



National Library of Canada
Collections Development Branch

Canadian Theses on
Microfiche Service

Bibliothèque nationale du Canada
Direction du développement des collections

Service des thèses canadiennes
sur microfiche

NOTICE

The quality of this microfiche is heavily dependent upon the quality of the original thesis submitted for microfilming. Every effort has been made to ensure the highest quality of reproduction possible.

If pages are missing, contact the university which granted the degree.

Some pages may have indistinct print especially if the original pages were typed with a poor typewriter ribbon or if the university sent us a poor photocopy.

Previously copyrighted materials (journal articles, published tests, etc.) are not filmed.

Reproduction in full or in part of this film is governed by the Canadian Copyright Act, R.S.C. 1970, c. C-30. Please read the authorization forms which accompany this thesis.

THIS DISSERTATION
HAS BEEN MICROFILMED
EXACTLY AS RECEIVED

AVIS

La qualité de cette microfiche dépend grandement de la qualité de la thèse soumise au microfilmage. Nous avons tout fait pour assurer une qualité supérieure de reproduction.

S'il manque des pages, veuillez communiquer avec l'université qui a conféré le grade.

La qualité d'impression de certaines pages peut laisser à désirer, surtout si les pages originales ont été dactylographiées à l'aide d'un ruban usé ou si l'université nous a fait parvenir une photocopie de mauvaise qualité.

Les documents qui font déjà l'objet d'un droit d'auteur (articles de revue, examens publiés, etc.) ne sont pas microfilmés.

La reproduction, même partielle, de ce microfilm est soumise à la Loi canadienne sur le droit d'auteur, SRC 1970, c. C-30. Veuillez prendre connaissance des formules d'autorisation qui accompagnent cette thèse.

LA THÈSE A ÉTÉ
MICROFILMÉE TELLE QUE
NOUS L'AVONS REÇUE

STOCK ADJUSTMENT MODELS, CANADA'S
EAST COAST GROUND FISH FISHERIES

by Carlyle L. Mitchell

Thesis presented to the School of
Graduate Studies of the University
of Ottawa as partial fulfillment of
the requirements for the degree of
Doctor of Philosophy in Economics

Ottawa, Ontario, 1978



Carlyle L. Mitchell, Ottawa, Canada, 1979.

ACKNOWLEDGEMENTS

This thesis was prepared under the direction and supervision of Professor C. Dagum, Department of Economics, University of Ottawa. I would like to thank him for his encouragement, guidance and understanding of my problem of writing a thesis and performing a full time and challenging job at the same time.

I also wish to acknowledge my great indebtedness to Professor O.J. Firestone who was responsible for my pursuing doctoral work at the University of Ottawa; and to Professor I. Spry for her interest and encouragement in my work. I owe a great deal also to my professors in the Quantitative Analysis Course, sponsored by Treasury Board and the Department of Finance and run by the Institute of Policy Analysis, University of Toronto, for the excellent training I received in quantitative and policy analysis.

Finally I would like to thank the examiners of this thesis whose constructive comments aided greatly in improving it; Miss P. Chung, who did the computer work; and my family for the many sacrifices they had to make because of my academic pursuits. My greatest debt, however, is to my father, Rupert William Mitchell, and my mother, Amy Mitchell. Their faith and confidence in my ability to obtain high academic levels never wavered, particularly in my formative years, despite my best efforts to prove the contrary.

CURRICULUM STUDIORUM

The author, Carlyle L. Mitchell, was born July 27, 1936, in Grenada in the West Indies. He received his B.A. degree (cum laude) in economics from St. Francis Xavier University, Antigonish, Nova Scotia in 1961, and his M.A. (Econ.) from the University of Alberta, Edmonton, Alberta in 1963. In 1972, he received a diploma in Quantitative and Policy Analysis from the Treasury Board and Finance sponsored course in Quantitative Analysis which was mounted by the Institute of Policy Analysis, University of Toronto.

TABLE OF CONTENTS

Chapter	page
I INTRODUCTION.	1
1. Purpose of Study	2
2. Scope and Method	5
3. Description of Contents	7
II THE NORTHWEST ATLANTIC GROUND FISH FISHERIES, 1954-1974.	8
1. Marine Resources, Northwest Atlantic Fisheries	10
Groundfish Landings, Northwest Atlantic	12
2. Fleet Expansion Northwest Atlantic ICNAF Areas, 1954-1974	17
ICNAF Fishing Effort, Groundfish Fisheries	25
3. Economic Systems, Northwest Atlantic Fisheries	27
Recent Economic Conditions, 1968-1974	29
4. Conclusion	34
III CANADA'S EAST COAST GROUND FISH FISHERIES, 1953-1974.	36
1. Structure, East Coast Groundfish Fisheries	37
The Offshore Sector	38
The Inshore Sector	38
2. Canada's East Coast Groundfish Landings, 1953-1974	39
3. Factor Inputs, East Coast Groundfish Fisheries	44
Employment in Fisheries	45
4. Changes in the Primary Groundfish Fisheries	49
The Offshore Groundfish Fisheries, 1953-1974	49
The Inshore Groundfish Fisheries, 1953-1974	57
5. Management Problems, Groundfish Fisheries	62
IV CANADA'S EAST COAST GROUND FISH INDUSTRY, 1953-1974.	64
1. The Secondary Manufacturing Industry, 1953-1974	65
Groundfish Products	67
Processing Plants, Capacity Utilization and Employment	72
2. The Economic Importance of the Fishing Industry	75
Fisheries and Regional Development	76
The Regional Development Strategy "Growth Pole" Concept	79
3. Conclusion	83

TABLE OF CONTENTS

Chapter	page
V BIOLOGICAL MODELS OF FISHERIES.	86
1. The Biological Theory of Fish Population Growth	87
The Logistic Model	90
2. Steady State Models of Fisheries Exploitation	94
The Single Resource Model: The Logistic Model	94
The Multiple Resource Model: Predator-Prey	97
3. The Gulland-Fox Exponential Model	104
4. Conclusion	107
VI STOCK ADJUSTMENT MODELS AND FISHERIES ECONOMICS. .	108
1. Stock Adjustment Models of Fisheries	109
The Continuous Time Formulation, H-T Model	110
A Discrete Time Formulation, H-T Model	116
Structural Coefficients, Houthakker-Taylor Models	119
The Long Run Derivative of Catching and Catching Elasticities	120
2. The Economic Theory of Fisheries: Static Analysis	123
The Gordon Model	123
The Scott Model: The Effects of Sole Ownership and Discounting	127
3. Refinements in the Economic Theory of Fisheries	130
The Social Optimum of Fisheries Exploitation	130
The General Economic Model	133
4. Conclusion	136
VII SPECIFICATION AND ESTIMATION, GROUND FISH MODELS. .	138
1. Tests for Comparison of Models	138
2. Specification of Models, Canada's East Coast Groundfish Fisheries	144
Sector 1: The Northwest Atlantic Groundfish Fisheries	145
Sector 2: Canada's East Coast Offshore Groundfish Fisheries	147
3. Estimation Results of Models	147
Sector 1: ICNAF Northwest Atlantic Groundfish Fisheries	148
Sector 2: Canada's Offshore Groundfish Fisheries	153
4. A Comparative Analysis of the Models	159

TABLE OF CONTENTS

Chapter	page
VIII POLICY IMPLICATIONS AND CONCLUSION.	161
1. The End of ICNAF's Management Regime	162
1974-1976	162
ICNAF's Control Over Exploitation by TAC's	166
Crisis in Canada's Groundfish Industry	166
1974-1976	166
2. The 200 Mile Economic Zone for Canada,	172
1977 to 1985	174
The Strategy for Development	175
Canada's Management Objectives, Groundfish	178
Fisheries	179
3. The Models as Management Tools	179
Resource Projections: Rates of Recovery	184
Canada's Groundfish Fleet Capability	189
4. Conclusion	192
REFERENCES	200
APPENDIX 1: THE SINGLE RESOURCE MODEL: THE	200
CASE OF DECREASING MARGINAL PHYSICAL	
PRODUCTIVITY	
ABSTRACT	

LIST OF TABLES

Table

page

I.- Total Landings Northwest Atlantic, ICNAF Convention Area, 1954-1974 by Country, Subarea and Principal Species.	14
II.- Number of Vessels 50 Gross Tons and Over ICNAF Areas by Country, Selected Years 1953-1974 . . .	20.
III.- Total Tonnage of Vessels Over 50 Gross Tons by Major Country, ICNAF, 1971 and 1974	22
IV.- Number of Trawlers and Groundfish Fishing Effort ICNAF Areas, Selected Years 1954-1974 . .	24
V.- Average Prices Fish Production per Ton, U.S. Dollars Major OECD Countries 1968-1974	31
VI.- Performance Indicators for Fisheries, Selected Countries and Years 1968-1974.	33
VII.- Canada's East Coast Fisheries Landings, Major Species, Quantity and Value 1953-1974.	40
VIII.- Major Groundfish Species Landings, Volume, Value and Average Prices, Canada's East Coast Fisheries 1953-1974.	43
IX.- Capital Inputs, Canada's East Coast Fisheries, Selected Years 1953-1974	46
X.- Number of Fishermen and Extent of Employment, Canada's East Coast Fisheries 1953-1974.	48.
XI.- Canada's East Coast Offshore Groundfish Landings by Major Species, Volume and Value 1953-1974 . .	51
XII.- Factor Inputs, Offshore Groundfish Fisheries, Selected Years 1953-1974	53
XIII.- Revenues, Estimated Costs and Incomes, Offshore Groundfish Fisheries, Selected Years 1953-1974 .	55
XIV.- Inshore Landings, Groundfish and Pelagic Species, 1953-1974.	58

LIST OF TABLES

Table	page
XV.- Factor Inputs and Estimated Per Capita Incomes, Inshore Groundfish Fisheries, Selected Years 1953-1974.	60
XVI.- Value of Products Produced, Sea Fish Species, Canada's Fish Processing Industry, Selected Years 1953-1974.	68
XVII.- Major Groundfish Food Products, Canada's East Coast Fish Food Processing Industry, Selected Years 1953-1974.	70
XVIII.- The East Coast Fish Products Industry, Selected Years 1953-1974.	73
XIX.- Contribution of Fisheries to Value Added Atlantic Provinces and Quebec, Selected Years 1956 and 1973	77
XX.- List of Variables.	146
XXI.- Results of Models I and II, ICNAF Northwest Atlantic Fisheries by Major Species.	149
XXII.- Results of Models I and II, Canada's Offshore Groundfish Fisheries by Major Species.	155
XXIII.- ICNAF's TAC's Groundfish Landings by Major Species, and Total Groundfish Fishing Effort 1974-1976.	164
XXIV.- Groundfish Landings, Volume and Value, Canada's East Coast Groundfish Fisheries and Fishing Effort 1974-1976	167
XXV.- Projected TAC's Major Groundfish Species, Selected Years 1978-1985.	180
XXVI.- Effort Reductions and Rates of Growth of Northwest Atlantic Groundfish Stocks and Landings, Houthakker-Taylor Model.	183
XXVII.- Short Term Projections 1980-1985, Canada's East Coast Groundfish Fisheries	188

LIST OF FIGURES

Figure		page
1.	Offshore Fishing Banks - Cape Cod to Newfoundland.	9
2.	International Commission for the Northwest Atlantic Fisheries.	13
3.	Tonnage of Fishing Vessels, 50 Gross Tons and Over, Northwest Atlantic Areas, 1959-1974	19
4.	Distribution and Total Capacity of Fish Processing Plants in the Atlantic Regions.	66
5.	The Optimum Physical Level of Exploitation: The Biological Model.	90
6.	The Economic Optimum and Equilibrium Levels of Fisheries Exploitation: The Gordon Model. / . . .	125
7.	The Economic Optimum Level with Discounting: The Scott Model	129
8.	Estimated and Actual Landings Major Species, Northwest Atlantic, ICNAF Areas	151
9.	Estimated and Actual Landings Major Species, Canada's Offshore Groundfish Fisheries.	157

CHAPTER I

INTRODUCTION

Resource management problems now dominate fisheries exploitation all over the world, particularly in the international fisheries where many resources have, or are becoming, overexploited. The overexploitation of the resources has been due to their common property nature which has led to considerable economic problems in fisheries. A good example is the northwest Atlantic fisheries, situated in one of the world's richest fishing grounds. These fisheries have been exploited by many countries from the time of their discovery in the late fifteenth century. Since World War II, there has been such an expansion in fishing effort, brought about by improved technology and increases in the number of fishing units, that many fisheries resources have become overexploited. The International Commission for the Northwest Atlantic Fisheries, hereafter referred to as ICNAF, was established February 8, 1949 to manage exploitation. From 1969, this Commission had to introduce quotas on threatened species. It was not, however, until 1974 that these quotas became widespread and stringent enough to effectively control the over expansion of fishing effort and the depletion of stocks.

The more stringent quotas by ICNAF, exacerbated by the oil crisis in 1973 and resulting inflationary pressures, caused serious economic problems for the fishing fleets of the nations exploiting the fisheries resources of the northwest Atlantic. Concomitant with these was the third Law of the Sea Conference which commenced in 1974 and is still meeting for the purpose of establishing international management regimes for fisheries. In 1977, all these forces led the coastal states of Canada and the United States to unilaterally declare management jurisdiction of the northwest Atlantic fisheries off their coast out to the 200 mile limit, i.e., 200 mile Economic Zones. The major purpose for this was the conservation and protection of the resources because the economic livelihood of many of their coastal communities depends, to a great extent, on fisheries exploitation. Therefore, the necessity of these states to manage their new "Economic Zones" stems from fundamental biological and economic considerations. This thesis addresses itself to these considerations.

1. Purpose of Study.

The main purposes of this thesis are: (1) to develop and test supply or production models in the context of the northwest Atlantic, particularly Canada's groundfish fisheries in this area during the period 1953-1974, and (2)

to examine the applicability of the models as tools in resource management and the economic implications of this management. This thesis is, therefore, a study in fisheries resource management, with particular emphasis on the biological aspects and their impact on the economics of the fisheries.

Fisheries exploitation has been difficult to model since neither the underlying resource, the fish population, nor its growth rates or natural mortality are known. In recent years, however, there has been extensive development of mathematical models of fisheries exploitation by biologists and economists. Several biological models were developed; the most widely used among them, which has provided the main foundation for economic models, is the steady state logistic model applied to fisheries by Schaefer¹. Fish populations, however, are in transient rather than steady states². As a result, a stock adjustment model based on the Houthakker-Taylor formulation³ was adapted to

1 M.B. Schaefer, "Fisheries Dynamics and the Concept of Maximum Equilibrium Catch", Proceedings, Gulf and Caribbean Fisheries Institute, Sixth Annual Session, November, 1953.

2 The difference between steady state and stock adjustment models will be explained in Chapter IV.

3 H.S. Houthakker and L.D. Taylor, Consumer Demand in the United States, 1929-1970, Cambridge, Massachusetts: Harvard University Press, Second Edition, 1970.

fisheries and used to specify a supply equation for the northwest Atlantic fisheries and for Canada's offshore groundfish fisheries. This will be the major contribution of this thesis since this is the first time that the Houthakker-Taylor version of the stock adjustment model has been applied to fisheries.

The economic implications of ICNAF management regime on Canada's east coast groundfish industry during the period under review, i.e., 1953-1974, and up to 1976, will be analysed. For the greater part of this period, from 1953 to 1968, ICNAF exerted no significant control over fishing effort. The results of this, due to the common property nature of fisheries, were increased competition amongst nations for the resources, as well as biological and economic overfishing. In Canada's east coast fisheries, for example, the period was one of substantial expansion in the groundfish fleet and plant processing capacity. From 1969 onwards, ICNAF management measures, which restricted and reduced landings through quotas, brought about economic problems because of excess capacity in both the fleet and processing plants. Economic problems have, therefore, been directly attributable to resource management measures. As a result, the analysis of these problems will be helpful in indicating the resource management strategy which Canada can now pursue with management control over the exploitation of fisheries

resources out to the 200 mile limit.

2. Scope and Method.

Biological models, concerned mainly with supply in physical terms, have provided the starting point of economic models which have introduced economic factors affecting both supply and demand. This study will emphasize biological supply models. This emphasis is motivated by the following factors: (1) that supply rather than demand is the most uncertain and problematic area in fisheries economics; and (2) that unless supply is known with accuracy, complete models of fisheries exploitation, showing the effects of supply and demand factors, cannot be attempted.

Supply models have concentrated on the effects of fishing effort on catch or output from the fisheries. These models, depending on biological theories of fisheries population dynamics, are of the two main types mentioned earlier: (1) steady state; and (2) stock adjustment. This study will, therefore, apply the previously mentioned stock adjustment model to Canada's east coast groundfish fisheries and also to the international northwest Atlantic groundfish fisheries off Canada's coast. It will test whether or not it is superior to the steady state logistic model.

The models will be based on some of the major characteristics of primary fishing activities in Canada's

east coast groundfish fisheries. "Primary" activities refer to actual fishing operations, while "secondary" activities refer to processing of fish in plants on shore⁴. The primary fisheries industry can be divided, by types and areas of fishing operations, into two main sectors: (1) an offshore sector; and (2) an inshore sector⁵. Emphasis will be given; however, to the former which is international in character and now the major sector in Canada's east coast groundfish fisheries.

The economics of Canada's primary groundfish fisheries industry, and its impact on the secondary and processing sector during the period 1953-1974, will be described. An examination will be made of the main theoretical developments in the economics of fisheries exploitation, outlining the peculiar economic nature of this exploitation due to common property ownership. Emphasis here will be on resource management problems, since these are the unifying link between the biological and the economic aspects of the thesis.

4 Both primary and secondary operations are combined in factory vessels which not only catch but also process the fish into finished or semi-finished forms. Canada, however, does not possess any factory vessels, with the result that processing or manufacturing activities are shore based.

5 These sectors will be defined in Chapter III.

3. Description of Contents.

This study comprises three major parts. Part 1, consisting of Chapters II, III and IV, describes the northwest Atlantic groundfish fisheries, Canada's east coast groundfish fisheries, and the groundfish industry based on these fisheries from the early 1950's to 1974. Part 2, consisting of Chapters V and VI, deals with the theoretical basis, namely biological models of fisheries and stock adjustment models and fisheries economics. Finally, Part 3, consisting of Chapters VII and VIII, deals with the estimation and comparative analysis of fisheries supply models, based on data for the virtually uncontrolled exploitation period of the early 1950's to 1974; and the policy implications of the model's results, in the light of recent changes in jurisdictional responsibilities in the northwest Atlantic groundfish fisheries.

CHAPTER II

THE NORTHWEST ATLANTIC GROUND FISH FISHERIES, 1954-1974

The northwest Atlantic is one of the world's richest fishing areas. The most prolific parts of this area are the famous banks which lie within the continental shelf of North America, off the northeastern United States and the Atlantic Provinces of Canada (Figure 1). On these banks and surrounding areas, conditions are particularly favourable for marine life, resulting in a great abundance and diversity of marine resources¹.

The marine resources of the northwest Atlantic have been exploited almost continually from their discovery, in the late fifteenth century, by fishing fleets of many European countries. After the end of World War II, there was a substantial expansion in fishing effort by these countries, and by Canada and the United States, which produced signs of depletion for some resources. As a result, the International Commission for the Northwest Atlantic Fisheries, ICNAF, was established in 1949 for the investigation, protection and conservation of the fisheries resources

¹ For a description of the hydrographic, oceanographic and climatic factors responsible, see F.A.O. The Fish Resources of the Ocean, compiled and edited by J.A. Gulland, London: The Whitefriars Press Limited, 1971, pp. 1 and 2.

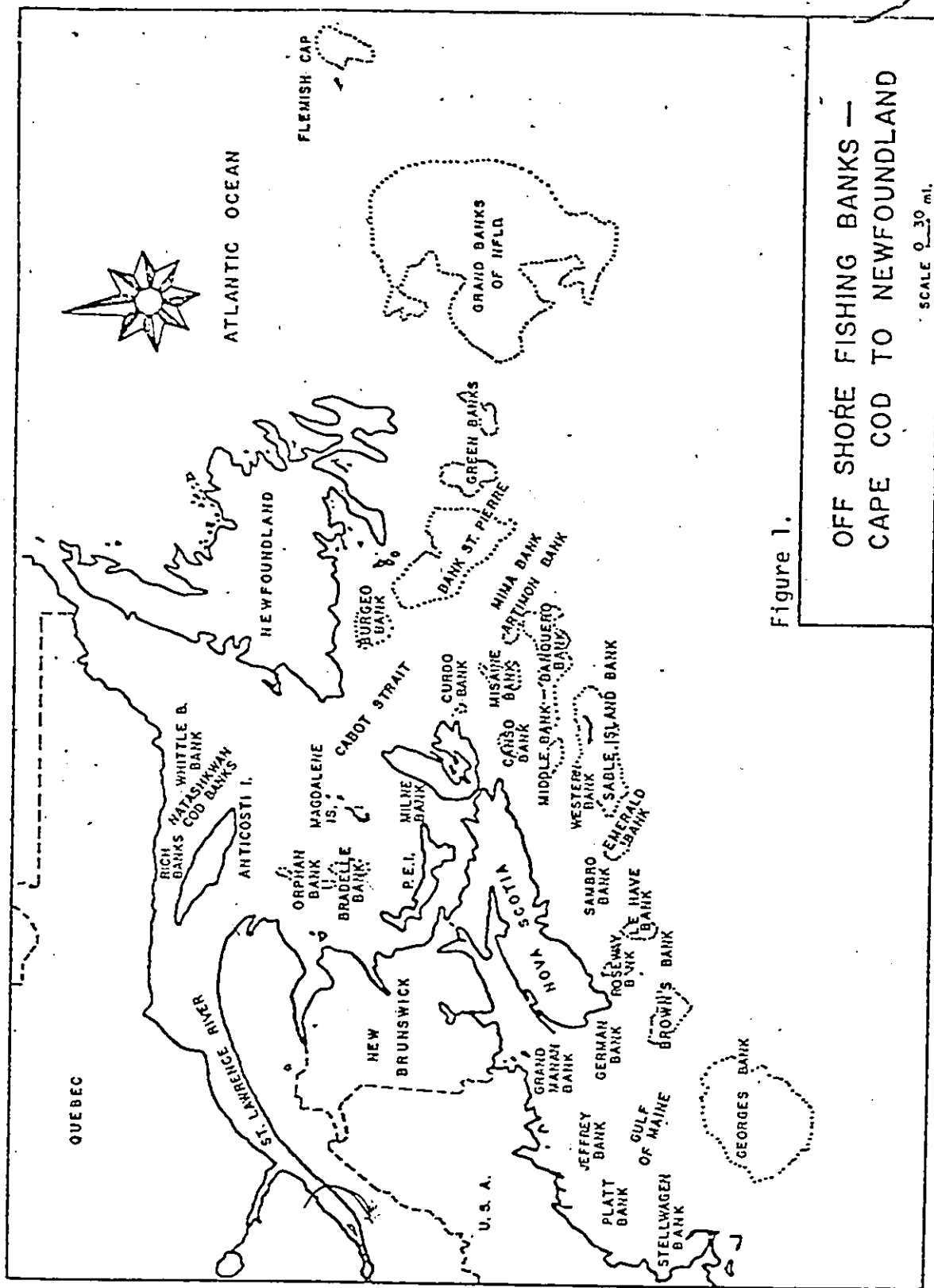


Figure 1.

OFF SHORE FISHING BANKS —
CAPE COD TO NEWFOUNDLAND

of the northwest Atlantic ocean with the objective of ensuring a maximum sustainable yield from their exploitation.

The original member nations of this Commission, consisting then of major countries fishing in the area, agreed to a specified number of management controls to achieve this objective².

1. Marine Resources, Northwest Atlantic Fisheries.

The marine living resources of the northwest Atlantic include many species of fish, mollusks, crustaceans and marine mammals. The fish species component, with which this thesis deals, comprises two main groups: (1) demersal or groundfish, and (2) pelagic. The former, because of their greater value, are the major concern. Groundfish species are generally bottom dwellers found mainly in deeper water on the banks, the continental shelf and part of the continental slope, although some species migrate into inshore and shallow waters at certain times of the year. The most abundant commercial species is cod, found throughout the area, followed by redfish and flatfish. Pelagic species are off bottom feeders, schools of which

² These were as follows: (a) establishing open and closed areas, (b) closure of spawning areas, (c) fish size limits, (d) mesh size limits, and (e) total catch limits for any species. ICNAF Convention article VIII, Dartmouth, Nova Scotia, 1949.

move considerable distances, generally within the confines of the continental shelf and slope. Herring is presently the most abundant of the pelagic species exploited but mackerel and Atlantic salmon are also important.

The migratory movements of species, both groundfish and pelagic, result from changes in ecological conditions, or are related to feeding and reproduction. There are also considerable interrelationships between species. Many species prey on each other and also compete for food and space. W. Templeman points out that cod, the most abundant species in the area, controls the number of fish by their feeding on other groundfish and pelagic species³. The relationship between ecological conditions and feeding habits is brought about by the movement of cod and other groundfish into warmer inshore waters. This occurs during the summer months when they follow and feed on pelagic species such as herring and capelin that move inshore, often for spawning. During the winter and early spring, however, as inshore waters cool down, cod and other groundfish retreat offshore into deeper water. Such movements thus affect the location of resources in the northwest Atlantic.

