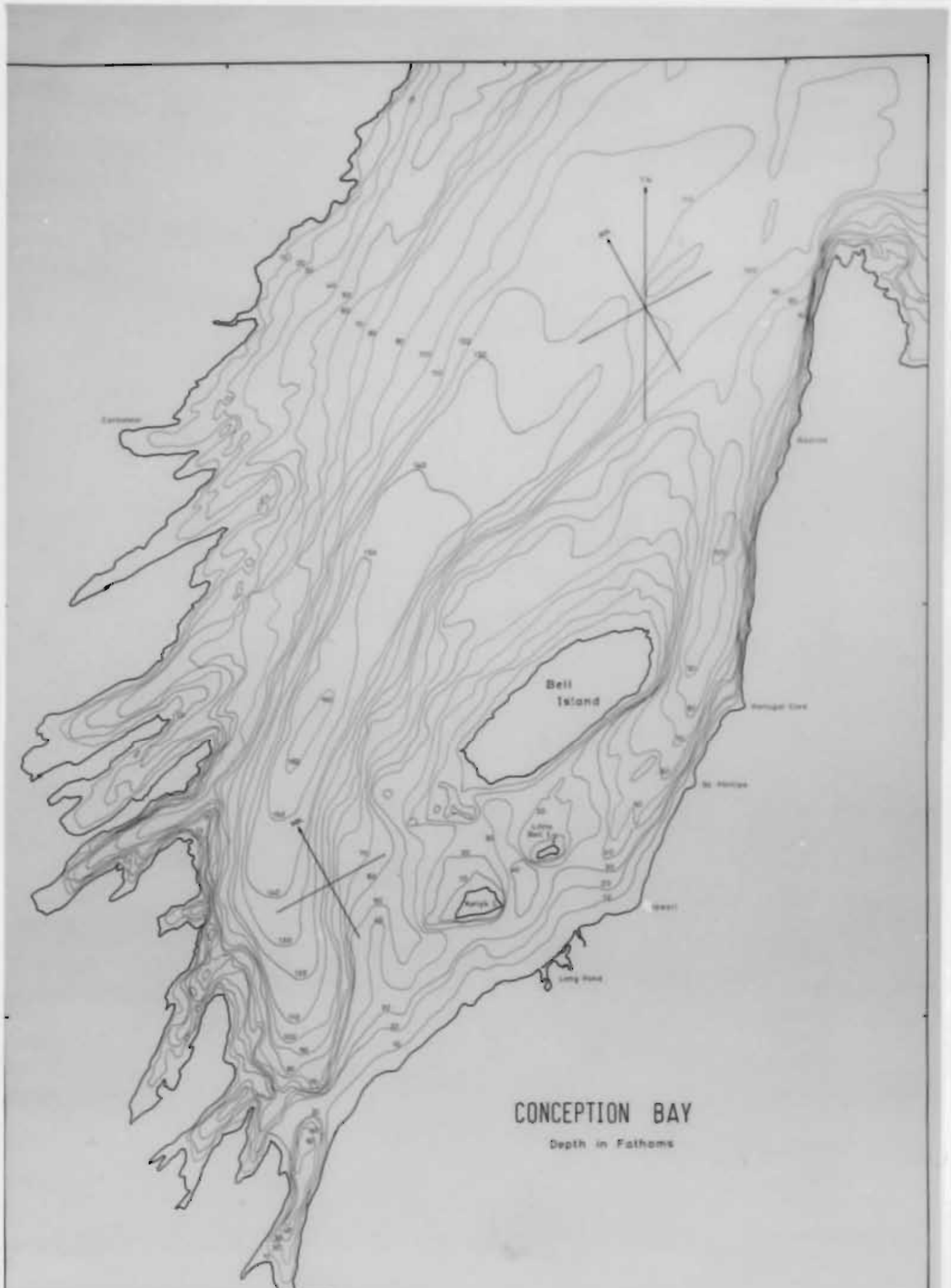


FIGURE 40

THE SUBMARINE TOPOGRAPHY OF CONCEPTION BAY

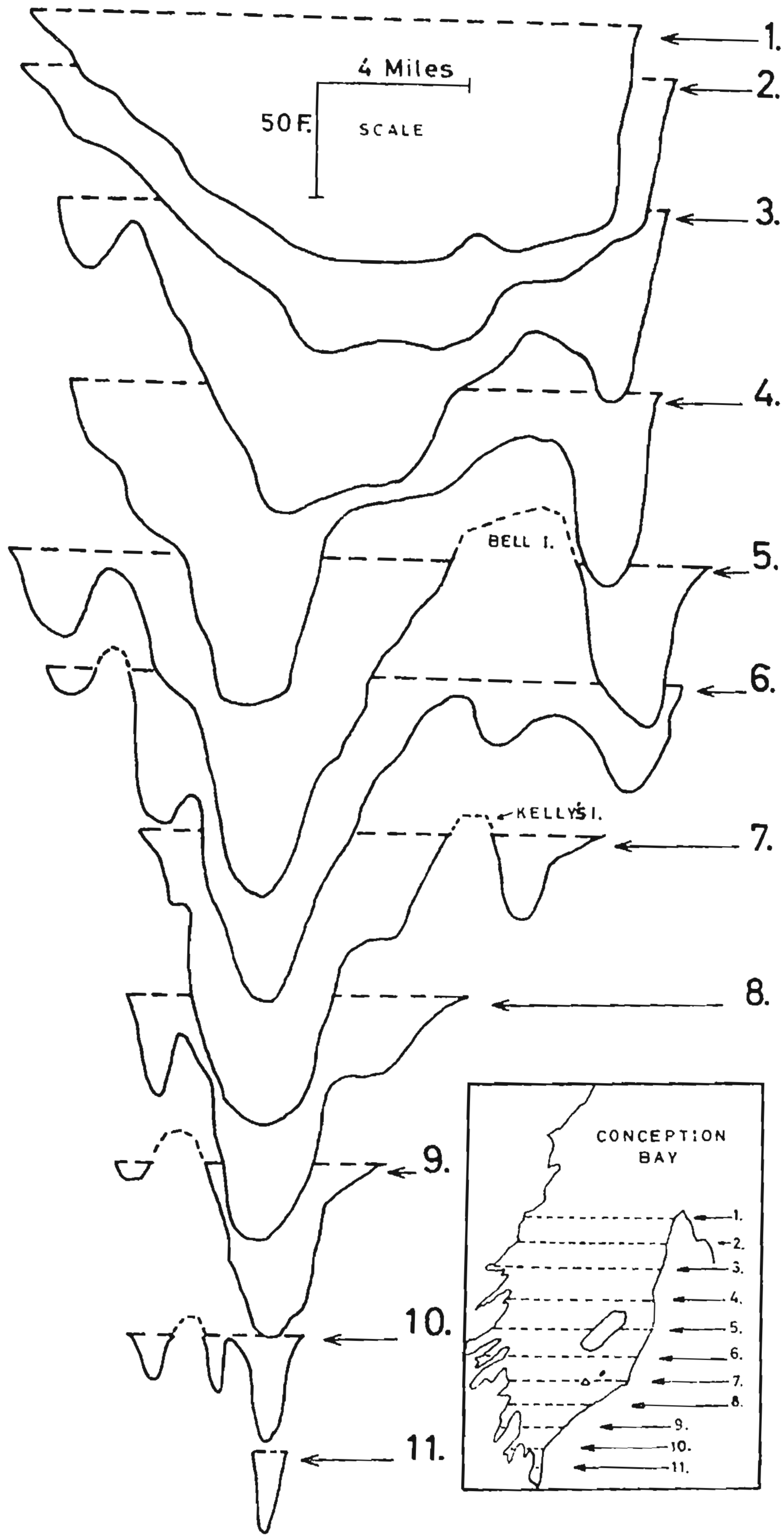


FIGURE 41

EAST-WEST PROFILES OF CONCEPTION BAY

4. The primary and secondary trenches are separated by Bell Island and its associated north-south submarine extensions.

5. The eastern margin of the bay is marked by a rapid increase in depth of water with distance from land. This region extends from Cape St. Francis to Bauline.

6. The southeastern region of the bay is comparatively shallow, rarely exceeding 50 fathoms. Kelly's Island and Little Bell Island are major features.

7. The western margin of Conception Bay is deeply indented by numerous northeast-southwest bays, one of which reaches a depth of nearly 80 fathoms (Bay de Grave). Harbour Grace Island and Carbonear Island are extensions of Harbour Grace and Carbonear promontories. The western shore profile is markedly steeper in the south than in the north.

General Circulation

A southerly flowing inshore branch of the Labrador Current flows into Conception Bay in the region of Baccalieu Island. Under the influence of Coriolis Forces it is assumed that the major volume of water follows the western margin of the bay, veering to the northeast as it approaches the southern extremity of the bay and flowing out of the bay via the secondary trench to the east of Bell Island. Some evidence supporting this assumption is provided by a consideration of water densities in the area, the densities having been deduced from bathythermographic data, (discussed later in this section). In addition, the current in Trinity Bay, immediately north of Conception Bay and geographically similiar to it, is believed by local fisherman to follow a course corresponding to that proposed by the author for Conception Bay. The current thus rejoins the dominant southerly flowing Labrador water mass in the region of Cape St. Francis prior to passing through the north-south Avalon Channel to the east of the Avalon Peninsula (Figure 42).

Horizontal and Vertical Temperature Distribution in Conception Bay (1966)

Materials and Methods

1. Bathythermographic Surveys: Surveys were carried out on July 6, August 2 and October 27, 1966. The September survey was aborted by loss of the bathythermograph due to mechanical failure in the winch apparatus. A 900 foot type was used on the first two surveys and a 450 foot type was used on the final survey. Gold surfaced rather than smoked slides were used on all occasions. The stations are indicated in Figure 42. Limited ship-time and cruising speeds restricted the area of the bay surveyed and necessitated the unorthodox pattern of stations. However, the surveyed areas were chosen to coincide with the major bluefin fishing zones.

2. Thermographic Recordings: A Ryan thermograph (model D-8) was placed in Conception Bay approximately 100 feet offshore in the vicinity of St. Phillips at a depth of two feet. Water

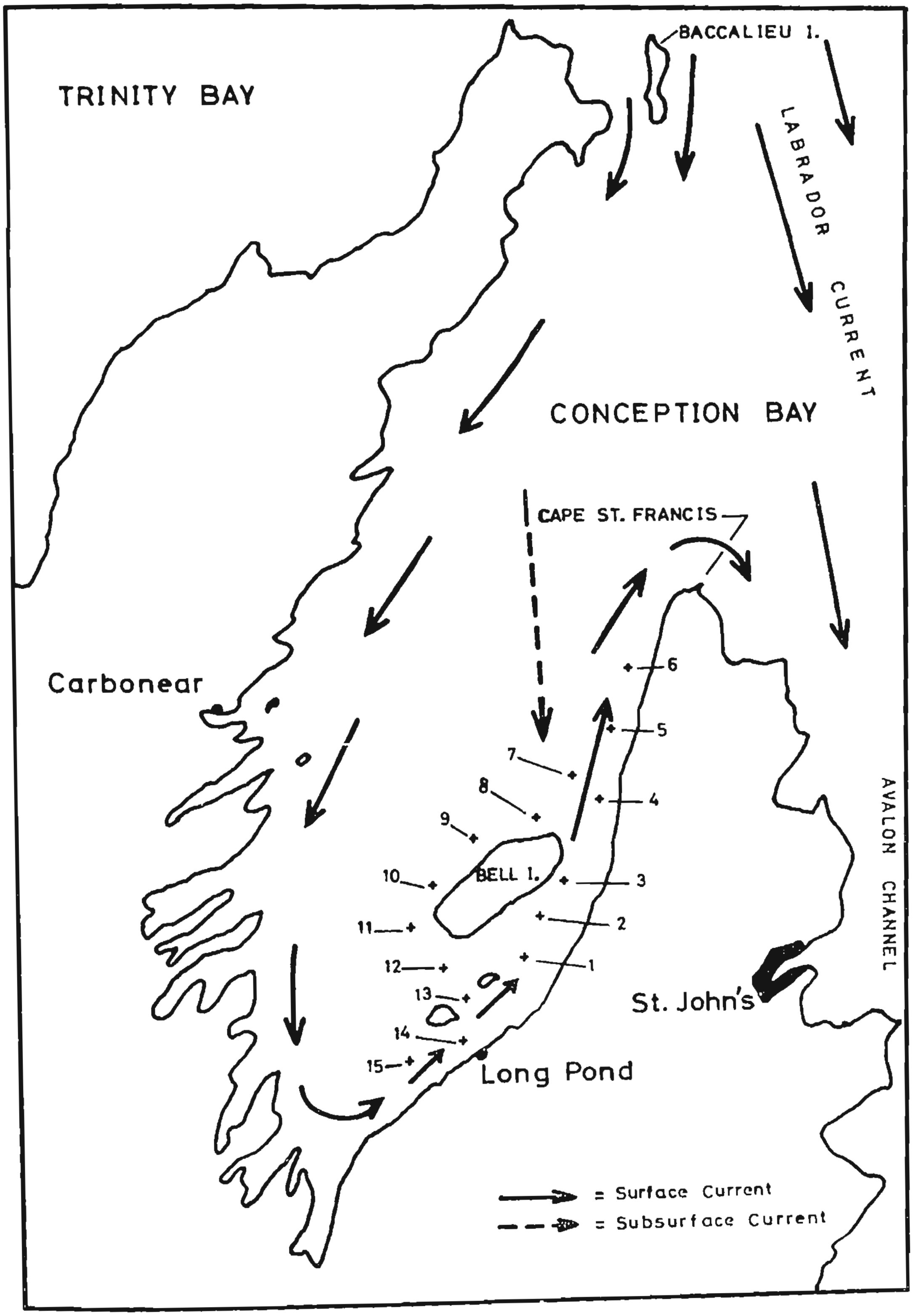


FIGURE 42

THE PRESUMED DIRECTION OF CURRENT FLOW IN CONCEPTION BAY. HYDROGRAPHIC STATION LOCATIONS ARE ALSO INCLUDED temperatures were recorded continuously from July 24 - October 23, 1966. The suspension system and apparatus are illustrated in Figures 43 A & B. The apparatus was serviced weekly, i.e. mechanism rewound, strip chart changed and water seal checked. In addition, the surface water temperature was recorded with a thermometer.

3. Long Pond Temperatures: The surface water temperature was recorded daily at 18:30 hours from August 15 - October 29, 1966. A bucket and a thermometer were used. The water sample for this purpose was collected from the seaward end of the wharf and from its west side in order to minimize the effect of the fresh water run-off from Long Pond basin. The water depth was approximately 15 feet, plus or minus tidal variation.

4. Surface Water Temperature Spot Checks: Six tuna boats were provided with thermometers and buckets. The crews kindly agreed to make as many surface temperature recordings as possible, particularly in bluefin strike areas. The time and result of the spot check was recorded by the crew on a grid-patterned map of Conception Bay prepared by the author. In addition, members of the Department of Biology made similar spot checks when working on other projects in Conception Bay. A total of 318 temperatures were recorded, the majority between July 6 and September 1, 1966.

Results

1. Bathythermographic Surveys: The vertical temperature

A.

B.

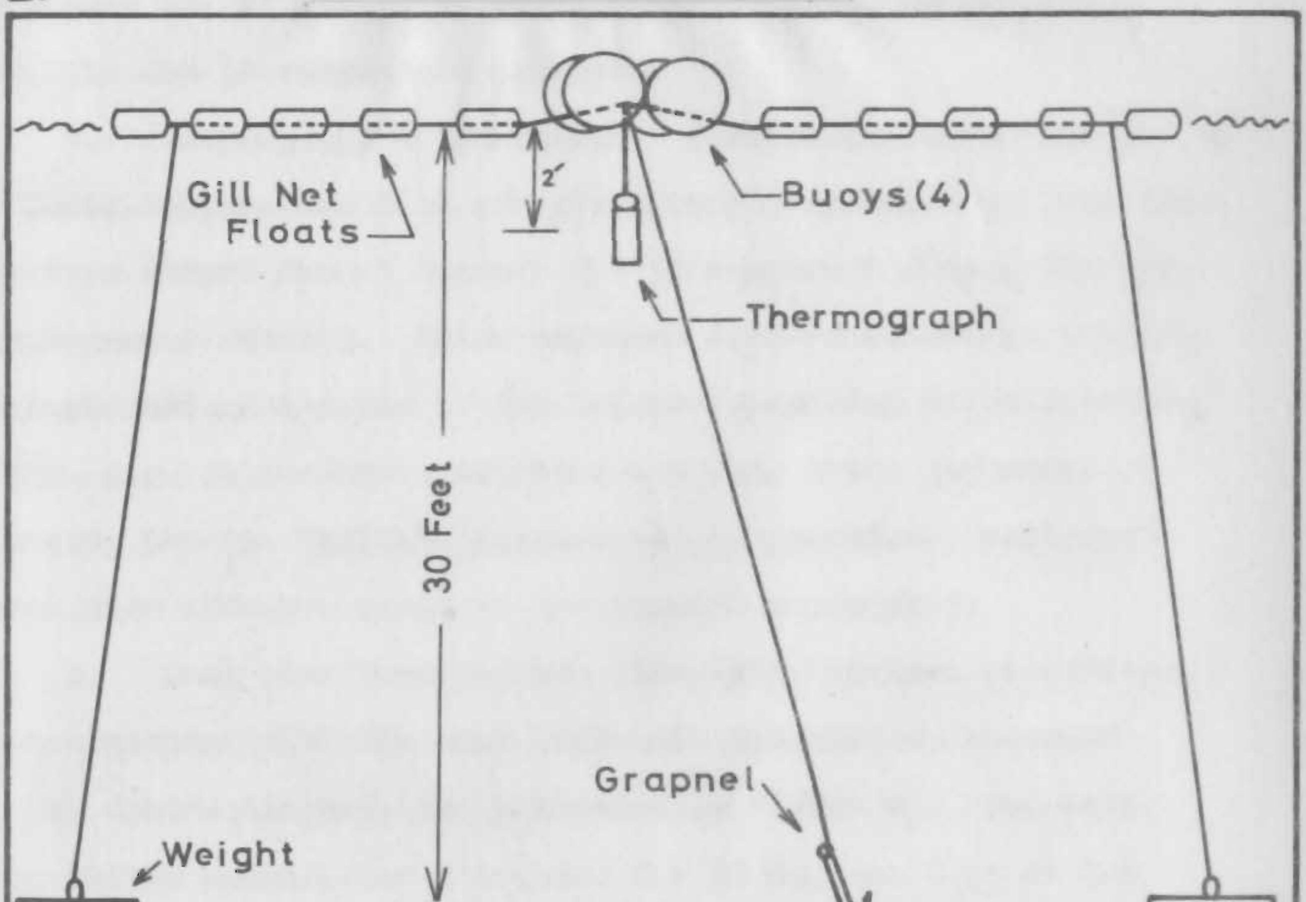


FIGURE 43

THE THERMOGRAPH (A) AND SUSPENSION SYSTEM (B)
USED IN CONCEPTION BAY

profiles of fifteen stations in Conception Bay are presented in Figures 44 and 45. A developing thermocline is evident in July (15 - 20 metres) but its decrease in depth during August to 5 - 10 metres is atypical. Increased wind mixing and net loss of heat energy from the sea in September leads to the erosion of the thermocline. The October profile indicates that final stages of thermocline decay, the water mass having almost reached the isothermal conditions of winter. Irregular July and August profiles (stations 10, 11 and 12 at depths between 10-20 metres are probably due to subsurface currents.

2. Thermographic Recordings: Continuous subsurface (2 feet) temperature data are presented in Appendix 4. The temperature ranged from 7 degrees C - 15 degrees C during the three month period studied. Brisk offshore winds resulted in temperature reductions because of the induced upwelling of cold bottom water, e.g. temperature recording for July 30th, (Appendix 4). However, the St. Phillips station was comparatively well sheltered from offshore winds by the coastal topography.