3 W. Templeman, Marine Resources of Newfoundland, Ottawa: The Fisheries Research Board of Canada, 1966, p. 53.

1.1 Groundfish Landings, Northwest Atlantic.

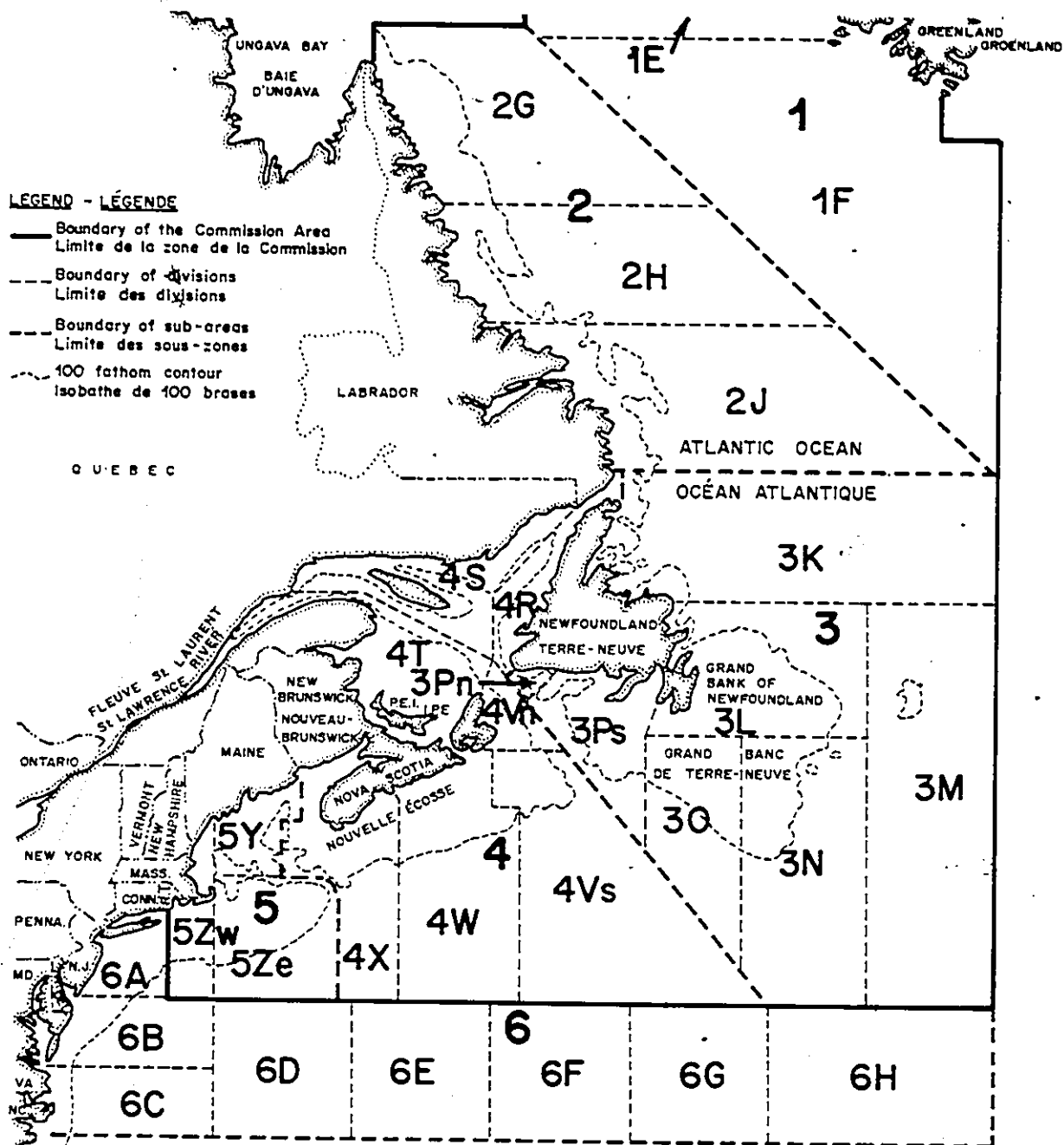
For management and statistical purposes, ICNAF divided the northwest Atlantic fisheries into five sub-areas for most of the period 1954-1974⁴. These sub-areas, with which this thesis will deal and which encompass the major fishing areas for groundfish species, are as follows: sub-area 1, west Greenland; sub-area 2, Labrador; sub-area 3, the eastern and southern Newfoundland area from the Strait of Bell Isle to Cabot Strait; sub-area 4, the Nova Scotian area and the Gulf of St. Lawrence; and sub-area 5, Georges Bank and the Gulf of Maine (Figure 2).

During the period 1954-1974, total landings from ICNAF areas (1-5) increased from 1.8 million metric tons to a peak of nearly 4 million metric tons in 1968 but declined to 3.0 million metric tons by 1974 (Table 1). The major species landed were groundfish, the most important of which was cod. Groundfish landings increased from 1.5 million metric tons to a peak of 2.7 million metric tons in 1968 but declined to 1.7 million metric tons by 1974, accounting, therefore, for 56 percent of the volume of total landings

⁴ Two sub-areas were added during the latter part of the period covered: in 1963 sub-area 6, which lies south of sub-area 5 and covers the areas off the New England States down to North Carolina; and in 1968 sub-area 0, west of sub-area 1, from Northern Labrador and the Arctic Islands of Canada.

THE NORTHWEST ATLANTIC GROUND FISH FISHERIES, 1954-1974 13
Figure 2

INTERNATIONAL COMMISSION FOR THE NORTHWEST ATLANTIC FISHERIES



THE NORTHWEST ATLANTIC GROUND FISH FISHER

TABLE I:

Total Landings Northwest Atlantic, ICNAF Convention Area, 1954-1974 by

	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964
	(Thousand Metric Tons Round)										
Bulgaria	-	-	-	-	-	-	-	-	-	-	-
Canada	682	658	714	699	634	707	723	655	744	801	82
Cuba	-	-	-	-	-	-	-	-	-	-	-
Denmark	54	60	58	65	79	79	94	104	138	125	12
France	158	143	119	128	128	138	151	180	166	123	16
Germany, F.R.	2	22	37	27	71	85	97	174	197	200	14
Germany, D.R.	-	-	-	-	-	-	-	-	-	-	-
Iceland	18	28	17	23	91	83	40	24	8	12	-
Italy	12	10	9	7	3	5	2	4	1	-	-
Japan	-	-	-	-	-	-	-	-	-	-	-
Norway	50	44	43	37	44	32	38	49	36	43	5
Poland	-	-	-	-	-	-	-	4	9	23	3
Portugal	196	206	225	205	179	160	185	197	218	231	21
Romania	-	-	-	-	-	-	-	-	-	-	-
Spain	140	161	149	146	123	143	177	208	206	225	23
USSR	-	-	17	69	117	182	258	341	370	491	61
UK	21	9	5	13	13	18	25	19	27	42	5
USA	513	504	541	560	515	501	477	441	482	465	38
Non-member	-	-	-	-	4	11	12	-	-	2	9
Total	1846	1845	1934	1979	2001	2144	2279	2400	2602	2783	295
Subarea 1	323	305	343	304	346	274	296	417	528	478	41
Subarea 2	22	26	35	32	119	114	280	297	266	223	25
Subarea 3	599	591	540	631	555	768	711	694	535	609	78
Subarea 4	451	462	511	491	522	524	549	498	578	753	74
Subarea 5	414	428	470	514	459	459	443	489	693	714	75
Subarea NK	37	33	35	7	-	5	-	5	2	6	-
Total	1846	1845	1934	1979	2001	2144	2279	2400	2602	2783	295
Cod	969	902	967	958	884	954	1134	1304	1340	1336	140
Haddock	162	198	194	171	138	129	159	179	138	126	14
Redfish	120	123	122	159	325	389	288	226	187	190	21
Halibut	4	4	5	6	6	6	7	6	5	4	-
Silver Hake	41	46	40	57	49	53	47	43	95	270	30
Flounders	49	60	56	67	68	71	90	89	91	117	15
Other Groundfish	151	166	160	161	161	160	120	116	101	167	13
Herring	152	149	152	172	184	154	180	179	344	285	30
Other Pelagic	27	16	52	34	21	38	31	26	29	29	2
Other Fish	27	27	33	28	22	22	23	22	48	41	8
Shellfish	144	154	153	166	143	168	200	210	224	218	19
Total	1846	1845	1934	1979	2001	2144	2279	2400	2602	2783	295

^aExcludes catches by Non-members A and B in 1969 and 1970. ^bReported in Vol. 15 a and Greenland Halibut.

Source: ICNAF, Statistical Bulletin, Vol. 24, 1974, Dartmouth, Nova Scotia: 1976

TABLE I.

NAF Convention Area, 1954-1974 by Country, Subarea and Principal Species

(Thousand Metric Tons Round Fresh)																
1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969 ^a	1970 ^a	1971	1972	1973	1974	
-	-	-	-	-	-	-	-	-	-	-	-	-	21	29	8	
707	723	655	744	801	827	861	974	1040	1259	1202	1169	1104	923	885	845	
-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-	
79	94	104	138	125	127	121	124	124	97	78	64	73	73	70	71	
138	151	180	166	123	160	140	152	159	176	113	73	56	51	41	38	
85	97	174	197	200	149	181	178	217	281	253	205	134	85	92	83	
-	-	-	-	-	-	-	-	-	-	-	-	-	113	161	80	
83	40	24	8	12	8	9	7	3	1	13	-	-	-	-	-	
5	2	4	1	-	-	-	-	-	-	-	-	-	-	-	-	
-	-	-	-	-	-	-	-	-	5	12	19	29	19	19	17	
32	38	49	36	43	50	44	42	59	74	54	47	35	43	71	59	
-	-	4	9	23	38	57	72	120	187	160	171	173	174	235	152	
160	185	197	218	231	210	197	202	237	219	182	163	153	136	135	145	
-	-	-	-	-	-	3 ^b	3 ^b	2	3	4	10	8	7	5	4	
143	177	208	206	225	230	234	241	290	341	294	276	265	232	176	175	
182	258	341	370	491	617	853	710	576	741	875	709	902	1053	1294	1101	
18	25	19	27	42	52	56	60	80	47	6	7	8	16	8	15	
501	477	441	482	465	388	350	329	304	307	262	272	259	217	240	257	
11	12	-	-	2	96	93	95	141	182	1	-	81	-	-	-	
2144	2279	2400	2602	2783	2952	3199	3189	3352	3906	3528	3185	3280	3165	3461	3045	
274	296	417	528	478	413	404	404	465	408	225	141	150	138	104	111	
114	280	297	266	223	251	377	366	329	482	441	239	246	219	159	255	
768	711	694	535	609	784	740	748	1103	1146	984	960	954	958	996	936	
524	549	498	578	753	740	777	802	723	963	1004	1158	1064	911	1139	937	
459	443	489	693	714	756	890	867	732	907	873	687	866	939	1063	806	
5	-	5	2	6	8	11	2	-	-	-	-	-	-	-	-	
2144	2279	2400	2602	2783	2952	3199	3189	3352	3906	3528	3185	3280	3165	3461	3045	
954	1134	1304	1340	1336	1402	1463	1477	1685	1861	1438	1152	1055	1038	808	790	
129	159	179	138	126	142	249	203	117	97	72	48	49	29	26	23	
389	288	226	187	190	213	231	225	218	183	222	224	274	285	313	232	
6	7	6	5	4	5	5	5	13 ^c	17 ^c	2	2	2	37	39	44	
53	47	43	95	270	302	373	172	103	85	135	218	226	221	418	214	
71	90	89	91	117	151	196	226	247	282	289	272	284	235	231	197	
160	120	116	101	167	138	210	215	152	172	166	111	215	186	202	189	
154	180	179	344	285	302	263	425	590	922	827	771	705	533	471	421	
38	31	26	29	29	23	23	31	35	80	99	137	154	239	397	248	
22	23	22	48	41	83	53	85	56	61	108	79	132	203	372	431	
168	200	210	224	218	191	133	125	136	146	168	171	184	159	184	256	
2144	2279	2400	2602	2783	2952	3199	3189	3352	3906	3528	3185	3280	3165	3461	3045	

9 and 1970. ^bReported in Vol. 15 and 16 as Non-member. ^cIncludes mixed catches of Halibut

1974, Dartmouth, Nova Scotia: 1976.

in that year.

The changes in these landings were due to a substantial expansion in fishing effort. This effort resulted from an increase in the number of countries exploiting the resources and in the size of many of their fleets. In 1954, there were eleven countries fishing in the ICNAF convention area: Canada, Denmark, France, Germany F.R., Iceland, Italy, Norway, Portugal, Spain, the United Kingdom and the United States. Since then, however, other countries entered the fisheries, the most important of which were the U.S.S.R. and Poland, and some left. In 1974 there were eighteen countries, excluding one non-member country (Ireland), operating in the ICNAF convention area. Of these, four countries, Canada, the United States, France (St. Pierre Miquelon) and Denmark (Greenland) are coastal states, i.e., states bordering the ICNAF areas with jurisdiction for fisheries within their territorial limits ranging from 3 to 12 miles. The others are distant water states.

There were significant changes in landings by country. Landings increased for most countries, particularly up to 1968. For Canada, the most important country during the period, total landings increased from 682 thousand metric tons in 1953 to a peak of 1,254 thousand metric tons in 1968 but declined to 845 thousand metric tons in 1974. The countries with the greatest increases were

the U.S.S.R. and Poland, which did not even engage in fishing operations before 1956 and 1961 respectively. U.S.S.R. landings increased, however, from 17 thousand metric tons to 1.1 million metric tons during the period 1956-1974, surpassing Canada as the country with the largest volume of landings in the area. For many of the traditional exploiting countries, landings declined during the period 1953-1974, particularly for the United States, Spain, Portugal and France.

The decline in landings since 1968 in the northwest Atlantic was mainly the result of overexploitation of fisheries resources. Because of this, ICNAF imposed quotas on threatened species. These were first introduced in 1969 for haddock and American plaice and in 1972 it was agreed by member countries that quotas would be applied to other species such as cod and herring. By 1974, ICNAF quota restrictions, involving both species and areas, resulted in virtually all groundfish species being covered by total allowable catches (TAC's) for the areas under ICNAF jurisdiction⁵. The overall TAC, i.e., the summation of the TAC's, was then allocated to exploiting countries on the basis of

⁵ The TAC is lower than what is considered the maximum sustainable yield. It allows for a margin of error, generally about 10 percent, to take into account interrelationships between species.

whether they were coastal states or distant water states⁶. In 1974, the overall TAC for groundfish was 2,050 thousand metric tons which consisted of 1,165 thousand metric tons of cod, 209 thousand metric tons for redfish and 676 thousand metric tons for other groundfish⁷. Thus, during the period 1969-1974, the fisheries of the northwest Atlantic moved from a partial to a fully regulated regime. This amounted to a basic change in the structure of these fisheries.

2. Fleet Expansion Northwest Atlantic ICNAF Areas,
1954-1974.

The northwest Atlantic fishing fleet can be divided into two segments on the basis of size: (1) a large vessel fleet consisting of vessels of 50 gross tons and over; and (2) a small vessel and boat fleet consisting of vessels and boats under 50 gross tons. There are numerous vessels and boats in this latter fleet. In 1971 there were forty-seven thousand, but these, because of their size, operate

⁶ ICNAF quotas were established on a 10:10, 40:40 principle (10 percent for the coastal state, 10 percent for contingency, 40 percent on the basis of average catch over the previous 3 years, and 40 percent on the basis of the previous 10-years).

⁷ The TAC's are agreed upon in ICNAF annual meetings by member countries. The data given for 1974 were obtained from ICNAF, Annual Meeting, June 1973.

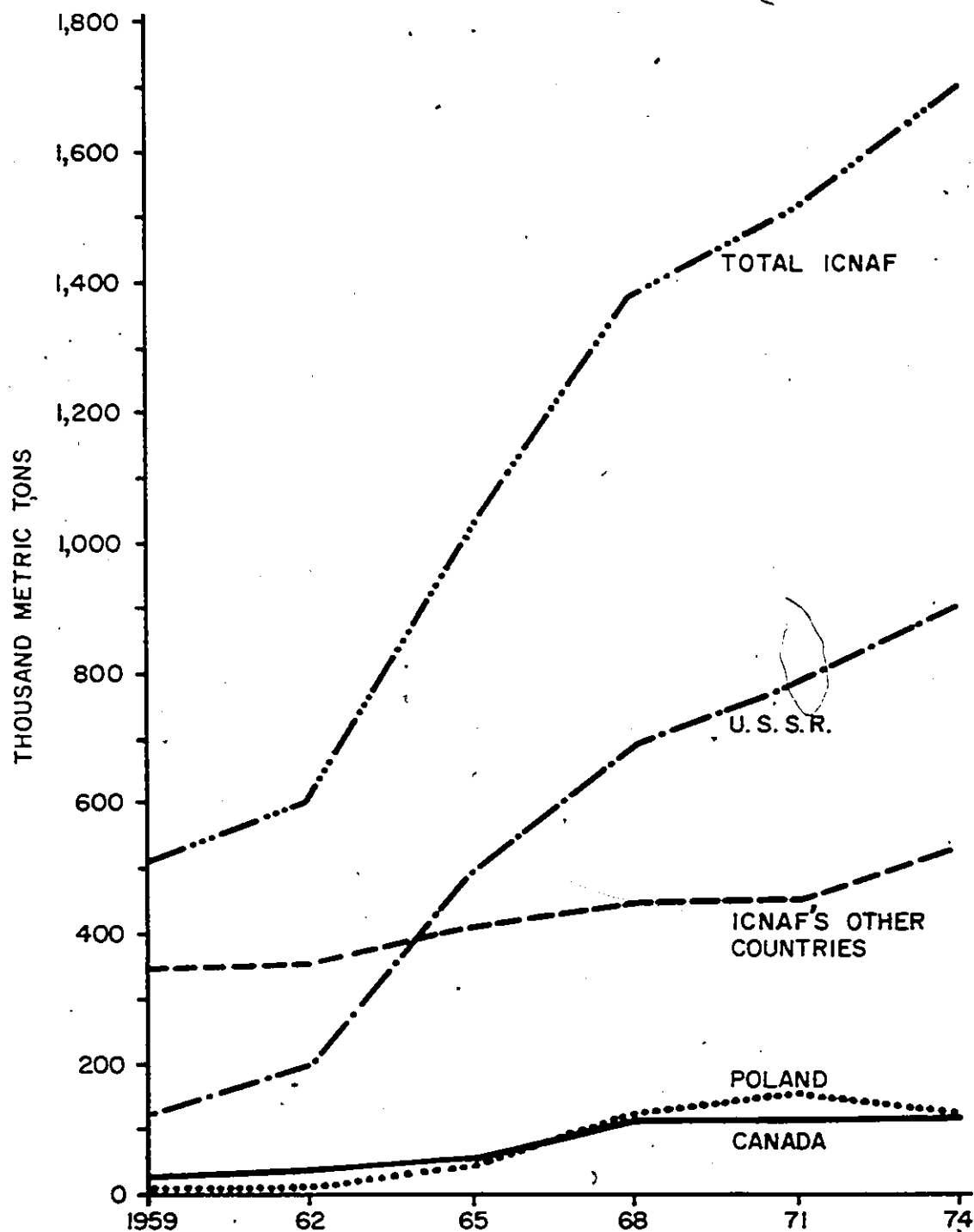
mainly in coastal waters⁸. As a result, changes in fishing effort in the northwest Atlantic, ICNAF areas, will be judged by the large vessel fleet which, because of technology, makes the more substantial contribution to this effort⁹.

The total number of vessels of 50 gross tons and over in the fleets from the countries operating in ICNAF areas in the northwest Atlantic, increased from 804 vessels in 1954 to 2,057 in 1974 (Table II); and their total gross tonnage from 500 thousand in 1959 to 1,691 thousand by 1974 (Figure 3). Table II shows that the number of vessels in the fishing fleets of virtually all countries increased up to 1968 and although there were some declines in the fishing fleets of many countries between 1968 and 1974, there was still an overall net increase in the number of vessels in the ICNAF fleet. The countries experiencing the largest increases for the period on the whole were the U.S.S.R. and Poland. The U.S.S.R. fleet increased from zero in 1953 to 510 vessels in 1974, with a peak of 553 vessels in 1968. Although this fleet was second in number only to

⁸ ICNAF published data on these vessels only for 1971. See ICNAF, List of Fishing Vessels, 1971, (Tri-Annual Publication) Dartmouth, Nova Scotia: 1972.

⁹ How fishing effort is measured will be described later in this section.

Figure 3 TONNAGE OF FISHING VESSELS, 50 GROSS TONS AND OVER, NORTHWEST ATLANTIC AREAS, 1959-1974.



Source: ICNAF, List of Fishing Vessels, Ibid.

TABLE II.
Number of Vessels 50 Gross Tons and Over
ICNAF Areas by Country, Selected Years 1953-1974

	1953	1956	1959	1962	1965	1968	1971	1974
Canada	105	136	211	272	410	558	534	524
Denmark	44	51	69	70	67	71	62	67
France	36	38	37	33	32	33	32	24
Germany F.R.	-	66	81	84	80	75	45	32
Germany D.R.	-	-	-	-	-	-	-	58
Iceland	23	16	41	12	13	3	1	-
Japan	-	-	-	-	-	5	17	16
Norway	59	73	54	46	53	53	42	56
Poland	-	-	3	6	19	84	100	65
Portugal	67	72	72	72	67	63	58	59
Romania	-	-	-	-	2	2	7	4
Spain	90	102	111	132	118	171	161	160
USSR	-	-	111	344	531	553	502	510
UK	96	9	31	34	61	33	16	27
USA	281	326	321	308	326	301	463	445
Others	3	2	4	3	-	-	-	10
Total*	804	891	1,146	1,416	1,779	2,005	2,040	2,057

* Excludes non-member countries since data for these countries were not available.

Source: ICNAF, List of Fishing Vessels, 1974, *ibid.*

that of Canada in 1974, it far surpassed all other fleets in terms of gross tonnage of vessels, which is a more significant measure of fishing power or capacity (Table III).

The increase in the number of vessels and their gross tonnage in the fleets of many countries between 1971 and 1974, in face of declining resource availability, can be attributed to the influence of the third Law of the Sea Conference which commenced in Caracas, Venezuela in June 1974. Since there were possibilities that the marine resources of the oceans might be shared on the basis of historic and existing levels of landings, many countries no doubt decided that it was advantageous for them to maintain as large a presence as possible in the northwest Atlantic ICNAF area fisheries.

The European countries such as the U.S.S.R., Poland, Germany F.R., Portugal, France and the United Kingdom have the largest vessels in operation based on average tonnage per vessel. The main reason for this is that the U.S.S.R. operates large factory or mother ships, which cater to many fishing vessels, while the others operate factory trawlers or large vessels capable of operating far from their main bases for long periods of time. For countries with locational advantages, such as Canada and the United States, processing operations are shore based with the result that

TABLE III.

Total Tonnage of Vessels Over 50 Gross Tons by Major Country,

ICNAF, 1971 and 1974

Country	Number of Vessels		Number of Crew		Gross Tonnage		Average Tonnage per Vessel	
	1971	1974	1971	1974	1971	1974	1971	1974
USSR	502	510	22,434	29,946	782,223	901,050	1,558	1,767
Poland	100	65	5,878	4,774	156,947	131,353	1,569	2,021
Canada	534	524	4,991	4,926	115,752	120,044	217	229
Spain	161	160	4,325	4,008	91,669	91,738	569	573
Portugal	58	59	4,149	4,008	76,323	83,467	1,316	1,415
Germany F.R.	45	32	1,970	1,956	67,875	80,938	1,508	2,529
USA	463	445	3,391	2,242	58,682	48,812	127	110
France	32	24	1,658	664	45,248	31,694	1,414	1,321
UK	16	27	382	647	17,852	27,561	1,116	1,021
Others	129	211	8,097	5,585	93,281	174,754	723	828
Total	2,040	2,057	57,275	58,756	1,505,852	1,691,411	738	822

Source: ICNAF, List of Fishing Vessels, 1974, *ibid.*

smaller vessels are more suitable for these countries than the larger ones¹⁰.

In 1974, the number of crew places in the total fleet of vessels of 50 gross tons and over in the northwest Atlantic ICNAF area amounted to 58,756. The Russian fleet accounted for 51 percent of this with about 30 thousand places. Crew places, however, do not take into account crew turnover, with the result that the actual number of men engaged by these fleets during the year would be larger.

There are many different types of vessels in the ICNAF fleet. Three major types of trawlers (side, stern and pair) fishing mainly for groundfish species, are the largest and most numerous vessels in this fleet. These vessels increased from about 620 in 1954, with an estimated tonnage of 312 thousand metric tons, to 1,537 in 1974 with a tonnage of 1.5 million metric tons, thereby accounting for 90 percent of the total tonnage of the ICNAF fleet in that year (Table IV). There was also a change in the size structure of the fleet, with a trend towards the use of larger and more modern vessels. Since the early 1960's, for example, many European countries began replacing side

¹⁰ See P. Copes "International Fishery-Resource Management: A Position for Canada", (unpublished paper, Simon Fraser University, Burnaby, British Columbia), 1972, p. 5.