3. Long Pond Temperature: The daily surface recordings, in conjunction with the mean daily air temperature recorded at St. John's Airport, are presented in Figure 46. The water temperature ranged from 7 degrees C - 15 degrees C as at the St. Phillips station, but the fluctuation was more marked. This is to be expected from surface recordings. In addition, offshore

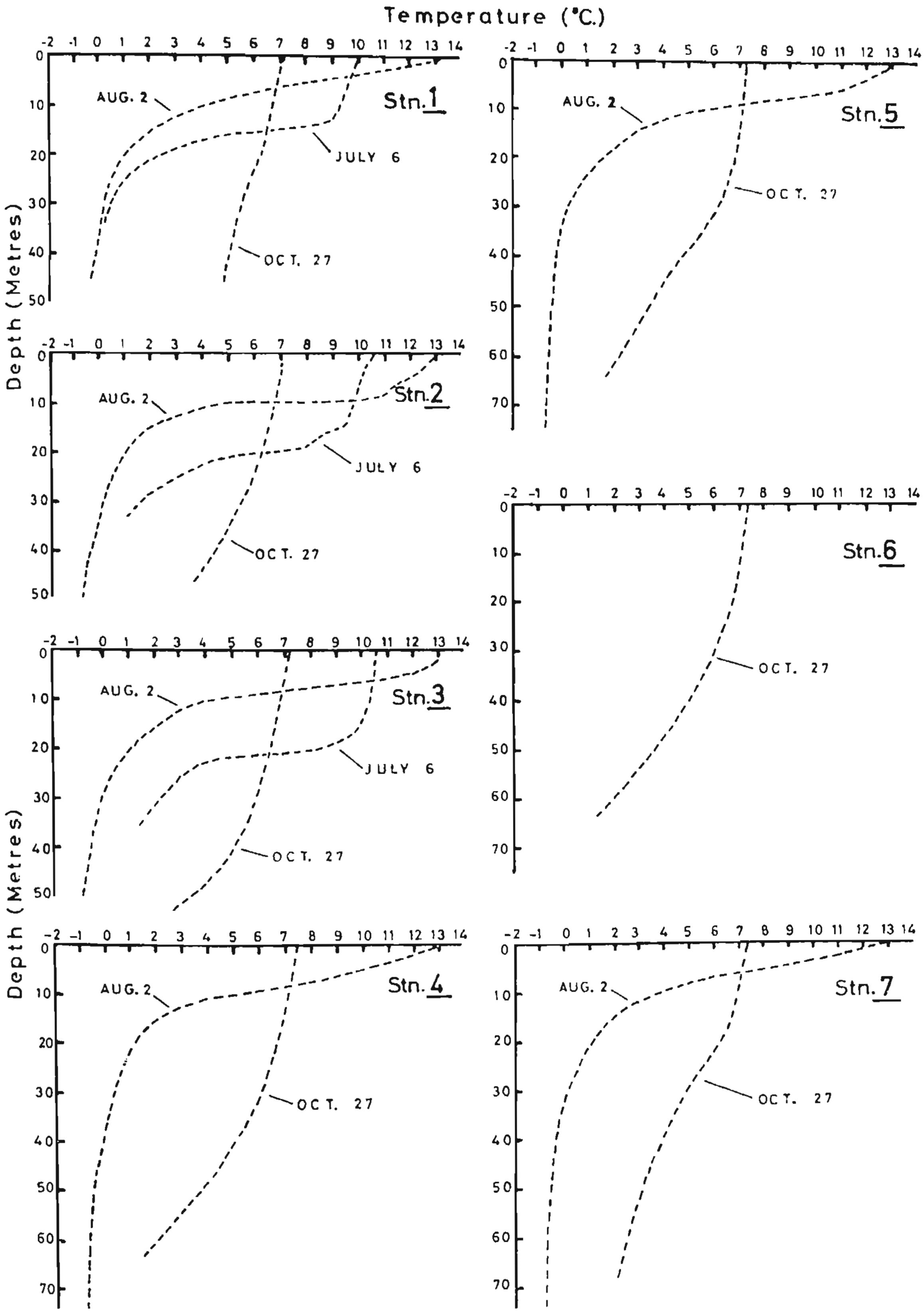


FIGURE 44

VERTICAL TEMPERATURE PROFILES OF CONCEPTION BAY, 1966,
STATIONS 1-7

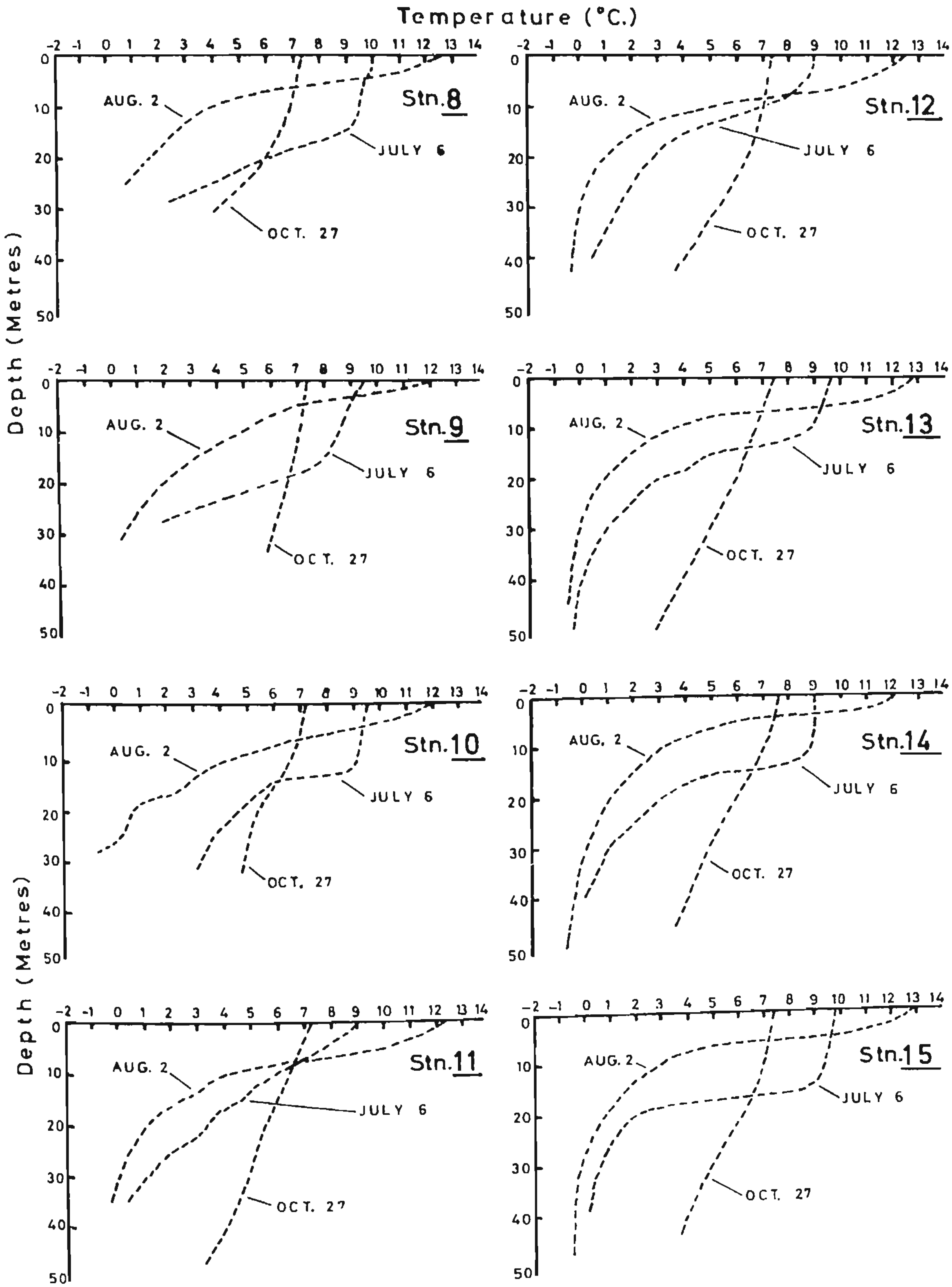


FIGURE 45

VERTICAL TEMPERATURE PROFILES OF CONCEPTION BAY, 1966, STATIONS 8-15

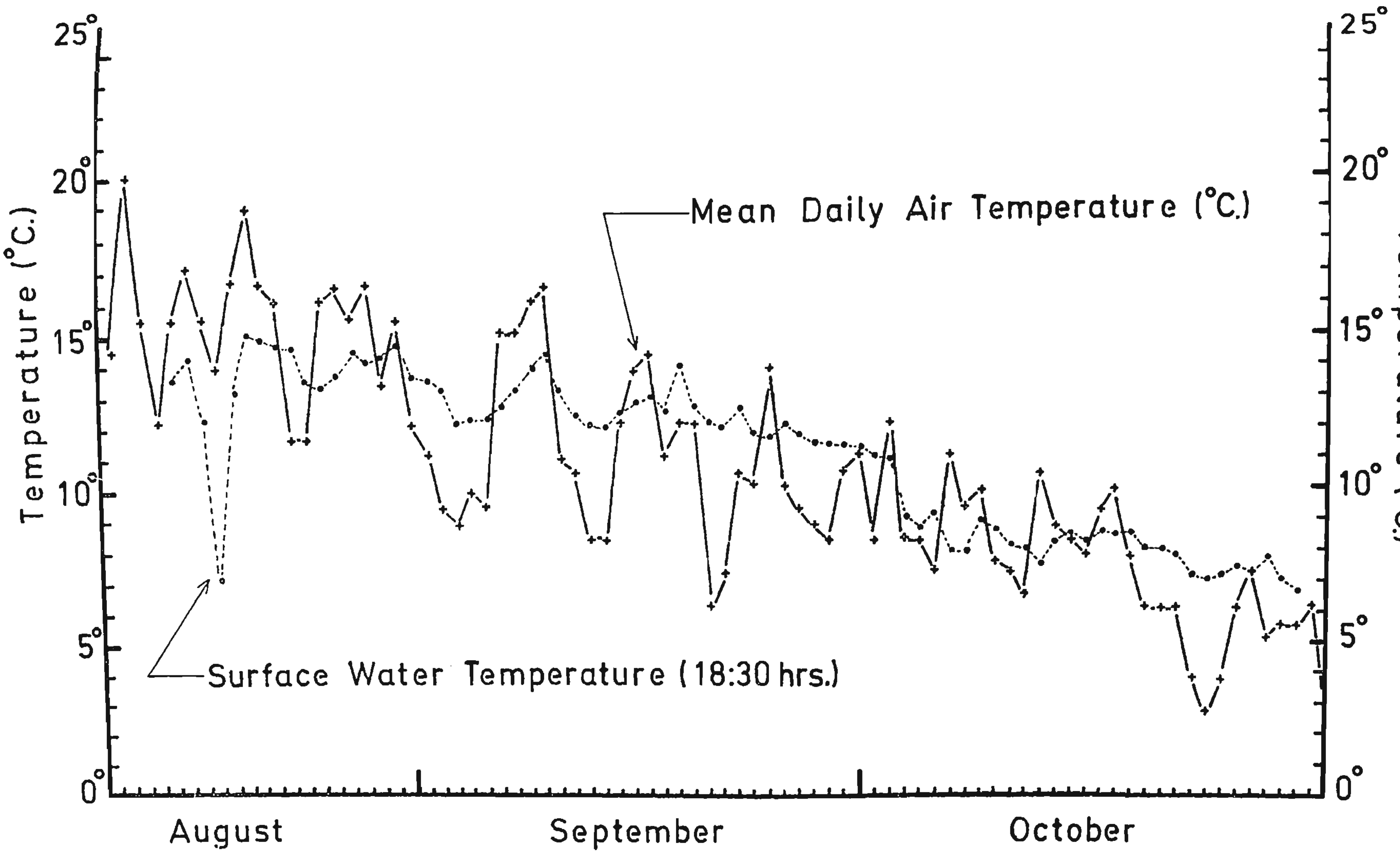


FIGURE 46

LONG POND SURFACE WATER TEMPERATURE DATA (°C) RECORDED DAILY AT 18:30 HOURS FOR THE MONTHS OF AUGUST, SEPTEMBER AND OCTOBER 1966, IN CONJUNCTION WITH THE MEAN DAILY AIR TEMPERATURE (°C) RECORDED AT ST. JOHN'S AIRPORT winds resulted in rapid temperature reductions because of the exposed nature of the Long Pond station.

4. Surface Water Temperature Spot Checks: The spot check results were combined with the temperature data obtained by the previously described techniques to determine the horizontal distribution of temperature in Conception Bay during the 1966 bluefin fishing season. Diurnal temperature variations were taken into consideration.

Horizontal Temperature Distribution in Conception Bay (July 11 - September 26, 1966.).

The northwestward progress of the surface isotherms during July and August and the reverse movement in September is evident in Figure 47. The eastern region of Conception Bay, particularly between Long Pond and Portugal Cove, is markedly warmer than the western region. The prevailing southwest winds partly account for this temperature disparity, which is evident throughout the bluefin season, because they tend to force the warmer surface waters into the eastern zone of the bay andcause upwelling of cold bottom water along the western margin of it. In addition, the inshore branch of the Labrador Current associated with Conception Bay is assumed to follow the western margin of the bay initially, hence its water mass is subjected to considerable solar radiation in comparatively sheltered and shallow conditions before it recurves into the eastern area. Maximum summer temperatures of 18 degrees C - 19 degrees C were recorded in the latter half of August in the shallow Topsail Beach area.

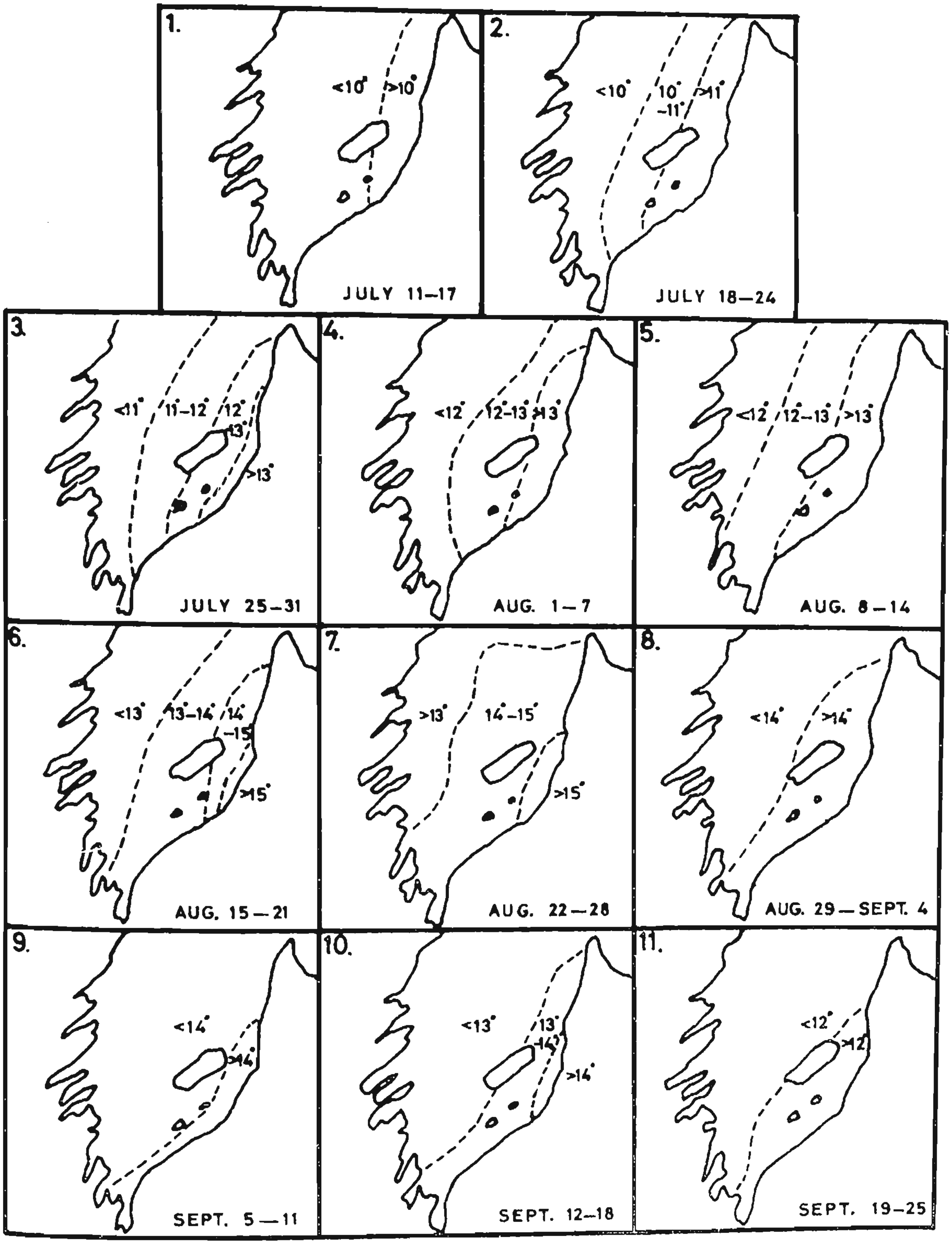


FIGURE 47

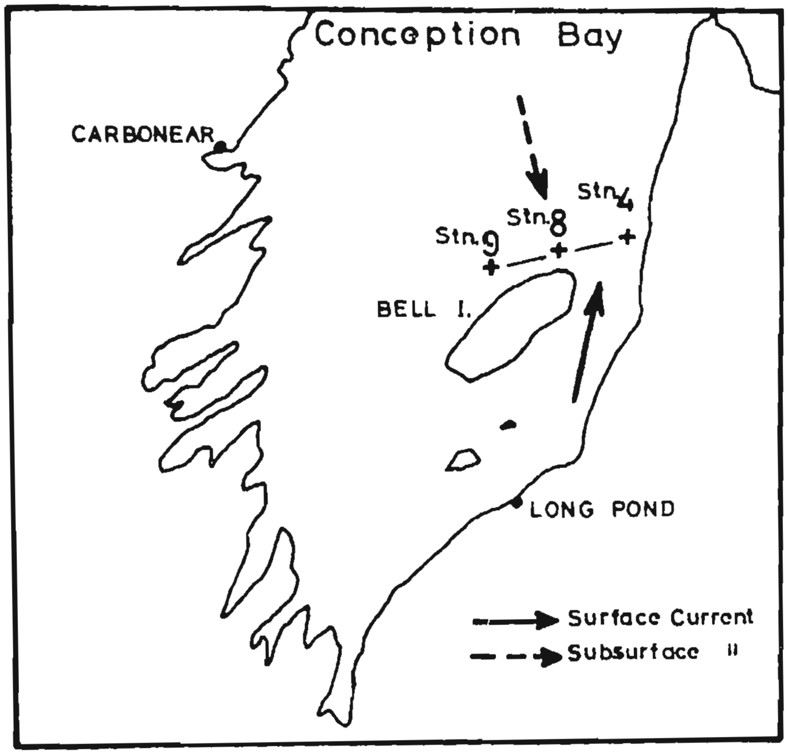
THE MOVEMENT OF SURFACE WATER ISOTHERMS
IN CONCEPTION BAY, JULY - SEPTEMBER, 1966

Vertical Temperature Distribution in Conception Bay (1966).

Evaluation of the bathythermographic profiles (Figure 44 and 45) indicates that bluefin inhabiting Conception Bay in early June (1966) were generally restricted to the upper 10 - 20 metres, assuming a minimum tolerated temperature of 6 degrees C. The surface temperature at this time varied between 9 degrees C - 10.5 degrees C depending on the stationà location in the bay. Bluefin reported in the bay in June (1966) were possibly further restricted in their vertical movements, although this is uncertain in view of the anomolous rising of the thermocline between July and August (1966). For instance, the 6 degrees C isotherm in August was between 5 - 10 metres.

The surface temperatures at inshore stations (1 - 6, 14 and 15) were generally warmer than those at the offshore stations (7 - 13 and 14). Similarly, the critical 6 degrees C isotherm was usually deeper at the inshore stations because of the influence of the prevailing southwest winds. A vertical temperature section of stations 4, 8 and 9 (Figure 48) demonstrates this point and also provides some supporting evidence for the assumption of a north flowing current east of Bell Island, i.e. the density of the water is generally more dependent on the temperature than on the salinity and pressure in surface waters. Thus the isobaric surfaces in Figure 48B may be assumed to slope upward to the right and, according to Sverdrup et al (1946:394), "In the northern hemisphere the lighter water lies on the righthand side of an observer looking in the direction of the current

A.



B.