TABLE IV.
Number of Trawlers & Groundfish Fishing Effort ICNAF Areas,
Selected Years 1954-74

Years	Trawlers			Total	Tonnage	Total Tonnage All Vessels	Number of Days Fished	Fishing Effort Groundfish Species	C.P.U.E. Groundfish Species
	Stern	Side	Pair						
							10 ⁶		(Index)
1954	n.a.	n.a.	n.a.	620*	310,834*	353,760*	42,725	13,280	245
1956	n.a.	n.a.	n.a.	615	307,500*	392,040*	82,544	25,382	133
1959	n.a.	717	78	798	409,537	507,970	92,800	38,005	100
1962	n.a.	975	106	1,081	496,276	599,354	125,353	83,163	50
1965	n.a.	1,316	94	1,410	901,551	1,019,432	189,704	171,027	35
1968	351	1,047	145	1,534	1,212,550	1,374,262	199,128	241,453	24
1971	493	875	137	1,505	1,324,198	1,505,852	161,253	213,530	22
1974	659	762	116	1,537	1,523,088	1,691,409	152,705	232,583	15

* Estimated on the basis that the average tonnage per vessel remained constant at 500 tons per trawler and 440 tons for all vessels for 1956 and 1953.

Source: ICNAF, List of Fishing Vessels 1974, op.cit.

trawlers with the larger stern trawlers which are capable of operating under more severe weather conditions. Other changes such as the use of more powerful engines and improved gear also took place. An example of the latter is the replacement, since 1963, of the Yankee trawl by the hardier and larger Western type trawl. All these measures resulted in increases in the catching efficiency of fishing vessels.

2.1 ICNAF Fishing Effort, Groundfish Fisheries.

The non homogeneous nature of vessels and gear and changes in technology have made the measurement of fishing effort a difficult problem. In this thesis, fishing effort will be measured by the total tonnage of the fleet times the number of days fished. This has been the accepted measure by biologists¹¹. Economists have been concerned with this measurement from the standpoint that it does not take into account technological change. However, it is argued here that: (i) by reducing effort to its lowest common denominator, i.e., a vessel ton unit, this shortcoming is minimized; and (ii) technological change is implied or embodied in the data since the total number of

¹¹ W.E. Ricker, Computation and Interpretation of Biological Statistics of Fish Populations, Ottawa: Fisheries and Marine Service, Department of Environment, 1975, p. 18.

days fished is affected by changes in technology¹².

The groundfish fishing effort exerted by the ICNAF fleet increased substantially, about eighteen fold, from 1954 to 1968 as the result of increases in both the total tonnage of the groundfish fleet and the number of days fished. Effort declined slightly, by about 12 percent between 1968 and 1971, but since then increased by about 9 percent between 1971 and 1974 (Table IV). This increase was probably a result of the Law of the Sea Conference mentioned earlier since it was brought about by an increase in the total tonnage of the groundfish fleet rather than in the total number of days fished. The Catch Per Unit of Effort, i.e., the C.P.U.E., which measures the productivity of a unit of effort, declined during the period by 85 percent between 1959 and 1974¹³. The changes in fishing effort and the substantial decline in the C.P.U.E. are all good indicators that ICNAF groundfish fishing effort is far too large for the groundfish resources in the area.

¹² R. Hannesson, Economics of Fisheries: Some Problems of Efficiency, Lund Economic Studies, Lund, Sweden: 1974, p. 63.

¹³ The C.P.U.E. data varies with the measurement of effort used. ICNAF scientists, for example, have measured fishing effort on the basis of days fished, which would give much smaller decreases in the C.P.U.E. than those given in Table IV.

3. Economic Systems, Northwest Atlantic Fisheries.

The countries exploiting the northwest Atlantic fisheries resources can be divided into two economic systems: 1) the capitalist or market system of many of the western European countries, Canada and the United States; and 2) the centralized or planning system of the communist-bloc countries of the U.S.S.R., Poland, Bulgaria, Germany D.R., and Romania. There is also the geographical division of countries mentioned earlier into (a) coastal states such as Canada and the United States, and (b) distant water states. For the coastal states, regional interests involving economic, social and political factors are important¹⁴ and influence the structure of their fisheries. For example, coastal state fishing operations range from small, labour intensive inshore ones along the coast to large capital intensive ones on the banks.

Because of the differences in economic systems, conditions and geographical location, production practices vary significantly between countries. However, most

¹⁴ For example, in regions which have traditionally been dependent on the fisheries and where employment difficulties or manpower utilization can have important economic, social and political considerations. ICNAF "Report of the Working Group on Joint Biological and Economic Assessment of Conservation Actions", Annual Proceedings, Vol. 17, 1968, p. 51.

countries, even some of the communist block ones¹⁵, dispose of their fisheries products in similar markets; the main ones being the United States and western Europe. Thus, market prices are determined by factors such as population and income levels in these countries. These prices, in turn, affect demand and prices at the primary or ex-vessel fishing level. The exception to this is the communist countries where (although in their trade with the non-communist bloc they have to accept prices established by market forces) ex-vessel and market prices for their products and production plans are established by central planning agencies. Ex-vessel prices set by these agencies cover fishing operating costs¹⁶ with the result that the economics of vessel operations can be controlled to some extent. For these countries, investment plans for fisheries production and the level of fishing effort depend on alternative costs and returns from other sources of animal protein, i.e., red meat and poultry from the livestock and poultry industries. The decision to curtail fishing effort,

¹⁵ These countries export their fisheries products as a means of obtaining foreign currency such as U.S. dollars.

¹⁶ B.G. Noelzel, A Report on the Economics of Polish Factory Trawlers, Working Paper No. 9, Division of Economic Research, U.S. Bureau of Commercial Fisheries, February 1969, p. 15.

therefore, does not depend on fishing costs alone but on whether or not costs and returns per protein unit from fisheries exceed those from livestock and poultry. Under these conditions, economic forces which, because of poor and decreasing returns, lead to a curtailment of fishing effort in non-communist countries have little influence, per se, in restricting effort in the communist countries.

Despite the great differences in fishing operations between countries, it is possible to obtain some idea of recent economic conditions in the northwest Atlantic fisheries. These conditions can be discerned from trends in fish prices, productivity, and vessel construction costs in some of the major fishing countries which are members of the Organization for Economic Cooperation and Development, OECD¹⁷.

3.1. Recent Economic Conditions 1968-1974.

Economic conditions in the northwest Atlantic fisheries in recent years have been influenced by two main factors: (a) buoyant demand for fisheries products resulting in increased prices; and (b) increased costs of vessels and vessel operations. Of these, the second is the more persuasive. For example, it has been widely recognized

¹⁷ OECD, Review of Fisheries in OECD Member Countries, (Annals since 1967), Paris.

since 1968 that there is an overabundance of fishing effort in the northwest Atlantic fisheries and that the costs of harvesting the resources are much greater than necessary. Fishing effort, however, increased since then, and also the costs of these vessels and their operations¹⁸. The oil crisis in 1973 and world wide inflationary pressures in 1973 and 1974 exacerbated cost conditions in the fisheries, especially for the non-communist states.

On the demand side, sluggish demand conditions in 1968 and 1969 led to small changes in fish market prices in most of the large fish producing OECD countries. Demand conditions, however, improved and these, accompanied by decreased supplies of fisheries products, brought about increased average prices from 1970 to 1974 in most of the countries covered (Table V). The largest price increases from 1970 to 1974, almost three fold in real terms, were experienced in Germany and Spain, followed by the United Kingdom, Portugal, Canada and the United States.

The supply side, however, has been characterized by decreasing physical productivity of vessels, and increased costs of vessels and their operations. The physical productivity of vessels, based on indices of

¹⁸ ICNAF does not provide economic data on fishing effort and effort data are only in terms of days fished. See ICNAF, Statistical Bulletins, op.cit.

average catch per vessel ton, declined for most of the major producing countries between 1968 and 1974 (Table VI). This, compared with the price indices for these countries for the years given, indicates that price increases by 1974 seemed to have compensated for the declines in physical productivity experienced, as shown by the gross revenue performance indices. These latter indices, however, do not take into consideration vessel capital and operating costs which would have permitted economic performance indices to be obtained. These costs, however, increased substantially during the period.

High construction costs of vessels¹⁹, increased operating costs due to increased wages and prices for oil and supplies have been responsible for the serious economic difficulties faced by the fishing fleets of many nations. Some of the large freezer and factory trawlers, for example, now cost from \$7 million to \$15 million, making it difficult for private enterprise to undertake, from their own resources, construction of new deep sea fishing craft. This has led almost all governments to introduce measures

¹⁹ Construction costs of vessels in North America and western Europe increased substantially during the 1960's. This is exemplified by the Netherlands, one of the major fishing vessel producing nations in Europe. Indices of vessel construction costs and consumer prices show that vessel construction costs increased much more rapidly than general price levels OECD, Review of Fisheries 1970, op.cit.

TABLE VI.

Performance Indicators for Fisheries,
Selected Countries and Years 1968 - 1974.

	<u>1968</u>	<u>1971</u>	<u>1974</u>
Canada			
(a) Price Index, Fish Products*	100	147	229
(b) Vessel Physical Productivity Index**	100	91	62
(c) Gross Revenue Performance Index (a)x(b)	100	134	142
U.S.A.			
(a) Price Index, Fish Products**	100	114	159
(b) Vessel Physical Productivity Index	100	55	59
(c) Gross Revenue Performance Index (a)x(b)	100	63	94
Portugal			
(a) Price Index, Fish Products	100	126	201
(b) Vessel Physical Productivity Index	100	59	46
(c) Gross Revenue Performance Index (a)x(b)	100	74	92
Spain			
(a) Price Index, Fish Products	100	175	354
(b) Vessel Physical Productivity Index	100	79	48
(c) Gross Revenue Performance Index (a)x(b)	100	138	170
U.S.S.R.			
Vessel Physical Productivity Index (a)	100	110	86
Poland			
Vessel Physical Productivity Index (a)	100	36	47
Total ICNAF, Vessel Physical Productivity Index (a)	100	72	51

* Based on data from Table V.

** Based on landings per vessel ton.

to foster new construction through subsidy programs²⁰, since costs, exacerbated by the oil crisis and world wide inflationary pressures in 1973 and 1974, have become quite prohibitive. The evidence available, therefore, indicates that economic conditions in the northwest Atlantic fisheries have deteriorated, mainly as a result of excessive inputs of effort in relation to resource availability.

4. Conclusion.

This chapter purports to: (a) offer a general description of the northwest Atlantic fisheries under ICNAF jurisdiction; (b) summarize recent trends in economic conditions in these fisheries up to 1974; and (c) establish an empirical basis for this thesis. It pointed out that the management of the exploitation of these fisheries by ICNAF was based on biological considerations; ICNAF's major objective being the attainment of maximum sustainable yields. Due to the international nature of ICNAF, however, it was difficult for ICNAF to impose effective control until there were obvious signs that the resources were overexploited. Thus, it was only from 1969 that quotas were introduced

²⁰ Every one of the countries has a structure of subsidies. In the Communist countries subsidies are built into their pricing system. OECD, Financial Support to the Fishing Industry, Paris: 1971.

and progressively applied until virtually all species were covered by 1974.

Economic factors played an important role in bringing about the resource management measures by ICNAF. This was because the uncontrolled exploitation of the fisheries of the northwest Atlantic, for most of the period 1954-1974, led to increased competition for the resources from the fleets of ICNAF member nations and others. As a result, both biological (i.e., overexploitation) and economic aspects were adversely affected. The latter were caused by increasing production costs due to decreasing productivity. These costs, it has been pointed out, probably increased faster than the gross revenues from fishing leading to the decreasing profitability of fleet operations.

In the chapter to follow, the importance of the groundfish fisheries in Canada's sea fisheries in this area will be analyzed.

CHAPTER III

CANADA'S EAST COAST GROUND FISH FISHERIES, 1953-1974

Canada's east coast sea fisheries are conducted in ICNAF sub-areas (2, 3, 4 and part of 5) closest to Canada's coast, which stretches 12,000 miles from the Bay of Fundy to Hudson Strait including Newfoundland and other islands¹. The groundfish fisheries are the most important of these fisheries in terms of: (1) the magnitude of resources, value of output, and the number of vessels and fishermen employed; (2) their contribution to output and employment in the secondary manufacturing or fish processing industry; and (3) the contribution of the fishing industry, both primary and secondary sectors, in Canada's Atlantic regional economy. These latter contributions, that is (2) and (3), will be examined in Chapter IV although the main emphasis of this thesis will be on the primary groundfish industry.

There are great differences in Canada's primary groundfish fisheries, due to factors such as location of resources and technology employed, which influence economic returns to vessels and incomes to fishermen. These factors and jurisdictional responsibilities between ICNAF and Canada

¹ The Royal Commission Canada's Economic Prospects Study, The Commercial Fisheries of Canada, Ottawa: The Queen's Printer, 1956, p. 10.

determine the basic structure of the primary industry. The jurisdictional responsibilities for the management of Canada's sea fisheries are vested in the Fisheries and Marine Service, Department of Fisheries and the Environment².

1. Structure, East Coast Groundfish Fisheries.

Canada's east coast groundfish fisheries are divided into two major, but not mutually exclusive, sectors³: (1) an offshore sector; and (2) an inshore sector. The inshore sector is confined to the coastal or territorial waters within Canadian jurisdiction and control; while the offshore sector is the international fishery conducted outside these limits, generally on the banks. Location,

2 Under the Terms of the British North America Act, the sea fisheries of Canada came under Federal jurisdiction. For the period under review in this thesis, this jurisdiction was exercised by the Department of Fisheries from 1953 to 1965, the Department of Fisheries and Forestry from 1966 to 1968, and since then up to 1977 by the Department of Environment, now the Department of Fisheries and the Environment.

3 Reference is now made to the development in recent times of a new fisheries sector - the middle distance or near offshore fisheries "... which emerged from the inshore fishery, with the acquisition by private fishermen of somewhat larger, more seaworthy and more sophisticated vessels". P. Copes, "Canada's Atlantic Coast Fisheries: Policy Development and the Impact of Extended Jurisdiction", Discussion Paper 77-17-2, Department of Economics, Simon Fraser University, 1977, p. 13.

abundance, mobility of resources, and fishing technology have been responsible for great differences between these sectors.

1.1 The Offshore Sector.

Offshore fishing for groundfish is carried out mainly on the banks (ICNAF sub-areas 3 and 4) from large vessels (trawlers and draggers) generally over fifty gross tons. These vessels are capital intensive, require skilled crews and operate out of large ports in the Atlantic Provinces and Quebec. Because of the large vessels used for groundfish, many of which are over 100 gross tons; and the availability of groundfish species on the banks throughout the year, offshore operations are carried out on a year round basis.

1.2 The Inshore Sector.

Inshore groundfish operations are carried out not far from shore, normally within territorial limits, all along Canada's east coast. The major characteristics of this fishery are labour intensity, seasonality, and the predominance of the cod fishery. Inshore fishermen have been the mainstay of Canada's east coast fisheries for centuries. Many live in tiny settlements scattered along the coast and operate from small vessels and boats, the majority of which are under ten gross tons.

The gear used for groundfish species are mainly fixed gear such as traps and nets⁴. As pointed out earlier, cod migrate from offshore into inshore waters following herring, capelin and other pelagic species during the late spring and early summer months, with the result that resources in inshore waters are abundant at this time. This, and the small vessels and boats used by the fishermen, have been responsible for inshore operations, especially in the more exposed areas along the coast, being primarily confined to the period from May to September.

2. Canada's East Coast Groundfish Landings, 1953-1974.

Canada's east coast sea fisheries experienced growth in output from 1953 to 1968, but since then landings declined due to the overexploitation of the fisheries resources in the northwest Atlantic. Sea fish landings increased in volume from 568 thousand metric tons in 1953 to a peak of 1,175 thousand metric tons in 1971 but declined to 661 thousand metric tons in 1974 (Table VII). There was a sharp drop in landings between 1973 and 1974, the result of both a trawler strike in Newfoundland, which

⁴ For example, for cod, the trap is the most important gear but gill nets, handlines, jiggers and long and trawl lines are also used. For salmon, gill nets, drift nets and traps are utilized, and for herring, gill nets, seines, traps and weirs.

TABLE VII.
Canada's East Coast Fisheries Landings, Major Species, Quantity and Value 1953-1974

	Groundfish		Pelagic		Total	
	Q	V \$'000 (Constant 1971) Dollars	Q Metric Tons (Round Weight)	V \$'000 (Constant 1971) Dollars	Q Metric Tons (Round Weight)	V \$'000 (Constant 1971) Dollars
1953	419,475	32,418	148,715	11,611	568,190	44,029
1954	514,130	36,638	143,534	11,216	657,664	49,854
1955	481,812	37,610	134,655	9,661	616,467	47,271
1956	541,542	40,859	128,284	9,743	669,826	50,602
1957	490,252	37,951	133,847	9,486	624,099	47,437
1958	416,089	35,578	135,153	10,561	551,242	46,139
1959	482,747	40,914	132,480	10,756	615,227	51,670
1960	503,707	39,950	135,043	11,209	638,750	51,159
1961	472,405	39,288	103,194	9,424	575,599	48,712
1962	510,190	44,683	133,256	11,211	643,446	55,894
1963	522,966	48,539	143,400	12,183	666,366	60,727
1964	534,565	52,337	173,270	14,177	707,835	66,514
1965	579,033	56,059	212,937	14,693	791,970	70,752
1966	615,028	62,014	285,970	16,755	900,998	78,770
1967	588,931	57,008	373,298	18,992	962,229	76,000
1968	621,360	55,588	554,571	23,643	1,175,931	79,231
1969	606,200	53,494	509,543	21,699	1,115,743	75,193
1970	577,520	55,570	509,459	24,168	1,086,979	79,738
1971	567,441	59,566	459,974	19,382	1,027,385	78,948
1972	519,837	58,427	313,356	18,831	833,193	77,258
1973	541,179	71,602	247,355	20,930	788,534	92,532
1974	418,302	59,089	243,305	20,582	661,607	79,671

Sources: ICNAF, Statistical Bulletins, op.cit.. Quantity data obtained from ICNAF
Environment Canada, Statistical Review of Canadian Fisheries, Vols. 1 to 8, Ottawa.

tied up a large segment of Canada's offshore groundfish fleet, and severe ice conditions which curtailed inshore operations. In terms of value, the value of sea fish landings increased in real terms from \$44 million in 1953 to a peak of \$92 million in 1973⁵. The sharp drop in landings in 1974, however, reduced the value of landings to \$80 million in that year.

Groundfish landings were the most important sea fish landings, accounting for 68 percent of the volume and 77 percent of their value in 1973 (1974 can be considered an unusual year because of the trawler strike mentioned).

Groundfish landings had increased in volume from 419 thousand metric tons in 1953 to a peak of 621 thousand metric tons in 1968 but dropped to 541 thousand metric tons in 1973 and to 418 thousand metric tons in 1974. They increased steadily in value, however, from \$32 million in 1953 to \$72 million in 1973 and were at \$59 million in 1974.

There are many species of groundfish landed in Canada's east coast fisheries, the most important being cod, flounders (of which there are many sub-species), redfish and

⁵ All value figures will be given in constant 1971 dollar terms throughout this thesis unless otherwise specified. This was done by using the Consumer Price Index as the deflator for landings and incomes and the Implicit Price Index as the deflator for equipment, i.e., vessels and gear.

haddock. The number of groundfish species landed increased significantly during the period 1953-1974, from six to nineteen species⁶. Of these, cod, the largest single species landed, declined from nearly seventy percent in 1953 to thirty-eight percent in 1974, with the result that the other species combined increased from thirty to sixty-two percent. Because of their large numbers, groundfish species will be divided into three major species; cod, redfish and other⁷, which will also be referred to as flatfish since the majority are flounders and soles.

Cod landings increased from 290 thousand metric tons, valued at \$19.7 million in 1953, to a peak of 355 thousand metric tons, valued at \$23.8 million in 1959 but declined to 157 thousand metric tons, valued at \$25.7 million in 1974 (Table VIII). Flatfish landings also increased for most of the period from 108 thousand metric tons, valued at \$11 million, to a peak of 224 thousand metric tons, valued at \$25.6 million in 1966 but dropped to 174 thousand metric tons, valued at \$25.8 million in 1974. Redfish landings increased from 21 thousand metric tons, valued at \$1.6

6 See ICNAF Statistical Bulletins, op.cit., and Environment Canada, Statistical Reviews of Canadian Fisheries, op.cit.

7 This will be the classification used in the models to be specified in Chapter V.

TABLE VIII.

Major Groundfish Species Landings, Volume, Value and Average Prices,

Canada's East Coast Fisheries 1953-1974

	Cod			Redfish			Flatfish		
	V			V			V		
	Metric Tons	\$'000 (Constant 1971) Dollars	Price Per Ton Dollars	Metric Tons	\$'000 (Constant 1971) Dollars	Price Per Ton Dollars	Metric Tons	\$'000 (Constant 1971) Dollars	Price Per Ton Dollars
1953	290,274	19,762	68.08	21,510	1,656	77.00	107,691	11,001	102.15
1954	354,791	24,715	69.66	22,494	1,710	76.00	136,845	12,215	89.26
1955	315,730	22,066	69.89	19,584	1,559	79.62	146,498	14,003	95.62
1956	353,277	24,291	68.76	25,815	1,887	73.11	162,450	14,681	90.37
1957	352,271	21,851	62.03	21,103	1,493	70.97	116,878	14,599	124.91
1958	287,896	18,926	65.74	27,542	2,129	77.30	100,651	14,525	114.31
1959	355,975	23,875	67.07	18,672	1,370	73.38	108,100	15,657	144.84
1960	336,117	22,903	68.14	21,162	1,623	76.70	146,428	15,422	105.32
1961	286,030	21,550	75.34	25,581	2,008	78.51	160,794	15,729	97.82
1962	320,643	25,687	80.11	27,400	2,154	78.60	162,147	16,845	103.89
1963	334,266	28,035	83.87	37,458	2,963	79.09	151,242	17,543	115.99
1964	315,565	28,716	91.00	36,042	2,827	78.44	182,958	20,795	113.66
1965	313,905	29,846	95.08	57,332	4,317	75.30	207,796	21,898	105.38
1966	308,138	30,312	98.37	82,615	6,139	74.31	224,275	25,565	113.99
1967	285,673	27,502	96.27	78,813	5,771	73.23	224,445	23,735	105.75
1968	322,872	27,422	84.93	89,353	6,245	69.89	208,935	21,951	104.92
1969	293,856	23,268	79.18	95,852	6,204	64.72	216,492	24,033	111.91
1970	262,922	22,433	85.32	106,893	7,993	74.82	207,705	25,310	122.00
1971	244,612	25,130	102.73	110,689	8,654	78.18	212,140	25,731	121.53
1972	218,799	24,955	114.05	107,798	9,040	83.86	193,240	24,432	126.43
1973	177,283	26,317	148.45	158,439	15,350	96.88	205,457	29,935	146.70
1974	157,138	25,706	163.59	87,204	7,583	86.95	173,948	25,800	148.32

Sources: ICNAF, Statistical Bulletins, op.cit.

Environment Canada, Statistical Review of Canadian Fisheries, Vols. 1 to 8, Ottawa.

million, to a peak of 158 thousand metric tons, valued at \$15.4 million in 1973, but dropped to 87 thousand metric tons, valued at \$7.6 million in 1974.

The decline in cod and flatfish landings since the late 1960's was the result of increasing scarcity of these resources which led to a shift in fishing effort to the greater exploitation of lower valued groundfish species, such as redfish. This scarcity also affected prices. For example, for the period 1953-1971 average price increases for the major species were small, remaining relatively stable for redfish and increasing at average annual rates of 2.3 percent for cod and 1 percent for other. With the increasing scarcity of resources and buoyant demand in 1973 and 1974, prices increased sharply between 1971 and 1974: 59 percent for cod, 11 percent for redfish and 22 percent for flatfish, or at average annual rates of growth of 16.8 percent, 3.6 percent, and 5.1 percent respectively.

3. Factor Inputs, East Coast Groundfish Fisheries.

The growth in total sea fish and groundfish landings during the period 1953-1974 was brought about by an increase in factor inputs, mainly capital for vessels and gear. Capital inputs in fishing craft (including carrying smacks)

and gear used in primary fishing operations⁸ increased from \$67 million in 1953 to \$205 million by 1968 but decreased to \$178 million by 1974 (Table IX). These changes were due to an expansion in the fishing fleet from thirty-three thousand craft in 1953 to nearly forty thousand by 1965; and after 1965 to an increase in the size, tonnage and cost of these craft since their number declined to twenty-eight thousand by 1974. Groundfish fishing craft were estimated to have increased in number from nineteen thousand in 1953 to twenty-five thousand in 1962 but declined to fifteen thousand by 1974; and in value from \$29 million in 1953 to a peak of \$131 million in 1968 but dropped to \$111 million in 1974. These craft, therefore, accounted for about 55 percent of the total number and 73 percent of the value of craft in 1974.

3.1 Employment in Fisheries

Primary fishing operations on Canada's east coast fisheries provide only part-time and occasional employment

⁸ Excluded are investment in infrastructural facilities such as ports, wharves, breakwaters, etc., without which these craft could not operate.