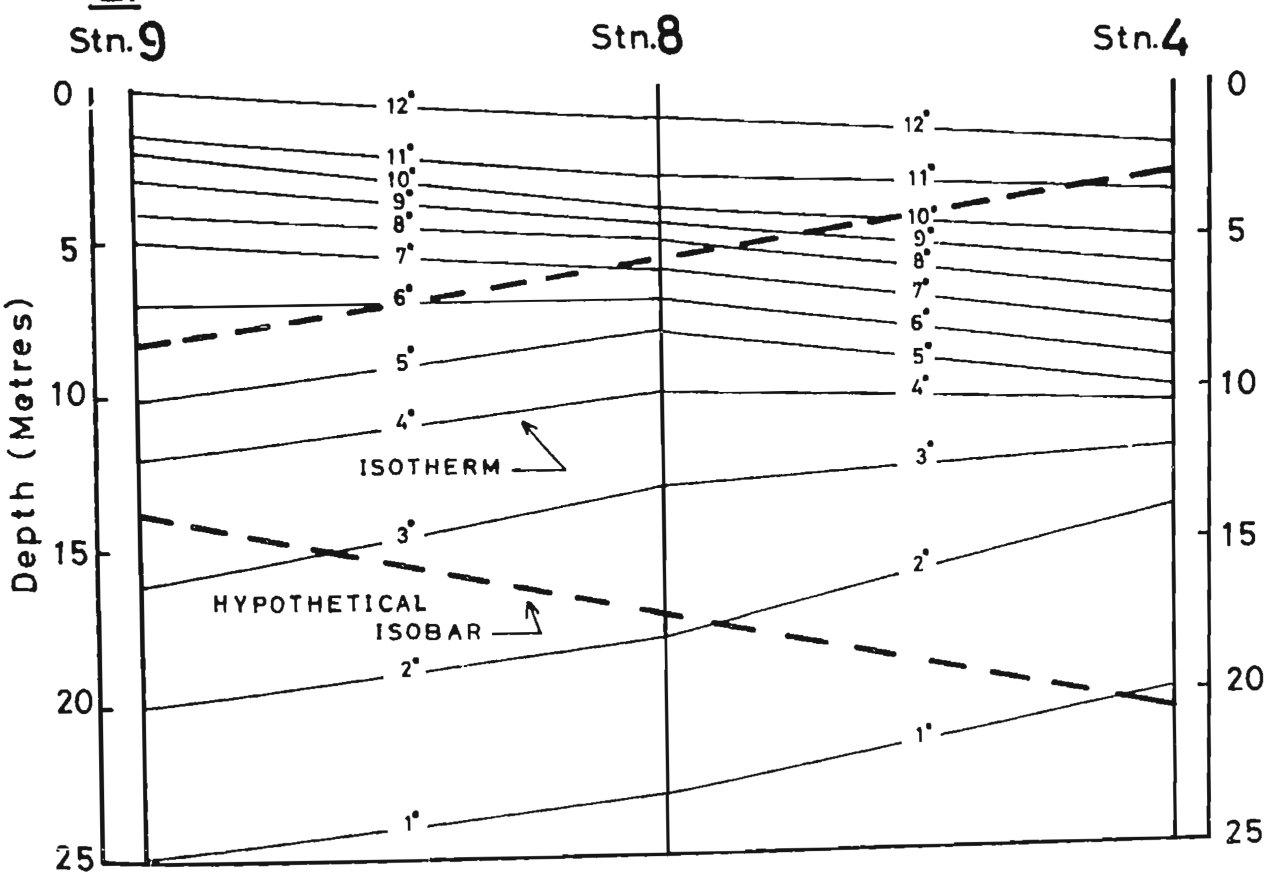


FIGURE 48

THE LOCATIONS (A) AND A VERTICAL TEMPERATURE SECTION (B) OF STATIONS 4, 8 AND 9 and the denser water lies on the lefthand." Therefore, the current should theoretically flow north. The reverse slope of the isobathytherms below the depth of 15 metres similarly suggests a deeper counter current. However, because of inadequate data and lack of relevant computations, the direction of current flow must remain a speculation.

Temperature in Relation to Bluefin Distribution.

The latitudinal distribution of the bluefin (and most other scombrids) is approximately symmetrical with respect to the equator and the poles in both hemispheres and therefore suggests a relationship with a similarly distributed property (or properties), i.e. temperature (Blackburn, 1965).

This has been clearly demonstrated, in particular in relation to the commercially important tuna species (Laevastu and Rosa, 1962). The albacore (Thunnus alalunga), for example, was initially studied in this respect by Thompson (1917) in the North East Pacific. Subsequent studies in this area include Anon. (1925); Hubbs and Schultz (1929); Walford (1931); Hubbs (1948); Clemens (1957, 1958); Craig (1959, 1960); Radovich (1960, 1961, 1962); Johnson (1960, 1961, 1962); Alverson (1961); Hester (1961); in Europe, Le Gall (1949) and Postel (1962; in Japan, Uda and Tokunaga (1937); Inoue (1958) and Van Campen (1960). However, according to Radovich (1962), the concept that water temperature could affect tuna distribution only gained general acceptance following the Rancho Santa Fe Symposium (Calif. Mar. Res. Comm., 1960).

The surface occurrences of bluefin in relation to temperature have been investigated mainly in the Pacific. Radovich (1961) noted the northward extension of the California bluefin's range during the warm years of 1957, 1958 and 1959. Hester (1961) attempted, with some success, to predict the 1960 bluefin catch in the same population by using coastal sea surface temperatures. Other Pacific bluefin studies include Radovich (1962); Robins (1963); Bell (1963), q.v. for references; Yamanaka et al (1962), q.v. for references.

In the eastern Atlantic, bluefin are found only in areas containing rich food concentrations and where the sea surface temperature is above 12 degrees C (Tiews, 1962), although Sella (1931) claimed that bluefin may become dormant at a temperature of 14 degrees C. However, under these conditions they are able to make temporary excursions into deeper, hence colder, water in pursuit of prey (Tiews, 1957). Lühmann (1959) observed that the migration of bluefin into and from the North Sea is closely associated with the movement of the 12 degree C isotherm. In the Black Sea, the bluefin is found only when the surface temperature is above 12 degrees C - 14 degrees C (Sara, 1960), although they are caught throughout the year in the nearby Mamara Sea and the Bosphorus, where the temperature does not fall below the critical 12 degrees C minimum (Akyüz and Artüz, 1957).

In the western Atlantic, the bluefin appears to tolerate considerably lower temperatures. The "Delaware" surveys in the northwestern Atlantic indicate that bluefin are caught within the following temperature ranges (Squire, 1962b), which may vary with size of fish (Inoue, 1958; Clemens 1961):

	Observed Range	68% caught (1 standard deviation)	Mean temperature
Surface	6.4°C - 28.8°C	11°C - 21°C	16.2°C
Fish Depth	6.5°C - 26.9°C	11°C - 19°C	15.5°C

The mean catch temperature (15 degrees - 16 degrees C) closely approximates the "optimum water temperature" described by Uda (1957) for the North West Pacific bluefin.

The author considers the minimum temperature of the above observed range to be too high. Bluefin were reliably reported in Conception Bay in the first week of June, 1967, when the surface water temperature was approximately 6 degrees C. In addition, a large school of bluefin were reported swimming north, off St. Phillips, on December 4, 1966, when the surface water temperature was estimated to be 5 degrees C. The critical minimum temperature is likely to be lower at the end of the northern feeding season than at the beginning, i.e. bluefin are probably capable of considerable acclimation to the gradually diminishing water temperature.

The presence of bluefin in Conception Bay is by no means synonomous with catchability. They do not appear to take the hook and line bait (mullet or squid) until surface water temperature has risen to at least 10 degrees C. In addition, the 10 degrees C isotherm continued to effectively delineate the successful fishing area during its ten day northward progress through Conception Bay at the beginning of the 1966 season.

The majority of the 1966 bluefin catch (62%) were hooked in waters with surface temperatures between 12 degrees - 12.9 degrees C and 98% were hooked at temperatures between 11 degrees - 15 degrees C (Figure 49). Although temperature determines the overall limits of tuna distribution, it is not considered to affect, to any appreciable extent, the changing pattern of distribution within those limits (Nakamura, 1951; Broadhead and Barrett, 1964). Food availability probably then becomes the major controlling factor.

Salinity Distribution in Conception Bay

Materials and Methods

An Industrial Instruments salinometer (model R SS - 1) was used to record salinity, conductivity and temperature at stations indicated in Figure 42. Water samples were also taken to check the results by means of titration with silver nitrate.

Results

The salinity ranged from 29‰ - 33‰ depending on the prevailing meteorological conditions and the location of the station in relation to fresh water run-off. The salinity in the major catch zones ranged from 31‰ - 32‰.

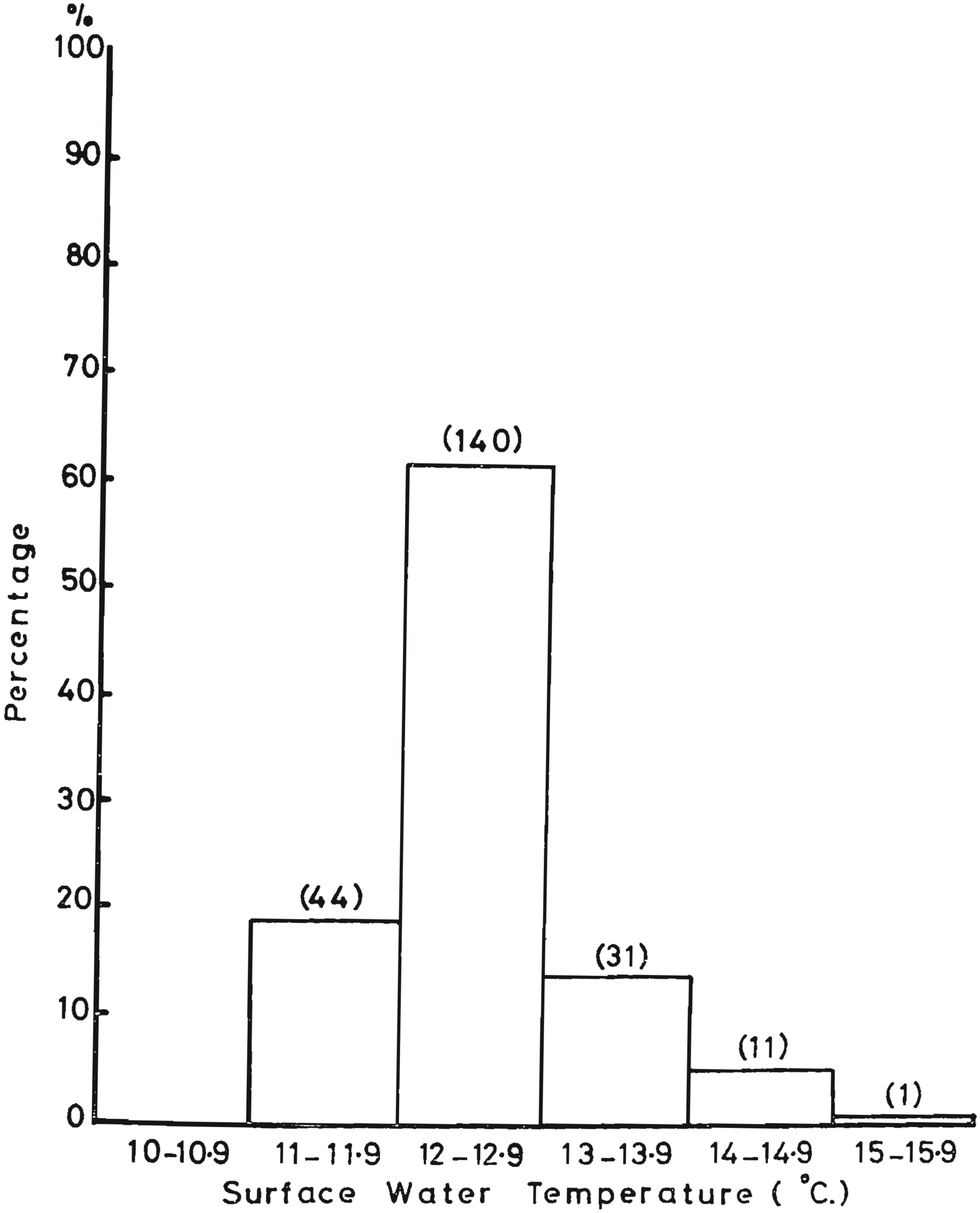


FIGURE 49

THE NUMBER (IN PARENTHESIS) AND PERCENTAGE OF BLUEFIN STRIKES IN RELATION TO THE SURFACE WATER TEMPERATURE, CONCEPTION BAY, 1966

Salinity in Relation to Bluefin Distribution

Roule (1924) stated that breeding bluefin seek the most saline (and warmest) water. However, during their subsequent feeding migration they show little such sensitivity and may be found in waters with salinities as low as 18‰ - 20‰ (Bosphorus) or as high as 38‰ (Cyrenaica Coast). Salinities in excess of this latter figure seem to be avoided (Sella, 1931). Thus, according to Blackburn (1965), salinity per se has no direct effect on tuna distribution. It can, however, be important in detecting and characterising oceanic features with which tuna are associated.

Hydrographic Features in Relation to Bluefin Distribution

The features included in this section are mainly responsible for the distribution of bluefin within their overall (temperature determined) limits.

Surface Currents

The greater poleward distribution of bluefin in the eastern Atlantic, in comparison with the western Atlantic, results from the northeasterly flow of the North Atlantic Current which bathes the northern European coast in comparatively warm water (Tiews, 1962). In contrast, the Canadian coast at similar latitudes is under the influence of the cold Labrador and Baffin Island Currents. A phenomenon which may not necessarily be temperature dependent is the observed association of the Atlantic bluefin with the Gulf Stream (Rivas, 1955; Squire, 1962b and Tiews, 1962) and the Pacific bluefin with the analogous Kuroshio (Waldron, 1963, q.v. for references). Transport facilitation has been suggested as a reason for such an association (Imamura, 1949), although this seems unlikely in view of the tuna's proven swimming ability and examples of poleward counter current migrations (Blackburn 1965). Food availability and environmental preferences are other possibilities.

Fronts

Fronts are lines of convergence between surface waters of different densities. They can be recognised by strong horizontal gradients of temperature and/or salinity. Some sinking of one or both types of water is involved (Blackburn, 1965). Tuna concentrations are known to be generally associated with such convergent water masses (Squire, 1962b).

Weakly swimming and drifting zooplankton are believed to be carried towards a front, where their concentrations attract nekton, the tuna being one of the climax predators. Beklemishev and Burkhov (1958) indicate that the frontal region between the Kuroshio (warm) and Oyashio (cool) is richer in zooplankton than neighbouring waters. Tunas, including bluefin, are reported to be concentrated in this region (Uda, 1953; Uda and Ishino, 1958). In the analogous region of the North West Atlantic, Squire (1962b) notes that the well developed convergence zone, cyclonic eddies and fluctuating wave structure is conducive to concentrations of tuna resources. Excellent catches were reported in the zone of maximum convergence from the Cape Hatteras area to Longitude 70 degrees W. (Squire, 1962b).

The presence of a front is often indicated by the accumulation of flotsam, which may provide shelter for various animals. The resulting concentration of potential forage organisms may in turn attract tuna (Magnuson, 1962; Schaefer, Broadhead and Orange, 1962). Gulls are another "sign of tuna" as they feed on the flotsam and scraps left by feeding fish. This phenomenon is commonly used by Conception Bay skippers to locate bluefin schools, although fronts per se are probably not present other than as a temporary occurrence.

Upwelling

Upwelling may be defined as the upward motion of the water resulting from wind-induced divergence (Cromwell, 1958; Austin, 1960). It occurs mainly in the eastern parts of oceans where trade winds transport surface water away from the coasts (Wooster and Reid, 1963). The concentrations of chemically and biologically rich water in such an area attract tuna. However, DeJaeger (1963) reported that bluefin occurred in larger numbers in the absence of upwelling off the east coast of South Africa. Blackburn (1965) suggests that this might be due to the displacement of small biota from the time and place of upwelling or because of the inhibiting effect of the cold upwelled water. In contrast, oceanic rather than coastal upwellings have convincingly linked with tuna abundance (Cromwell, 1953; Sette, 1955; King and Hida, 1957).

Islands and Banks

Islands and banks may deflect currents into downstream eddies and hence concentrate plankton (Uda and Ishino, 1958). Tunas are often reported to be locally abundant around islands (Blackburn, 1965). The author considered that this phenomenon might have been responsible for the location of the two major catch zones in Conception Bay (see Section VIII) both of which occur downstream of islands (Harbour Grace Island and Bell Island respectively). However, preliminary plankton surveys have not indicated any abnormal concentrations in these areas (pers. comm. Dr. G. Moskovits, 1966).

Nishimura (1962) located, with a fish finder, especially dense concentrations of bluefin "at the steep incline" around the bank of Oma in Tsugaru Strait (Japan). The bluefin were similarly distributed along the steep inshore slope of the secondary trench in the Bauline region of Conception Bay (see Section VIII).

Thermoclines

In the northern part of its range the bluefin is usually found above the thermocline (Tiews, 1957). As the lowest temperature normally tolerated by the bluefin is 5 - 6 degrees C and the minimum thermocline temperature recorded in Conception Bay was 1 - 2 degrees C (see Figures 44 and 45) this would appear to be true. Studies relating thermocline topography, productivity and tuna concentrations are summarised by Blackburn (1965), q.v. for references.

SECTION XI

METEOROLOGY

Aggregations of tuna may be found associated with a number of hydrographic features (see Section X), each of which may contribute to the enrichment of the surface waters. Although temperature is a good indicator of many of these features, it may not be the main factor directing the behaviour and distribution of tuna. Changes in the environmental factors in the sea are the result of interaction between the sea and atmosphere and thus a correlation between meteorological factors and behaviour of the tunas can be found (Rosa and Laevastu, 1961). The majority of work in this field and its application to possible predictive techniques, has been associated with the commercially important tuna species in the Pacific.

The oceanic circulation in the North West Atlantic conforms closely with the prevailing wind systems associated with the cyclonic Iceland Low (anti-clockwise circulation) and the anti-cyclonic Bermuda-Azores High (clockwise circulation). The winds exert a frictional force on the water surface and hence maintain, in conjunction with differential density distribution, the movement of water. Cyclonic movement (anti-clockwise circulation) in the atmosphere and in the oceans results in downwelling, i.e. a wind stress on a level ocean surface in the northern hemisphere produces a water displacement to the right of the wind direction (Hachey, 1961). Thus the Labrador Sea, in the centre of a low pressure air system is considered to be the most effective source of aerated water for the deep water circulation of the whole Atlantic Ocean. However, bathysonde recordings in the Labrador Sea indicated that the aeration process is due to inclined convection along density surfaces rather than the commonly assumed vertical convection (Dietrich, 1964).

The Icelandic Low pressure system is dominant in the winter with the result that the winter atmospheric circulation is more intense. The Bermuda-Azores High pressure system is dominant in summer because of its northward movement of as much as 500 miles. It is therefore responsible for the prevailing southwesterly winds in Conception Bay during the tuna season. Intensification of the Bermuda-Azores High tends to increase the ocean circulation of the Gulf Stream system and so induces greater heat transfer to higher latitudes. Intensification of the Icelandic Low, in contrast, increases the flow of the cold Labrador Current (Hachey, 1961). In the analogous region of the Pacific, bluefin catches have shown periodic fluctuations, with a decline in catch associated with periods of cold water intrusion (strong Oyashio Current), and an increase with periods of warming (strong Kuroshio Current) (Uda, 1961). Thus, in addition to direct solar radiation, major changes in surface water temperature and associated change in tuna distribution can be related to differences in atmospheric pressure gradients, i.e. the resulting changes in the wind field affect sea temperatures through their effects on upwelling and horizontal circulation (Namais, 1959; Wooster, 1960; Bjerknes, 1961; Eber, 1961; Roden and Reid, 1961). Hamre (1961) described the effect of a sudden wind reversal (in the Norwegian Sea) which resulted in the offshore transport of warm surface waters rich in food organisms, and the associated movement of bluefin concentrations in pursuit of the food. Rodewald (1960) found that good catches of bluefin in the North Sea seem to depend on the anomalies of the atmosphere circulation which exist along the migration route of the tuna, i.e. in the years with good catches, the June distribution of pressure resulted in southerly winds which may have positively influenced the northward migration of tuna.

Other meteorological parameters have received little attention in relation to bluefin catches.

CONCEPTION BAY

Methods and materials

Meteorological and hydrographic conditions present at the time of strike of 227 bluefin were recorded by the boat crews on the log-sheets provided. This information consisted of the following "strike parameters": wind speed, wind direction, surface water temperature, sea conditions, sunlight, cloud cover, fog and mist, rainfall. The wind velocities were compared with, and when necessary supplemented by, data obtained from the St. John's Airport Meteorological Office, which is situated approximately 5 miles east of the mid-eastern margin of Conception Bay and at an elevation of 463 feet. The calculations involved the number of bluefin caught in relation to the condition of each parameter, and with the aid of an IBM Tabulator, the relative importance of the various parameter combinations, and the effect on the combination ranking of removing successive single and pairs of the parameters from the tabulations.

The data associated with each bluefin strike was encoded on a separate punch-card, the parameters represented by different columns and the conditions of each parameter recorded as a different number:

Column 1 (Wind direction)	1 (N), 2 (N.E.), 3 (E), 4 (S.E.), 5 (S), 6 (S.W.), 7 (W), 8 (N.W.).
Column 2 (Wind speed) m.p.h.	1 (0-1), 2 (2-3), 3 (4-5, 4 (6-6), 5 (8-9), 6 (10-11), 7 (12-13), 8 (14-15), 9 (16-17), 10 (18-19).
Column 3 (Rain)	1 (None), 2 (Light), 3 (Medium), 4 (Heavy).
Column 4 (Sea)	1 (Calm), 2 (Swell), 3 (Choppy), 4 (Rough).
Column 5 (Sun)	1 (None), 2 (Weak), 3 (Medium), 4 (Bright).
Column 6 (Fog)	1 (None), 2 (Light), 3 (Medium), 4 (Thick).
Column 7 (Cloud)	1 (None), 2 (1/10), 3 (2/10), 4 (3/10), 5 (4/10), 6 (5/10), 7 (6/10), 8 (7/10), 9 (8/10), 10 (9/10), 11 (10/10).
Column 8 (Water Temp.) degrees C	1 (10-10.9), 2 (11-11.9), 3 (12-12.2), 4 (13-13.9), 5 (14-14.9), 6 (15-15.9).

Results

The number of bluefin strikes associated with each condition of the individual parameters is indicated in Figure 50. Thus over fifty percent of the strikes occurred under bright comparatively cloudless skies, with 12 - 15 m.p.h. south-west to west winds, on calm or choppy sea and with surface water temperatures between 12 - 12.9 degrees C. These optimal strike conditions were further confirmed by analysis of the tabulated combination frequencies. When all of the parameters were considered, the two most frequent combinations (6 each) differed in wind speed only: wind direction (S.W.); wind speed (10 - 11 m.p.h. or 14 - 15 m.p.h.); rain (none); sea (calm); sun (bright); fog (none); cloud (none); water temperature (12 - 12.9 degrees C). The exclusion of each parameter (recorded below) in turn from the tabulations increased the most prevalent combination (recorded in parenthesis) as follows: wind direction (9); wind speed (18); rain (6); sea (9); sun (6); fog (6); cloud (8); water temperature (6). When the parameters were excluded in pairs from the tabulations the maximum frequency of any combination increased to 36 (wind speed and direction omitted): rain (none); sea (calm); sun (bright); fog (none); cloud (none); water temperature (12 - 12.9 degrees C).

The considerable variation of wind direction and speed apparent in the strike data is probably related to their more numerous and precise terms of definition in comparison to the other parameters. The inter-relationship of many of the parameters is

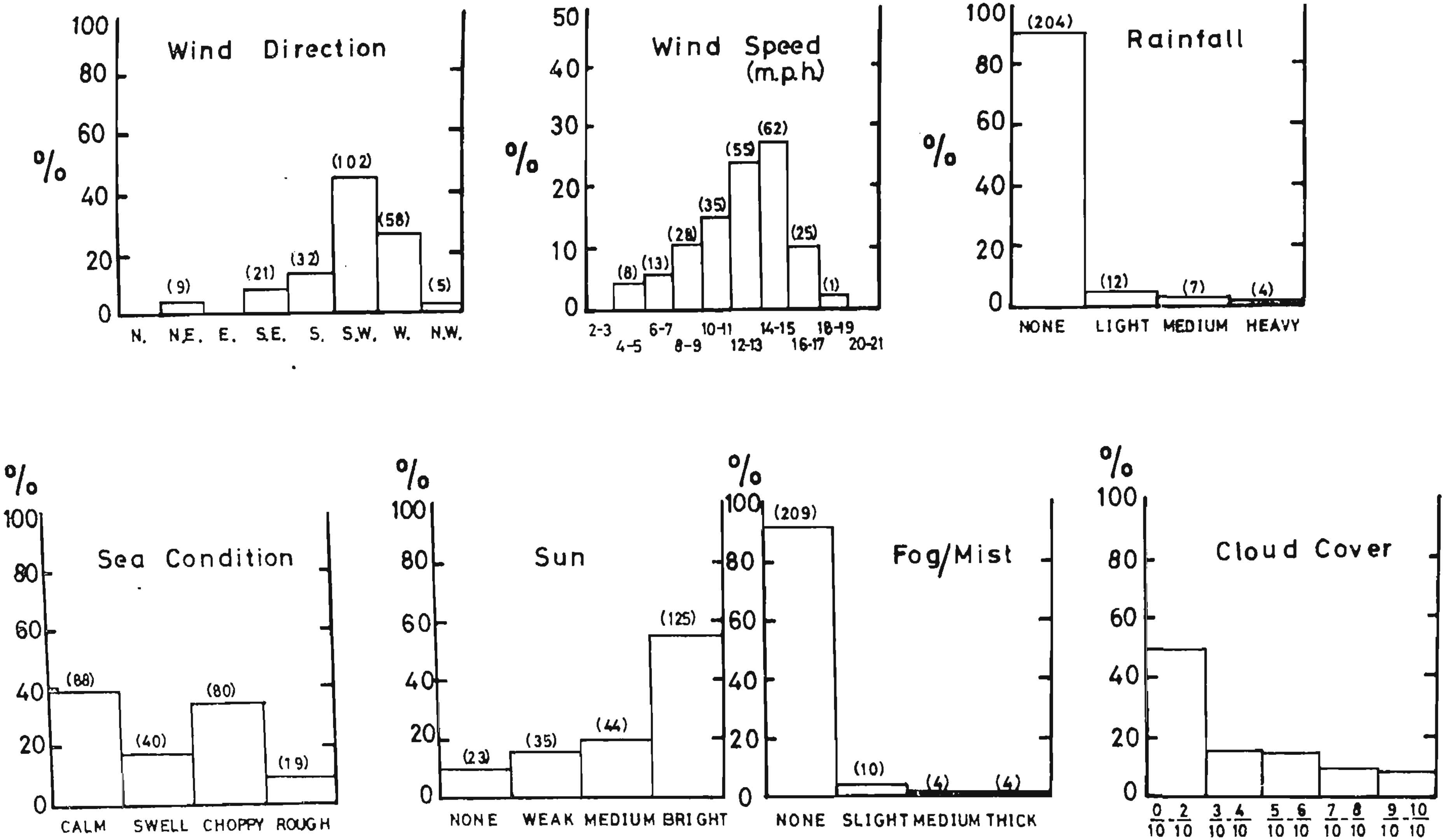


FIGURE 50

THE NUMBER (IN PARENTHESIS) AND PERCENTAGE OF BLUEFIN STRIKES IN RELATION TO THE METEOROLOGICAL AND HYDROGRAPHIC CONDITIONS CONCEPTION BAY, 1966 also clear, i.e. the sea conditions classified as "swell" or "rough" are generally associated with strong northeast winds (or gales) which penetrate Conception Bay from the Atlantic unhindered by the surrounding topography. An increased surface inflow of cold Labrador water results from this condition and the reduced water temperature and possible disruption or displacement of concentrations of food organisms may be responsible for the reduced number of strikes. However, brisk south-west winds are prevalent during the bluefin season and tend to transport the warm surface water and the possibly associated food concentrations to the eastern margin of the bay. Because of the limited "fetch," south-west winds are rarely associated with rough sea conditions. But a calm sea is a relative term and in Newfoundland usually describes considerable surface ripple which can rapidly develop into choppy conditions. A bright sun and minimum overcast would maximize under-water visibility thus aiding the bluefin's visual search for food. The prevalent surface water turbulence, although reducing light penetration, would also tend to obscure the bluefin's vision of the tuna boat but not of the trolled subsurface bait and hence be to the advantage of the fisherman. The water temperatures are considered in Section X.

Attempts to correlate bluefin strikes with the tidal cycle have proved unsuccessful (Lozano Cabo, 1957, 1958; Arena, 1959). The author was similarly unable to find any relationship between the phases of the moon and strike frequency.

SECTION XII

PREDICTION TECHNIQUES

An important objective of oceanographic studies in relation to the availability of the tunas is to forecast the location, time and quantity of fish which will be available to fishermen. Synopticity and continuity of data collection concerning the marine environment (and catches) are fundamental to successful forecasting. Johnson, Flittner and Cline (1965) indicate the degree of sophistication required in their description of the automatic data processing program (ADP) operated in the eastern Pacific. Laevastu (1965) reviewed the development of oceanographic forecasting (hydrosis) in relation to fisheries.

Prediction techniques have been generally based on sea-surface temperature data because more is known about this parameter in relation to the distribution of the tunas. Large scale sea temperature anomalies usually persist for several months which is an added prognostic advantage (Howard, 1962). Hester (1961) attempted to predict not only the distribution but also the total 1960 bluefin catch in California. As previously mentioned, his partially successful predictions were based on coastal sea-surface temperatures (SST). Radovich (1962, q.v. for references) summarized the work of other authors in this field. More recent papers involving the occurrence and distribution of various tuna species in relation to sea-surface temperature are those of Flittner (1963), Broadhead and Barrett (1964) and Quast (1964).

It is apparent that the northerly coastal penetration of the bluefin (and other tuna species) is a function of ocean temperature along the coast, i,e. they are distributed farther north during warm-water years.

Along the Atlantic seaboard of the USA and Canada there appears to be an inter-relationship of trends and anomalies in air and sea temperatures (Bumpus and Chase, 1965; Templeman, 1965). Because air temperature has a delayed effect on water temperature, its analysis may be of considerable predictive significance.

CONCEPTION BAY

The distribution of hookable bluefin at the beginning of the 1966 season (July) was apparently delimited by the 10 degrees C isotherm (see Section VIII). Analysis of available surface water temperature data for the 1964 and 1965 seasons indicated a similar delimitation. In recent years, however, bluefin have been reliably reported in Conception Bay between two and four weeks before the first strike, when the surface water temperature was as much as 4 degrees C cooler. Thus the presence of the bluefin and their inclination to strike a trolled bait are associated with two different isotherms. Surface water temperature data for the North West Atlantic, available from federal, provincial and naval research institutions, in conjunction with locally recorded water and air temperature information, should theoretically permit a forecast of the northward progression to these latitudes of the 6 degrees C isotherm, which appears to be associated with the initial penetration into Conception Bay of the bluefin and the 10 degrees C isotherm associated with the possibility of actually hooking a bluefin.

Quantitative predictions are of a more speculative nature. However, evaluation of the "catch per unit effort" data for the years 1961 - 1966 does appear to indicate an inter-relationship with the relative abundance of squid in Newfoundland coastal waters (Figure 51). This is not surprising when the importance of squid to the diet of the bluefin is considered (see Section VI). According to Hodder (1964), the quantity of squid caught in May to June along the southwest slopes of the Grand Bank and St. Pierre Bank, is usually related to the catch in July to November in coastal waters, i.e. scarce offshore catches are followed by scarce inshore catches in the same year, and vise-versa. Thus an estimate of the season's inshore squid abundance, based on May/June offshore catch data (when available), in conjunction with water temperature predictions (to deduce the probable length of the fishing season) and the likely fishing effort (number of tuna boat registrations) during this period, may permit a prediction of the year's bluefin catch.

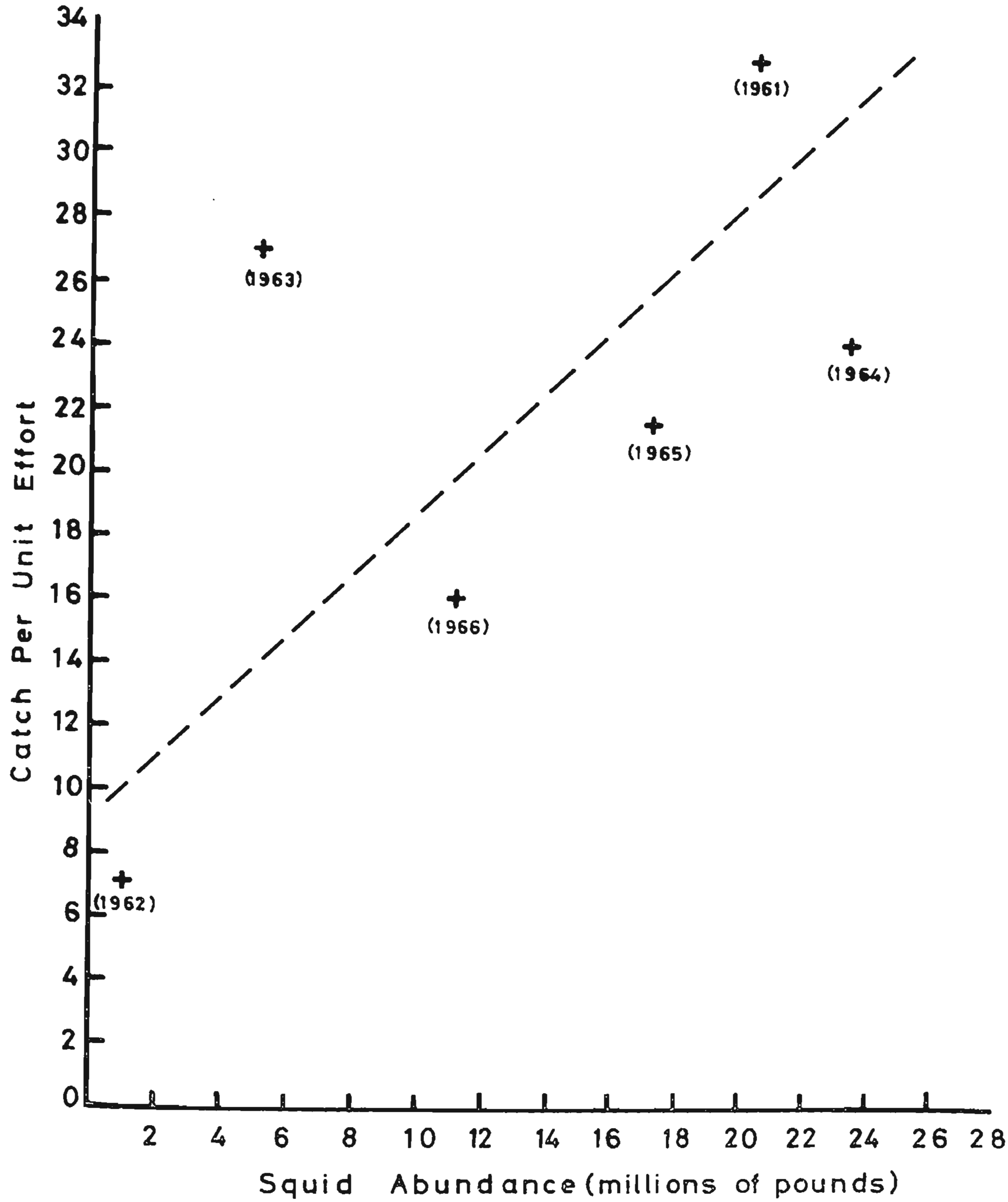


FIGURE 51

THE POSSIBLE INTER-RELATIONSHIP OF RELATIVE SQUID ABUNDANCE IN NEWFOUNDLAND WATERS AND CATCH PER UNIT EFFORT (NUMBER OF BLUEFIN CAUGHT ÷ NUMBER OF TUNA BOATS OPERATING) IN CONCEPTION BAY

SECTION XIII

THE LOG-SHEETS

The log-sheets were designed with the purpose of obtaining as much biological data as possible in addition to the information required by the provincial government. By combining these two requirements, time consuming "paper-work" was reduced to the minimum. With familiarity a log could be completed within two minutes, which was not considered unduly inconvenient even by the naturally conservative crew members.

A log-sheet consisted of two foolscap sized pages (stapled), one containing the data questionnaire and the other the associated grid patterned map of Conception Bay (Figure 52 A&B). The questionnaire covered five major topics: Strike information; meteorological and hydrographic conditions at the time of strike; morphometric data; general bluefin observations; information concerning the angler etc. Much of the morphometric and meteorological data was supplemented by the author's own measurements and information. The grid map of Conception Bay enabled the crews to record accurately the location of each strike. This information, obtained from all of the tuna boats, was transferred by the author to a large wall map (suitably grid-patterned), thus providing a continuous series of situation reports on the shifting catch zones and hence on bluefin concentrations within Conception Bay. In

A

CONCEPTION BAY BLUEFIN DATA SHEET 19[illegible]

PLEASE COMPLETE A SEPARATE QUESTIONNAIRE FOR EACH SUCCESSFUL STRIKE BY TICKING OR FILLING IN THE INDICATED SPACE.

UNSUCCESSFUL STRIKE INFORMATION NEED ONLY BE FILLED IN ON ONE OF THE DATA SHEETS DAILY.

B

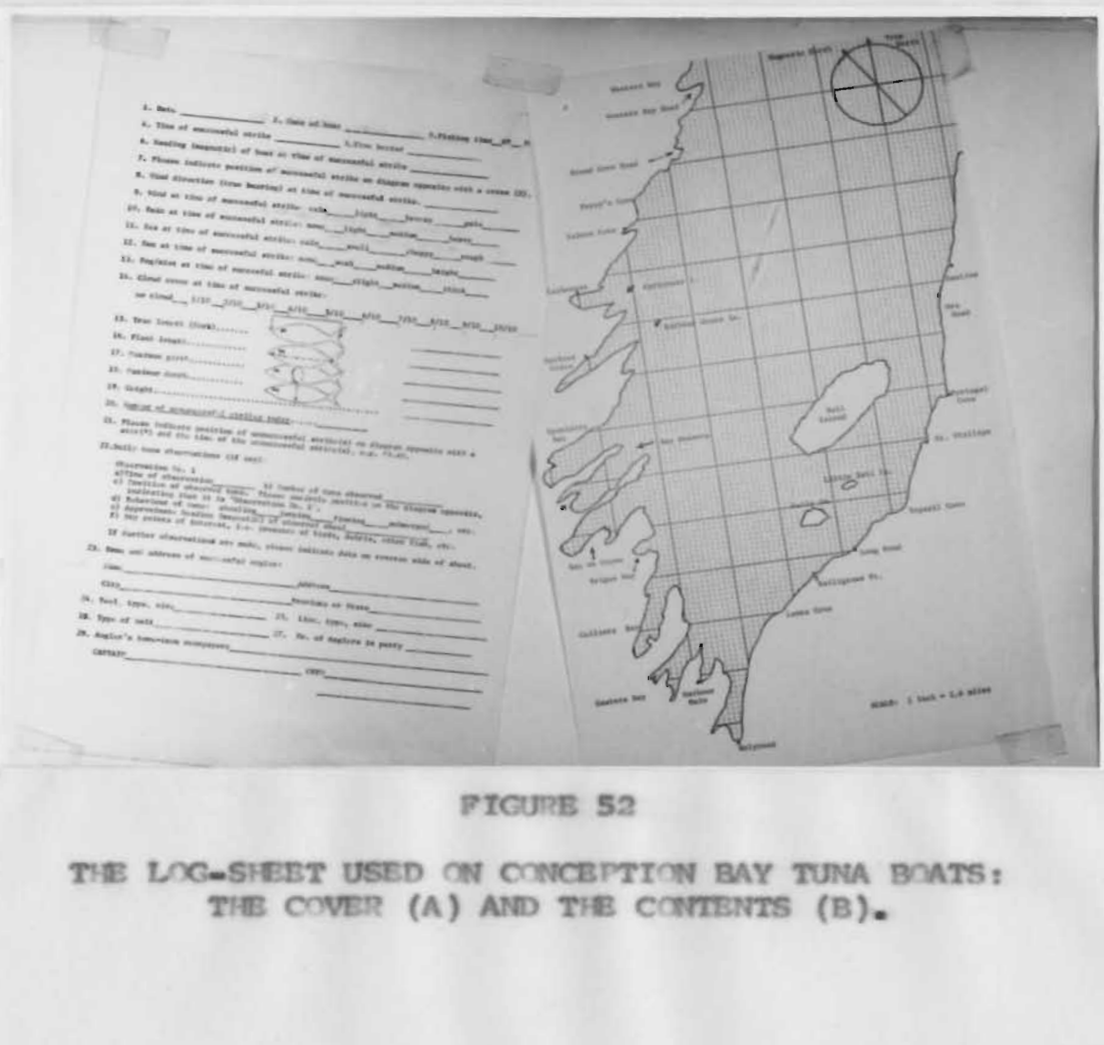


FIGURE 52

THE LOG-SHEET USED ON CONCEPTION BAY TUNA BOATS: THE COVER (A) AND THE CONTENTS (B).

theory, a separate log-sheet had to be completed for each successful and unsuccessful strike during the 1966 season. In contrast to successful strike information, unsuccessful strike data were inadequately recorded. Thus the requirements were modified in 1967 so that the information concerning all unsuccessful strikes on a particular day (time, location etc.) could be recorded on one log-sheet only. In spite of this modification, unsuccessful strike data were only obtained with difficulty, presumably for reasons of prestige. In these circumstances verbal "interrogation" of the crews was the only satisfactory technique for collecting this information. As previously mentioned the ratio of unsuccessful to successful strikes varied from approximately 2:1 to 3:1 depending on the proficiency of the crew and the angler.

In spite of the reticence of the crews to provide unsuccessful strike information the author considers that the log-sheets provided a successful and efficient means of data collection. In consultation with the Tourist Development Office and the Newfoundland Tuna Fishing Association, further modifications could probably be made to the log-sheet format to include the requirements of future research projects.

SECTION XIV

DISCUSSION

Because of the wide range of subjects considered in this thesis, much of the material normally reserved for the "Discussion" has been included in the appropriate section. The author felt justified in doing this for the sake of continuity and comprehension. However, a number of topics warrant further discussion.

Considerable efforts have been made to establish or refute the existence of subpopulations of bluefin within the Atlantic (Tiews, 1962, q.v. for references). Such information would be essential to any future management of the bluefin fishery. The present inconclusive evidence has generally been based on morphometric characteristics which can be altered radically by the environment. A further complication has been the adoption of different indices of measurement on either side of the Atlantic. However, these problems have now been superceded by the introduction of genetic techniques, based on blood analysis, for the identification of subpopulations (Sprague, 1965; Sprague et al, 1962; Mayr and Sprague, 1961).

Tagging is also a method of subpopulation research, but it is primarily used to estimate population size, mortality rates and migration patterns. According to Hamre et al (1966), tagging results in conjunction with year-class analysis indicates that the European Atlantic bluefin fishery depends to a greater extent on the size of the West Atlantic stock than previously supposed. The present commercial development of the West Atlantic fishery could thus have far reaching implications not only for the Conception Bay sports fishery but also for the European Commercial fishery. The high percentage of tag returns in recent years (see Section III), indicates the vulnerability of the bluefin to modern fishing techniques. However, insufficient tagging has taken place to accurately calculate the population size, mortality rates, etc., and hence forecast the maximum sustainable yield of bluefin. In this respects, the sports fishermen visiting Conception Bay could make a valuable contribution to bluefin research by participating in greater numbers in the tagging programs organized by the St. Andrew's Biological Station or the Woods Hole Oceanographic Institution. Such participation would be of far greater benefit than the suggested daily catch limit per boat, which would not significantly conserve the western Atlantic stock because of the relatively small catch in Conception Bay. In addition a returned tag provides international publicity for the Conception Bay sport fishery and satisfaction to the acknowledged angler.