TABLE IX.
Capital Inputs, Canada's East Coast Fisheries, Selected Years 1953-1974

	Value of Craft and Gear			
	Number of Fishing Craft	Value of Fishing Craft	Value of Fishing Gear**	Total Value of Craft and Gear
	Groundfish* Total	Groundfish* Total (\$'000, 1971 Dollars)		
1953	19,200	33,072	29,400	45,550
1956	21,100	35,736	30,900	47,904
1959	19,500	35,149	33,200	48,853
1962	24,600	36,548	44,900	62,068
1965	24,200	39,367	82,800	111,623
1968	19,400	34,258	131,100	185,075
1971	18,400	31,702	107,600	159,966
1974	15,200	27,559	111,100	151,324
				21,492
				27,326
				24,699
				16,309
				19,370
				19,564
				21,663
				26,428
				67,042
				75,230
				73,552
				78,377
				130,993
				204,639
				181,629
				177,752***

* No data are available on the number of groundfish fishing craft, especially since these craft could be used in other fisheries. The number and value of groundfish fishing craft were therefore estimated.

** Since 1962, there was a change in classification for the Maritimes and Quebec to expenditures in gear and equipment rather than inventory value which was used in the years previous to this.

*** Data on Newfoundland were not available for 1953 and 1974 and were therefore estimated.

Source: Statistics Canada, Fisheries Statistics of Canada, (annuals, Cat No. 6507-742), Ottawa,

Environment Canada, Annual Review of Canadian Fisheries, Vol. 4, op.cit.

(less than ten months duration)⁹ since the majority of fishermen are in the seasonal inshore fisheries. Because offshore fishing operations are year round, most full-time fishermen (those fishing for ten months and over) are offshore fishermen. Consistent data on the number of inshore-offshore fishermen are not available for the whole period covered by the thesis. As a result, full-time fishermen will be used to represent offshore fishermen and part-time and occasional to represent inshore fishermen (Table X). This representation is widely accepted although it is known that many fishermen engage in both inshore and offshore fishing.

The number of fishermen on Canada's east coast, nearly 90 percent of which were in the inshore fisheries, fluctuated from a low of forty-five thousand to a high of forty-nine thousand between 1953 and 1965 but declined to thirty-nine thousand by 1974. Groundfish fishermen accounted for well over 50 percent of the total number of fishermen, increasing from about twenty-nine thousand to thirty-two thousand between 1953 and 1964 and declining thereafter to twenty-one thousand by 1974¹⁰.

⁹ This is the classification of part-time and occasional fishermen used in official fisheries statistics. See Footnote 1, Table X, p. 48.

¹⁰ The second most important fisheries in terms of employment on the east coast are the lobster fisheries which are not treated in this study.

TABLE X.

Number of Fishermen and Extent of Employment,
Canada's East Coast Fisheries 1953-1974

	Groundfish*	Total	Extent of Employment ¹	
			Part-Time and Occasional	Full-Time**
1953	28,643	48,548	43,338	5,210
1954	28,603	48,481	43,124	5,357
1955	28,235	47,865	43,196	4,669
1956	27,724	46,991	41,535	5,456
1957	28,579	48,439	42,838	5,357
1958	28,174	47,753	42,838	4,915
1959	25,601	46,471	41,561	4,910
1960	25,553	45,509	40,594	4,915
1961	29,026	44,797	39,968	4,829
1962	30,799	45,709	40,910	4,799
1963	32,054	47,753	42,691	5,062
1964	32,487	48,579	43,143	5,436
1965	30,311	49,335	43,324	6,011
1966	28,386	45,918	40,233	5,685
1967	26,864	45,210	39,534	5,676
1968	26,234	45,709	39,757	5,952
1969	23,040	42,931	36,768	6,163
1970	22,631	41,757	35,668	6,089
1971	22,984	39,726	34,604	5,122
1972	21,579	39,741	34,213	5,528
1973	21,572	38,996	33,659	5,337
1974	21,203	38,552	33,271	5,281

* Estimated for the period 1953-1958 based on groundfish fishermen accounting for 59 percent of the total number of fishermen--the average for the period 1959-1961.

** Estimated for all years with the exception of the years from 1969 to 1973 for which data are available.

¹ The classification of fishermen was based on the time spent in fishing activities: full-time those engaged in fishing for 10 months or over; part-time and occasional less than 10 months.

Source: Environment Canada, Annual Statistical Review of Canadian Fisheries, Vols. 1, 2 and 3, op.cit.

4. Changes in the Primary Groundfish Fisheries.

There were extensive changes in the primary groundfish fisheries during the period 1953-1974. These were caused by increased factor inputs, mainly capital in the offshore sector because of greater resource availability in this sector than in the inshore sector. In the latter, decreasing resource availability led to a reduction in labour input, the more significant factor of production in this sector. For most of the period, these changes brought about: (1) growth in the offshore sector; and (2) instability and decline in the inshore sector.

4.1 The Offshore Groundfish Fisheries, 1953-1974.

Canada's east coast offshore fisheries are primarily for groundfish species. It was only during the second half of the 1960's that large scale offshore operations for pelagic species, mainly for herring, took place¹¹. Groundfish landings increased from 114 thousand metric tons in 1953 to a peak of 350 thousand metric tons in 1968 but declined to 261 thousand metric tons in 1974; and in value from \$9.6 million to \$34.4 million with a peak of \$40.7

¹¹ C.L. Mitchell and D.B. McEachran, Developments in the Atlantic Coast Herring Fishery and Fish Meal Industry, 1964-1968. Canadian Fisheries Reports No. 16, Department of Fisheries and Forestry, Ottawa: August, 1970.

million in 1973 (Table XI)¹². Because of the expansion in the offshore fisheries, offshore groundfish landings increased from 27 percent of the volume of total groundfish landings in 1953 to 62 percent in 1974.

The most important groundfish species landed by Canadian offshore vessels, in terms of volume and value, were flatfish rather than cod. In fact, during the period 1953-1974, landings of flatfish and redfish increased much more substantially than cod: flatfish from 49 thousand metric tons, valued at \$5.1 million, to 122 thousand metric tons, valued at \$18.0 million; redfish from 21 thousand metric tons, valued at \$1.6 million, to 85 thousand metric tons, valued at \$7.4 million; while cod increased from 44 thousand metric tons, valued at \$3 million, to 54 thousand metric tons, valued at \$8.9 million. Landings of both flatfish and cod have, however, declined from 1967 and 1968 when flatfish landings peaked at 169 thousand metric tons and cod at 111 thousand metric tons, while redfish landings peaked in 1973 at 156 thousand metric tons.

The growth in offshore groundfish landings up to 1968 was due to a substantial expansion in Canadian offshore groundfish effort, characterized by an increase in the

¹² The sharp drop in offshore groundfish landings between 1973 and 1974 was due to the Newfoundland trawler strike mentioned earlier.

TABLE XI.
Canada's East Coast Offshore Groundfish Landings by Major Species, Volume and Value 1953-1974

	Cod			Redfish			Flatfish			Total Groundfish		
	Q	V	\$'000 (Constant 1971) Dollars	Q	V	\$'000 (Constant 1971) Dollars	Q	V	\$'000 (Constant 1971) Dollars	Q	Metric Tons	\$'000 (Constant 1971) Dollars
1953	43,557	2,965		20,751	1,598		49,531	5,060		113,839	9,623	
1954	54,546	3,730		21,823	1,658		61,903	5,526		137,272	10,914	
1955	52,479	3,668		18,631	1,484		80,917	7,737		152,027	12,889	
1956	51,326	3,529		24,789	1,812		93,740	8,471		169,855	13,812	
1957	45,418	2,817		19,308	1,370		89,847	11,222		154,573	15,409	
1958	45,595	2,997		25,737	1,990		76,020	10,970		147,352	15,957	
1959	51,265	3,438		18,244	1,339		79,209	11,473		148,718	16,250	
1960	48,131	3,280		19,050	1,461		95,832	10,093		163,013	14,834	
1961	45,179	3,404		22,461	1,763		107,874	10,552		175,514	15,719	
1962	48,566	3,890		24,306	1,910		110,463	11,476		183,335	17,276	
1963	57,765	4,845		35,338	2,794		101,411	11,764		194,514	19,403	
1964	71,646	6,520		32,645	2,561		136,241	15,484		240,532	24,565	
1965	92,493	8,794		52,407	3,951		149,986	15,806		294,946	28,551	
1966	94,718	9,318		74,867	5,564		165,884	18,908		335,469	33,790	
1967	77,868	7,985		71,604	5,244		168,967	17,868		318,439	31,097	
1968	111,285	9,452		82,903	5,794		156,195	16,389		350,383	31,635	
1969	109,595	8,677		92,015	5,956		138,832	15,412		340,432	30,045	
1970	88,584	7,558		103,092	7,713		148,604	18,130		340,280	33,401	
1971	79,586	8,176		106,991	8,365		151,444	18,405		338,021	34,946	
1972	76,428	8,717		105,602	8,856		139,735	17,667		321,765	35,240	
1973	50,456	7,490		155,992	15,112		123,236	18,079		329,684	40,681	
1974	54,401	8,899		85,454	7,430		121,612	18,037		261,467	34,366	

Sources: ICNAF Statistical Bulletins; Environment Canada, Annual Review of Canadian Fisheries, op.cit.

number and tonnage of offshore vessels and days fished (Table XII). Since, however, offshore groundfish effort, measured by the tonnage of the fleet times days fished, has been on the decline. The number of offshore groundfish vessels increased from 101, valued at \$13.9 million in 1953, to 372, valued at \$109.1 million in 1968 but declined to 335, valued at \$86.1 million in 1974. The average number of days fished per vessel in the fleet was 124 days in 1968 and 1971 in comparison with 115 days in 1974, as a result of the trawler strike.

There were significant changes in the size structure of the groundfish fleet as a result of changes in technology. In the period of the 1950's, the average size of vessels decreased as large dory vessels were withdrawn from the fisheries¹³ and replaced by side and stern trawlers. The average size of vessels began to increase in the 1960's when there was a trend towards the larger and costlier stern trawlers. This trend was, to a large extent, fostered by Government programs of assistance, both Federal and

¹³ In 1962 there was only one dory vessel in the Canadian offshore groundfish fleet. ICNAF, List of Fishing Vessels and Fishing Effort, op.cit.

TABLE XII.
Factor Inputs, Offshore Groundfish Fisheries, Selected Years 1953-1974

	Groundfish ¹ Vessels	Tonnage	Average Tonnage Per Vessel	Estimated ² Value of Groundfish Vessels*	Days Fished Groundfish Species	Average Number of Days Fished Per Vessel	Estimated Effort Groundfish Species
	No.	(Metric Tons)		(\$'000 { Constant 1971 } Dollars)			10 ⁶
1953	101	18,476	183	13,900	8,117	80.3	149.96
1956	124	19,374	156	18,600	11,916	96.1	230.86
1959	192	25,118	132	17,600	16,768	56.1	287.96
1962	201	27,739	138	19,100	22,225	110.6	616.50
1965	321	52,828	165	58,400	34,889	108.7	1,843.12
1968	372	83,717	225	109,100	45,898	123.4	3,842.44
1971	341	82,214	241	86,900	42,217	123.8	3,470.83
1974	335	87,642	261	86,100	38,436	114.7	3,368.61

* Estimated based on cost per vessel ton.

1 These include trawlers (stern and side), dory vessels, longliners and dragners (excluding scallop dragners).

2 Values not comparable for the whole period since prior to 1960, values given were for vessels 40 tons and over whereas offshore vessels given by ICNAF were vessels of 50 tons and over.

Sources: Environment Canada, Annual Statistical Review of Canadian Fisheries, Vols. 1 to 4 ICNAF, List of Fishing Vessels and Fishing Effort, op.cit.

Provincial, for vessel construction on the Atlantic coast¹⁴.

The decline in the offshore groundfish fleet since 1968 was due to the increasing scarcity of groundfish resources which resulted in increased fishing costs and deteriorating economic returns in the offshore groundfish fisheries. Estimates of total revenues and costs from these fisheries indicate that in recent years total costs have been exceeding total revenues, i.e., fishing operations are experiencing an economic loss characterized by the absence of economic rents (Table XIII). This conforms to the economic theory of fisheries exploitation, to be discussed in Chapter VI, which indicates that uncontrolled exploitation of fisheries leads to an economic equilibrium in the long run where total cost equals total revenue and zero economic rent. The absence of economic rent might be misleading, however, since this could be accruing to plants, i.e., the secondary level, rather than vessels. This is because there is a high degree of vertical integration in the industry¹⁵; most of the offshore vessels are owned by

14 C.L. Mitchell and H.C. Frick, Government Programs of Assistance for Fishing Craft Construction in Canada: An Economic Appraisal, Canada Fisheries Reports No. 14, Ottawa: June, 1970.

15 Although this study is confined to the primary sector, some attention will be given to the structure of the industry in the following chapter.

TABLE XIII.

Revenues, Estimated Costs and Incomes, Offshore Groundfish Fisheries, Selected Years 1953-1974

	<u>Revenues and Costs*</u>		Profit or Loss	Estimated Number of Groundfish Fishermen**	<u>Estimated Incomes Offshore Groundfish Fishermen</u>		Estimated Net Income Per Fisherman***
	Estimated Costs	Revenues			Gross Value of Output Per Fisherman		
	(\$'000, Constant 1971 Dollars)				(Constant 1971 Dollars)		
1953	8,757	9,623	866	3,959	2,430	950	
1956	12,295	13,812	1,517	3,928	3,520	1,370	
1959	15,438	16,250	812	4,566	3,560	1,640	
1962	15,894	17,276	1,382	3,839	4,500	2,070	
1965	28,322	28,551	229	4,929	5,790	2,660	
1968	33,287	31,635	-1,652	4,464	7,090	3,260	
1971	39,662	34,946	-4,716	3,637	9,610	4,420	
1973	41,698	40,681	1,017	3,843	10,590	4,870	
1974	41,926	34,366	-7,560	3,855	8,910	4,100	

* Based on average cost per pound of fish landed and price received per pound for the vessels in the sample studies of Proskie, J. and Charron, J.P., Costs and Earnings of Selected Fishing Enterprises, Atlantic Provinces (annuals) Ottawa, Department of Fisheries and the Environment.

** The proportion of the tonnage of groundfish vessels to the total tonnage of the offshore fleet was applied to the number of offshore fishermen to obtain these estimates.

*** Based on Cope's estimates of returns to labour at 39 percent of gross output for the years up to 1957 and 46 percent thereafter. P. Copes, Fisheries Development in Newfoundland, a report commissioned by the Department of Regional Economic Expansion, Ottawa: October, 1967.

large processing plants or companies. These companies control vessel prices to a great extent, keeping them low since their vessel operating losses can be recouped by profits from their processing operations¹⁶.

The excess of costs over revenues from the offshore groundfish fisheries, estimated at \$7.6 million in 1974, indicates low returns to capital, i.e., to vessels, in the offshore groundfish fleet. This is supported by findings from the Costs and Earnings Studies which show that the various types of groundfish vessels on average experienced profits before 1968 but since that time many of these vessels, particularly the large side and stern trawlers over 100 gross tons, experienced persistent losses¹⁷.

Incomes to offshore groundfish fishermen, the number of whom were estimated between three and five thousand during the period 1951-1974, increased as a result of growth in the volume and value of landings¹⁸. The estimated per capita income increased in constant dollar terms from \$950 in 1953

¹⁶ For a fuller account of this see P. Copes The Resettlement of Fishing Communities in Newfoundland, Canadian Council on Rural Development, April, 1972, footnote 2, pp. 60-61.

¹⁷ J. Proskie and J.P. Charron, op.cit.

¹⁸ Offshore fishermen are generally paid by the lay or share system which is based on a percentage of the gross revenue of the vessel. Thus, their incomes do not depend on the vessel's profitability.

to \$4,870 in 1973 and dropped to \$4,100 in 1974. There is, however, quite a range in incomes for offshore fishermen depending on the level of skills required. The skippers, mates, and engineers in some of the larger and more technically sophisticated vessels receive high incomes; some skippers' incomes in the larger stern trawlers were in the \$20,000 - \$30,000 a year range in 1973 and 1974¹⁹.

4.2 The Inshore Groundfish Fisheries, 1953-1974.

The inshore fisheries, once the mainstay of Canada's east coast fisheries as pointed out earlier, decreased during the period 1953-1974 from 454 thousand metric tons, valued at \$34.4 million, to 291 thousand metric tons, valued at \$36 million (Table XIV). Most of this decrease took place from 1967; before that, inshore landings fluctuated in volume and value. The sharp drop in landings in 1974 was due to the severe ice conditions in that year which curtailed inshore fishing operations for up to six weeks during the fishing season. Groundfish landings, the most important in terms of both volume and value and composed mainly of cod, fluctuated between 1953 and 1963; but declined steadily afterwards from 328 thousand metric tons, valued at \$29.1 million, to 157 thousand metric tons, valued at \$24.7

¹⁹ J.P. Charron, Costs and Earnings of Selected Fishing Enterprises Nova Scotia 1974, Ottawa: Dept. of Environment, 1975, Table 9, p. 19.

TABLE XIV.
Inshore Landings, Groundfish and Pelagic Species, 1953-1974

	Groundfish Species				Sea Fish Species			
	Groundfish		Pelagic		Groundfish		Pelagic	
	Q	V	Q	V	Q	V	Q	V
	Metric Tons (Constant 1971)	\$'000 Dollars	Metric Tons (Constant 1971)	\$'000 Dollars	Metric Tons (Constant 1971)	\$'000 Dollars	Metric Tons (Constant 1971)	\$'000 Dollars
1953	246,717	16,797	305,636	22,794	148,715	11,611	454,351	34,405
1954	301,245	20,985	376,858	27,725	143,534	11,216	520,392	38,941
1955	263,251	18,398	329,785	24,722	134,655	9,661	464,440	34,383
1956	301,951	20,762	371,687	27,044	128,284	9,744	499,971	36,788
1957	306,853	19,034	335,679	22,541	133,847	9,486	469,526	32,027
1958	242,301	15,929	268,737	19,621	135,153	10,561	403,890	30,182
1959	304,710	20,437	334,029	24,665	132,480	10,756	466,509	35,421
1960	287,986	19,623	340,694	25,116	135,043	11,209	475,737	36,325
1961	240,851	18,146	296,891	23,569	103,194	9,424	400,085	32,993
1962	272,077	21,797	326,855	27,408	133,256	11,211	460,111	38,619
1963	276,501	23,190	328,452	29,136	143,400	12,188	471,852	41,324
1964	243,919	22,196	294,033	27,772	173,270	14,177	467,303	41,949
1965	221,412	21,052	284,087	27,509	209,599	14,463	493,686	41,972
1966	213,420	20,994	279,559	28,226	228,703	13,401	508,262	41,627
1967	207,805	19,517	270,492	25,912	261,156	13,287	531,648	39,199
1968	211,587	17,970	270,977	23,954	202,924	8,651	473,901	32,605
1969	184,271	14,591	265,768	23,449	156,158	6,648	421,926	30,097
1970	174,338	14,875	237,240	22,369	133,219	6,321	370,459	28,690
1971	165,026	16,953	229,420	24,621	111,871	4,713	341,291	29,334
1972	142,371	16,238	198,072	23,187	140,983	8,472	339,055	31,659
1973	126,827	18,827	211,495	30,921	136,228	11,526	347,723	42,447
1974	102,737	16,807	156,823	24,723	134,180	11,350	291,003	36,073

Source: Landings from vessels under 50 gross tons, ICNAF, Statistical Bulletins, op.cit.

million in 1974.

The decline in inshore groundfish landings was the result of reduced resource availability, particularly in the latter part of the period. This reduction has been attributed to the effects of the expansion of international fishing effort in the offshore fisheries because of the inter-relationships between offshore and inshore resources with the movement of cod, herring and other species from offshore into inshore waters during the summer months.

Since 1965, inshore resource availability problems were largely responsible for the withdrawal of fishermen and boats; indicative of a reduction in fishing effort²⁰ (Table XV).

The number of inshore fishing craft which had increased up to 1965, decreased from thirty-nine thousand, valued at \$40.0 million, to twenty-eight thousand, valued at \$47 million in 1974. This decline was confined to smaller craft, many of them sail and row boats, since the number of vessels, mainly longliners, increased from 1.2 thousand to 3.1 thousand during the period 1953-1974. Groundfish vessels and boats accounted for about 50 percent

20 No data are available on the number of days fished by inshore fishermen during the year. This, multiplied by the number of fishermen or boats, would give a good estimate of inshore effort.

TABLE XV.
Factor Inputs and Estimated Per Capita Incomes, Inshore Groundfish Fisheries
Selected Years 1953-1974

	Number of Vessels 10 to 49.9 Gross Tons*	Total Number of Vessels & Boats - Inshore Fisheries	Value of Vessels & Boats (\$'000 Constant 1971)	Estimated Number of Groundfish Vessels & Boats	Estimated Value of Groundfish Vessels & Boats (\$'000 Constant 1971)	Number of Groundfish Fishermen	Gross Value of Output Per Groundfish Fishermen	Net Income Per Groundfish Fishermen**
							(Constant 1971 Dollars)	
1953	1,208	33,788	27,342	19,100	15,500	23,433	973	730
1956	1,115	37,491	21,952	21,000	12,300	22,268	1,214	910
1959	1,600	37,381	30,171	19,300	15,600	20,691	1,192	894
1962	1,795	36,280	38,246	24,400	25,800	26,000	1,054	790
1965	2,168	38,925	40,001	23,900	24,400	24,300	1,132	849
1968	2,465	33,659	38,845	19,000	22,000	20,642	1,160	870
1971	2,728	31,130	35,556	18,100	20,700	17,862	1,378	1,030
1973	2,928	28,374	41,336	15,400	22,400	16,235	1,904	1,428
1974	3,100	28,000*	47,000*	14,900	25,000	15,922	1,553	1,164

* Vessels, 10 to 40 tons up to 1956 and 10 to 49.9 tons afterwards were estimated for the years 1953, 1959 and 1974. These numbers are therefore not comparable for the whole period.

** Estimated on the basis that non-labour costs represent one-quarter of the value of landings. Copes, op.cit.

Sources: Statistics Canada, Fisheries, Statistics of Canada, op.cit.
Environment Canada, Annual Statistical Review of Canadian Fisheries, Vol. 1-8, op.cit.

of the inshore fleet during the period, increasing from nineteen thousand in 1953, valued at \$15 million, to twenty-four thousand, valued at \$26 million in 1962 but declining since to fifteen thousand, valued at \$25 million.

The number of inshore groundfish fishermen fluctuated between twenty-one thousand and twenty-six thousand from 1953 to 1962 but declined to sixteen thousand by 1974, accounting for 48 percent of the total number of inshore fishermen in that year.

High labour intensity, relative to resource availability, and seasonality of operations in the inshore fisheries have resulted in low incomes to fishermen. Per capita incomes from groundfish were estimated to have increased from \$730 a year in 1953 to \$1,428 a year in 1973, but dropped to \$1,164 in 1974. These low incomes of inshore groundfish fishermen have necessitated high levels of government welfare programs, particularly unemployment benefits, and other assistance programs. These latter programs, which were in large measure designed to encourage inshore fishermen to move into other occupations, will be discussed in the next chapter.

5.. Management Problems, Groundfish Fisheries.

The foregoing analysis examined the significant changes taking place in Canada's east coast groundfish fisheries and industry during the period 1953-1974, a period during which fisheries exploitation was virtually unregulated. As a result, there was a substantial expansion in fishing effort by Canada and foreign countries in the north-west Atlantic, leading to the overexploitation of the groundfish resources in that area. This overexploitation, which became evident towards the end of the 1960's, resulted in increasing management measures by ICNAF which had jurisdiction over the offshore groundfish fisheries. These measures, as described in Chapter II, were based mainly on quotas.

The analysis indicated that the expansion in Canada's groundfish fishing effort during the period was primarily in the offshore fisheries, which was capital rather than labour intensive. This expansion led first, in the early 1960's to a reduction in the availability of groundfish resources in the inshore fisheries, which are very labour intensive; and secondly, in the late 1960's to the overexploitation of offshore groundfish resources. The economic effects of these two aspects were that the first, through decreasing returns and low incomes, brought about a decline in the number of inshore fishermen which was not

compensated for by increased employment opportunities in the offshore sector. The second led to decreasing returns to capital in the offshore sector. Thus, resource constraints and largely unregulated entry into the groundfish fisheries, have been the major factors responsible for economic problems at the primary industry level.

There are many problems associated with managing the exploitation of the groundfish resources. These stem from the structure of the primary groundfish fishery, i.e., the inshore-offshore sectors, the inter-relationships between inshore and offshore resources, and the division of management responsibility between Canada and ICNAF. This latter division made it difficult for Canada to pursue any clear cut management objectives for its fisheries during the period under review. As a result, although all large Canadian offshore groundfish vessels were licenced for a small fee, Canadian regulations placed no restrictions on entry into the groundfish fisheries.

This chapter concentrated on developments taking place in the primary sector of Canada's east coast fishing industry during the period 1953-1974. In the next chapter, the economic impact of these developments on the secondary manufacturing or processing sector of the groundfish industry and other sectors of the Atlantic regional economy will be analyzed.

CHAPTER IV

CANADA'S EAST COAST GROUND FISH INDUSTRY, 1953-1974

The growth in output in the primary groundfish fisheries on Canada's east coast during the period 1953-1974 induced growth in the secondary manufacturing or processing sector of the groundfish industry and also in other sectors of the Atlantic regional economy. This was through the operation of linkage effects¹: (1) forward linkage on the secondary manufacturing sector which utilizes the output from the primary sector as an input; (2) backward linkage on other industries such as ship building, construction and service industries which cater to the industry; and (3) demand linkage by increased demands, through increased incomes and employment, for consumer goods and services.