The bluefin are customarily held responsible for the decimation of commercially important species such as cod. According to the stomach analysis data, this does not appear to be the case in Conception Bay (see Section VI). The author's analysis also revealed points of behavioural and physiological interest. The prey were generally swallowed whole which is apparently a scombrid characteristic (Suyehiro, 1942). The bluefin's teeth are poorly developed and according to Nakamura (1949), the prey are not mortally wounded before ingestion, although large prey are bitten in the trunk before being swallowed head first. A rapid rate of digestion was also apparent which may be related to the ability of the tunas to maintain their body temperature several degrees above that of their environment (Carey and Teal, 1966).

The tunas are considered an exception to the rule that fishes are poikilothermic. Blood temperatures in the bluefin have been reported as 5 degrees - 8 degrees C (Sintesis and Bellon, 1954) or 10 degrees C (Ehrenbaum, 1936) higher than the surrounding water temperature. Homiothermy is achieved by means of a countercurrent heat exchange system located in the vascular system of the muscles. This thermal barrier prevents heat from being carried off by the blood and lost through the gills; it also lowers the thermal gradient between the surface of the body and the water, so reducing heat loss through surface cooling (Carey and Teal, 1966). This ability is generally related to the great muscular power of the tunas (Ehrenbaum, 1936; Norman and Fraser, 1948; Sintesis and Bellon, 1954), but increased rates of processes such as the conduction of nerve impulses and digestion are additional benefits (Carey and Teal, 1966).

Perhaps the ability of the bluefin to tolerate a water temperature range of as much as twenty five degrees centigrade, experienced during its feeding migration, is also associated with this phenomenon.

The Conception Bay bluefin sport fishery presents unlimited research opportunities not only because of the availability of a regular supply of specimens but also because of the proximity of the bay to research institutions and the support of the necessary government, commercial and private agencies in Newfoundland. Because of the limited duration of the present study several of the topics considered have, however, suffered from lack of available data. It is therefore, necessary to consider some of the author's conclusions as being of a tentative nature. The collection of further information in future seasons is thus essential. The log-sheet and morphometric program, in fact, was continued successfully throughout the 1967 fishing season. In addition to a more detailed consideration of the topics included in this thesis, there are numerous other bluefin projects which could be undertaken: the detailed histology and anatomy of the bluefin's sense organs; subpopulation analysis by means of genetic techniques; behaviour characteristics, e.g. feeding; experimental fishing; current analysis within Conception Bay and the mapping of basic biological properties such as productivity and standing crop as well as physical and chemical parameters; the development of an anchored data collecting device which will operate unattended and record synoptic oceanographic and meteorological observations. This will enable the study of temporal variations in the oceanic climate and the corresponding change in the bluefin's distribution. Preliminary discussions were held with Technical Services personnel of Memorial University concerning the feasibility of the latter project.

SECTION XV

SUMMARY

1. The bluefin tuna, *Thunnus thynnus*, Linnaeus (1758), caught in the Conception Bay sport fishery during the 1965 and 1966 fishing seasons, formed the basis for a general biological study of the species.

2. The bluefin was described in terms of its morphology, size, colour, and distinguishing features.

3. The taxonomic status of bluefin within the family Scombridae was discussed. The most recent interpretation recognizes an Atlantic subspecies (*Thunnus thynnus thynnus*), an Indo-Pacific subspecies (*Thunnus thynnus orientalis*), and the southern bluefin (*Thunnus maccoyii*).

4. The three members of the *Thunnus thynnus* - *maccoyii* complex were distinguished by means of the number of their gill rakers. The means and modes (in parenthesis) are as follows: Atlantic 38.9 (39), Pacific 35.9 (35), *T. maccoyii* 33.7 (34). The frequency of combination of gill rakers on the upper and lower limb of the first gill arch of Conception Bay and European bluefin were compared.

5. The valid scientific synonyms and English vernacular names for the bluefin were listed.

6. The distribution of the bluefin is circumglobal in subtropical and temperate water, extending into the tropics in

the winter and as far as the Arctic Circle in summer. In the western Atlantic the bluefin is found from Labrador to Argentina. The vertical range of the adults is considered to be at least 0-200 metres, and the larvae mainly between 0-50 metres.

7. The life history of the western Atlantic bluefin was described with particular reference to the feeding migration (June to October). The speed and endurance required for such a migration were considered in terms of the morphological and physiological adaptations of the bluefin.

8. The technique, uses and results of tagging were examined, particularly in relation to the western Atlantic bluefin population. The occurrence of trans-Atlantic migration from west to east has been confirmed. The high tag-return rate (18% in 1964) indicated the vulnerability of bluefin to modern fishing methods; particularly the purse seine. The total number of bluefin tagged in Conception Bay up to the end of the 1966 season was 177 fish. No returns have been reported.

9. The number of bluefin in a school tends to vary inversely with the size of the individuals. Three common behavioural patterns exhibited by bluefin are pushing, milling and smashing. The possible advantages of schooling: propagation, protection, capture of prey and "learning" ability were considered.

10. The biology of bluefin reproduction was described. There appeared to be a reversal in the sex ratio when Caribbean

and Canadian data were compared. Erythrocyte analysis was suggested as a means of sex determination other than gonadectomy.

11. The majority of the bluefin caught in Conception Bay were aged 11, 12 or 13 years, as determined by vertebral ring counts and length frequency analysis. Age, length and weight inter-relationships were also computed. Bluefin increased their weight by 8.5 - 10% per month during the northern feeding season. Because of the limited size range of the fish examined (215 - 250 cm fork length) isometric and allometric trends were difficult to detect in relative growth studies.

12. In Conception Bay, food consisted predominantly of squid (Illex illecebrosus). Capelin (Mallotus villosus) and billfish (Scomberesox saurus) were of secondary importance. Commercially important species such as cod were rarely observed in the stomach contents. The major feeding period was calculated to be from 11:00 - 15:00 hours.

13. The relationship of water transparency to catch success was considered. In this respect a submarine photometer was constructed and operated in Conception Bay, but technical problems prevented its effective use during the 1966 bluefin season.

14. The major catch zones in Conception Bay, the Bauline and Harbour Grace Island areas, were determined from log-sheet data.

15. The hydrography of the North West Atlantic and in particular Conception Bay, was examined in relation to the distribution and behaviour of the bluefin.

16. The effect of meteorological and hydrographic conditions on catch success was analysed and the optimum combination of conditions determined. Over 50% of the strikes occurred during bright comparatively cloudless skies, with 12 - 15 mph south-west to west winds, on calm or choppy seas and with surface water temperatures between 12 degrees - 12.9 degrees C.

17. Possible techniques to predict the time of arrival and total catch were considered. The 6 degrees C isotherm appeared to be associated with the initial penetration of the bluefin into Conception Bay and the 10 degrees C isotherm with the possibility of actually hooking a bluefin. A quantitative prediction technique, based on the analysis of estimated squid abundance, surface water temperature and fishing effort, was suggested.

18. The log-sheet, as used by the Conception Bay sport fishery, was designed to meet both biological and commercial requirements.

REFERENCES

ANONYMOUS. 1925. Albacore appear near San Francisco. Calif. Fish Game, 11(4): 185-6.

ANONYMOUS. 1932. First list of fishes in the Newfoundland fishing area. Ann. Rep. Newfoundland Fish. Res. Comm. for 1931, 1(4): 107-110.

ANONYMOUS. 1957. North Atlantic fisheries exploration and gear research. (M/V) DELAWARE cruises). Comm. Fish. Rev., 19(5): 28-29; 19(8): 27-29.

__________ 1958. North Atlantic fisheries exploration and gear research. (M/V) DELAWARE cruise). Comm. Fish. Rev., 20(7): 35-36.

__________ 1959. North Atlantic fisheries exploration and gear research. (M/V) DELAWARE cruises). Comm. Fish. Rev., 21(4): 46-47; 21(7): 40-41.

ANONYMOUS. 1964. Bluefin tuna tagged of Mexico recaptured near Japan. Comm. Fish. Rev., 26(12): 62-63.

ANONYMOUS. 1967. Referred to in F.T. MOSS. 1967. Countdown on tuna. Sportfishing, May: 11-13; 34-36.

AKYÜZ, B.F. and I. ARTÜZ. 1957. Some observations on the biology of tuna (Thunnus thynnus) caught in Turkish waters. Proc. gen. Fish. Coun. Medit., 4: 93-9.

ALVERSON, D.L. 1961. Ocean temperatures and their relationship to albacore tuna (Thunnus germo) distribution in waters off the coast of the states of Oregon, Washington, and the province of British Columbia. J. Fish. Res. Bd. Can., 18(6): 1145-52.

ARENA, P. 1959. Observations accomplices pendant la saison de peche 1958 dans une madrague le long des côtes de la Sicile. Proc. gen. Fish. Coun. Medit., 5: 501-4.

ARICÒ, F. and S. GENOVESE. 1953. Sui caratteri biometrici del tonno (Thunnus thynnus) tirrenico. Bull. Pesca. Piscic. Idrobiol., 8(1): 1-44.

ATKINS, W.R.G., et al. 1938. Measurement of submarine daylight. Conseil Perm. Internat. p. l'Explor. de la Mer, Journal du Conseil, 13: 37-57.

AUSTIN, T.S. 1960. Oceanography of the east central equatorial Pacific as observed during expedition Eastropic. Fish. Bull., U.S., 60(168): 257-82.

BACKUS, R.H. 1957. The fishes of Labrador. Bull. Amer. Mus. Nat. Hist., 113(4): 273-337.

BAHR, K. 1952. Untersuchungen über den roten Thun (Thunnus thynnus L.) in der Nordsee. Ber. dtsch. Komm. Meeresforsch., 13(1): 64-78.

BEKLEMISHEV, K.V. and V.A. BURKOV. 1958. Relationship between plankton and water masses in the frontal region in the northwest Pacific. Trud. Inst. Okeanol., 27(4): 1-12. (In Russian).

BELL, R.R. 1962. A history of tuna age determinations. Proceedings of the Symposium on Scombroid Fishes held at Mandapam Camp from Jan. 12-15, 1962, Part 2: 693-706.

BERG, L.S. 1955. Classification of fishes and fishlike animals, both recent and fossil. Trud. zool. Inst. Akad. Nauk SSSR, 20: 286 pp. (In Russian).

BEVERTON, R.J.H. and S.J. HOLT. 1957. On the dynamics of exploited fish populations. Fish. Invest., Lond. (2), 19: 533 pp.

BIGELOW, H.B. and W.C. SCHROEDER. 1953. Fishes of the Gulf of Maine. U.S. Fish. and Wildlife Serv., Fish. Bull., 74, vol. 53, pp. 1-577.

BJERKAN, P. 1919. Results of the hydrographical observations made by Dr. Johan Hjort in the Canadian Atlantic waters during 1915. Can. Fish. Exped. 1914-15 (1919) Dept. Naval Service. Ottawa, 1919.

BJERKNES, J. 1961. "El nino" study based on analysis of ocean surface temperatures 1935-1957. Bull. Inter-Amer. Trop. Tuna Comm., 5(3): 217-303. (In English and Spanish).

BLACKBURN, M. 1965. Oceanography and the ecology of tunas. Oceanog. Mar. biol. Ann. Rev., 3: 299-322.

BLAXTER, J.H. 1965. Effect of change of light intensity on fish. ICNAF Spec. Publ., vol. 6: 647-661.

BOREL, J.F. 1962. Vox Sang., 7: 632. Referred to in E. Cohen. Sex differentiation of avian erythrocytes by lectin of Aesculus hippocastanum and by heteroagglutinins of Limulus polyphemus. Paper presented to the Xth Congress of the International Society of Haematology.

BORISOV, P.G. and V. PROTASOV. 1960. Some aspects of light perception in fish and selective light sources. I.C.E.S. Comp. Fish Committee, Paper 139.

BREDER, C.M., Jr. 1954. Equations descriptive of fish schools and other animal aggregations. Ecology, 35(3): 361-70.

__________ 1959. Studies on social groupings in fishes. Bull. Amer. Mus. nat. Hist., 117(2): 397-481.

BROADHEAD, G.C. and I. BARRETT. 1964. Some factors affecting the distribution and apparent abundance of yellowfin and skipjack tuna in the eastern Pacific Ocean. Bull. Inter-Amer. Trop. Tuna Comm., 8(8): 419-473.

BROCK, V.E. 1954. Some aspects of the biology of aku, Katsuwonus pelamis, in the Hawaiian Islands. Pacif. Sci., 8(1): 94-104.

BROCK, V.E. and R.H. RIFFENBURGH. 1960. Fish schooling: a possible factor in reducing predation. J. Cons., 25(3): 307-17.

BULLIS, H.R. and F.J. MATHER III. 1956. Tunas of the genus Thunnus of the northern Caribbean. Amer. Mus. Novit., (1765): 1-12.

BUMPUS, D.F. and J. CHASE. 1965. Changes in the hydrography observed along the east coast of the United States. ICNAF Spec. Publ. No. 6: 847-854.

CAREY, F.C. and J.M. TEAL. 1966. Heat conservation in tuna fish muscle. Reprinted from Proc. Nat. Acad. Sci., 56(5): 1464-1469.

CASSIE, R.M. 1950. The analysis of polymodal frequency distributions by the probability paper method. N.Z. Sci. Rev., 8: 89-91.

__________ 1954. Some uses of probability paper in the analysis of size frequency distributions. Aust. J. Mar. Freshw. Res., 5(3): 513-22.

CHAPMAN, W.M. 1962. World-wide tuna research planning. Paper presented to the World Scientific Meeting on the Biology of Tunas and Related Species, La Jolla, California, 2-14 July 1962. Also in FAO Fish. Rep., (6), vol. 3: 1097-107, 1963.

CLEMENS, H.B. 1957. Logging the longfins. Skippers help DFG predict albacore run. Outdoor Calif., 18(11): 6-7.

__________ 1958. Albacore newsletter. California Department of Fish and Game, Marine Research Operations, 4 pp., mimeo.

__________ 1961. The distribution of California bluefin tuna in the eastern North Pacific. Paper presented to the Pacific Tuna Biology Conference, Honolulu, Hawaii, 14-19 August 1961, (1-4): 8 pp. mimeo. (SS/13a and IP/2b).

COHEN, E. no date. Sex differentiation of avian erythrocytes by lectin of Aesculus hippocastanum and by heteroagglutinins of Limulus polyphemus. Paper presented to the Xth Congress of the International Society of Haematology. (Abstract).

COLLETTE, B.B. and R.H. GIBBS, Jr. 1962. A preliminary review of the fishes of the family Scombridae. Paper presented to the World Scientific Meeting on the Biology of Tunas and Related Species, La Jolla, California, 2-14 July 1962. Also in FAO Fish. Rep., (6), vol. 1: 23-32, 1963.

CORNISH, G.A. 1907. Notes on the fishes of Canso. Contrib. Canadian Biol., 1902-1905, No. 9: 81-90.

COX, P. 1896. History and present state of the ichthyology of New Brunswick. Bull. Nat. Hist. Soc. New Brunswick, 13: 27-61.

CRAIG, W.L. 1959. Albacore newsletter. California Department of Fish and Game, Marine Research Operations, 3 pp., mimeo.

__________ 1960. Albacore newsletter. California Department of Fish and Game, Marine Research Operations, 3 pp., mimeo.

CRANE, J. 1936. Notes on the biology and ecology of the giant tuna, Thunnus thynnus Linnaeus, observed at Portland, Maine. Zoologica, N.Y., (21): 207-11.

CROMWELL, T. 1953. Circulation in the meridional plane in the central equatorial Pacific. J. Mar. Res., 12(2): 196-213.

__________ 1958. Thermocline topography, horizontal currents and 'ridging' in the eastern tropical Pacific. Bull. Inter-Amer. trop. Tuna Comm., 3(3): 133-64. (In English and Spanish).

De JAGER, B.v.D. 1963. Synopsis of biological data on bluefin tuna *Thunnus thynnus orientalis* (Temminck and Schlegel) 1842, longfin tuna *Thunnus albacares* (Bonnaterre) 1788 and bigeye tuna *Thunnus obesus* (Lowe) 1839 (South Africa). *FAO Fish. Rep.*, (6), vol. 2: 588-607.

DeSYLVA, D.P. 1955. The osteology and phylogenetic relationships of the blackfin tuna, *Thunnus atlanticus* (Lesson). *Bull. Mar. Sci. Gulf Carib.*, 5(1): 1-41.

__________ 1956. The food of tunas. *Bull. intern. Oceanogr. Found.*, 2(1): 37-48.

DIETRICH, G. 1964. Oceanic polar front survey in the North Atlantic in the IGY. *US Nat. Acad. Sc., Spec. Vol. for IGY.*

DIEUZEIDE, R. 1951. Campagne en Méditerranée du navire oceanographique de l'Office Scientifique et Technique des Pêches Maritimes PRESIDENT THEODORE TISSIER. *Bull. Sta. Aquic. Pêche Castiglione, N.S.*, (3): 135-8.

DIEUZEIDE, R. and J. ROLAND. 1955. Contribution à la connaissance des formes jeunes de *Thunnus thynnus* Linné. *Bull. Sta. Aquic. Pêche Castiglione, N.S.*, (7): 307-39.

DUNBAR, M.J. 1951. Eastern Arctic waters. *Bull. Fish. Res. Bd. Can.*, No. 88: 131 pp.

EBER, L.E. 1961. Effects of wind-induced advection on sea surface temperature. *J. geophys. Res.*, 66(3): 839-44.

EHRENBAUM, E. 1924. Scombriformes. *Rep. Danish oceanogr. Exped. Medit.*, 2(8) (Biology), A 11, pp. 1-30.

__________ 1936. Naturgeschichte und wirtschaftliche Bedeutung der Seefische Nordeuropas. *Handb. Seefisch. Nordeurop.*, Band 2: 337 pp.

FAO. 1964. Fisheries Division, *Yearb. Fish Statist. FAO*, 1963, vol. 16, Rome, 1964.

FARRINGTON, S.K. 1949. Fishing the Atlantic offshore and on. New York, Coward-McCann Inc., 312 pp.

FLITTNER, G.A. 1963. Review of the 1962 seasonal movement of albacore tuna off the Pacific coast of the United States. *U.S. Fish Wildl. Serv., Comm. Fish. Rev.*, 25(4): 7-13.

FLOWER, B. and E. ROSENBAUM. 1958. The Roman cookery book, a critical translation of the Art of Cooking by Apicius for use in the study and the kitchen. Peter Nevill Ltd., London and New York, 239 pp.

FORD, E. 1933. An account of the herring investigations conducted at Plymouth during the years from 1924-1933. J. Marine Biol. Assn., 19: 305-384.

FRADE, F. 1931. Données biométriques pour l'étude du thon rouge de l'Algarve. Bull. Soc. portug. Sci. nat., 11(7): 89-130.

________ 1950. Estudos de pescarias do ultramar portugues. Os atuns. Coloq. Jta. Invest. colon.

FRADE, F. and S. MANACAS. 1933. Sur l'état de maturité des gonades chez le thon rouge génétique (Note préliminaire). Trav. Sta. Biol. marit. Lisbonne, (33): 1-15.

FRADE, F. and H. VILELA. 1960. Rapport sur Thunnus thynnus (L.) et Germo alalunga (Bonn.). CCTA/CSA, Colloque sur les Thonidés, Dakar, 12-17 décembre 1960, Tunny, (60) 8, 32 pp., mimeo.

FRASER-BRUNNER, A. 1950. The fishes of the family Scombridae. Ann. Mag. nat. Hist., ser. 12, 3(26): 131-63.

FRY, F.E.J. 1957. The aquatic respiration of fish. In Physiology of Fishes. vol. 1. Ed. Brown, M.E. Academic Press Inc., New York, 1-63.

FUGLISTER, F.C. and L. WORTHINGTON. 1951. Some results of a multiple-ship survey of the Gulf Stream. Tellus, 3(1): 1-14.

FUJINO, K. 1967. Instructions for collecting blood and serum samples from tuna fishes. FAO Fish. Circ. No. 26, Rev. 1: 1-15.

GALTSOFF, P.S. 1952. Staining of growth rings in the vertebrae of tuna (Thunnus thynnus). Copeia, (2): 103-5.

GENOVESE, S. 1956. Ulteriori osservazioni sui caratteri biometrici del tonno (Thunnus thynnus L.) tirrenico. Il tonno intergenetico dello Stretto di Messina. Boll. Pesca Piscic. Idrobiol., N.S., 11(1): 83-120.

GIBBS, R.H. and B.B. COLLETTE. 1966. Comparative anatomy and systematics of the tunas, Genus Thunnus. U.S. Fish Wildl. Serv., Fish. Bull., 66(1): 65-130.

GINSBURG, I. 1953. The taxonomic status and nomenclature of some Atlantic and Pacific populations of yellowfin and bluefin tunas. Copeia, (1): 1-10.

GODSIL, H.C. 1954. A comparison of Japanese and Hawaiian specimens of the black skipjack, Euthynnus yaito. Calif. Fish Game, 40(4): 411-3.

GODSIL, H.C. and R.D. BYERS. 1944. A systematic study of Pacific tunas. Fish Bull., Sacramento, (60): 131 pp.

GODSIL, H.C. and E.K. HOLMBERG. 1950. A comparison of the bluefin tunas, genus Thunnus from New England, Australia and California. Fish Bull., Sacramento, (77): 55 pp.

HACHEY, H.B. 1961. Oceanography and Canadian Atlantic waters. Bull. Fish. Res. Bd. Can., No. 134,: 120 pp.

HACHEY, H.B., F. HERMANN and W.B. BAILEY. 1954. The waters of the ICNAF Convention area. Ann. Proc. ICNAF., vol. 4, 1953-54: 67-102.

HAMRE, J. 1958. About the age composition of Norwegian tuna catches in the years 1954-1958. ICES Scombriform Fish Committee, No. 91, 6 pp.

________ 1959. The tuna tagging experiments in Norwegian waters. ICES Scombriform Fish Committee, No. 92, 3 pp.

________ 1961. Some results of the Norwegian bluefin tuna investigations. ICES Scombriform Fish Committee, No. 90, 7 pp.

________ 1962. Size and composition of tuna stocks. Paper presented to the World Scientific Meeting on the Biology of Tunas and Related Species, La Jolla, California, 2-14 July 1962. Also in FAO Fish. Rep., (6), vol. 3: 1023-39, 1963.

________ 1965. Observations on the depth range of tagged bluefin tuna (Thunnus thynnus L.) based on pressure marks on the Lea tag. Arch. Fischereiwiss., 15(3): 204-209.

HAMRE, J., *et al.* 1966. Report from the Bluefin Tuna Working Group. On the development of the bluefin tuna fisheries from 1950-1964 and further observations on the size composition of bluefin tuna catches. Statistical News Letters, No. 26, Cons. perm. Int. Explor. Mer., 34 pp.

HARDING, J.P. 1949. The use of probability paper for the graphical analysis of polymodal frequency distributions. J. Mar. Biol. Ass. U.K., 28(1): 141-153.

HAYASHI, S. 1958. A review of age determination of the Pacific tunas. Proc. Indo-Pac. Fish., Comm. 7th Sess. Sec. 2-3: 53-64.

HEINCKE, F. 1905. Das vorkommen und die Verbreitung der Eier, de Larven und der verschiedenen Altersstufen der Nutzfische in der Nordsee. Rapp. Conseil Expl Mer, 3, App. E.: 41 pp.

HELDT, H. 1926. Résumé de nos connaissance actuelles sur le thon rouge *Thunnus thynnus* L. Bull. Sta. océanogr. Salammbô, (5): 1-44. Also in Rapp. Comm. Int. Mer. Médit., n.s., 1: 99-120.

________ 1927. Contribution à l'étude des races de thon (*Thunnus thynnus* L.). Caractères biométriques du thon tunisien et considérations sur sa croissance. Ann. Sta. océanogr. Salammbô, (4): 1-54.

________ 1931. Le thon rouge et sa pêche, elements d'un nouveau rapport. Bull. Sta. océanogr. Salammbô, (21): 165 pp.

________ 1932. Le thon rouge et sa pêche, rapport pour 1931. Bull. Sta. océanogr. Salammbô, (29): 168 pp.

________ 1938. Le thon rouge et sa pêche. Rapp. Comm. int. Mer. Médit., 11: 311-58.

HESTER, F.J. 1961. A method of predicting tuna catch by using coastal sea-surface temperatures. Calif. Fish Game, 47(4): 313-26 (MP/4a).

HESTER, F. and J.H. TAYLOR. 1965. How tuna see a net. Comm. Fish. Rev., 27(3): 11-16.

HODDER, V.M. 1964. The Newfoundland squid fishery in 1964. Trade News, 171: 16-18.

HOLLISTER, G. 1934. Cleaning and dyeing fish for bone study. Zoologica, N.Y., 12(10): 89-101.

HOTTA, G., T. KARIYA and T. OGAWA. 1959. A study on the "biting" of skipjack in the live-bait fishery. Part 1. Relation between the "biting" and the alimental canal in the Tohoku Sea area. Bull. Tohoku Fish. Res. Lab., (13): 60-78 (In Japanese with English summary).

HOWARD, G.V. 1962. The matter of availability and harvest of tunas. Paper presented to the World Scientific Meeting on the Biology of Tunas and Related Species, La Jolla, California, 2-14 July 1962. Also in FAO Fish. Rep., (6), vol. 3: 1041-55, 1963.

HSIAO, S.C. and A.L. TESTER. 1955. Reaction of tunas to stimuli, 1952-53, Part 2. Response of tuna to visual and to visual-chemical stimuli. Spec. sci. Rep. U.S. Fish Wildl. Serv. -Fish., (130): 63-76.

HUBBS, C.L. 1948. Changes in the fish fauna of western North America correlated with changes in ocean temperature. J. Mar. Res., 7(3): 459-82.

HUBBS, C.L. and L.P. SCHULTZ. 1929. The northward occurrence of southern forms of marine life along the Pacific coast in 1926. Calif. Fish Game, 15(3): 234-40.

HUNTSMAN, A.G. 1922. The fishes of the Bay of Fundy. Contrib. Canadian Biol., 1921, No. 3: 49-72.

IMAMURA, Y. 1949. The skipjack fishery. Text Fish., Tokyo, 6: 17-94 (In Japanese). English transl. in Spec. sci. Rep. U.S. Fish Wildl. Serv. -Fish., (49): 67 pp., publ. 1951.

INOUE, M. 1958. Studies on movements of albacore fishing grounds in the northwest Pacific Ocean. 1. Adaptability of water temperatures for albacores in the winter season from observations of records on catches and optimum water temperatures by fishing boats. Bull. Jap. Soc. sci. Fish., 23: 673-9. (In Japanese with English summary).

________ 1959. Studies on the movements of albacore fishing grounds in the northwest Pacific Ocean. 2. Influence of fluctuations of the oceanographical conditions upon the migration and distribution of albacore in winter-summer season and its fishing ground in the southern waters off Japan. Bull. Jap. Soc. sci. Fish., 25(6): 424-30. (In Japanese with English summary).

ISELIN, C.O'D. 1927. A study of the Northern part of the Labrador Current. Bull. Nat. Res. Coun. No. 61, Washington 1927.

_____________ 1960. The Gulf Stream System. Oceanus, vol. 6, No. 4: 20-23. Woods Hole Oceanographic Institution, Woods Hole, Massachusetts.

IVERSEN, R.T.B. 1962. Food of albacore tuna, Thunnus germo (Lacépède) in the central and northeastern Pacific. Fish. Bull., U.S., 62(214): 459-81.

IWAI, T., I. NAKAMURA and K. MATSUBARA. 1965. Taxonomic study of the tunas. Misaki Mar. Biol. Inst. Spec. Rep., 2: 1-51. (In Japanese with English summary; Bur. Comm. Fish. Ichthyological Lab., Translation No. 38).

IYIGÜNGÖR, D. 1957. Méthodes et moyens de pêche au thon actuellement en usage en Turquie. Proc. gen. Fish. Coun. Médit., 4: 251-5.

JERLOV, N.G. 1951. Optical studies of ocean waters. Report of the Swedish Deep Sea Expedition, 1947-1948.

JOHNSON, J.H. 1960. Navy vessels troll for albacore. Calif. Fish. Mark. News Summ. (2), August 1960: 2-4.

_____________ 1961. Sea temperatures and the availability of albacore (Thunnus germo) off the coast of Oregon and Washington. Paper presented to the Pacific Tuna Biology Conference, Honolulu, Hawaii, 14-19 August 1961, (V-6): 14 pp., mimeo.

_____________ 1962. Changes in availability of albacore in the eastern Pacific Ocean 1952 and 1958. Paper presented to the World Scientific Meeting on the Biology of Tunas and Related Species, La Jolla, California, 2-14 July 1962. Also in FAO Fish. Rep., (6), vol. 3: 1227-35, 1963 (MP/4a).

JOHNSON, J.H., G.A. FLITTNER and M.W. CLINE. 1965. Automatic data processing program for marine synoptic radio weather reports. U.S. Fish Wildl. Serv., Spec. sci. Rep., -Fish., 503: 1-74.

JONES, S. and E.G. SILAS. 1960. Indian tunas - a preliminary review with a key for their identification. Indian J. Fish., 7(2): 369-93.

JORDAN, D.S. and B.W. EVERMANN. 1926. A review of the giant mackerel-like fishes, tunnies, spearfishes, and sword fishes. Occ. Pap. Calif. Acad. Sci., (12): 8-25.

KALLE, K. 1938. Zum problem der meereswasserfarbe (On the problem of the colour of sea water). Ann. d. Hydrogr. und Mar. Meteor., Bd. 66, S. 1-13.

KAWADA, S., Y. TAWARA and C. YOSHIMUTA. 1958. An attempt for determining the swimming speed of fish schools by the fish finder - Preliminary report. Bull. Jap. Soc. sci. Fish., 24: 1-4.

KING, J.E. and T.S. HIDA. 1957. Zooplankton abundance in the central Pacific. 2. Fish. Bull., U.S., 57(118): 365-95.

KING, J.E. and I.I. IKEHARA. 1956. Comparative study of food of bigeye and yellowfin tuna in the central Pacific. Fish. Bull., U.S., 57(108): 61-85.

KISHINOUYE, K. 1915. A study of mackerels, cybiids, and tunas. Proc. sci. Fish Ass., Tokyo, 1(1): 1-24 (In Japanese).

____________ 1917. The food of tunas. Proc. sci. Fish. Ass., Tokyo, 2(1): 106-8 (In Japanese) (SS/8b).

____________ 1923. Contributions to the comparative study of the so-called scombroid fishes. J. Coll. Agric. Tokyo, 8(3): 293-475.

KOOPMAN, B.O. 1956. The theory of search. II. Target detection. Operations Research, 4: 503-31.

KRUMHOLZ, L.A. 1959. Stomach contents and organ weights of some bluefin tuna (Thunnus thynnus Linnaeus), near Bimini, Bahamas. Zoologica, N.Y., 44, part 3(6-8): 127-31.

LAEVASTU, T. 1965. Is oceanographic forecasting (Hydrosis) feasible for fisheries? ICNAF Spec. Publ. No. 6: 881-884.

LAEVASTU, T. and H. ROSA, Jr. 1962. Distribution and relative abundance of tunas in relation to their environment. Paper presented to the World Scientific Meeting on the Biology of Tunas and Related Species, La Jolla, California, 2-14 July 1962. Also in FAO Fish. Rep., (6), vol. 3: 1835-51, 1963.

LAGLER, K.F., J.E. BARDACH and R.R. MILLER. 1962. Ichthyology. John Wiley & Sons Inc., New York, 545 pp.

LeGALL, J. 1949. Germon. Résumé des connaissances acquises sur la biologie du germon. Rev. Trav. Off. Pêch. marit., 15: 1-42.

__________ 1954. Recherches sur les poissons Scombriformes: germon-thon rouge. Rev. Trav. Inst. Pêch. marit., 18(2-4): 59-67.

LEIM, A.H. and W.B. SCOTT. 1966. Fishes of the atlantic coast of Canada. Fisheries Research Board of Canada, Ottawa, 485 pp.

LIPPMAN. 1935. Reffered to in P.S. GALTSOFF. 1952. Staining of growth rings in the vertebrae of tuna (Thunnus thynnus). Copeia, (2): 103-5.

LOZANO CABO, F. 1957. Notes sur la biologie et la pêche des thons. Proc. gen. Fish Coun. Médit., (4): 113-7.

__________ 1958. Los escombridos de las aguas españolas y marroquies y su pesca. Trab. Inst. esp. Oceanogr., (25): 254 pp.

LÜHMANN, M. 1959. Die deutsche Tunifischerei und ihre Fänge in den Jahren 1956-1958. Arch. FischWiss., 10 (1/2): 68-9.

McKENZIE, R.A. 1959. Marine and freshwater fishes of the Miramichi River and estuary, New Brunswick. J. Fish. Res. Bd. Can., 16(6): 807-33.

__________ 1965. The Northwest Atlantic tunas, bonitos and their fishery. A Review Prepared for the Industrial Development Service of the Department of Fisheries of Canada, 85 pp.

MAGNUSON, J.J. 1962. Tuna behavior and physiology, a review. Paper presented to the World Scientific Meeting on the Biology of Tunas and Related Species, La Jolla, California, 2-14 July 1962. Also in FAO Fish Rep., (6), vol. 3: 1057-66, 1963.

MANAR, T.A. 1965. Tuna behavior, a growing field for research. Pacific Fisherman, 63(11): 9-11.

MARR, J.C. and M.B. SCHAEFER. 1949. Definitions of body dimensions used in describing tunas. Fish. Bull., U.S., 51(47): 241-244.

MARR, J.C. and L.M. SPRAGUE. 1961. The use of blood group characteristics in studying sub-populations of fishes. Paper presented to the Pacific Tuna Biology Conference, Honolulu, Hawaii, 14-19 August 1961. (111-4): 18 pp., mimeo.

MARSHALL, N.B. 1965. The life of fishes. Weidenfeld and Nicolson, London, 402 pp.

MATHER, F.J. III. 1959. A preliminary report on biometric studies of tunas (genus <u>Thunnus</u>) of the western North Atlantic. Paper presented to the 39th National Annual Meeting of the American Society of Ichthyologists and Herpetologists, San Diego, California. Woods Hole Oceanographic Institution, 9 pp.

________________ 1960. Recaptures of tuna, marlin and sailfish tagged in the western North Atlantic. <u>Copeia</u>, (2): 149-51. Also in <u>Contr. Woods Hole oceanogr. Instn.</u>, (1098).

________________ 1962a. Tunas (genus <u>Thunnus</u>) of the western North Atlantic. Part 2. Description, comparison and identification of species of <u>Thunnus</u> based on external characters. Paper presented to the World Scientific Meeting on the Biology of Tunas and Related Species, La Jolla, California 2-14 July 1962. Also in <u>FAO Fish. Rep.</u>, (6), vol. 3: 1155-7, 1963 (SS/12a and 23a).

________________ 1962b. Tunas (genus <u>Thunnus</u>) of the western North Atlantic. Part 3. Distribution and behavior of <u>Thunnus</u> species. Paper presented to the World Scientific Meeting on the Biology of Tunas and Related Species, La Jolla, California, 2-14 July 1962. Also in <u>FAO Fish. Rep.</u>, (6), vol. 3: 1159-61, 1963. (SS/12b and 23b).

________________ 1962c. Transatlantic migration of two large bluefin tuna. <u>J. Cons.</u>, 27(3): 325-7 (SS/12c).

________________ 1962d. Distribution and migration of North Atlantic bluefin tuna. Paper presented at the Seventh International Game Fish Conference, Galveston, Texas. 7 pp., mimeo.

________________ 1963. Tags and tagging techniques for large pelagic fishes. Reprinted from <u>ICNAF Special Publication, No. 4</u>, North Atlantic Fish Marking Symposium, Woods Hole, Mass., May 1961. Issued from the Headquarters of the Commission, Dartmouth, N.S., Canada. 1963.

MATHER, F.J. III. 1962. Cooperative Game Fish Tagging Program. Woods Hole Oceanographic Institution, 9 pp., mimeo.

_______________ 1963. Cooperative Game Fish Tagging Program. Woods Hole Oceanographic Institution, 9 pp., mimeo.

_______________ 1965. Cooperative Game Fish Tagging Program. Woods Hole Oceanographic Institution, 14 pp., mimeo.

MATHER, F.J. III. and H.A. SCHUCK. 1960. Growth of bluefin tuna of the western North Atlantic. Fish. Bull., U.S., 61(179): 39-52.

MATSUMOTO, W.M. 1958. Description and distribution of larvae of four species of tuna in central Pacific waters. Fish. Bull., U.S., 58(128): 31-72.

MATTHEWS, (MS). Referred to in R.T.B. IVERSEN. 1962. Food of albacore tuna, Thunnus germo (Lacépède) in the central and northeastern Pacific. Fish. Bull. U.S., 62(214): 459-81.

MIGDALSKI, E.C. 1958. Angler's guide to the salt water game fishes - Atlantic and Pacific. New York, Ronald Press Co., 506 pp.

MOROVIC, D. 1961. Observations sur les variations du nombre de pinnules chez le thon rouge (Thunnus thynnus L.) pêche en Adriatique à la senne tournante. Rapp. Comm. int. Mer Médit., 16(2): 341-4.

MOSS, F.T. 1967. Countdown on tuna. Sportfishing, May, pp. 11-13; 34-36.

MOWBRAY, L. 1949. In S.K. FARRINGTON. 1949. Fishing the Atlantic offshore and on. New York, Coward-McCann Inc., 312 pp.

MURPHY, G.I. 1959. Effect of water clarity on albacore catches. Limnol. and Oceanogr., 4(1): 86-93.

MURRAY, J.J. 1953. Gulf of Maine bluefin tuna exploration 1952. Comm. Fish. Rev., 15(7): 1-17.

_____________ 1955. Gulf of Maine bluefin tuna exploration 1954. Comm. Fish. Rev., 17(6): 17-21.

NAKAMURA, E.L. (MS). Referred to in R.T.B. IVERSEN. 1962. Food of albacore tuna, Thunnus germo (Lacépède) in the central and northeastern Pacific. Fish. Bull., U.S., 62(214): 459-81.

____________ 1964. A method of measuring visual acuity of scombrids. (Abstract). Proc. Hawaiian Acad. Sci., 39 Annu. Mtg., 1963-1964: 26-27.

NAKAMURA, E.L. and W.M. MATSUMOTO. 1966. Distribution of larval tunas in Marquesan waters. U.S. Fish Wildl. Serv., Fish. Bull., 66(1): 1-12.

NAKAMURA, H. 1949. The tunas and their fisheries. Tokyo, Takeuchi Shobo (Translated from the Japanese by W.G. Van Campen, In: Spec. sci. Rep. U.S. Fish Wildl. Serv. -Fish., (82): 115 pp.

____________ 1951. A review on the fishing ground of tuna long-line based on the past data. Rep. Nankai Fish. Res. Lab., (1): 144 pp. (In Japanese). (Eng. trans. 1954, in Spec. sci Rep. U.S. Fish Wildl. Serv. -Fish., No. 112: 168 pp.).

NAMAIS, J. 1959. Recent seasonal interactions between North Pacific waters and the overlying atmospheric circulation. J. geophys. Res., 64(6): 631-46.

NICHOLS, J.T. 1922. Color of tuna. Copeia, (111): 73-4.

NIGRELLI, R.F. and H.W. STUNKARD. 1947. Studies on the genus Hirudinella, giant trematode of scombriform fishes. Zoologica, 31(13): 185-196.

NISHIMURA, M. 1962. Investigation of tuna behavior by fish finder. Paper presented to the World Scientific Meeting on the Biology of Tunas and Related Species, La Jolla, California, 2-14 July 1962. Also in FAO Fish. Rep., (6), vol. 3: 1113-23, 1963.

NORMAN, J.R. and F.C. FRASER. 1948. Giant fishes, whales and dolphins. London, Publ. Putnam, 376 pp.

OLSON, F.C.W. 1964. The survival value of fish schooling. J. Cons., 29(1): 115-6.

ORANGE, C.J. and B.D. FINK. 1963. Migration of a tagged bluefin tuna across the Pacific Ocean. Calif. Fish Game, 49(4): 307-308.

OREN, O.H., A. BEN TUVIA and E. GOTTLIEB. 1959. Experimental tuna fishing cruise in the eastern Mediterranean. Proc. gen. Fish Coun. Medit., 5: 269-79.

OTSU, T. and R.N. UCHIDA. 1959. Study of age determination by hard parts of albacore from central North Pacific and Hawaiian waters. Fish Bull., U.S., 59(150): 353-63.

PAVESI, P. 1889. L'industria del tonno (Orcynus thynnus). Relazione alla Commissione Reale per le Tonnare. Atti Min. Agric. Ind. Comm.

PETTERSSON, H. 1936. The transparency of sea water. Conseil Perm. Intern. p. l'Explor. de la Mer, Rapp. et Proc. -Verb, v. 101, pt. 2 (6): 7 pp.

POSTEL, E. 1962. Expose synoptique sur la biologie du germon Germo alalunga (Getti) 1777 (Atlantique oriental). Paper presented to the World Scientific Meeting on the Biology of Tunas and Related Species, La Jolla, California, 2-14 July 1962. Also in FAO Fish.Rep., (6), vol. 2: 931-75, 1963.

QUAST, J.C. 1964. Occurrence of the Pacific bonito in coastal Alaskan waters. Copeia, No. 2: p. 448.

RADOVICH, J. 1960. Redistribution of fishes in the eastern North Pacific Ocean in 1957 and 1958. Rep. Calif. ocean Fish. Invest., (7): 163-71.

__________ 1961. Relationships of some marine organisms of the northeast Pacific to water temperatures, particularly during 1957 through 1959. Fish. Bull., Sacramento, (112): 62 pp.