Although this thesis is concerned mainly with the primary fisheries, the growth influences of these fisheries will be analysed in this chapter. This analysis will concentrate on the contribution that the primary fisheries made to the secondary manufacturing sector of the fishing industry; and the role and importance of this industry on the whole in the development of the Atlantic regional economy.

¹ A.O. Hirschman, The Strategy of Economic Development, New Haven: Yale University Press, 1965, pp. 98-116.

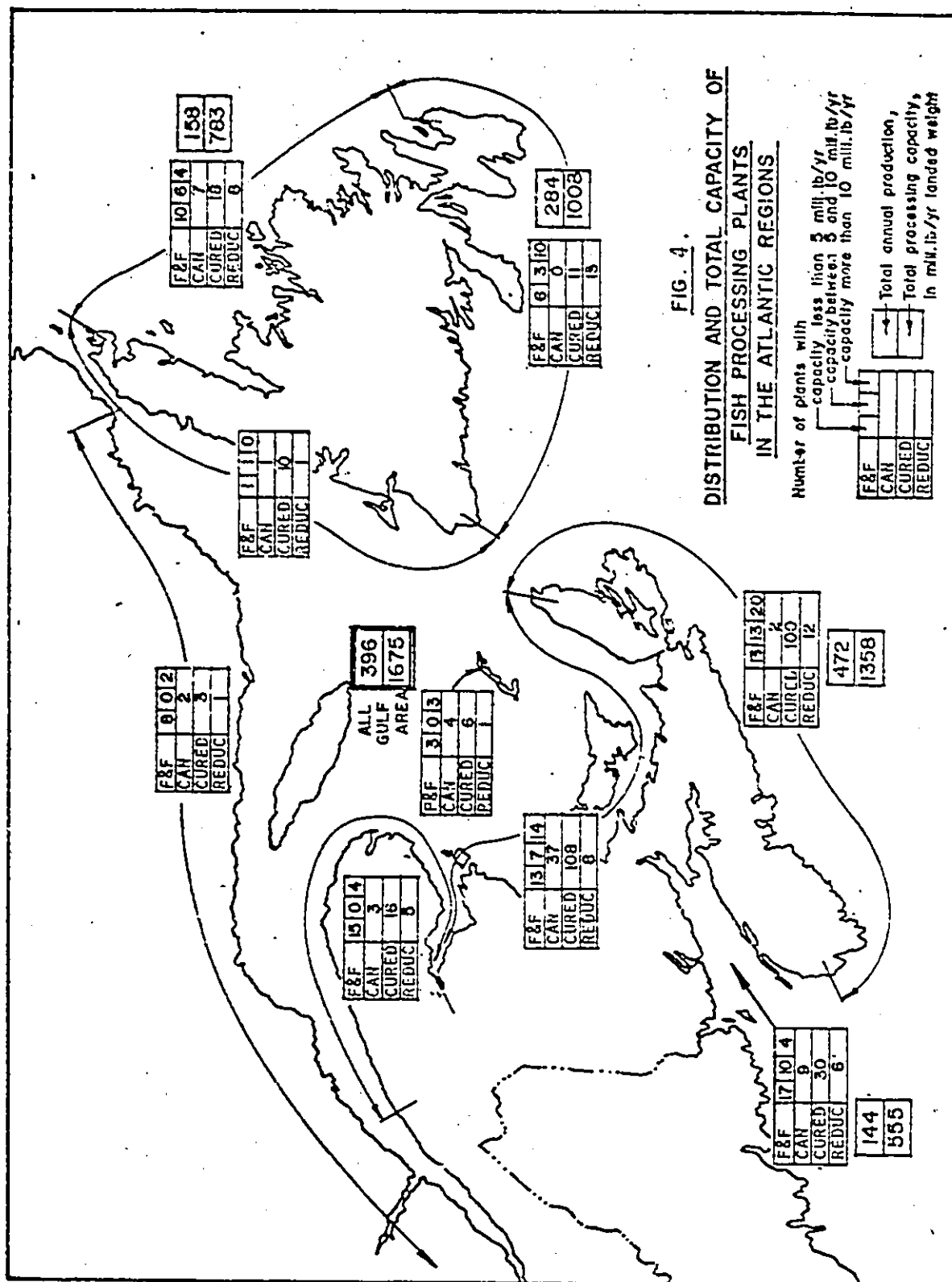
1. The Secondary Manufacturing Industry, 1953-1974.

The secondary manufacturing sector of the east coast fishing industry² consists of a large number of processing plants situated all along Canada's east coast (Figure 4). In 1972, there were 611 plants in operation of which 187 were freezing plants, 65 were canneries, 302 were curing plants, and 57 were reduction plants³. These plants vary widely in size, diversity of operations, and types of ownership ranging from single or family ownership to large corporations. Many plants are integrated horizontally, i.e., as branch plants of large companies, or vertically, i.e., owning vessels and boats which cater to them. In 1974 there were 12 vertically integrated companies (excluding producer's cooperatives and crown corporations) which owned about 50 plants, 25 of which were served mainly by the offshore fleet⁴.

2 For a detailed study of the industry, see J. John, Atlantic Coast Groundfish Marketing, a background study for the Department of Regional Economic Expansion, Ottawa: June, 1970; K.J. Brewer, "The Canadian East Coast Groundfish Industry", (unpublished Ph.D. thesis), McGill University, 1972.

3 This is based on a 1972 survey of fish processing plants. See C.M. Blackwood, "Fish Processing Capability of Plants in the Atlantic Region", Proceedings Government-Industry Meeting on the Utilization of Atlantic Marine Resources, Ottawa:—Environment Canada, 1974, p. 208.

4. Environment Canada, Policy for Canada's Commercial Fisheries, op.cit., pp. 26-27.



1.1 Groundfish Products.

Groundfish species have been the mainstay of the secondary manufacturing sector of the fishing industry on the east coast. Many plants, however, engage in multi-species operations processing groundfish, pelagic and molluscs and crustaceans species for food products for human consumption and reducing their offal or waste into fish meal and oil⁵. The total value of the products from the major species increased from \$85.2 million in 1953 to \$229 million in 1974 with a peak of \$294 million in 1973 (Table XVI). This was due mainly to groundfish since the value of groundfish products increased from \$69.1 million in 1953 to \$146.8 million in 1974 with a peak of \$207.3 million in 1973. At the peak year in 1973, groundfish products accounted for 70 percent of the value of total production of sea fish products.

Virtually all groundfish landings are processed into food products while their offal is used for reduction purposes. During the period 1953-1974, groundfish food products increased from about 119 thousand metric tons, valued at \$67.5 million, to 125 thousand metric tons, valued at \$139.3 million, with a peak production level of 175 thousand

⁵ Since the expansion in the herring fishery, a number of large plants specializing in reduction have been built. See C.L. Mitchell and D.B. McEachran, op.cit.

TABLE XVI.
Value of Products Produced, Sea Fish Species, Canada's Fish Processing Industry,
Selected Years 1953-1974

Groundfish Species						
	Food Products		Average Price Per Ton	Reduction	Total Groundfish Products	Total Production Sea Fish Products
(Q in Metric Tons and V in Constant 1971 Dollars)						
Q	V \$'000	V	V	V \$'000	V \$'000	V \$'000
1953	118,631*	67,524	569	1,579	69,103	85,202
1956	128,421	76,366	571	3,422	79,788	108,825
1959	138,878	79,935	576	2,160*	82,095	110,663
1962	139,306	92,834	666	6,102	98,936	131,809
1965	162,915	119,880	736	5,700	125,580	167,886
1968	174,869	110,154	630	7,184	117,338	182,465
1971	160,394	140,625	877	6,757	147,382	221,506
1973	156,697	194,379	1,240	12,923	207,302	294,476
1974	125,178	139,259	1,112	7,510	146,769	229,126

* Estimated since data not available.

Source: Environment Canada, Annual Statistical Reviews, Vols. 1-9 op.cit.

metric tons in 1968, and a peak value of \$194.4 million in 1976⁶. The increase in the value of these products was brought about by increased prices for the products produced: these prices increased from \$569 per metric ton in 1953 to \$1,112 per metric ton in 1974 or by nearly 100 percent. The value of groundfish reduction products also increased during the period from \$1.6 million to \$7.5 million with a peak of \$12.9 million in 1973.

The volume of groundfish food products accounted for 28 percent of the volume of groundfish landings during the period 1953-1974 indicating that, on average, 3.6 metric tons of groundfish raw material inputs were required to produce one metric ton of finished product. There are, however, many product forms, the most important of which are frozen fillets and blocks, salted fish, fresh fillets, fresh frozen round or dressed and smoked and canned products (Table XVII). Frozen fillet production increased from 17 thousand metric tons, valued at \$13 million in 1953 to 62 thousand metric tons, valued at \$69.8 million in 1974 with a peak of 78

6 Data on the volume of fish products were not available for all products before 1977 when volume 9 of the Annual Statistical Review of Canadian Fisheries, op.cit., was published. This publication revised data for all the years 1955-1976 and provided new data on a metric ton basis. Since changes in landings data were small and these data did not correspond with data from ICNAF sources, no changes were made in this thesis on data presented before this.

TABLE XVII.
Major Groundfish Food Products, Canada's East Coast Fish Food Processing Industry,
Selected Years 1953-1974

	1953	1956	1959	1962	1965	1968	1971	1973	1974
	(Quantities in Metric Tons and Values in '000 Constant 1971)								
Fresh Fillets									
Q	10,862	10,280	8,051	11,330	14,891	9,852	9,505	14,397	11,201
V	8,168	6,958	6,378	9,979	13,847	8,296	10,270	17,813	13,879
Frozen Fillets									
Q	17,301	42,172	40,804	37,568	43,410	66,466	68,310	77,893	62,129
V	13,022	25,849	29,780	29,182	34,040	44,680	61,182	98,117	69,803
Frozen Blocks									
Q	15,673	18,214	23,646	36,960	59,403	50,008	48,374	35,922	23,088
V	10,823	11,257	14,874	22,538	41,180	27,017	42,365	46,303	22,754
Fresh Frozen Round or Dressed									
Q	10,495	11,012	12,654	8,173	8,959	8,629	8,434	9,127	8,810
V	4,614	4,184	5,048	4,403	5,318	3,915	4,336	6,876	5,963
Salted Fish									
Q	62,000*	53,179	51,453	42,407	32,886	35,438	23,610	17,927	18,295
V	28,386	25,437	22,107	24,338	22,419	22,503	20,230	23,112	24,376
Canned									
Q	1,100*	982	798	765	572	715	603	501	862
V	750	653	522	545	494	581	528	747	1,106
Smoked									
Q	1,200*	2,582	1,418	2,103	2,794	3,761	1,558	930	793
V	1,761	2,028	1,226	1,849	2,581	3,162	1,714	1,411	1,378
Total									
Q	118,631*	128,421	138,878	139,306	162,915	174,869	160,394	156,697	125,178
V	67,524	76,366	79,935	92,834	119,880	110,154	140,625	194,379	139,259

* These quantities were estimated based on price trends between 1956 and 1959.

Source: Environment Canada, Annual Statistical Review of Canadian Fisheries, Vols. 1-9.

thousand metric tons, valued at \$98.1 million in 1973. Frozen block production increased for most of the period from 16 thousand metric tons, valued at \$10.8 million in 1953 to 59 thousand metric tons, valued at \$41.2 million in 1965 but declined to 23 thousand metric tons, valued at \$22.7 million in 1974. The changes in the production of these products were brought about by the expansion in offshore groundfish landings since large groundfish trawlers are often the main source of supply for processing plants, particularly during the off season for inshore operations. Salted fish production, on the other hand, relies mainly on inshore landings, with inshore fishermen doing most of the salting themselves. Production of this product declined from an estimated 60 thousand metric tons, valued at \$28.4 million in 1953 to 18 thousand metric tons, valued at \$24.4 million in 1974.

Most of the products of Canada's east coast fishing industry are exported mainly to the United States but also to many other markets in Europe and the Caribbean. Data on the breakdown of exports by region are not available for the whole range of products. However, exports of total fish products from Canada's fisheries, east central and west coast areas, indicate that they accounted for over sixty-five percent of the value of total production during the

period 1953-1974⁷. The domestic market has, therefore, been relatively small, accounting for approximately thirty-five percent of the total value of production. As a result, market prices for Canada's fish products are established in export markets, in particular the United States, where these products compete with products from many other countries.

1.2 Processing Plants, Capacity Utilization and Employment.

The number of fish processing plants in operation on Canada's east coast declined during the period 1953-1974. Some idea of the magnitude of this decline can be realized from Table XVIII. This Table, however, includes only the larger plants with a value of shipment of goods of own manufacture of \$50,000 and over for the later years of the period⁸. These plants, the number of which declined by 49 percent from 1953 to 1974, accounted for about 90 percent of the value of total production of groundfish products.

The reduction in the number of plants was indicative of a trend towards consolidation and the use of larger plants in the industry. As a result, output per plant, judging from the average value of shipments of goods of own manufacture, more than quadrupled during the period from

⁷ Environment Canada, Annual Statistical Review of Canadian Fisheries, Vol. 8, op.cit.

⁸ Statistics Canada, Fish Products Industry, (Annuaire Cat. 32-216) Ottawa.

TABLE XVIII.
The East Coast Fish Products Industry, Selected Years 1953-1974

	Number* of Establishments	Number of Persons Employed by Plants	Value of Shipments of Goods of Own Manufacture	Average Value of Shipments of Goods of Own Manufacture Per Plant	Estimated** Value of Groundfish Products	Estimated** Value of Sea Fish Products	Wages Per Capita***
					('000 Constant 1971 Dollars)		
1953	530	10,339	112,023	211	60,800	76,682	2,125
1956	434	11,833	131,037	302	70,000	92,448	2,679
1959	356	11,148	117,401	330	74,400	n.a.	2,463
1962	288	10,729	147,636	513	86,200	119,358	2,640
1965	233	12,969	209,447	899	110,000	145,797	2,940
1968	293	15,101	225,030	768	106,700	159,163	3,090
1971	272	14,995	247,257	908	129,000	179,893	3,736
1973	253	16,630	304,559	1,203	187,500	238,510	4,138
1974	272	14,236	266,310	979	137,340	191,028	4,672

* All plants are not included in this list since many small plants are excluded because of the classification criteria used. Due to changes on classification, the data for the number of establishments, number of workers, and value of shipments of goods of own manufacture are not comparable for the whole period.

** Estimated on the basis that 90 percent of the groundfish and pelagic products are produced by the larger plants given.

*** Based on salaries and wages for processing plants.

Source: Statistics Canada, Fish Products Industry, (Annuals, Cat. 32-216).

\$211 thousand to \$979 thousand. There is, however, considerable excess capacity in fish food processing plants. This can be attributed to: (1) seasonality of landings and the construction of plants with the capacity to cater to peak periods which last for only a short time during the year; and (2) to government financial assistance programs to the industry in the 1960's, such as the Department of Regional Economic Expansion (DREE) subsidies for plant construction and the price support schemes of the Fisheries and Marine Service, Department of Fisheries and the Environment. These governmental measures not only encouraged modernization and capacity expansion in the industry but probably supported marginal firms which otherwise would have been forced out. Although excess capacity is a fact of life in a seasonal industry, it has been estimated that plants could probably increase their output by over 50 percent without the necessity for any extra investment⁹.

Total employment in the secondary manufacturing sector has been on the increase, especially since the early 1960's, as a result of the expansion in sea fish landings on the east coast. The number of persons employed in plants

⁹ This is based on a recent study of the processing industry. The Research and Productivity Council, Onsite and Data Analysis of East Coast Fish Processing Plants, (Unpublished report), Fredricton, New Brunswick, 1977, p. 7.

increased from 10,700 in 1962 to 14,200 by 1974, constituting about 40 percent of the total number of fishermen in that year. Moreover, per capita incomes received by these workers, many of whom are women, increased from \$2,125 in 1953 to \$4,672 in 1974. Since 1962, these incomes were fairly close to those received by offshore groundfish¹⁰ fishermen.

2. The Economic Importance of the Fishing Industry.

Canada's east coast marine fisheries industry, consisting of both primary and secondary manufacturing operations, is a small sector in Canada's economy. In 1973, the year with the highest value of output from fisheries during the period, this industry contributed less than half of one percent to Canada's G.N.P.¹¹ The east coast fishing industry is, however, important in a regional context. In terms of its contribution to the Atlantic regional economy, i.e., the Atlantic provinces and Quebec, this industry increased from 1.7 percent of the total value of output of all commodity producing industries in 1956 to 2.3 percent in 1973; and in terms of employment, it accounted for 2.9 percent of

¹⁰ See Tables XIII and XVIII of text.

¹¹ Department of Finance, Economic Review, Ottawa: The Queen's Printer, April, 1975, Reference Table 2, p. 103.

the labour force in 1956 and for 1.8 percent in 1973 (Table XIX). If Quebec is excluded, the fisheries contribution to the Atlantic provinces is more significant. In 1973, this industry accounted for 10.1 percent of the total value of all commodity producing industries and for 5.4 percent of the employment in the Maritime provinces; and for 13.7 percent and 13.2 percent respectively in Newfoundland¹².

2.1 Fisheries and Regional Development.

The important contribution that the fishing industry makes to the Atlantic provinces' economy through its exertion of linkage effects, can be realized from the input-output studies of the Atlantic provinces' economy by K. Levitt¹³. These studies revealed that although incomes, particularly from primary fishing activity, were low the fishing industry, both primary and secondary sectors, exerted the largest amount of employment per dollar value of output in the Atlantic regional economy. Of this, the secondary processing sector exerted a more significant effect, about twice as much, on employment as the primary

¹² Environment Canada, Annual Statistical Review of Canadian Fisheries, Vol. 8, op.cit., Table 5, p. 26.

¹³ K. Levitt, "A Macro Economic Analysis of the Structure of the Economy of the Atlantic Provinces, 1960", a paper presented to the Canadian Economic Association at York University, June 6, 1969;.....Input-Output Study of the Atlantic Provinces 1965, Ottawa: Statistics Canada, 1975.

TABLE XIX.

Contribution of Fisheries to Value Added Atlantic Provinces and Quebec,
Selected Years 1956 and 1973

	1956			1971			1973		
	Groundfish (\$'000 1971 Dollars)*	Total Fisheries	Employment ('000)	Groundfish (\$'000 1971 Dollars)*	Total Fisheries	Employment ('000)	Groundfish (\$'000 1971 Dollars)*	Total Fisheries	Employment ('000)
Primary Fisheries	40.8	85.9	47	59.6	133.9	40	71.6	152.4	39
Secondary** Manufacturing	33.5	47.1	12	90.5	109.3	15	139.0	147.2	17
Total Fishery Industry	74.3	133.0	59	150.1	243.2	55	210.6	299.6	56
All Commodity Producing Industries	7,739.9	7,739.9	2,024	11,375.0	11,357.9	2,816	12,797.4	12,797.4	3,053
Fisheries as a Percent of Total	1.0	1.7	2.9	1.3	2.1	1.9	1.6	2.3	1.8

* Fisheries products deflated by the Consumer Price Index and all commodities by the implicit price index.

** The calculation for value added includes an adjustment for changes in inventory.

Source: Environment Canada, Annual Statistical Review of Canadian Fisheries, Vol. 8, Table 5, p. 26.

fishing sector. For example, employment multipliers for fisheries in the Atlantic provinces in 1965 were 1.35 for the primary sector and 3.0 for the secondary sector¹⁴. This means that for every job created or lost in primary fisheries, .35 jobs are created or lost elsewhere, and for every job created or lost in the processing sector two jobs are created or lost elsewhere, one of which is in the primary sector. Taking into consideration that the fishing industry constitutes an important sector in the Atlantic regional economy, expansion or decline in this sector exerts a significant impact on employment and incomes in the area.

The importance of the fishing industry in regional development has long been recognized by the Government of Canada but it was only in the 1960's that the Federal Government began to play an active role in fisheries as a means of regional development. This role concentrated on (1) measures to encourage expansion in the offshore fisheries, and (2) measures to reduce labour inputs in the inshore fisheries due to the low incomes of inshore fishermen. These measures were closely tied in with general regional development measures. Since 1961, a series of legislation were passed and agencies established to solve the problem of regional

¹⁴ This is based on the average of employment multipliers in the primary and secondary sectors of the fishing industry in the Atlantic region, *ibid*, Table 5.47A, p. 106.

disparities in Canada. These culminated in 1969 with the establishment of the Department of Regional Economic Expansion which pulled together the various pieces of Federal legislation relating to regional development¹⁵.

2.2 The Regional Development Strategy, "Growth Pole" Concept.

The regional development strategy adopted for fisheries was based on the growth pole (Pôle de croissance) concept of Perroux¹⁶, further developed by Hirschman¹⁷ and others, and on regional development planning. For Perroux, the points of growth are manifested through the twin concepts of (1) a propulsive firm or industry, and (2) a key firm or industry. For example, growth takes place when a propulsive firm raises its output and induces expansion in the output of other industries. Hirschman elaborated the mechanism by which this inducement takes place by his introduction of the linkage effects mentioned earlier. In a geographical context, a village or town in which a strong development impulse takes place is designated a "growth pole", signifying a "location where major concentrated development has occurred or can be sparked because of the

15 B. Higgins, "Growth Pole Policy in Canada", Growth Centers in Regional Economic Development, edited by N.M. Hansen, New York: The Free Press, 1972, pp. 204-214.

16 F. Perroux, "Note sure la notion de Pôle de Croissance", Economic Appliquee, January - June, 1955.

17 Hirschman, op.cit.

location's resource base, import substitution possibilities, externalities, exploitation of amenities, and a host of other factors¹⁸. The "growth pole" can induce, through trade and a transfer of capital, growth in other towns and villages or its hinterland by its "spread or trickling down" effects; or, retard growth in these through its "dampening or polarization" effects if it drains these other areas of its manpower and capital resources¹⁹..

The most interesting example of the growth pole strategy of regional development in a fisheries context took place in Newfoundland. In this province a "centralization program", administered by the Provincial Government, was introduced early in the 1950's. This program provided relocation subsidies to encourage inshore fishermen to move from the "outports" to find employment in more centrally located towns. In 1965, the program became a joint Federal-Provincial "Newfoundland Fisheries Resettlement Program". This program provided larger relocation subsidies coupled with a complex regional economic grants and incentives. The purpose was to encourage inshore fishermen "... to settle in 'major fishery growth centres', which were being expanded as

¹⁸ W. Isard, Introduction to Regional Science, Englewood Cliffs, N.J.: Prentice-Hall, Inc., 1975, p. 382.

¹⁹ *ibid.*, p. 382.

bases for the offshore fishery and processing industry and in 'other designated growth centres' which were expected to have prospects for further industrial development"²⁰.

The resettlement program was beneficial to Newfoundland's fisheries in that it was responsible for moving fishermen from the inshore sector and into the offshore and processing sectors of the fishing industry. Since the start of the program in 1954 to 1970 a total of 4,746 households involving 23,614 persons were relocated. The majority, 3,242 households, were resettled during the period 1965-1970, resulting in reducing the number of inshore fishermen by 5,342²¹. Since 1970, the program, which was severely criticized on sociological²² and political grounds, leading to a considerable backlash against it, tapered off considerably. This tapering off was due to reduced demands for relocation subsidies as a result of (1) the inability of "growth centres" to provide the alternative employment

20 P. Copes, The Resettlement of Fishing Communities in Newfoundland, op.cit., p. 110.

21 *ibid.*, pp. 119-149.

22 O. Brox, "Resettlement in Newfoundland: Some Sociological Comments". Viewpoints on Communities in Crisis, edited by M.L. Skolnik, St. Johns: Institute of Social and Economic Research, Memorial University of Newfoundland, 1968, pp. 11-25.

opportunities²³, and (2) improved transportation facilities in Newfoundland which did away with the isolation problem.

For the Atlantic provinces on the whole the Federal Government's strategy was to bring about a rationalization of the fishing industry through a reduction in labour inputs in the inshore fisheries. Copes pointed out that this policy was actively pursued during the late 1960's as Government attempted, through provincial plans and area agreements with the Department of Regional Economic Expansion, to do this²⁴. This vigour, however, slackened in the 1970's as a result of the backlash against the Resettlement Program in Newfoundland, rising unemployment levels in Canada and a decline in the offshore fisheries which severely impaired the ability of both the primary and secondary sectors to provide for increased employment opportunities.

23 For an interesting article on whether or not growth poles exist see B. Higgins, "Development Poles: Do They Exist", Research Paper No. 7503, Faculty of Social Sciences, University of Ottawa.

24 Copes, "Canada's Atlantic Coast Fisheries: Policy Development and the Impact of Extended Jurisdiction", Canadian Public Policy, IV: 2, Spring 1978, pp. 163-165.

3. Conclusion.

This chapter examined the impact that the primary groundfish fisheries made on the secondary manufacturing sector of the groundfish industry; and in turn the role of this industry in the development of the Atlantic regional economy. It also reviewed the problems associated with primary fisheries in an economic development context and the overall strategy for this development based on the "growth pole" concept.