__________ 1962. Effects of water temperature on the distribution of some scombrid fishes along the Pacific coast of North America. Paper presented to the World Scientific Meeting on the Biology of Tunas and Related Species, La Jolla, California, 2-14 July 1962. Also in FAO Fish. Rep., (6), vol. 3: 1459-75, 1963.

REGAN, C.T. 1909. On the anatomy and classification of the scombroid fishes. Ann. Mag. Nat. Hist., (8), 3(13): 66-75.

REINTJES, J.W. and J.E. KING. 1953. Food of yellowfin tuna in the central Pacific. Fish. Bull., U.S., 54(81): 91-110.

RICKER, W.E. 1958. Handbook of computations for biological statistics of fish populations. Bull. Fish. Res. Bd. Can., (119): 300 pp.

RIVAS, L.R. 1951. A preliminary review of the western North Atlantic fishes of the family Scombridae. Bull Mar. Sci. Gulf Caribb., 1(3): 209-30.

__________ 1953. The pineal apparatus of tunas and related scombrid fishes as a possible light receptor controlling phototactic movements. Bull. Mar. Sci. Gulf Caribb., 3(3): 168-80.

__________ 1954a. A preliminary report on the spawning of the western North Atlantic bluefin tuna (Thunnus thynnus) in the Straits of Florida. Bull. Mar. Sci. Gulf Caribb., 4(4): 302-22. (SS/12a).

__________ 1954b. Western North Atlantic bluefin tuna cooperative research program. Summary of the results of investigations for the two-year period 1952-1953. Univ. Miami Marine Laboratory, 5 pp., mimeo.

__________ 1955. A comparison between giant bluefin tuna (Thunnus thynnus) from the Straits of Florida and the Gulf of Maine, with reference to migration and population identity. Proc. Gulf. Caribb. Fish. Inst., 1954, 7th sess.: 133-49.

__________ 1961. A review of the tuna fishes of the subgenera Parathunnus and Neothunnus (genus Thunnus). Ann. Mus. Stor. nat. Genova, 72: 126-48.

ROBINS, C.R. 1957. The Charles F. Johnson oceanic gamefish investigations. A study of bluefin tuna populations from the eastern and western North Atlantic based on an analysis of finray and gill-raker counts. Publ. Mar. Lab. Univ. Miami, (57-13): 1-8.

ROBINS, J.P. 1962. Synopsis of the biological data on bluefin tuna Thunnus thynnus maccoyii (Castelnau) 1872. Paper presented to the World Scientific Meeting on the Biology of Tunas and Related Species, La Jolla, California, 2-14 July 1962. Also in FAO Fish. Rep., (6), vol. 2: 562-87, 1963.

RODEN, G.I. and J.L. REID, Jr. 1961. Sea surface temperature, radiation, and wind anomalies in the North Pacific Ocean. Rec. oceanogr. Wks. Jap., 6(1): 36-52.

RODEWALD, M. 1960. Die deutschen Thunfangertrage in der Nordsee 1954 bis 1959 und die Zirkulationsanomalien. Arch. Fischwiss., 9(2): 160-6.

RODRIGUEZ-RODA, J. 1960. Consideraciones sobre la biologia del atun, Thunnus thynnus (L.), de Barbate (costa sudatlantica de espana). Bol. Soc. esp. Hist. Nat., 58(2): 347-62.

ROSA, H. Jr. 1950. Scientific and common names applied to tunas, mackerels and spearfishes of the world, with notes on their geographical distribution. Washington, D.C., FAO, 235 pp., mimeo.

ROSA, H. Jr. and T. LAEVASTU. 1961. World distribution of tunas and tuna fisheries in relation to environment. Paper presented to the Pacific Tuna Biology Conference, Honolulu, Hawaii, 14-19 August 1961, (V-1): 7 pp., mimeo.

ROULE, L. 1924. Etude sur les déplacements at la pêche du thon (Orcynus thynnus L.) en Tunisie dans la Méditerranée occidentale. Bull. Sta. océanogr., Salammbô, (2): 1-39.

RUSSELL, F.S. 1934. The tunny, Thunnus thynnus, Linnaeus - An account of its distribution and biology. Sci. Progr. Twent. Cent., 28(112): 634-49.

__________ 1936. Submarine illumination in relation to animal life. Rapp. Cons. Explor. Mer, 101(2): 1-8.

SANZO, L. 1910. Studi sulla biologia del tonno (Orcynus thynnus L.). Riv. mens. Pesca (12), 5: 1-15. Also in Boll. Minist. Agric. (1), 3: 40-5.

__________ 1929. Uova e larve di tonno, Orcynus thynnus. R.C. Accad. Lincei (6), 9: 816-20.

__________ 1932. Uova e primi stadi larvali di tonno (Orcynus thynnus Ltkn.). Mem. Com. talassogr. ital., (189): 1-16. (MP/155).

SARA, R. 1960. Observations systématiques sur la présence du thon dans les madragues siciliennes. Tech. Pap. gen. Fish. Coun., 6(4): 27 pp.

SCACCINI, A. 1959. Bio-écologie des jeunes thons dans les mers italiennes. Proc. gen Fish Coun. Medit., 5(70): 495-9.

__________ 1965. Biologia e pesca dei tonni nei mari italiani. Minist. della Marina Mercantile, Memoria n. 12., 99 pp.

SCATTERGOOD, L.W. 1952. Notes on Gulf of Maine fishes in 1950 and 1951. Copeia, No. 3: 205-206.

SCHAEFER, M.B., G.C. BROADHEAD and C.J. ORANGE. 1962. Synopsis on the biology of yellowfin tuna Thunnus (Neothunnus) albacares (Bonaterre) 1788 (Pacific Ocean). Paper presented to the World Scientific Meeting on the Biology of Tunas and Related Species, La Jolla, California, 2-14 July 1962. Also in FAO Fish. Rep., (6), vol. 2: 538-61, 1963.

SCHMITT, J. 1904. Monographie d'Ile d'Anticosti (Golfe Saint Laurent). Poissons, pp. 282-287. Paris. 367 pp.

SCOTT, T. and R. SCOTT. 1913. The British parasitic copepoda (2 volumes). London, The Ray Society.

SELLA, M. 1911. Contributo alla conoscenza della riproduzione e dello sviluppo del pesce spada (Xiphias gladius L.). Mem. Com. talassogr. ital., (2): 16 pp.

________ 1929. Migrazioni e habitat del tonno (Thunnus thynnus L.) studiati col metodo degli ami, con osservazioni sull'accrescimento sul regime delle tonnare, ecc. Mem. Com. talassogr. ital., (156): 24 pp.

________ 1931. The tuna (Thunnus thynnus L.) of the western Atlantic. An appeal to fishermen for the collection of hooks found in tuna fish. Int. Rev. Hydrobiol., 25(1/2): 46-7.

________ 1932. Il tonno. Conferenza. Not. dtsch -ital. Inst. Meeresbiol. Rovigno d'Istria, (3): 3-24.

SERVENTY, D.L. 1956. The southern bluefin tuna, Thunnus thynnus maccoyii (Castelnau), in Australian waters. Aust. J. Mar. Freshw. Res., 7(1): 1-43. (MP/1Aa).

SETTE, O.E. 1950. Biology of the Atlantic mackerel (Scomber scombrus) of North America. Part 2. Migrations and habits. Fish Bull., U.S., 51(49): 251-358.

________ 1955. Consideration of mid-ocean fish production as related to oceanic circulatory systems. J. Mar. Res., 14(4): 398-414.

SHEPARD, F.P. 1948. Submarine geology. New York, 1948: 348 pp.

SHOMURA, R.S. 1955. A comparative study of longline baits. Spec. sci. Rep. U.S. Fish Wildl. Serv. -Fish., (151): 34 pp.

_____________ 1966. Age and growth studies of four species of tunas in the Pacific Ocean. Proceedings of the Governor's Conference on Central Pacific Fishery Resources, Honolulu, Hawaii, November 1966, 203-217.

SINTESIS, E. and L. BELLON. 1954. Historia natural del atun, Thunnus thynnus L. Bol. Inst. esp. Oceanogr., (67): 3-88.

SMITH, H.B., F.M. SOULE and O. MOSBY. 1937. The Marion and General Greene Expeditions to Davis Strait and Labrador Sea. U.S. Coast Guard Bull. 19, Washington.

SPRAGUE, L.M. 1965. Fish immunogenetics research. Science, 148(3674): 1252-1254.

SPRAGUE, L.M., J.R. HOLLOWAY and L.I. NAKASHIMA. 1962. Studies of the erythrocyte antigens of albacore, bigeye, skipjack, and yellowfin tunas. Paper presented to the World Scientific Meeting on the Biology of Tunas and Related Species, La Jolla, California, 2-14 July 1962. Also in FAO Fish. Rep., (6), vol. 3: 1381-93, 1963.

SQUIRE, J.L. 1962a. Distribution of tuna species in the oceanic northwest Atlantic. Paper presented to the World Scientific Meeting on the Biology of Tunas and Related Species, La Jolla, California, 2-14 July 1962. Also in FAO Fish. Rep., (6), vol. 3: 1477-1541, 1963.

SQUIRE, J.L. Jr. 1962b. Thermal relationships of tuna in the oceanic northwest Atlantic. Paper presented to the World Scientific Meeting on the Biology of Tunas and Related Species, La Jolla, California, 2-14 July, 1962. Also in FAO Fish. Rep., (6), vol. 3: 1639-57, 1963.

SQUIRES, H.J. 1957. Squid, Illex illecebrosus (LeSueur), in the Newfoundland fishing area. J. Fish. Res. Bd. Can., 14(5): 693-728.

STAFFORD, J. 1912. On the fauna of the Atlantic coast. Contrib. Canadian Biol., 1906-10, 3 reports, pp. 37--44; 45-67; 69-78.

STARKS, E.C. 1910. The osteology and mutual relationships of fishes belonging to the family Scombridae. J. Morph., 21(1): 77-99.

STRASBURG, D.W. 1960. Estimates of larval tuna abundance in the central Pacific. Fish Bull., U.S., 60(167): 231-55.

SUYEHIRO, Y. 1942. A study of the digestive system and feeding habits of fish. Jap. J. Zool., 10(1): 1-303.

SVERDRUP, H.U., M.W. JOHNSON and R.H. FLEMING. 1946. The oceans. Their physics, chemistry and General biology. New York, Prentice-Hall. 1087 pp.

TAKAHASHI, N. 1924. On the order Plecostei established by Dr. Kishinouye. Dobutsugaku Zasshi (Zool. Mag) 36: 397-408. (In Japanese, translation by W.G. Van Campen published in U.S. Fish Wildl. Serv., Spec. sci. Rep. Fish., 50: 3-16.).

__________ 1926. On the Plecostei, an order of the Teleotomi, established by Prof. Kishinouye. J. College Agric., Imp. Univ. Tokyo, 7(4): 383-398.

TALBOT, F.H. 1964. The South African tunas. Symposium Scombroid Fishes, Mar. Biol. Assoc. India, ser. 1: 187-209.

TEMPLEMAN, W. 1948. The life history of the caplin (Mallotus villosus O.F. Muller) in Newfoundland waters. Nfld. Gov. Lab., Res. Ser., Bull. No. 17: 151 pp.

__________ 1965. Anomalies of sea temperature at Station 27 off Cape Spear and of air temperature at Torbay - St. John's. ICNAF Spec. Publ. No. 6: 795-806.

__________ 1966. Marine resources of Newfoundland. Bull. Fish. Res. Bd. Can., No. 154: 170 pp.

TEMPLEMAN, W. and A.M. FLEMING. 1963. Longlining experiments for cod off the east coast of Newfoundland and southern Labrador, 1950-1955. Bull. Fish. Res. Bd. Can., No. 141: 65 pp.

TESTER, A.L., H. YUEN and M. TAKATA. 1954. Reaction of tuna to stimuli, 1953. Spec. sci. Rep. U.S. Fish Wildl. Serv. -Fish., (134): 33 pp.

THOMPSON, W.F. 1917. Temperature and the albacore. Calif. Fish Game, 3(4): 153-9.

TIBBO, S.N. 1967. Bluefin tuna. Fisheries of Canada, 19(8): 10-12.

TIEWS, K. 1957. Biologische Untersuchungen am Roten Thunfisch (Thunnus thynnus, Linnaeus) in der Nordsee. Ber. dtsch. Komm. Meeresforsch., 14(3): 192-220. (SS/12a).

________ 1960. Bestimmung des Altersaufbaues des Roten Thunes (Thunnus thynnus L.) in der Nordsee mit Hilfe des allometrischen Wachstums der Augenhöhle. Arch. FischWiss., 7(2): 43-4. (SS/12a).

________ 1962. Synopsis of biological data on bluefin tuna (Thunnus thynnus (Linnaeus) 1758 (Atlantic and Mediterranean). Paper presented to the World Scientific Meeting on the Biology of Tunas and Related Species, La Jolla, California, 2-14 July 1962. Also in FAO Fish. Rep., (6), vol. 2: 422-81, 1963.

________ 1963. The German tuna fishery in 1961. Ann. biol., Copenhague, 18.

UDA, M. 1940. A note on the fisheries condition of "katuo" as a function of several oceanographic factors. Bull. Jap. Soc. sci. Fish., 9(4): 145-8. (In Japanese). English transl. in Spec. sci. Rep. U.S. Fish Wildl. Serv. -Fish., (51): 30 pp., publ. 1951.

________ 1953. On convergence and divergence in the northwest Pacific in relation to fishing grounds and productivity. Bull. Jap. Soc. sci. Fish., 19(4): 435-8.

________ 1957. A consideration of the long years trend of the fisheries fluctuation in relation to sea condition. Bull. Jap Soc. sci. Fish., 23(7-8): 368-72.

________ 1961. Cyclical fluctuation of the Pacific tuna fisheries in response to cold and warm water intrusions. Paper presented to the Pacific Tuna Biology Conference, Honolulu, Hawaii, 14-19 August 1961, (V-7): p. 39.

________ 1962. Future lines of tuna research, mainly in relation to fisheries oceanography. Paper presented to the World Scientific Meeting on the Biology of Tunas and Related Species, La Jolla, California, 2-14 July 1962. Also in FAO Fish. Rep., (6), vol. 3 1087-95, 1963.

UDA, M. and M. ISHINO. 1958. Enrichment pattern resulting from eddy systems in relation to fishing grounds. J. Tokyo Univ. Fish., 44(1-2): 105-29.

UDA, M. and B. TOKUNAGA. 1937. Fishing of Germo germo (Lacépède) in relation to the hydrography in the North Pacific waters. Bull. Jap. Soc. sci. Fish., 4(5): 307-9.

VAN CAMPEN, W.G. 1960. Japanese summer fishery for albacore. (Germo alalunga). Res. Rep. U.S. Fish. Serv., (52): 29 pp.

VILELA, H. 1960. Estudos sobre a biologia dos atuns em Portugal, 1956-1960. Bol. Pesca, Lisboa, 13(69): 11-29.

VILELA, H. and R. MONTEIRO. 1961. Etudes sur la biologie et la pêche des thons - Thunnus thynnus L. - des côtes portugaises 1960-61. ICES, Scombriform Fish Committee, No. 146: 6 pp.

WALFORD, L.A. 1931. Northward occurrence of southern fish off San Pedro in 1931. Calif. Fish Game, 17(4): 401-5.

__________ 1946. A new graphic method of describing the growth of animals. Biol. Bull., Woods Hole, 90(2): 141-7.

WALDRON, K.D. 1963. Synopsis of biological data on skipjack Katsuwonus pelamis (Linnaeus) 1758 (Pacific Ocean). FAO Fish. Rep., (6), vol. 2: 695-748.

WATANABE, H. 1958. On the difference of the stomach contents of the yellowfin and bigeye tunas from the western equatorial Pacific. Rep. Nankai Fish. Res. Lab., (7): 72-81. (In Japanese with English summary).

WATSON, M.E. 1961. Tunas (genus Thunnus) of the western North Atlantic. Part 1. Key to species of Thunnus based on skeletal and visceral anatomy. Paper presented to the World Scientific Meeting on the Biology of Tunas and Related Species, La Jolla, California, 2-14 July 1962. Also in FAO Fish. Rep., (6), vol. 3: 1153-4, 1963.

WESTMAN, J.R. and P.W. GILBERT. 1941. Notes on age determination and growth of the Atlantic bluefin tuna, Thunnus thynnus (Linnaeus). Copeia, (2): 70-2.

WESTMAN, J.R. and W.C. NEVILLE. 1942. The tuna fishery of Long Island. New York, Board of Supervisors, Nassau County, 30 pp.

WILLIAMSON, G.R. 1962. The bluefin tuna in Newfoundland waters. Newfoundland Tourist Development Office, 28 pp.

WILLIAMSON, G.R. 1965. Underwater observation of squid, *Illex illecebrosus* (Lesueur) in Newfoundland waters. *The Canadian Field Naturalist*, vol. 79.

WILSON, R.C. 1953. Tuna marking, a progress report. *Calif. Fish Game*, 39(4): 429-42.

WOOSTER, W.S. 1960. El Nino. *Calif. Co-op. Ocean. Fish. Invest., Rep. 7*: 43-45.

WOOSTER, W.S. and J.L. REID. 1963. In the sea: Ideas and observations on progress in the study of the seas, Vol. 2, ed. by M.N. Hill, Interscience Publishers, New York and London: 253-280.

YABE, H., Y. YABUTA and S. UEYANAGI. 1962. Comparative distribution of eggs, larvae and adults in relation to biotic and abiotic environmental factors. Paper presented to the World Scientific Meeting on the Biology of Tunas and Related Species, La Jolla, California, 2-14 July 1962. Also in *FAO Fish Rep.*, (6), vol. 3: 979-1009, 1963.

YAMAGUTI, S. 1958-1961. Systema helminthum. Vols. 1-3. New York and London, Interscience Publishers Limited.

YAMANAKA, H. *et al.* 1962. Synopsis of biological data on kuromaguro (*Thunnus orientalis*) (Temminck and Schlegel) 1842 (Pacific Ocean). Paper presented to the World Scientific Meeting on the Biology of Tunas and Related Species, La Jolla, California, 2-14 July 1962. Also in *FAO Fish. Rep.*, (6), vol. 2: 180-217, 1963.

YAMASHITA, D.T. and K.D. WALDRON. 1958. An all-plastic dart-type fish tag. *Calif. Fish Game*, 44(4): 311-7.

YAPP, W.B. 1965. Vertebrates. Their structure and life. Oxford University Press, London.

APPENDIX I

Bluefin Catch Statistics for Newfoundland (1956-1967).
The Majority Caught in Conception Bay

Bluefin Catch Statistics for Newfoundland (1956-1967), The Majority Caught in Conception Bay

		1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967
July	11											2	
	12											3	
	13											7	1
	14											2	
	15											4	
	16											16	
	17											29	
	18											8	
	19											11	2
	20											27	5
	21											12	
	22											3	
	23										6	18	
	24										4	32	
	25									1	8	17	
	26										2	333	4
	27								2		1	18	1
	28										7	29	4
	29								4	4	7	7	8
	30			1					5	1		6	8
	31								7	1		7	2
Aug.	1						1		5		5	9	2
	2						1		1		8	3	2
	3						3	5	8		5		4
	4		1	1			2	3	4		13	1	8
	5						1	2	8		19	3	5
	6						2	2	14	2	29	6	11
	7			1			7	2	8	4	29	5	13
	8						7	3	11	11	14	1	3
	9						7	2	10	17		1	7
	10						5		8	13		7	3
	11						5			4	3		1
	12			2			13		13	14	1	6	8
	13		1		1		10	1	16	17	6	1	1
	14		1				14	1	10	15	4	2	2
	15		2		1		8		9	7		2	1
	16						11		11	2	8	2	6
	17		3				1	3	3	10	3	3	6
	18						5	1	2	19	4		
	19						2		1	19	3	2	3
	20			1		1	5	2	1	13	1	1	3
	21						1	1	2	10	7	1	1
	22				2		1	7	1	5	6	3	2
	23								10	5	6	2	3
	24							1	8	2	4	3	
	25		1						10			2	2
	26					1			5	1		5	4
	27		1			1			4		4	1	2
	28					1		1	7	4	4	1	2
	29					1			4	2	3	2	
	30					2			9	1	4	3	
	31					1			3	8	4	1	

Bluefin Catch Statistics for Newfoundland (1956-1967). The Majority Caught in Conception Bay

		1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967
Sept.	1				2	1			6	10	9	1	3
	2								4	7	3		7
	3					2		1	6	8	2		1
	4								1		9		1
	5	2							3	2		3	2
	6				2			1	1	5		2	2
	7								4	1			
	8						1	1	4	8			1
	9								1	2	1		6
	10			1			3				5		2
	11			1			3		2	5	1		2
	12						1	1		8	8		
	13						1		4	4	1		
	14						1			5		1	
	15						2		4	2	1	1	
	16						4	1		2			1
	17						2		3	5		5	1
	18				2		2		1	10	2	1	1
	19							1	1	3		1	
	20									1	3		1
	21									3	1		
	22									1			
	23									3	2	1	1
	24									1	1		1
	25									3			
	26				1					5		2	
	27								1				
	28						1						
	29												1
	30												3
Oct.	1										1		
	2												1
	3												
	4												
	5										1		
	6												
	7												
	8												
	9										Y		1
	10										1		
Total		2	10	8	11	11	133	43	270	316	283	388	179

July
Aug.
Sept.
Oct.