The findings indicated that the growth in output from the primary fisheries induced growth and development in the secondary manufacturing sector. The value of output from this sector increased for the period on the whole, with a peak in this value in 1973, despite the fact that the volume of groundfish landings began to decline from 1968. There was a significant change in the structure of the industry during the period. Although there was a decrease in the number of plants, there was an expansion in processing capacity due to consolidation in the industry and a trend towards larger plants. This expansion in plant capacity and the decline in landings, exacerbated by the more stringent ICNAF quota measures, led to economic problems stemming from overcapacity. These problems came to the fore in 1974 when economic losses were experienced in both the primary

and secondary manufacturing sectors of the industry.

The study indicated that although the fishing industry is a small sector in Canada's economy it is an important sector in the Atlantic regional economy, and in the Atlantic provinces in particular. In these provinces, the fishing industry contributed significantly to development through increases in output and employment and the effects of these, through linkage effects, on growth and development in other sectors. It was found, for example, that the linkage effects exerted by the secondary sector of the fishing industry were higher than those for other sectors. Linkage effects operate, however, in both growth and decline with the result that changes in the fishing industry influence growth or decline in the regional economies where the fishing industry is important.

The experience of fisheries in a regional development context also indicated that the effective management of primary fisheries is dependent on economic conditions in the regional economy. Because of ease of entry, particularly in the inshore fisheries, the fisheries sector has traditionally been a sponge for the unemployed in the Atlantic regional economy. The success or failure of Government's ability to rationalize the fishery through a reduction in labour inputs therefore depends essentially on whether or not alternative employment opportunities exist in the region

or could be generated by regional development policies. Thus, the problem of the effective management of fisheries can be affected by policies and measures emanating from other sectors.

In the two chapters to follow, the theoretical basis for fisheries from a biological and economic standpoint will be analysed. The main purpose of this analysis is to introduce biological models of fisheries which would be applied later on to Canada's east coast groundfish fisheries for the period under study; and to review the economic theory of fisheries which has strong biological foundations.

CHAPTER V

BIOLOGICAL MODELS OF FISHERIES

It was only since the 1950's that the economics of fisheries exploitation began to receive some attention in the literature. A seminal article by H. Scott Gordon¹ was followed by contributions by many other economists. In recent years, a number of mathematical models have been reported in the literature on natural resources in general, and fisheries in particular². These models have been based on biological theories and models of fisheries population

¹ H. Scott Gordon, "An Economic Approach to the Optimum Utilization of Fishery Resources", Journal of the Fisheries Research Board, Vol. X, September, 1953.

² J.A. Crutchfield and A. Zellner, Economic Aspects of the Pacific Coast Halibut Industry, Washington: Fishery Industrial Research 1, U.S. Department of the Interior, 1962; V.L. Smith, "The Economics of Production from Natural Resources", A.E.R., June, 1968; C.G. Plourde, "A Simple Model of Replenishable Natural Resource Exploitation", A.E.R., June, 1970; J.P. Quirk and V.L. Smith "Dynamic Economic Models of Fishing", in A.D. Scott, ed., Economics of Fisheries Management: A Symposium, Vancouver: Institute of Animal Resource Ecology, University of British Columbia, 1970. O.R. Burt and R.G. Cummings, "Production and Investment in Natural Resource Industries", A.E.R., September, 1970. R.F. Fullenbaum, E.W. Carlson, and F.W. Bell, "Economics of Production from Natural Resources: Comment", A.E.R., June, 1971. C.W. Clark, "Economical Optimal Policy for the Utilization of Biologically Renewable Resources", Mathematical Biosciences, 12, 1971.... "Dynamics of Commercially Exploited Natural Animal Populations", Mathematical Biosciences, 12, 1972. J.R. Beddington, C.M.K. Watts and W.D.G. Wright, "Optimal Cropping of Self Reproducible Natural Resources", Econometrica, Vol. 43, No. 4, July, 1975.

dynamics. The majority are concerned with a single species or population but some have been extended through predator-prey models to multiple and interrelated species. An excellent review of the present state of bioeconomic models of fisheries has been written by C.W. Clark³.

The economic theories and models of fisheries have been influenced by two main factors: (1) the nature and characteristics of fisheries resources; and (2) the public or common property ownership of these resources which results in freedom of entry to exploit them. The first factor, which is biological, is the main concern of the chapter but this and, the second factor, the type of ownership, greatly affect the economics of fisheries exploitation which will be discussed in chapter VI.

1. The Biological Theory of Fish Population Growth.

Biologists distinguish two types of biological models of fisheries population growth: (1) the dynamic-pool model of Beverton and Holt; and (2) a logistic growth model which was specified by Verhulst in 1838 and has since been

³ C.W. Clark, Mathematical Bioeconomics: The Optimal Management of Renewable Resources, New York: John Wiley and Sons, 1976.

applied in a fisheries context by Schaefer⁴. The dynamic-pool model has not been widely used by economists who have, with some exceptions⁵, embraced the logistic model. This is due to the Beverton-Holt's model attempt to explain fisheries population growth by specifying its most crucial determinants. These determinants, which are growth rates of different year classes in the population, rates of recruitment, etc⁶, are difficult to measure and unavailable for most species. The Beverton-Holt model is also most reliable when fishing effort, another crucial factor, does not vary over time. Because of these limitations, this model will not be treated in this thesis.

The biological theory underlying the logistic growth model is called the theory of ecological equilibrium. This theory is described by Schaefer⁷ by exemplifying the effects of changes in fishing effort by man upon the population or biomass of fish. Starting from a period when there is no

4 For an extensive review of the biological models see W.E. Ricker, op.cit.

5 Notable exceptions are: J.M. Gates and V.J. Norton, The Benefits of Fisheries Regulations: A Case Study of the New England Yellowtail Flounder Fishery, University of Rhode Island Marine Technical Report No. 21, Kingston, Rhode Island: 1974; R. Hannesson, op.cit., pp. 53-70.

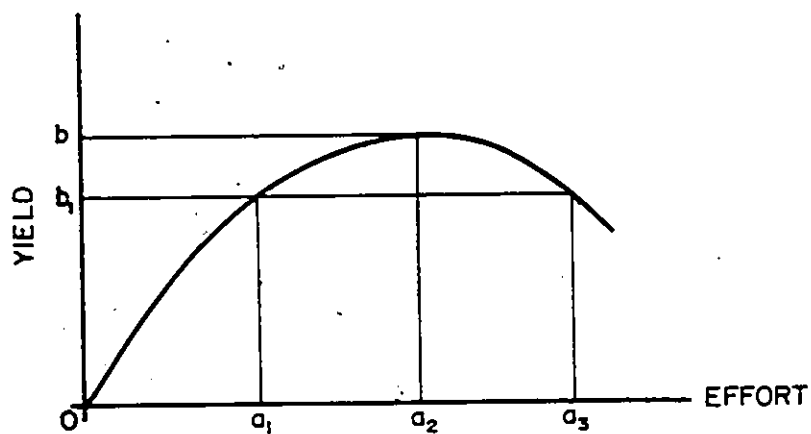
6 R. Hannesson, op.cit., p. 18.

7 M.B. Schaefer, op.cit., p. 54.

fishing the population tends to remain in ecological equilibrium i.e., its net growth is zero, whereby losses due to natural mortality are, on the average, offset by the natural rate of growth of the population due to reproduction and net recruitment. The commencement of fishing operations disturbs this equilibrium. Losses due to fishing effort at first diminish the population but these are in turn off-set by increases in its natural rate of growth, since at a lower population density fish tend to reproduce, survive and grow better due to less crowding and greater food availability. Thus, as fishing intensifies, the natural rate of growth of the population increases to match the rate of loss caused by this and natural mortality. Another equilibrium at a lower population level is eventually reached where the natural rate of growth of the population is at a maximum. At this level, fishing effort results in a maximum sustainable yield (MSY) for man. Disequilibrium sets in, however, when this is upset. In this case, where losses to the population due to mortality and fishing effort are greater than what the growth rates of the population can bear, there is overfishing. This can lead, if continued long enough, to the possible extinction of the species.

The effects of fishing effort on output from a fishery under the ecological equilibrium conditions mentioned above are shown in diagramatic form in Figure 5.

Figure 5 THE OPTIMUM PHYSICAL LEVEL OF EXPLOITATION :
THE BIOLOGICAL MODEL



There is a sustainable yield from the fishery which can be low for both low and high rates of fishing effort, e.g., output at ob_1 at levels of effort oa_1 and oa_3 . In between, there is some level of output where the maximum sustained yield can be obtained; i.e., ob output at oa_2 level of effort. This yield is not, however, the most efficient from an economic standpoint since it does not take fishing revenue and costs of fishing effort into consideration. These aspects will, however, be taken into consideration in the next chapter.

1.1 The Logistic Model.

Based on the theory of ecological equilibrium outlined in the previous section, a fishery growth model, specified by the logistic, was developed. This development commenced with defining the net rate of growth of the population or stock, i.e., the natural rate of growth of stock minus natural mortality, as a monotonic decreasing function of the size of stock:

$$(5.1) \quad \frac{dX}{dt} = \delta(X) \cdot X$$

where $\delta(X)$ is the relative natural growth rate, such that $\frac{d\delta(X)}{dX} < 0$

This specification takes into account the speed of a population growth due to the size of this population. In applied studies the functional form of $\delta(X)$ has been

represented by the Verhulst-Pearl logistic function as follows⁸:

$$(5.2) \quad \delta(X) = \psi \left(1 - \frac{X}{X_u}\right) \text{ with } \psi \text{ and } X_u \text{ constants,}$$

and where X_u is the upper limit of the population or largest biomass the environment can sustain; and ψ is a positive parameter, i.e., $\psi > 0$, and has dimension zero.

This implies that the relative rate of growth $\delta(X)$ is a monotonically decreasing function of the stock which holds when the growth rate of the population begins to decline converging asymptotically to zero.

Substituting $\psi \left(1 - \frac{X}{X_u}\right)$ for $\delta(X)$ in equation (5.1) results in⁹:

$$(5.3) \quad \frac{dX}{dt} = \psi X \left(1 - \frac{X}{X_u}\right), \quad \psi > 0.$$

Thus, (5.3) states that the growth of the population is a quadratic function of the population itself. The solution of this differential equation is:

⁸ P.F. Verhulst "Notice sur la loi que la population suit dans son accroissement", Correspondence Mathématique et physique publiée par A. Quételet, Brussels: X(1838) pp. 113-121; R. Pearl, Studies in Human Biology, Baltimore: Williams and Wilkins, 1924.

⁹ The parameter ψ is dimensionless, i.e., dimension zero, and X_u and $\frac{dX}{dt}$ have the dimension of X .

$$(5.4) \quad X(t) = \frac{X_u}{1 + \lambda e^{-\psi t}}$$

where t is time and X_u is the asymptotic value of $X(t)$, i.e.,

$$(5.5) \quad \lim_{t \rightarrow \infty} X(t) = X_u$$

and $\lambda > 0$ is the constant of integration.

The model therefore approximates the growth of a fish population in the absence of man's intervention as outlined by the ecological equilibrium theory of a fishery population growth. It shows that the population increases over time as a result of the natural rate of growth exceeding the rate of natural mortality; but will, due to growth in its size, grow at a decreasing rate which converges to zero at its stationary state X_u .

Man's intervention through fishing effort is another factor which influences fish population dynamics. This impact has been modeled by biologists¹⁰. The two most popular biological models are (1) the logistic, commonly called the Schaefer model in the literature, and (2) the Gulland-Fox exponential model. The first of these models, is but an extension of the logistic model described in this section, and is based on steady state assumptions.

¹⁰ W.E. Ricker, op.cit.

2. Steady State Models of Fisheries Exploitation.

The effects of man's fishing effort on fishery population growth were introduced for a single resource and extended to multiple resources under the steady state dynamic equilibrium assumptions. For this, two functions are necessary: (1) a biological growth function; and (2) an industry production function, i.e., output as a function of fishing effort.

2.1 The Single Resource Model: The Logistic Model.

The logistic version of the biological growth function derived from (5.3) can be specified as follows:

$$(5.6) \quad \frac{dX}{dt} = aX - bX^2 \quad a, b > 0,$$

$$\text{where } a = \psi \quad \text{and } b = \frac{\psi}{X_u}.$$

With the exploitation by man and the introduction of fishing effort E , the losses from the population through fishing or the catch is Ex , where x is the average catch per unit of effort. The impact of this on the population is shown by:

$$(5.7) \quad \frac{dX}{dt} = aX - bX^2 - Ex.$$

Under the steady state assumption, i.e., ecological equilibrium $\frac{dX}{dt} = 0$, the catch will be as follows:

$$(5.8) \quad Ex = aX - bX^2.$$

The industry production function was obtained by generally assuming that the catch Ex was a constant

proportion r of fishing effort and the population or stock. That is¹¹:

$$(5.9) \quad E_x = rEX$$

Substituting (5.9) into (5.8) yields the following steady state relationships between E and X :

$$(5.10) \quad X = \frac{(a - rE)}{b}, \quad 0 \leq E < \frac{a}{r}$$

which is, mathematically, the equilibrium level of the population X for a given level of effort E , assuming the logistic law of growth and the industry production function (5.9). Thus, the steady state relationship between X and E is a linear and decreasing function in (5.10). This functional relationship between X and E , which indicates that increases in effort E will always reduce the equilibrium size of the population, is one of the fundamental laws of fishery population dynamics. Under these assumptions (logistic growth and catch specified by (5.9)) the population would tend to disappear when $E \rightarrow \frac{a}{r}$. This is not economically meaningful since economic forces will come into action before this occurs with fishing costs exceeding fishing revenues, leading to a cessation of fishing effort. These economic forces will, as pointed out earlier, be discussed in chapter VI.

¹¹ A decreasing marginal physical productivity of catch with respect to fishing effort reflecting crowding externalities and decreasing returns, can also be assumed. This case will be treated in Appendix I.

Substituting (5.10) for X in the catch function (5.8) results in the catch being expressed as a quadratic function of fishing effort:

$$(5.11) \quad C = Ex = \frac{a(a - rE)}{b} - \frac{(a - rE)^2}{b}$$

Therefore:

$$(5.12) \quad C = B_1E - B_2E^2 \quad \text{where } B_1 = \frac{ar}{b}$$

$$\text{and } B_2 = \frac{r^2}{b}.$$

This effort reaches a maximum, i.e., where $\frac{dC}{dE} = 0$ and optimal effort is given by:

$$(5.13) \quad E^* = \frac{B_1}{2B_2} = \frac{a}{2r}$$

From this optimal level of effort, the MSY from the stock can be obtained by substituting E^* (5.13) for E in (5.12). This results in:

$$(5.14) \quad \text{MSY} = C^* = \frac{B_1^2}{4B_2} = \frac{a^2}{4b}$$

The equilibrium population at the optimal level of effort, obtained by substituting (5.13) into (5.10) is as follows:

$$(5.15) \quad X^* = \frac{a}{2b}$$

That is, the impact of optimal effort upon the population is to halve the maximum equilibrium biomass in the absence of man's intervention since $X_u = \frac{a}{b}$ according

to the notation in (5.6). If actual fishing effort is greater than $\frac{a}{2r}$ then X will reach a lower equilibrium level.

The properties and insights obtained from the logistic model in its application to fisheries by Schaefer have led to the popular utilization of this model by biologists for estimating stocks and MSY's in fisheries. The standard estimating form of this model is as follows:

$$(5.16) \quad \frac{C}{E} = B_1 - B_2 E$$

The main reason for this is because generally there are high correlations and strong linear relationships between the effort variables E and E^2 in (5.12) leading to the problems of multicollinearity. The solution to this problem involves dividing through by effort E making $\frac{C}{E}$ or the C.P.U.E. the dependent variable which results in the estimation form given by (5.16).

2.2 The Multiple Resource Model: Predator-Prey.

The single resource model was extended to multiple fisheries resources, based on the pioneering work of Lotka and Volterra¹², by making the biological growth function dependent on two or more resources¹³. For example, in the

¹² A.J. Lotka, The Elements of Physical Biology, Baltimore: Williams and Wilkins, 1925; V. Volterra, "Variazioni e fluttuazioni del numero d'individui in specie animali conviventi", Mem. Acad. Lincei, 2, 1926, pp. 1-110.

¹³ Quirk & Smith, op.cit.; Burt & Cummings, op.cit.

case of two species X_1 and X_2 the biological growth functions of these species can be expressed as first order differential equations of the form:

$$(5.17.a) \quad \dot{X}_1 = F(X_1, X_2)$$

$$(5.17.b) \quad \dot{X}_2 = G(X_1, X_2)$$

The interactions that may occur between X_1 and X_2 , such as mutual independence where $F_2 = G_1 = 0$; or predator-prey relationships $F_2 > 0$, $G_1 < 0$ or vice versa, can be taken into consideration. In the case of the latter, assuming that the rate of growth of X_1 , the prey, increases with X_1 and decreases with the product X_1X_2 and the rate of growth of the predator X_2 decreases with X_2 and increases with the product X_1X_2 , then the deterministic equations for the growth of both populations are as follows:

$$(5.18.a) \quad \dot{X}_1 = aX_1 - bX_1 X_2 \quad a, b > 0$$

$$(5.18.b) \quad \dot{X}_2 = -gX_2 + nX_1 X_2 \quad g, n > 0.$$

These equations take into account the death of X_1 due to X_2 , and the growth in X_2 brought about by the presence of the prey X_1 . The effects of the predator-prey populations on the rate of change of the predator and the rate of change of the prey can be derived from the partial derivatives of equations (5.18.a) for the prey and (5.18.b) for the predator. Thus, for the prey population:

$$(5.19) \quad \frac{\partial \dot{X}_1}{\partial X_1} = a - bX_2 \quad \begin{array}{l} < 0 \text{ if } a < bX_2 \\ = 0 \text{ if } a = bX_2 \\ > 0 \text{ if } a > bX_2 \end{array}$$

Hence, the rate of growth of $\dot{X}_1$ with respect to X_1 is a decreasing function of X_1 . It will be decreasing and negative if $a < bX_2$; and decreasing and positive if $a > bX_2$.

$$(5.20) \quad \frac{\partial \dot{X}_1}{\partial X_2} = -bX_1 \quad \begin{array}{l} \text{which is always negative for} \\ b > 0. \text{ That is, the rate of} \\ \text{growth of } \dot{X}_1 \text{ is a decreas-} \\ \text{ing function of the popula-} \\ \text{tion size of } X_2. \end{array}$$

Similarly, for the predator population:

$$(5.21) \quad \frac{\partial \dot{X}_2}{\partial X_2} = -g + nX_1 \quad \begin{array}{l} < 0 \text{ if } g > nX_1 \\ = 0 \text{ if } g = nX_1 \\ > 0 \text{ if } g < nX_1 \end{array}$$

$$(5.22) \quad \frac{\partial \dot{X}_2}{\partial X_1} = nX_2 \quad \begin{array}{l} \text{which is always positive} \\ \text{for } n > 0. \end{array}$$

The growth of both populations in the predator-prey model is oscillatory¹⁴. If it is stable, it converges towards a situation in which both populations are in dynamic equilibrium. If it is unstable, it diverges from this

¹⁴ C. Clark, Mathematical Bioeconomics, op.cit., p. 195.

equilibrium point leading to the extinction of both species. The equilibrium solution is obtained when the derivatives with respect to time of both X_1 and X_2 are equal to zero. That is:

$$(5.23.a) \quad aX_1 - bX_1 X_2 = 0$$

$$(5.23.b) \quad -gX_2 + nX_1 X_2 = 0.$$

The dynamic equilibrium for both species deduced from (5.23.a) and (5.23.b) is where:

$$(5.24) \quad X_1 = \frac{g}{n} \text{ and } X_2 = \frac{a}{b}.$$

The effects of man's intervention through fishing effort on both species can now be taken into consideration. Assuming that both resources are exploited by different technology and therefore different efforts, E_1 for X_1 and E_2 for X_2 ¹⁵, then the losses from their populations due to fishing effort will be E_1X_1 and E_2X_2 respectively. Thus, the growth of X_1 and X_2 will be:

$$(5.25.a) \quad \dot{X}_1 = aX_1 - bX_1 X_2 - E_1X_1$$

$$(5.25.b) \quad \dot{X}_2 = -gX_2 + nX_1 X_2 - E_2X_2$$

which under ecological equilibrium assumptions of $\dot{X}_1 = 0$ and $\dot{X}_2 = 0$, result in fishing effort being expressed as follows:

¹⁵ This assumption is a realistic one for the north-west Atlantic fisheries since groundfish which are predators of many pelagics require different technology and fleets for their exploitation (trawlers and draggers) than the pelagics (seiners).

$$(5.26.a) \quad E_1 x_1 = a x_1 - b x_1 x_2$$

$$(5.26.b) \quad E_2 x_2 = -g x_2 + n x_1 x_2.$$

Assuming also that the rate of loss is proportional to fishing effort, $r_1 E_1 x_1$ and $r_2 E_2 x_2$, the industry's production function for both species would be:

$$(5.27.a) \quad r_1 E_1 x_1 = a x_1 - b x_1 x_2$$

$$(5.27.b) \quad r_2 E_2 x_2 = -g x_2 + n x_1 x_2.$$

The steady state relationship between E_1 , E_2 and x_1 , x_2 respectively derived from (5.27.a) and (5.27.b) are as follows:

$$(5.28.a) \quad E_1 = \frac{1}{r_1} (a - b x_2) \Rightarrow x_2 = \frac{a - r_1 E_1}{b}$$

$$(5.28.b) \quad E_2 = \frac{1}{r_2} (-g + n x_1) \Rightarrow x_1 = \frac{g + r_2 E_2}{n}$$

This shows that the predator population x_2 is a decreasing function of the effort E_1 on the prey population x_1 while the prey population x_1 is an increasing function of the effort E_2 on the predator population x_2 . In fact,

$$(5.29.a) \quad E_1 \uparrow \Rightarrow x_2 \downarrow \Rightarrow x_1 \uparrow$$

$$(5.29.b) \quad E_2 \uparrow \Rightarrow x_1 \uparrow \Rightarrow x_2 \uparrow$$

Replacing x_2 and x_1 from (5.28.a) and (5.28.b) into (5.26.a) and (5.26.b), the relationship of catch to effort takes the following forms:

$$(5.30.a) \quad C_1 = E_1 x_1 = k E_1 + \ell E_1 E_2$$

$$(5.30.b) \quad C_2 = E_2 x_2 = m E_2 - n E_1 E_2$$

$$k = \frac{gr_1}{n} ; \ell = \frac{r_1 r_2}{n}$$

$$m = \frac{ar_2}{b} ; n = \frac{r_1 r_2}{b}$$

Thus, the multi-species model indicates that landings of both species are a quadratic function of fishing effort in E_1 and E_2 . For the predator, equation (5.30.b), landings are adversely affected by E_1 , i.e., fishing effort on the prey. The optimum level of effort for both these species can be derived starting from the total catch of both species, i.e.,

$$(5.31) \quad C = C_1 + C_2$$

Hence:

$$(5.32) \quad C = \frac{gr_1}{n} E_1 + \frac{ar_2}{b} E_2 + r_1 r_2 \frac{(b-n)}{bn} E_1 E_2$$

Differentiating (5.33) with respect to E_1 and E_2 respectively results in:

$$(5.33) \quad \frac{\partial C}{\partial E_1} = \frac{gr_1}{n} + r_1 r_2 \frac{(b-n)}{bn} E_2$$

$$(5.34) \quad \frac{\partial C}{\partial E_2} = \frac{ar_2}{b} + r_1 r_2 \frac{(b-n)}{bn} E_1$$

from which the optimal level of effort E_1^* and E_2^* for both species are derived, after setting the partial derivatives equal to zero. Thus:

$$(5.35.a) \quad E_1^* = \frac{an}{r_1(n-b)}, \quad n > b$$

$$(5.35.b) \quad E_2^* = \frac{bg}{r_2(n-b)}, \quad n > b$$

Little empirical work has been done in fisheries using the predator-prey or multi-species model. However, the model exemplifies important inter-relationships between species, and the effects of fishing effort on these. As such, this is a promising model for empirical testing in cases of predator-prey relationships. Although some predator-prey relationships exist amongst and between the groundfish species covered in this thesis, the major predator-prey relationships are between groundfish and pelagic species. For this reason and data constraints, particularly with respect to fishing effort data for pelagic species¹⁶, the predator-prey model will not be applied in this thesis.

In the next section an alternative to the Schaefer logistic model, the Gulland-Fox exponential model, will be described.

¹⁶ Data were unavailable from ICNAF sources on the number of days fished for pelagic species by seiners and midwater trawlers for most of the period covered by this thesis. As a result, it was not possible to obtain good effort data for these species.

3. The Gulland-Fox Exponential Model.

The Gulland-Fox exponential model is not based on the steady state assumptions of the Schaefer logistic model. It has, however, the same biological foundations¹⁷. In this model the Catch Per Unit of Effort, the C.P.U.E., is used as a measure of stock abundance. There is a high C.P.U.E. for low levels of fishing effort and high stock abundance but this declines exponentially with increased fishing effort. More specifically, and in agreement with frequent approaches to economic model building, it can be stated, based on empirical regularities, that the elasticity of catch (C) with respect to effort (E) is a decreasing function of effort. Hence, assuming a linear decreasing function:

$$(5.36) \quad \frac{E}{C} \cdot \frac{dC}{dE} = \delta - \beta E, \quad \delta > 0 \quad \beta > 0$$

and solving (5.36) results in:

$$(5.37) \quad C = \alpha E^{\delta} e^{-\beta E}, \quad \alpha > 0$$

which is a non-linear model with α as a positive constant of integration.