APPENDIX II

A Series of Figures Showing the Bluefin Sports Fishery of Newfoundland in action: Finning Bluefin, Notre Dame Bay (A); Hauling Aboard; Notre Dame Bay (B); Returning Fleet, Conception Bay (C); Off-loading, Long Pond (D); Weighing-in, Long Pond (E); Photographic Session, Long Pond (F); Morphometric and Meristic Data Collection, Long Pond (G-L).

Figures A and B were kindly contributed by Mr. R. Riewe (Dept. of Biology, M.U.N) and Figures G-K by Mr. N. Squires.

APPENDIX II

A

B

C

APPENDIX II

D

E

F

G

APPENDIX II

H

I

J

K

L

APPENDIX III

The Qualitative and Quantitative Stomach
Analysis of 112 Bluefin Caught in
Conception Bay, 1966.

QUALITATIVE AND QUANTITATIVE STOMACH ANALYSIS OF BLUEFIN TUNA

Tuna number		1	2	3	4	5
Date Caught	July	20	24	24	24	24
Time of Strike		14:30	10:30	13:35	-	12:15
Weight (pounds)		450	535	495	483	653
No. Intact Squid		1	-	-	-	-
Mantle Length(s)[1]		1b	-	-	-	-
Intact Squid Vol.(cc)		50	-	-	-	-
No. Detached Beaks upper (lower)		7(-)	-(-)	2(6)	1(-)	-(-)
Squid Remains Vol.(cc)		1	-	1	-	-
Capelin Vol.(cc)		1650	-	-	-	3300
Needlefish Vol.(cc)		-	-	-	-	-
Other fish Vol.(cc) H(Herring) G(Gadidae) M(Mullet)		-	-	-	-	-
Oddments Vol.(cc)		-	-	-	-	-
Parasites[2]		N(L)	N(L)	N(L)	N(L)	N(L)
Parasite Vol.(cc)		1	1	1	1	1
Total Vol.(cc)		1702	1	2	1	3301

Note: 1. a = 10-12 cm, b = 13-15 cm, c = 16-18 cm, d = 19-21 cm.

2. N = Nematode

(L) = Light infestation (0-20 parasites)
(M) = Medium infestation (20-100 parasites)
(H) = Heavy infestation (100 plus parasites)

T = Trematode

TW = Tapeworm

C = Copepod

6	7	8	9	10	11	12	13	14
24	24	24	24	24	24	24	24	24
10:00	11:00	-	-	12:50	16:05	11:00	11:30	17:00
606	567	576	565	476	657	555	543	467
-	-	-	-	-	-	-	21	-
-	-	-	-	-	-	-	6b 12c 3d	-
-	-	-	-	-	-	-	640	-
-(1)	-(-)	-(-)	-(-)	-(1)	-(-)	-(-)	-(-)	1(-)
-	-	-	-	-	-	-	20	-
60	210	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	H(149)	-	-	-	?(S)	-
-	-	-	-	-	-	-	-	-
N(L) T(1)	T(2)	N(L)	T(3)	-	N(M)	N(L)	N(L)	N(L) T(6)
1	-	1	1	-	5	1	1	1
61	210	1	150	-	5	1	666	1

14	15	16	17	18	19	20	21	22
24	24	24	24	24	24	24	24	24
17:00	13:30	14:40	12:40	-	-	19:20	16:00	17:00
467	624	458	572	508	502	450	472	440
-	-	-	-	3	-	-	-	-
-	-	-	-	2b 1c	-	-	-	-
-	-	-	-	70	-	-	-	-
1(-)	-(-)	1(-)	1(1)	-(-)	13(7)	-(-)	-(-)	1(1)
-	-	-	-	14	250	-	-	-
-	-	825	92	355	-	-	69	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	?(3)	-	H(314)
-	-	-	-	-	-	-	-	-
N(L) T(6)	N(M) T(5)	T(2)	N(L)	-	N(L) T(1)	N(M)	N(L) TW(1)	N(L)
1	5	1	1	-	1	1	1	-
1	5	826	93	439	251	4	70	314

Tuna Number		23	24	25	26	27
Date Caught	July	25	25	25	25	25
Time of Strike		11:40	11:45	15:53	10:55	14:40
Weight (pounds)		443	592	540	424	455
No. Intact Squid		-	-	-	-	-
Mantle Length(s)[1]		-	-	-	-	-
Intact Squid Vol.(cc)		-	-	-	-	-
No. Detached Beaks upper (lower)		-(-)	-(1)	1(1)	-(2)	-(-)
Squid Remains Vol.(cc)		-	-	-	-	15
Capelin Vol.(cc)		17	-	67	-	32
Needlefish Vol.(cc)		-	-	-	-	-
Other fish Vol.(cc) H(Herring) G(Gadidae) M(Mullet)		-	?(5)	-	-	-
Oddments Vol.(cc)		-	-	-	-	-
Parasites[2]		N(L) T(2)	-	N(M) T(2)	N(H)	N(H) T(9)
Parasite Vol.(cc)		1	-	3	13	10
Total Vol.(cc)		18	5	70	18	57

28	29	30	31	32	33	34	35	36
25	25	25	25	25	25	25	25	26
14:25	13:00	-	15:00	13:00	13:30	14:00	16:30	12:30
520	535	558	537	537	450	598	405	510
-	-	-	-	-	1	-	-	-
-	-	-	=	=	1b	-	-	-
-	-	-	-	-	25	-	-	-
1(-)	1(-)	-(-)	13(16)	8(11)	8(6)	-(-)	-(-)	1(1)
-	-	-	1	135	1	-	15	-
3	810	-	845	-	672	-	-	2940
-	-	-	-	-	-	-	-	-
-	-	-	-	M(275)	-	-	?(9)	-
-	-	-	-	-	-	-	-	-
N(L) T(3)	N(H) T(1)	-	N(M) T(3)	T(1)	N(M)	T(11)	N(11) T(5)	-
1	3	-	3	-	2	3	2	-
4	813	20	849	410	700	3	26	2940

36	37	38	39	40	41	42	43	44
26	26	26	26	26	26	26	26	26
12:30	-	12:00	13:15	15:35	13:20	11:18	10:40	14:08
510	600	584	485	660	500	445	535	485
-	-	-	-	-	-	10	-	-
-	-	-	-	-	-	1a 3b 6c	-	-
-	- -	-	-	-	-	530	-	-
1(1)	20(18)	1(1)	-(2)	3(-)	5(3)	-(-)	-(-)	-(-)
-	5	-	-	-	657	44	?	-
2940	-	-	-	10	4622	1285	?	960
-	-	-	-	-	-	-	-	-
-	G(72)	-	-	-	-	-	?	-
-	10(0)	1(F) 2cc	-	-	-	-	-	-
-	N(M) T(1) C(1) ?(3)	N(L)	N(M) T(3)	N(L) T(1)	N(L) T(11)	N(L)	-	N(L) T(2)
-	3	1	4	1	6	2	-	1
2940	80	3	4	11	5285	1861	420	961

Tuna Number		45	46	47	48	49
Date Caught	July	26	26	26	26	26
Time of Strike		16:50	12:28	12:15	13:20	16:40
Weight (pounds)		605	604	495	479	521
No. Intact Squid		-	-	-	-	-
Mantle Length(s)[1]		-	-	-	-	-
Intact Squid Vol.(cc)		-	-	-	-	-
No. Detached Beaks upper (lower)		2(1)	4(4)	1(-)	1(1)	-(-)
Squid Remains Vol.(cc)		100	110	-	-	-
Capelin Vol.(cc)		460	52	-	480	-
Needlefish Vol.(cc)		-	-	-	-	-
Other fish Vol.(cc) H(Herring) G(Gadidae) M(Mullet)		-	-	-	-	-
Oddments Vol.(cc)		-	-	2(0)	-	-
Parasites[2]		-	N(L) T(2)	N(L) T(4)	-	N(M)
Parasite Vol.(cc)		-	1	1	-	5
Total Vol.(cc)		560	163	1	480	5

50	51	52	53	54	55	56	57	58
27	27	27	27	27	28	28	28	28
11:15	15:30	10:00	-	14:30	17:30	14:00	12:55	10:55
558	467	560	455	491	465	455	450	451
-	-	-	-	-	-	3	2	1
-	-	-	-	-	-	3c	1c 1d	1d
-	-	-	-	-	-	127	100	12
-(-)	1(3)	1(1)	3(-)	1(-)	17(9)	4(2)	24(22)	5(4)
36	-	-	-	3	17	68	130	30
1325	-	122	830	435	652	372	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	G(320)	G(130)	-
-	-	-	-	-	-	-	14(0) 2cc	2(0)
T(5)	N(L)	N(M) T(1)	-	T(1)	N(M)	N(L) T(4) ?(2)	C(3)	N(L) C(2)
1	1	20	-	-	1	3	-	-
1362	1	142	830	438	670	570	552	172

58	59	60	61	62	63	64	65	66
28	28	28	28	28	28	28	28	28
10:55	15:40	12:55	16:42	12:10	14:10	16:00	17:30	15:10
451	470	510	552	336	459	585	517	427
1	-	-	-	-	-	-	-	-
1d	-	-	-	-	-	-	-	-
12	-	-	-	-	-	-	-	-
5(4)	-(-)	6(3)	3(1)	4(3)	1(-)	33(32)	4(2)	3(3)
30	-	1	-	9	-	10	-	17
-	-	632	-	-	-	-	-	15
-	-	-	-	-	-	-	-	-
-	-	-	H(50)	-	-	-	-	-
2(0)	-	-	-	-	-	1(0)	-	1(F) 1cc
N(L) C(2)	N(L)	N(L)	T(6)	N(L)	N(L) T(2)	T(1) C(3)	N(M)	-
-	-	1	1	1	1	1	1	-
172	-	634	1	10	6	11	1	33

Tuna Number	67	68	69	70	71	72
Date Caught July	29	31	31	31	31	31
Time of Strike	14:40	12:20	11:35	11:05	13:10	17:00
Weight (pounds)	505	532	475	485	502	648
No. Intact Squid	-	-	-	14	-	1
Mantle Length(s)[1]	-	-	-	11c 3d	-	1b
Intact Squid Vol (cc)	-	-	-	1050	-	40
No. Detached Beaks upper (lower)	4(3)	3(1)	-(2)	67(65)	4(3)	5(7)
Squid Remains Vol. (cc)	1	-	-	383	116	1
Capelin Vol. (cc	-	5	1440	-	3270	3
Needlefish Vol. (cc)	-	-	-	-	-	-
Other fish Vol. (cc) H(Herring) G(Gadidae) M(Mullet)	?(2)	-	-	-	H(?)	-
Oddments Vol. (cc)	-	-	-	-	-	-
Parasites[2]	-	N(L) T(3)	T(2)	N(L)	N(L)	N(L) T(3) ?(2)
Parasite Vol. (cc)	-	1	-	1	1	2
Total Vol. (cc)	3	6	1440	1434	3387	46

73	74	75	76	77	78	79	80
Aug.1	1	1	1	1	1	1	2
10:52	15:32	16:32	17:14	13:30	15:02	15:05	10:00
518	520	587	467	566	545	570	530
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-(-)	39(40)	1(-)	-(-)	8(1)	-(-)	1(4)	1(1)
-	51	-	-	12	-	62	1
3	-	-	-	400	20	1410	-
-	-	-	-	-	-	=	=
-	-	G(65)	-	-	-	G(?)	-
-	-	56(0) 7cc	-	-	-	2(0)	-
N(M) T(5)	N(L) T(1)	N(L) T(4) C(3)	N(L)	N(M)	N(H) ?(2)	N(L)	T(1) C(1)
2	1	1	1	1	12	1	1
5	52	73	1	413	32	1473	2

81	82	83	84	85	86	87	88
2	2	4	5	5	7	7	7
10:30	16:45	12:15	13:55	11:00	15:00	10:15	13:28
540	504	535	495	553	510	513	660
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-(-)	-(-)	19(17)	-(-)	5(2)	1(-)	1(1)	74(79)
-	20	32	1895	43	-	15	1410
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	M(235)	G(?)	-	?(240)	-	-	-
-	-	30(0) 2cc	-	-	-	-	-
N(M)	N(L)	N(L) C(1)	-	N(L) T(1) C(2)	N(M) T(1)	N(M)	N(H) T(2) ?(1)
1	-	3	-	1	1	2	25
1	255	37	1895	284	1	17	1435

Tuna Number		89	90	91	92	93	94
Date Caught	Aug.	7	7	10	10	10	12
Time of Strike		13:50	10:30	16:20	15:00	15:55	-
Weight (pounds)		560	590	553	504	590	607
No. Intact Squid		-	-	-	-	-	-
Mantle Length(s)[1]		-	-	-	-	-	-
Intact Squid Vol.(cc)		-	-	-	-	-	-
No. Detached Beaks upper (lower)		-(-)	14(14)	91(77)	-(6)	-(-)	84(86)
Squid Remains Vol.(cc)		-	48	17	3	-	10
Capelin Vol.(cc)		-	-	-	-	-	-
Needlefish Vol.(cc)		-	-	-	-	-	-
Other fish Vol.(cc) H(Herring G(Gadidae) M(Mullet)		?(5)	M(200)	M(163)	-	?(15)	-
Oddments Vol.(cc)		-	-	-	-	-	-
Parasites[2]		T(2)	N(H) C(2)	-	N(L)	N(L)	N(L) C(3)
Parasite Vol.(cc)		-	3	-	-	-	1
Total Vol.(cc)		5	251	180	3	15	11

95	96	97	98	99	100	101	102	103
12	12	12	14	14	16	16	31	Sept. 1
-	15:00	13:15	10:50	-	11:30	13:30	12:55	14:17
525	553	583	548	515	497	540	655	685
-	-	-	7	-	-	-	2	1
-	-	-	4c 2d 1e	-	-	-	2e	1d
-	-	-	229	-	-	-	426	165
19(19)	1(1)	1(1)	4(5)	6(7)	5(4)	(185)	6(5)	-(-)
20	-	70	169	70	30	70	66	70
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	490
G(5)	-	M(200)	G(345)	-	-	-	-	M(170)
6(C) 2cc	3(0)	-	2(0)	-	2(0)	10(0) 1cc	-	4(0)
N(L) T(3) C(2)	C(2)	T(1)	N(L) T(2)	T(4) C(1)	N(M) T(1) C(2)	T(1) C(7)	T(7)	T(4) TW
3	-	-	-	-	1	1	2	-
30	1	270	754	70	31	72	494	895

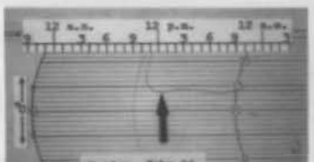
104	105	106	107	108	109	110	111	112
6	14	15	17	17	17	17	18	19
13:09	16:55	13:05	11:30	13:30	14:05	14:15	-	11:30
695	650	615	470	590	594	617	149	556
4	-	-	-	-	-	-	-	-
3e 1d	-	-	-	-	-	-	-	-
855	-	-	-	-	-	-	-	-
-(-)	86(64)	1(-)	10(5)	20(20)	25(26)	8(8)	1(1)	40(36)
115	30	1	2	205	285	60	-	115
-	-	-	-	-	-	-	-	-
445	-	2	457	-	-	-	-	-
-	-	-	-	-	G(67)	-	?(120)	G(2)
-	K 30(0) 3cc	-	1(0)	-	10(0) 1cc	1(0)	1(0)	8(0)
T(7)	T(8) C(4)	N(L)	N(L) C(1)	N(M) T(1)	N(L)	N(H) T(3)	N(L) T(1)	N(L) T(4) C(1)
-	1	1	-	1	-	14	-	2
1415	34	3	459	206	353	74	120	119

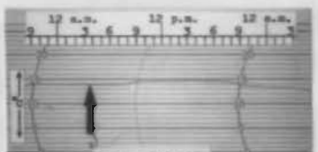
APPENDIX IV

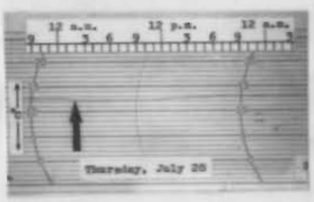
Subsurface (2 feet) Temperature Data, Recorded Continuously from July 24 - October 29, 1966, Approximately 100 Feet Offshore in the Vicinity of St. Phillips, Conception Bay.

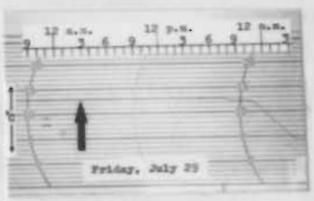
APPENDIX IV

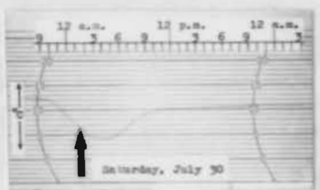
JULY, 1966

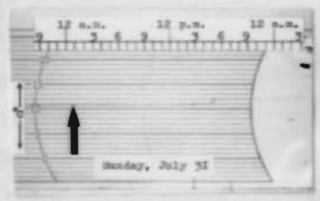










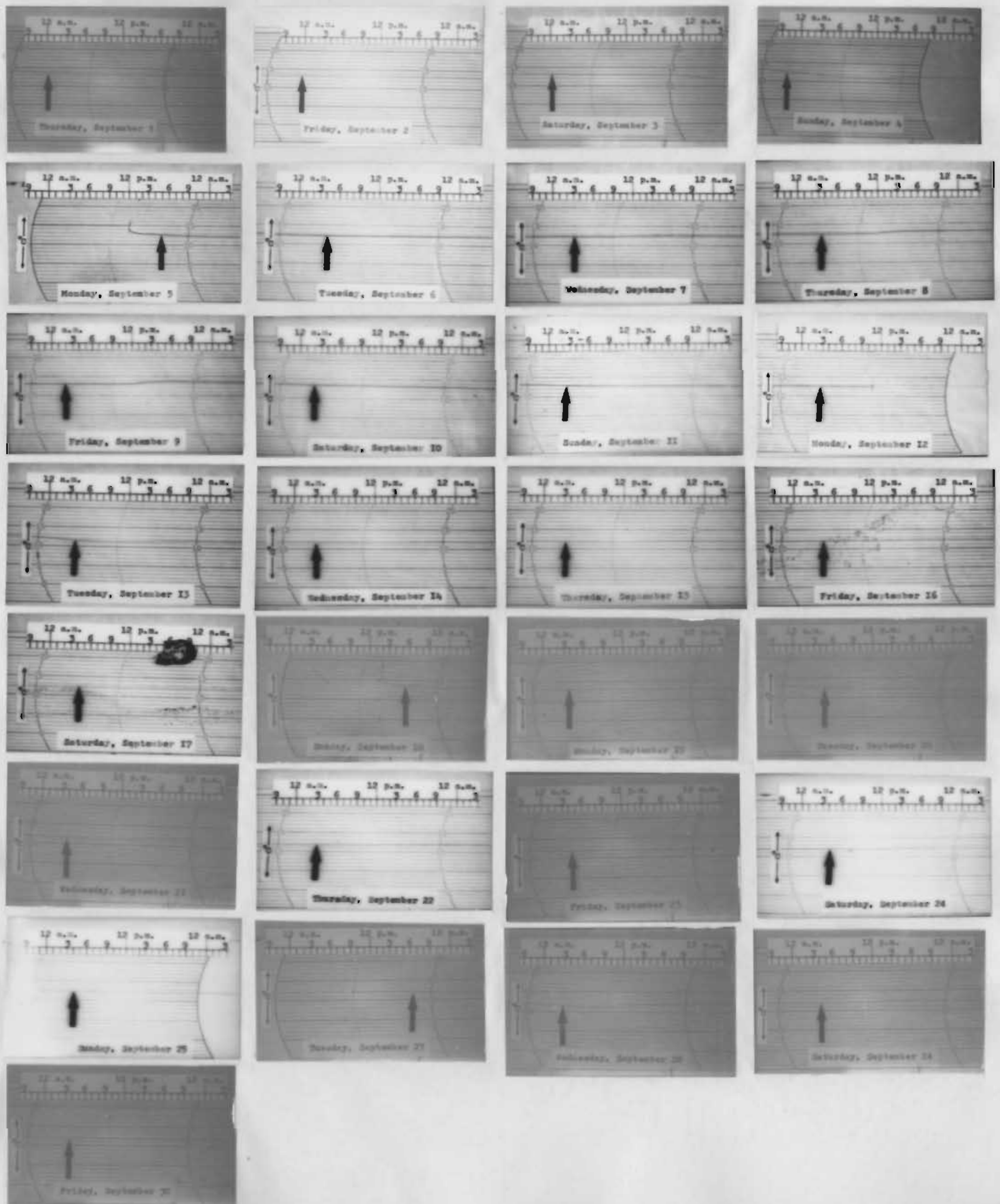


APPENDIX IV

AUGUST, 1966

APPENDIX IV

SEPTEMBER, 1966



APPENDIX IV

OCTOBER, 1966