¹⁷ The Gulland-Fox model is described in W.E. Ricker, op.cit., pp. 329-331. The articles on which this description was based are: J.A. Gulland, "Fishing and the Stocks of Fish at Iceland", Fisheries Investigations (Series 2). U.K. Ministry of Agriculture and Fisheries, 1961; and W.W. Fox, "An Exponential Yield Model for Optimizing Exploited Fish Populations", Transactions American Fisheries Society, No. 99, 1970, pp. 80-88.

The Gulland-Fox exponential model is a particular case of this model (5.37), since when $\delta = 1$, the basic form of this model is obtained¹⁸.

$$(5.38) \quad \frac{C}{E} = \alpha e^{-\beta E}$$

Econometric analysis of (5.37) accepts the null-hypothesis that $\delta = 1$, hence the model is fitted after performing a log transformation, in the following form:

$$(5.39) \quad \log \frac{C}{E} = \lambda - \beta E, \quad \lambda = \log \alpha$$

The first order condition for the optimal level of fishing effort corresponding with the maximum sustainable yield (MSY) of the fish population corresponds to the value E^* of E such that $\frac{dC}{dE} = 0$. Therefore, replacing δ by one in (5.36)¹⁹ the optimal effort E^* is deduced as follows:

$$(5.40) \quad 1 - \beta E^* = 0 \Rightarrow E^* = \frac{1}{\beta}, \text{ since}$$

$$(E, C) > 0$$

The second order derivative of the Gulland-Fox model (5.38) is:

$$(5.40) \quad \frac{d^2C}{dE^2} = \alpha \beta e^{-\beta E} (-2 + \beta E)$$

$$\text{and, for the optimal value } E^* = \frac{1}{\beta}$$

18 W.E. Ricker, op.cit., p. 330.

19 It should be noted that the derivation given here is more straight forward and simpler than the one given by Ricker, ibid.

$$(5.41) \quad \frac{d^2C}{dE^2} \bigg|_{E=E^*} = -\alpha\beta e^{-1} < 0$$

hence, $E^* = \frac{1}{\beta}$ is the optimal effort that maximizes the catch C , i.e., corresponds to the MSY of the population. Thus, the MSY is given by:

$$(5.42) \quad C^* = \alpha E^* e^{-\beta E^*} = \frac{\alpha}{\beta e}$$

The Gulland-Fox model is a useful alternative to the Schaefer logistic model. The models are similar in that they provide information on the optimal effort and catch levels. As a result, they are the two most popular biological methods used in empirical work. The use of one or the other is determined by whether empirical evidence indicates there is a linear or non-linear relationship between the C.P.U.E. and effort over time. If the former holds, then the Schaefer logistic model is more *à propos* but if the latter is the case then the Gulland-Fox model is more relevant. In Chapter VII, which will be concerned with the empirical testing of models, the choice of either the Schaefer logistic or the Gulland-Fox will be determined by this consideration.

4. Conclusion.

This concludes the treatment of the standard biological models used in the literature. The chapter started out with the biological theory of ecological equilibrium which explains fisheries population dynamics before and after man's exploitation. The model relevant to this theory was the logistic model first specified by Verhulst in 1838. This was applied in a fisheries context by Schaefer in 1954 and has since been referred to as the Schaefer model. This model was then examined in both a single species and multiple-species (predator-prey) context.

An alternative model to the Schaefer logistic is the Gulland-Fox exponential model which was shown to be a particular case of a non-linear exponential model. This model, though not based on steady state assumptions, has the same biological foundations as the Schaefer logistic model and provides similar results from empirical testings, i.e., the determination of the optimal fishing effort and catch.

In the next chapter, stock adjustment models of fisheries will be introduced; followed by an examination of the economic theory of fisheries.

CHAPTER VI

STOCK ADJUSTMENT MODELS AND FISHERIES ECONOMICS

The economic theory of fisheries, as pointed out in Chapter V, has biological foundations, namely biological theories and models of the effects of man's exploitation on fish population dynamics. Because of this, two popular biological models were examined in that chapter; (1) the Schaefer logistic, and (2) the Gulland-Fox exponential model. The steady state assumptions underlying the first of these models are, however, restrictive¹. Fish populations tend to react to external forces, such as man's fishing effort, over time and not instantaneously. Thus, these populations tend towards a dynamic equilibrium over time and not on a year by year (steady state) basis. As a result of the restrictiveness of the steady state assumption, this chapter, before proceeding to the economic theory of fisheries, will introduce stock adjustment models for fisheries. These models, which allow for adjustments in the population over time rather than instantaneously, seem much more relevant to fisheries than models based on steady state assumptions.

¹ C. Clark, Mathematical Bioeconomics, op.cit., p. 210.

1. Stock Adjustment Models of Fisheries.

There are many stock adjustment models, characterized by the use of lagged independent variables, in the econometric literature². The stock adjustment model which seems very applicable to fisheries is one developed by Houthakker and Taylor for consumer demand³. This model postulates a particular type of relationship between past and present where the effect of the past is assumed to be represented entirely by the current values of certain "state variables". These state variables are in turn changed by current decisions and the net result is that of a distributed lag: current behaviour depends on all past values of the predetermined variables though more on recent values than on very remote ones⁴.

The aspect of this model which is most appealing to its applications to fisheries is that it shows, based on the biological assumptions of fisheries population growth, that the underlying stock or population of fish variable can be eliminated from a regression equation comprised basically of

2 J. Johnston, Econometric Methods, 2nd edition, New York: McGraw Hill Book Company, 1972, pp. 300-303.

3 H.S. Houthakker and L.D. Taylor, Consumer Demand in the United States 1929-1970, Cambridge, Massachusetts: Harvard University Press, Second Edition, 1970.

4 *ibid.*, p. 8.

catch and effort variables. Thus, this model has the advantages of being dynamic and may be estimated from catch and effort statistics. In this section, two versions of the Houthakker-Taylor (H-T) model will be derived for fisheries based on: (1) a continuous time formulation, the original approach of Houthakker and Taylor, and (2) a discrete time formulation.

1.1 The Continuous Time Formulation, H-T Model.

The Houthakker-Taylor model applied to fisheries is based on the biological population dynamics theory analysed in the preceding chapter. According to this theory the net rate of growth of the fishery population when exploited by man is equal to the natural rate of growth of the stock minus the catch taken by man. Hence:

$$(6.1) \quad \dot{X}(t) = W(t) - C(t)$$

$$(6.2) \quad W(t) = \delta X(t)$$

$$(6.3) \quad C(t) = \beta X(t) + \gamma E(t)$$

where:

$X(t)$ = the population or stock in time t

$\dot{X}(t) = \frac{dX}{dt}$ = the net rate of growth of
population in time t

$W(t)$ = the natural rate of growth in stock
in time t

$C(t)$ = the catch in time t

$E(t)$ = fishing effort in time t

β , δ and γ are positive parameters.

Relation (6.1) indicates that the fish population will grow if the catch taken by man is less than the natural rate of population increase and will decline if vice versa. The population will be in ecological equilibrium if $\dot{X}(t) = 0$, that is when $W(t) = C(t)$. Relation (6.2) indicates that, as shown earlier in Chapter V, the natural rate of population increase is a function of the fish population expressed by δX where δ represents the combination of factors such as the rate of recruitment, rate of reproduction, and natural mortality per unit of time, where unit time is τ . Relation (6.3) shows that the catch from fishing is a linear function of the underlying fish population and fishing effort.

From (6.1) - (6.3) the reduced form of the model is deduced which converts it to an operational form since it eliminates the unobservable variable X , the fish population, and includes only observable variables. In fact, from (6.3) it is deduced that:

$$(6.4) \quad X(t) = \frac{1}{\beta} (C(t) - \gamma E(t))$$

$$(6.5) \quad \dot{X}(t) = \frac{1}{\beta} (\dot{C}(t) - \gamma \dot{E}(t))$$

and, from (6.1) and (6.2)

$$(6.6) \quad \dot{X}(t) = \delta X(t) - C(t)$$

Replacing (6.4) and (6.5) in (6.6), the following first order differential equation, involving only the

observable variables of catch and effort, i.e., the reduced form of model (6.1) - (6.3) is obtained:

$$(6.7) \quad \dot{C}(t) = (\delta - \beta) C(t) + \gamma \dot{E}(t) - \gamma \delta E(t)$$

Following the Houthakker-Taylor approach, the parameters β , γ and δ in the continuous model were estimated by obtaining the discrete analogue of this model⁵. This was done by first defining the variables of (6.4) as integrals for the period $(t_0, t_{0+\tau})$:

$$(6.8) \quad \bar{C}_{t_0} = \int_{t_0}^{t_{0+\tau}} C(t) dt$$

$$(6.9) \quad \bar{E}_{t_0} = \int_{t_0}^{t_{0+\tau}} E(t) dt$$

$$(6.10) \quad \bar{X}_{t_0} = \int_{t_0}^{t_{0+\tau}} X(t) dt$$

If (6.3) is integrated over time from t_0 to $t_{0+\tau}$ the structural equation becomes:

$$(6.11) \quad \bar{C}_{t_0} = \beta \bar{X}_{t_0} + \gamma \bar{E}_{t_0}$$

and similarly if integrated for the period $(t_{0+\tau}, t_{0+2\tau})$:

$$(6.12) \quad \bar{C}_{t_{0+\tau}} = \beta \bar{X}_{t_{0+\tau}} + \gamma \bar{E}_{t_{0+\tau}}$$

⁵ The meaning of these parameters will be given in section 1.3 of this chapter.

The changes in the level of the stock from t_0 and $t_{0+\tau}$ are respectively:

$$(6.13) \Delta X_{t_0} = \delta \bar{X}_{t_0} - \bar{C}_{t_0}$$

$$(6.14) \Delta X_{t_{0+\tau}} = \delta \bar{X}_{t_{0+\tau}} - \bar{C}_{t_{0+\tau}}$$

where: ΔX_{t_0} is the change in stock from time t_0 to $t_{0+\tau}$; and $\Delta X_{t_{0+\tau}}$ the change in stock given from time $t_{0+\tau}$ to $t_{0+2\tau}$.

Subtracting (6.11) from (6.12) gives:

$$(6.15) \bar{C}_{t_{0+\tau}} - \bar{C}_{t_0} = \beta(\bar{X}_{t_{0+\tau}} - \bar{X}_{t_0}) + \gamma(\bar{E}_{t_{0+\tau}} - \bar{E}_{t_0})$$

Rearranging (6.11) and (6.12) respectively with $\bar{X}_{t_0}$ and $\bar{X}_{t_{0+\tau}}$ as dependent variables, and substituting for these

in (6.13) and (6.14) result in:

$$(6.16) \Delta X_{t_0} = \frac{\delta}{\beta}(\bar{C}_{t_0} - \gamma \bar{E}_{t_0}) - \bar{C}_{t_0}$$

$$(6.17) \Delta X_{t_{0+\tau}} = \frac{\delta}{\beta}(\bar{C}_{t_{0+\tau}} - \gamma \bar{E}_{t_{0+\tau}}) - \bar{C}_{t_{0+\tau}}$$

The difference between $\bar{X}_{t_{0+\tau}}$ and $\bar{X}_{t_0}$ for two periods

may be approximated by taking the average:

$$(6.18) \bar{X}_{t_{0+\tau}} - \bar{X}_{t_0} = \frac{\tau}{2}(\Delta X_{t_{0+\tau}} + \Delta X_{t_0}).$$

This is a linear approximation and, assuming it is good enough for practical purposes, (6.15) can be written as:

$$(6.19) \quad \bar{C}_{t_0+\tau} - \bar{C}_{t_0} = \frac{\tau\beta}{2}(\Delta X_{t_0+\tau} + \Delta X_{t_0}) \\ + \gamma(\bar{E}_{t_0+\tau} - \bar{E}_{t_0})$$

which, on substituting (6.16) and (6.17) for ΔX_{t_0}

and $\Delta X_{t_0+\tau}$ gives:

$$(6.20) \quad \bar{C}_{t_0+\tau} - \bar{C}_{t_0} = \frac{\tau\beta}{2} \left[\frac{\delta}{\beta}(\bar{C}_{t_0+\tau} - \gamma\bar{E}_{t_0+\tau}) \right. \\ \left. - \bar{C}_{t_0+\tau} + \frac{\delta}{\beta}(\bar{C}_{t_0} - \gamma\bar{E}_{t_0}) \right. \\ \left. - \bar{C}_{t_0} \right] + \gamma(\bar{E}_{t_0+\tau} - \bar{E}_{t_0}).$$

This, on simplification and rearrangement, becomes:

$$(6.21) \quad \bar{C}_{t_0+\tau} = \frac{1 + \frac{\tau}{2}(\delta-\beta)}{1 - \frac{\tau}{2}(\delta-\beta)} \bar{C}_{t_0} + \frac{\gamma(\frac{-\tau\delta}{2} + 1)}{1 - \frac{\tau}{2}(\delta-\beta)} \bar{E}_{t_0+\tau} \\ - \frac{\gamma(\frac{\tau\delta}{2} + 1)}{1 - \frac{\tau}{2}(\delta-\beta)} \bar{E}_{t_0}.$$

which is the discrete analogue to equation (6.7).

If the time scale is established so that $\tau = 1$, the bars removed for notational ease, and t_0 replaced by $t-1$ we have:

$$(6.22) \quad C_t = \frac{1 + \frac{1}{2}(\delta - \beta)}{1 - \frac{1}{2}(\delta - \beta)} C_{t-1} + \frac{\gamma(1 - \frac{\delta}{2})}{1 - \frac{1}{2}(\delta - \beta)} E_t \\ - \frac{\gamma(1 + \frac{\delta}{2})}{1 - \frac{1}{2}(\delta - \beta)} E_{t-1}$$

A convenient presentation of this is obtained by substituting E_t by $(E_t - E_{t-1}) + E_{t-1} \equiv \Delta E_t + E_{t-1}$ which transforms (6.22) into:

$$(6.23) \quad C_t = \frac{1 + \frac{1}{2}(\delta - \beta)}{1 - \frac{1}{2}(\delta - \beta)} C_{t-1} + \frac{\gamma(1 - \frac{\delta}{2})}{1 - \frac{1}{2}(\delta - \beta)} \Delta E_t \\ - \frac{\gamma\delta}{1 - \frac{1}{2}(\delta - \beta)} E_{t-1}$$

The reduced form of this equation can be expressed as follows:

$$(6.24) \quad C_t = H_1 C_{t-1} + H_2 \Delta E_t + H_3 E_{t-1}.$$

It can be verified that the structural model is exactly identifiable⁶. In fact, after some algebraic transformation, the following relations between the reduced and the structural parameters are deduced:

$$(6.25) \quad \beta = \frac{H_3}{H_2 + \frac{1}{2}H_3} - \frac{2(H_1 - 1)}{H_1 + 1}$$

$$(6.26) \quad \gamma = \frac{2(H_2 + \frac{1}{2}H_3)}{H_1 + 1}$$

$$(6.27) \quad \delta = \frac{H_3}{H_2 + \frac{1}{2}H_3}$$

⁶ The inclusion of another variable in the model results in problems of autocorrelation and identification. See Houthakker-Taylor, op.cit., Chapter II.

1.2 A Discrete Time Formulation, H-T Model.

The Houthakker-Taylor approach has been criticized by Dagum as being unnecessarily sophisticated since a discrete time formulation would allow directly and in a more simple way the deduction of the reduced form⁷. As a result, a discrete time formulation of this model was developed⁸. This was done by expressing equations (6.3) and (6.6) in discrete time intervals with each interval being one year, i.e.,

$$(6.28) C_t = \beta X_t + \gamma E_t \text{ and}$$

$$(6.29) X_{t+1} - X_t = \delta X_t - C_t$$

where X_t = average population over the year t

C_t = total catch for the year t

E_t = total fishing effort for the year t

β , δ and γ are positive parameters.

Substituting for X_t and X_{t+1} from (6.28) into (6.29) results in:

$$(6.30) \frac{1}{\beta} (C_{t+1} - \gamma E_{t+1}) = \frac{(1 + \delta - \beta) (C_t - \gamma E_t)}{\beta} - \gamma E_t$$

hence:

7 C. Dagum, "Review of H.S. Houthakker and L.D. Taylor Consumer Demand in the United States", El Trimestre Economico, Vol. 24, N. 147, 1970, pp. 654-658.

8 N.G.F. Sancho and C.L. Mitchell "Economic Optimization in Controlled Fisheries"; Mathematical Biosciences, 27, 1976, pp. 1-7.

$$(6.31) C_{t+1} = (1 + \delta - \beta) C_t + \gamma E_{t+1} - (1 + \delta) \gamma E_t$$

Now $E_{t+1} - E_t = \Delta E_{t+1}$, therefore the reduced form becomes:

$$(6.32) C_{t+1} = (1 + \delta - \beta) C_t + \gamma \Delta E_{t+1} - \gamma \delta E_t$$

which can be expressed, replacing $t+1$ by t , as

follows:

$$(6.33) C_t = A_1 C_{t-1} + A_2 \Delta E_t - A_3 E_{t-1}$$

where:

$$(6.34) A_1 = 1 + \delta - \beta$$

$$(6.35) A_2 = \gamma$$

$$(6.36) A_3 = \gamma \delta.$$

This approach also allows for an exact identification of the structural parameters. In fact, from (6.34) - (6.36) the following are deduced:

$$(6.37) \delta = A_3/A_2$$

$$(6.38) \beta = 1 + \delta - A_1 = 1 + A_3/A_2 - A_1$$

$$(6.39) \gamma = A_2.$$

This model, therefore, results in essentially the same estimating equation, i.e., the reduced form, as the Houthakker-Taylor model and permits a much simpler estimation of the coefficients of the structural form confirming Dagum's criticism of the Houthakker-Taylor approach. This discrete version of the model was therefore the one used for estimating purposes. However, econometric results show that it was also subject, like the Schaefer logistic model, to

problems of multicollinearity. These were again solved by making the C.P.U.E. the dependent variable. That is, starting from (6.31) and dividing by effort E_t to obtain:

$$(6.40) \quad \frac{C_t}{E_t} = A_0 + A_1 \frac{C_{t-1}}{E_t} + A_2 \frac{E_{t-1}}{E_t}$$

where:

$$(6.41) \quad A_0 = \gamma$$

$$(6.42) \quad A_1 = 1 + \delta - \beta$$

$$(6.43) \quad A_2 = -(1+\delta)\gamma \quad \text{and}$$

$$(6.44) \quad \delta = -1 - \frac{A_2}{A_0}$$

$$(6.45) \quad \beta = -A_1 - \frac{A_2}{A_0}$$

There are other stock adjustment models which have simpler and less complicated reduced forms than the Houthakker-Taylor model which conform to the well known Koyck scheme⁹. An examination was made of these, particularly the partial adjustment model which Houthakker and Taylor considered a special case of their model¹⁰. The main difference between this model and the Houthakker-Taylor model was that the current level of fishing effort was used, i.e., E_t instead of changes in fishing effort, i.e., ΔE_t and E_{t-1} . The empirical test of this model indicated, because

⁹ J. Johnston, op.cit., p. 302.

¹⁰ Houthakker and Taylor, op.cit., p. 24.

of a poorer goodness of fit, that it was not as pertinent to fisheries as the Houthakker-Taylor model. This, which supports the contention that the catch in fisheries is influenced by past levels of fishing effort, led to the omission of this model from the thesis.

1.3 Structural Coefficients, Houthakker-Taylor Models.

The reduced form parameters of the Houthakker-Taylor model equation (6.24), and corresponding equation (6.33) for the discrete form show the relationships between the pre-determined variables, the catch lagged one year and fishing effort, on the dependent catch variable. The parameters β and δ in the structural form relate to the underlying stock, while γ pertains to fishing effort.

The natural rate of growth of the population is measured by δ , and β measures its stock adjustment due to fishing effort. A necessary condition for growth in the population X to take place is that $\delta > \beta$. A necessary and sufficient condition for growth, however, according to (6.3) and (6.6) is as follows:

$$(6.46) \quad (\delta - \beta) X_t > \gamma E_t.$$

If that inequality is not fulfilled, then population growth will either be zero or negative. In the latter, we have overexploitation and the fishery population will decline, hence:

$$(6.47) \quad (\delta - \beta) X_t < \gamma E_t \Rightarrow X_t \downarrow$$

The effort coefficient γ gives the changes in the catch per unit of effort before the state variables have a chance to adjust. Thus, it measures the short run derivative, i.e.,

$$(6.48) \quad \frac{\partial C_t}{\partial E_t} = \gamma \quad \text{from (6.3)}$$

The long run derivative of catching with respect to effort, which gives the changes in catch after the state variables have a chance to adjust, is more significant. This is because in fisheries an increase in fishing effort, either through improved technology or by the use of more vessels, would increase landings in the short run, though not necessarily in the long run. By definition, the long run derivative of catching (LRD) is as follows:

$$(6.49) \quad \text{LRD} = \sum_{i=0}^{\infty} \frac{\partial C_{t-i}}{\partial E_t}$$

1.4 The Long Run Derivative of Catching and Catching Elasticities.

The long run derivative of catching for the stock adjustment models can all be derived in a similar manner. As a result, this method¹¹ will be exemplified for the

¹¹ C. Dagum, "Un Modèle économétrique de l'offre et de la demande de produits énergétiques: Etude d'un cas concret, Le Mexique", Economies et Sociétés, Tome V, No. 8, Août, 1971, pp. 1393-1420.

discrete form of the Houthakker-Taylor model only starting with its reduced form (6.33). This can be expressed as follows:

$$(6.50) \quad C_t = A_1 C_{t-1} + A_2 E_t - A_2 E_{t-1} - A_3 E_{t-1} \text{ since}$$

$$\Delta E_t \equiv (E_t - E_{t-1})$$

and, introducing a lag operator L where:

$$(6.51) \quad LC_t = C_{t-1}, \quad LE_t = E_{t-1}$$

$$L^r C_t = C_{t-r}, \quad L^r E_t = E_{t-r} \text{ and}$$

$$L^r A = A, \text{ where } A \text{ is any constant.}$$

Then, (6.50) becomes:

$$(6.52) \quad C_t = A_1 LC_t + A_2 E_t - (A_2 + A_3)LE_t \text{ and}$$

$$(6.53) \quad (1 - A_1 L)C_t = [A_2 - (A_2 + A_3)L] E_t \text{ hence,}$$

$$(6.54) \quad C_t = \frac{A_2 - (A_2 + A_3)L}{1 - A_1 L} E_t.$$

The long run derivative of landings with respect to effort is:

$$(6.55) \quad \text{LRD} = \frac{A_2 - L(A_2 + A_3)}{1 - A_1 L} = - (1 - A_1 L)^{-1} A_3$$

$$\text{since } L(A_2 + A_3) = A_2 + A_3$$

Now, through the MacLaurin expansion of $(1 - A_1 L)^{-1}$

this becomes:

$$(6.56) \quad \text{LRD} = -(1 + A_1 L + A_1^2 L^2 + \dots) A_3 = \frac{A_3}{A_1 - 1}$$

From the structural coefficients of the discrete model (6.34) - (6.36):

$$(6.57) \frac{A_1}{A_1 - 1} = \frac{\gamma\delta}{1 + \delta - \beta - 1} = \frac{\gamma\delta}{\delta - \beta}.$$

Thus, the long run derivative of catch with respect to effort is given by:

$$(6.58) \gamma^* = \frac{\gamma\delta}{\delta - \beta}.$$

It is interesting to observe that exactly the same result is obtained for the LRD from the continuous version of the Houthakker-Taylor model.

The short and long term elasticities of catching with respect to effort in period t for the Houthakker-Taylor model are as follows:

$$(6.59) \text{ The short run elasticity } \epsilon_s = \gamma \cdot \frac{E_t}{C_t}$$

$$(6.60) \text{ The long run elasticity } \epsilon_L = \frac{\gamma\delta}{\delta - \beta} \cdot \frac{E_t}{C_t}$$

This section concludes the treatment of biological models which started in Chapter V with the application of the logistic model by Schaefer, followed by the Gulland-Fox exponential model. This chapter demonstrated the applicability of stock adjustment models, namely the Houthakker-Taylor model in continuous and discrete forms, to fisheries. These latter models seem to be consistent with the theory of fishery population dynamics.

2. The Economic Theory of Fisheries: Static Analysis.

The models discussed so far were biological since no economic variables were included. These models are, therefore, essentially supply models depicting the physical relationships of fishing effort and landings. The concern with the biological has been motivated by the fact that economic models of fisheries generally start with the biological and that supply aspects are usually the most problematic and uncertain areas in fisheries economics. This field has been developing steadily since Gordon's seminal work¹² and the highlights will be summarized in this section and the section to follow. This section will deal with the Gordon model, which has been static in nature, and early developments following this model, and section 3 will deal with more recent theoretical and dynamic developments.

2.1. The Gordon Model.

The economic theory of fishery exploitation developed by Gordon states that because fishery resources are common property, characterized by the free entry of capital and labour inputs (components of effort), their exploitation usually takes place, not at economic optimum levels, i.e., where marginal costs equal marginal revenues, but up to the

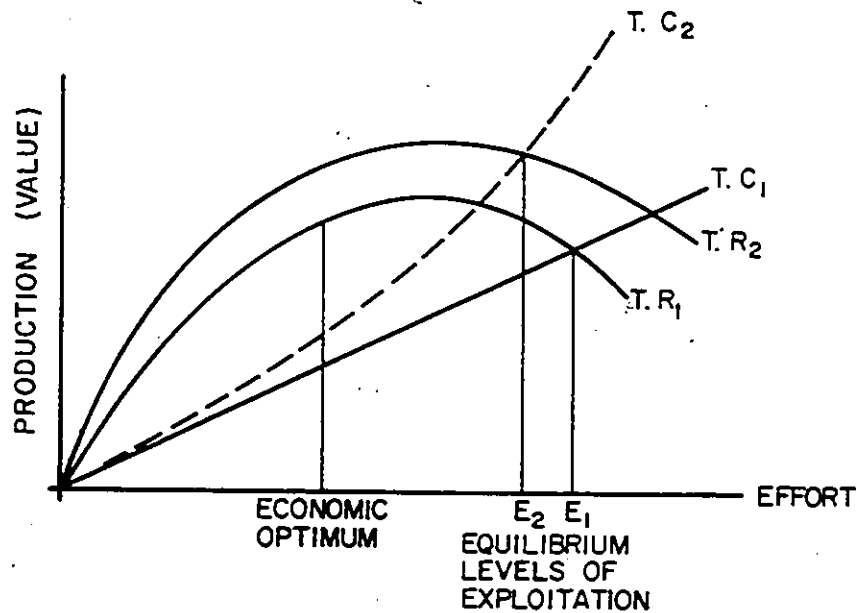
12 H. Scott Gordon, op.cit.

point where total revenues equal total costs. This is depicted in Figure 6. In this diagram the biological production function is converted to a total revenue function by assuming constant prices. The total cost of fishing effort, i.e., both fixed and variable costs, is assumed to increase linearly with effort. The economic optimum level of fishing is where marginal cost equals marginal revenue which occurs where $\frac{dR}{dE} = \frac{dC}{dE}$. However, it is argued that this level is generally surpassed with uncontrolled fishing resulting in an equilibrium situation where total revenues equal total costs.

The assumptions of this model, namely the price and cost assumptions, are not realistic--prices change because of supply-demand relationships, and marginal costs increase with effort, with the result that the cost function should not be linear but should slope upwards. For example, if price increases and costs are an increasing function of output, then the total revenue curve will be pushed up to $T.R._2$ and the equilibrium level of exploitation will be where $T.R._2 = T.C_2$ as shown in the diagram¹³. As a result, this model has been criticized for being rather rigid and restrictive and for not fitting well into classical micro-

¹³ Note that with increasing instead of constant cost per unit effort, both the economic optimum and the equilibrium situation would be moved to the left.

Figure 6 THE ECONOMIC OPTIMUM AND EQUILIBRIUM LEVELS OF FISHERIES EXPLOITATION: THE GORDON MODEL



economic theory¹⁴. This has led to numerous attempts to remedy these deficiencies but these have substantiated rather than shaken the basic thesis expounded that uncontrolled exploitation would lead to the over-exploitation of fisheries resources and the dissipation of economic rent. Gordon suggested sole ownership¹⁵, presumably by the state, as a means out of this dilemma, since the sole owner would endeavour to maximize economic returns through the control of fishing effort. A.D. Scott examined the impact of a sole owner on fisheries exploitation by making a comparison between the economic results of free entry and sole ownership on fisheries exploitation¹⁶. His approach, though critical of Gordon's assumptions, is important in that he took into consideration the value of discounting future benefits, an aspect C.W. Clark was later to scold economists for not taking into account¹⁷.

14 See E.W. Carlson, "Bio-Economic Model of a Fishery", Working Paper No. 2 Division of Economic Research, Bureau of Commercial Fisheries, March, 1969, pp. 20-23.

15 Gordon, *op.cit.*

16 A.D. Scott, "The Fishery, the Objectives of Sole Ownership", Journal of Political Economy, Vol. 63, 1965.

17 C.W. Clark, "Economical Optimal Policy for the Utilization of Biologically Renewable Resources", *op.cit.*

2.2 The Scott Model: The Effects of Sole Ownership and Discounting.

Scott's criticisms of Gordon's analysis is that his economic optimum level where marginal costs equal marginal revenue, i.e., the standard situation in pure competition, really holds only in the short run. Scott then endeavours to answer the question that if the fishery were under sole ownership whether the sole owner would operate in this manner. His answer is in the affirmative in a short run situation, e.g., a fishing season. However, in the long run, the sole owner would attempt to make the best use of the factors of production and of the fishery over time. From a social standpoint, the best use of the fishery and of all the factors invested in it can be attained by "allocating outputs and outlays over time in accordance with the current rate of discount"¹⁸.

To illustrate the best use of the fishery under sole ownership, where the sole owner would attempt to maximize his present value, i.e., future net returns discounted to the present, Scott made use of the concept of "user cost". This concept, invented by Keynes has largely passed into oblivion in the literature. Scott, however, found it useful in a fisheries context since in fisheries the catch today

¹⁸ A.D. Scott, op.cit., p. 122.

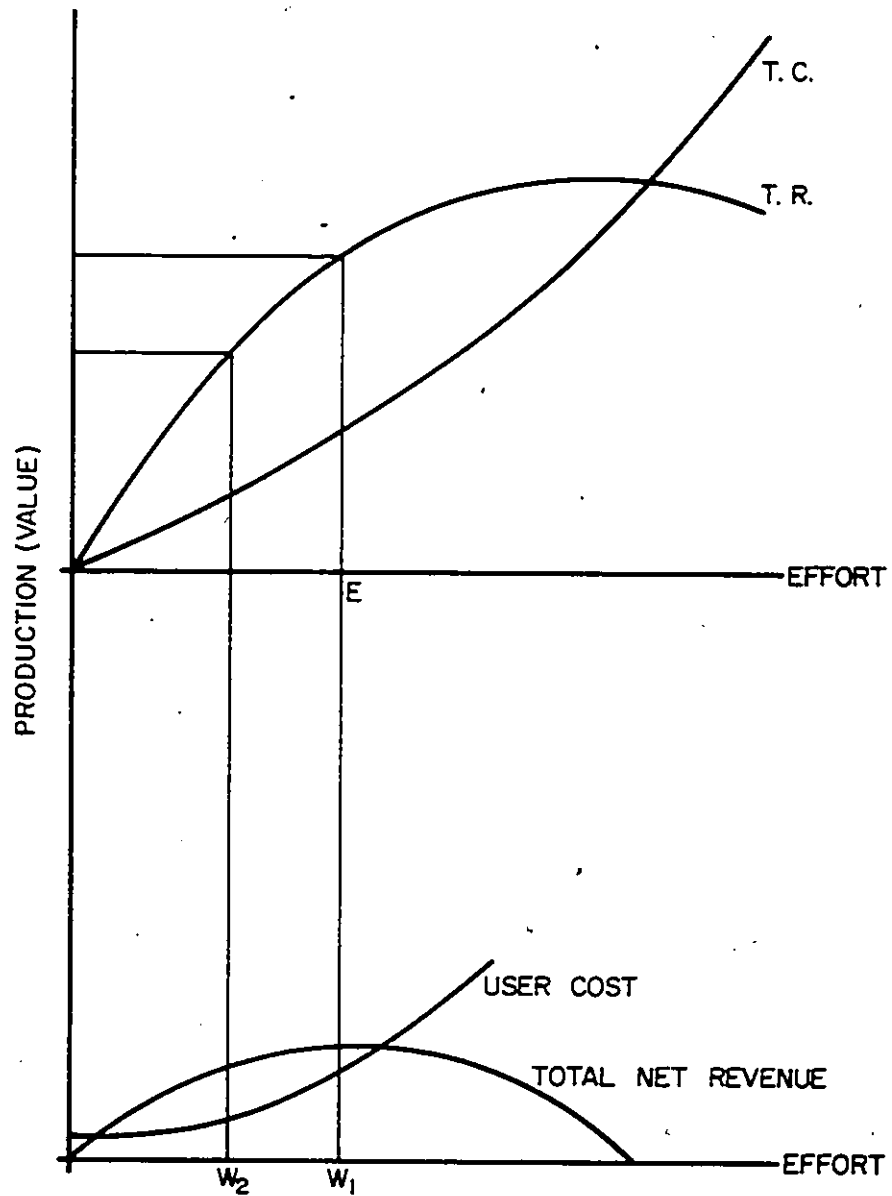
has an influence on the population and catch tomorrow; and user cost shows the effects of succeeding units of current output on the present value of the enterprise. Thus, for the sole owner in the long run, his economic optimum is where the tangent to the total revenue curve is parallel to the tangent of the user cost curve, i.e., where marginal revenue is equal to the marginal user costs (Figure 7).

In the Figure, which was made consistent with Gordon's (Figure 6), the long run optimum is shown to be to the left of what it would have been under common property ownership and free entry. This, Scott contends, could result in greater economic efficiency than free entry. Depending, however, on the discount rate selected, since the lower the valuation put on landings in the future the higher the discount rate and vice versa, the sole owner might follow a strategy either for the depletion or replenishment of the resource¹⁹. Clark, writing years later, arrives at essentially the same conclusion²⁰.

¹⁹ This situation has been a constant source of irritation to biologists in the management of fisheries resource exploitation. Their concern with maximum sustainable yields, which implies a zero discount rate, makes it difficult for them to understand exploitation beyond the MSY into a depletion stage. Although they recognize that the MSY level of exploitation might not be the most economic, they argue that it should be considered the production level constraint.

²⁰ C. Clark, "Economical Optimal Policy for the Utilization of Biologically Renewable Resource", op.cit.

Figure 7 THE ECONOMIC OPTIMUM LEVEL WITH DISCOUNTING
THE SCOTT MODEL



3. Refinements in the Economic Theory of Fisheries.

The further attempts in the literature to remedy the deficiencies of Gordon's analysis mentioned in the previous section can be divided into two approaches: (1) the reformation and extension of Gordon's analysis through the application of micro economic theory and through the removal of some of the restrictive assumptions, and (2) the development of more general and dynamic models of fisheries exploitation. The first approach associated with Turvey, Copes and Anderson²¹ raised the important question of whether the economic optimum of the Gordon model is the best situation from society's standpoint. This is of relevance for Canada's groundfish fisheries and therefore for this thesis.

3.1 The Social Optimum of Fisheries Exploitation.

Gordon considered that the economic optimum where economic rents were maximized was also the social optimum. This was based on assuming that the opportunity cost of fishermen represents the social value which their labour

²¹ R. Turvey, "Optimization and Suboptimization in Fishery Regulation", A.E.R., Vol. 54, 1964, pp. 64-77. P. Copes, "The Backward-bending Supply Curve of the Fishing Industry", Scottish Journal of Political Economy, Vol. 17, 1970, pp. 69-77.... "Factor Rents, Sole Ownership and the Optimum Level of Fisheries Exploitation", The Manchester School of Economic and Social Studies, Vol. 40, 1972, pp. 145-163. L. Anderson, "Optimum Economic Yield of a Fishery Given a Variable Price of Output", Journal of the Fisheries Research Board of Canada, Vol. 30, 1973, pp. 509-518.

and capital produce in the best alternative use, and the price of fish represents the social value of a marginal unit of that commodity. As a result, the intertemporal maximization of social welfare is equivalent to maximizing profits in the fishery. However, it has been pointed out that a competitive fisherman's private marginal product is less than his marginal social product because of the presence of stock and crowding externalities²². This is because stock externalities result from the failure to take into account the impact that fishermen make on the equilibrium stock size; while crowding externalities are caused by the detrimental effects of too many fishermen or vessels resulting in higher than necessary costs of fishing effort.

Copes, by the utilization of backward-bending supply curves, downward sloping demand curves and the application of criteria of welfare maximization indicated that the social optimum was the one which maximizes the combination of resource rent and consumers and producers surpluses²³. In his geometry, which was extended by Anderson²⁴ and which had problems with multiple equilibria, Copes showed that the fishing effort required would come closer to the fishing

22 R. Hannesson, op.cit., pp. 21 and 22.

23 P. Copes, "Factor rents....", op.cit.

24 L. Anderson, op.cit.

effort of free entry and the maximum sustainable yield than would the more strictly limited effort which would result from the maximization of resource rent only.

The importance of this finding is that the maximization of the economic rent is not necessarily the best objective for management of fisheries exploitation by, say, the state, if it exercises sole ownership rights. Although it is not possible to measure empirically both consumer's and producer's surpluses²⁵, an objective which takes biological, economic and social aspects into consideration would be more desirable than one based on rent maximization alone. This, which moves fisheries economic theory into the field of welfare economics, has also been recognized in fisheries management. It is interesting, for example, to note that the "best use" of fisheries resources defined by "the sum of net social benefits (personal income, occupational opportunity, consumer satisfaction and so on)" has been considered to be the guiding principle in fisheries management in Canada²⁶.

25 Since the need is to measure consumer's and producer's surplus at the margin only, the consumer's surplus can be measured empirically, as it is determined by the demand curve, but not the producer's surplus.

26 Environment Canada, Policy for Canada's Commercial Fisheries, op.cit., p. 53.

3.2 The General Economic Models.

General economic models have been developed by Crutchfield-Zellner, Smith, Plourde, Clark and others²⁷. These have as their origin the biological models given earlier. The approach of most of these has been to extend the biological models through the introduction of economic functions such as (1) a cost of fishing function; (2) a demand function for fish; (3) a total revenue function; (4) a profit function for the industry; and (5) a decision function specifying entry and exit conditions. Such a model can be described as follows:

$$(6.61) \quad C = f(X, E) \quad - \text{Production Function}$$

$$(6.62) \quad T.C. = g(E) \quad - \text{Total Cost Function}$$

$$(6.63) \quad P = h(C, Y) \quad - \text{Demand or Price Function}$$

$$(6.64) \quad T.R. = C.P. = C.h(C, Y) \quad - \text{Total Revenue Function}$$

$$(6.65) \quad \pi = j(T.R., T.C) \quad - \text{Profit Function}$$

$$(6.66) \quad \frac{dE}{dt} = p(\pi - \pi^*) \quad - \text{Entry and Exit Conditions}$$

²⁷ Two Ph.D theses which have recently come to my attention are examples of these. See D. Paulaha "A General Economic Model of Commercial Fisheries", (unpublished Ph.D thesis), University of Washington, 1970; E. Carlson, "Theoretical and Empirical Explorations in the Economics of Marine Resources", (unpublished Ph.D thesis), Boston College, 1971.

Where X = Fish Population
 C = Landings (Volume)
 P = Prices of Fish
 Y = Per Capita Income
 E = Fishing Effort
 $T.C.$ = Total Costs
 $T.R.$ = Total Revenues
 π = Profit Rate
 π^* = Rate of Return Necessary for
Steady-State Fishing Effort
 p = A Positive Parameter that
Relates to Entry and Exit.,

The economic model depicts that fisheries exploitation takes place for economic reasons, namely the obtaining of adequate returns or profits from fishing operations which depend on the revenues and costs of these operations. Thus, the economic functions in the model show that: the total cost of fishing, including fixed and variable costs, is a function of effort; the price received is a function of the quantity landed and per capita incomes; the total revenue from fishing is a function of price and quantity; profit depends on total revenues and costs; and finally effort will only enter the fishery if profits are greater than π^* and withdraw from it if returns are less than π^* .

The economic model given by (6.61) & (6.66) can be used to test the hypothesis that in the long run the equilibrium situation for a fishery is where total revenues equal total costs; and to indicate what the economic optimum level of exploitation is. Under this hypothesis, the long run equilibrium situation will be as follows:

$$(6.67) \quad \pi = Ch(C, Y) - g(E) = 0.$$

The economic optimum, if the fishery is regulated to attain this, can be obtained by means of traditional marginal analysis of long-run revenues and costs and the obtaining of average and marginal costs from them. This analysis, however, is essentially static in nature but dynamic elements have been introduced.

Recent developments in the literature have been concerned with the application of dynamic optimization techniques to fisheries, namely control theory²⁸ and dynamic programming²⁹. The similarities, differences and shortcomings of these approaches have been analysed in the

28 C.W. Clark and G.R. Munro, "The Economics of Fisheries and Modern Capital Theory: A Simplified Approach", Journal of Environmental Economics and Management, 2, 1975, pp. 92-106; C.W. Clark, Mathematical Bioeconomics, op.cit., pp. 88-125.

29 N.G.F. Sancho and C.L. Mitchell, op.cit.

literature³⁰. In general, these two approaches are mathematically difficult and limited in their application. Nevertheless, they are important to fisheries since they permit dynamic optimization over time taking into account the effects of discounting future revenues and costs. Thus, these techniques are not frills³¹: they can be considered a logical extension of fisheries economics.

4. Conclusion.

This, therefore, concludes the discussion on the theoretical underpinnings of what can be considered the bio-economics of fisheries. It started out with the biological, the attainment of a maximum sustainable yield (MSY) from fisheries exploitation; then moved on, with the introduction of economic factors, to the economic optimum of maximizing the economic rent from fisheries. The bio-economic implications of these two aspects were then taken into account by examining the effects of discounting the future to maximize the present value of returns from fisheries on the level of

³⁰ For a good elementary survey see M.D. Intriligator, Mathematical Optimization and Economic Theory, Englewood Cliffs, N.J: Prentice-Hall, Inc., 1971.

³¹ C.W. Clark, "Control Theory in Fisheries Economics: Frill or Fundamental", Economic Impacts of Extended Fisheries Jurisdiction, edited by L.G. Andersen, Ann Arbor, Mich: Ann Arbor Science, 1977, pp. 317-327.

exploitation. Finally, the social welfare implications of this exploitation were examined for the purpose of determining the "best use" of fisheries exploitation from society's standpoint.

CHAPTER VII

SPECIFICATION AND ESTIMATION, GROUND FISH MODELS

In Chapter V two biological models for fisheries were examined: (1) the steady state Schaefer logistic model, and (2) the Gulland-Fox exponential model. The steady state logistic model for the single species is the most widely used model in empirical work followed by the Gulland-Fox model. However, it was pointed out that fisheries' resources tend to be in transient rather than in steady states with the result that stock adjustment models of fisheries are more realistic. As a result, Chapter VI examined the applicability of the Houthakker-Taylor type stock adjustment model, in a continuous and discrete form formulation¹, to fisheries. In this chapter therefore this model will be subjected to empirical testing in the context of Canada's east coast offshore groundfish fisheries, and its results compared with those of the standard biological models mentioned above.

1. Tests for Comparison of Models.

One of the most neglected areas in econometrics is that dealing with methods for evaluating and comparing

¹ This form was used because of the simpler derivation of the reduced form.

different models. The criteria for these are not rigorous with the result that generally, models are compared on the basis of their explanatory and predictive powers and on the statistical and other tests associated with these. These have been classified as: parametric, i.e., if it relies on formal statistical tests that assume an a priori probability distribution function; and non-parametric, i.e., if it does not postulate a given mathematical form for the probability distribution function².

Although there is a dearth of rigorous criteria the process of evaluating models is fairly clear cut. It is based on assessing their validity and subject matter, purpose and operational viability³. This consists of three steps:

1. the assumptions underlying the behavioral equations of the model should be in accord with the basic postulates of theory;
2. these assumptions should be tested empirically; and
3. the predictive ability of the model should

² P.J. Dhrymes et al, "Criteria for Evaluation of Econometric Models", Annals of Economic and Social Measurement, Vol. 1, No. 3, July, 1972, pp. 291-322.

³ C. Dagum, "On Methods and Purposes of Econometric Model Building", Z. Nationalökonomie, No. 4, 1968, p. 381.

be tested⁴.

Of these, the first has already been treated since the models developed have proceeded from a given set of hypotheses based on biological theories of fisheries population growth. The system has the properties of consistency in that the underlying assumptions or postulates are not contradictory; independence in that these postulates are not derived from each other; and completeness in that the set of assumptions are sufficient to explain the set of endogenous variables. Given these properties of the structural form, a unique reduced form was deduced by a straightforward application of formal logic. For this form to have empirical validity, however, it is necessary to subject the model to empirical testing which in turn ties in with the main purpose of the model and its operational viability.

Models are classified as either purely predictive or causally predictive. The main purpose of a purely predictive model is to make reliable forecasts, while a causally predictive model has the additional task of providing

4 F.W. Gorbet, "Econometric Models: Some Comments on Their Use in Policy Analysis", Bank of Canada Review, Ottawa: October, 1973.

causal explanation of the phenomenon under study⁵. For the former, it is known that the assumptions underlying the behavioral equations need not accord with the basic postulates of the theory for the model's success as a forecasting tool⁶. However, these are necessary requirements if the major purpose of the model is explanatory. In this thesis, the purpose of the models under consideration is causally predictive whereby the models will be tested on the basis of both their explanatory and predictive powers. In both cases, their usefulness lies in their contribution to the decision-making process: in making it possible to analyse or test various policies which would otherwise be difficult or costly. For decision-making, however, the models must be operationally viable. This requires the classification of the exogenous variables into the categories of controllable and non-controllable, the determination of controllable exogenous variables which will act as instrumental variables, and endogenous variables which will be the objective of the

5 George Stojkovic, "Market Models for Agricultural Products", Econometric Model Building: Essays on the Causal Chain Approach, edited by H.O.A. Wold, Amsterdam: North Holland Publishing Co., 1964, p. 416.

6 For a discussion of this see M. Friedman, Essays in Positive Economics, Chicago: University of Chicago Press, 1953, pp. 1-43; T.C. Koopmans, Three Essays on the State of Economic Science, Toronto: McGraw Hill Book Co. Inc., 1957, pp. 138-140.

decision model⁷.

The models in this thesis will therefore be compared on how well they stand up to empirical testing of their explanatory and predictive capabilities. These latter capabilities, considered the acid test by Christ⁸, depend, however, on the degree of structural permanence, i.e., that there is no basic change in the structure under investigation due to technological, behavioral or institutional changes in related areas of the structure during the predictive period⁹. If there is a low degree of structural permanence during this period, then the model's predictive or decision making capabilities will be severely limited. The tests to be used will therefore be a combination of statistical tests: the goodness of fit, i.e., $\bar{R}^2$, the significance of the variables in the models, i.e., standard t- tests, etc., non-parametric tests, i.e., the number of turning points missed or falsely predicted; and tests developed for assessing predictive abilities. These latter

7 Dagum, op.cit., p. 396.

8 C.F. Christ, Econometric Models and Methods, New York: John Wiley & Sons Inc., 1966, p. 547.

9 Dagum, op.cit., p. 397.

include the Janus Quotient, the Theil¹⁰ and the Root Mean Square Error (R.M.S.E.) tests¹¹. In this thesis the R.M.S.E. test will be used, where necessary, to compare the forecasts made by the models. This involves essentially finding the R.M.S.E. of the prediction and comparing it with the Standard Error of Estimate (S.E.E.) during the sample period, i.e.,

$$(7.1) \quad \text{R.M.S.E.} = \sqrt{\frac{1}{n} \sum v^2} \quad \text{where } v = y - \hat{y}$$

y = actual data,
 predictive
 period
 $\hat{y}$ = predicted
 n = number of
 years in the
 predictive
 period

If the R.M.S.E. is less than the S.E.E. then the predictions made are good, but if it is significantly greater than the S.E.E., predictions are poor. The latter case, depending on how well the model performed from an empirical standpoint, could be indicative of significant structural change during the predictive period.

¹⁰ These tests have been developed to systematically measure the accuracy of model forecasts. H. Theil, Economic Forecast and Policy, Amsterdam: North Holland Publishing Company, 1961. A. Gadd and H.O.A. Wold, "The Janus Quotient: A Measure for the Accuracy of Prediction", Econometric Model Building, Essays in Causal Chain Approach, edited by H.O.A. Wold, Amsterdam: North Holland Publishing Company, 1964.

¹¹ The Root Mean Square Error tests and other tests for model's predictions are described by Christ, op.cit., Chapter X.

2. Specification of Models, Canada's East
Coast Groundfish Fisheries.

Three models were to be tested in this thesis: the Schaefer logistic, the Gulland-Fox and the discrete version of the Houthakker-Taylor. It was pointed out, however, in Chapter V that the Gulland-Fox model can be considered an alternative to Schaefer logistic depending on whether the C.P.U.E. over time displayed a linear or curvilinear pattern. The latter was found to be the case and in empirical testing very poor results were obtained from the Schaefer model indicating that the Gulland-Fox was the more pertinent model. As a result, although all three models were tested the results obtained are given only for the Gulland-Fox and Houthakker-Taylor models. These two models are specified as follows:

Model I. $\log \frac{C_t}{E_t} = \lambda - \beta E_t + v_t \dots$ The Gulland-Fox

Model II $\frac{C_t}{E_t} = A_0 + A_1 \frac{C_{t-1}}{E_{t-1}} + A_2 \frac{E_{t-1}}{E_t} + w_t \dots$ The Houthakker-Taylor

where C_t = landings in time t

E_t = fishing effort in time t

$\lambda = \log \alpha$

v_t, w_t are error terms

As outlined in Chapters II and III, the important aspects of Canada's east coast groundfish fisheries are: (1) their international nature since the resources of the northwest Atlantic are exploited by the fleets of many countries and Canada competes with these countries; and (2) the division of Canada's groundfish fisheries into two distinct sectors: an offshore sector; and an inshore sector. The offshore sector is characterized by the exploitation of many groundfish species while in the inshore sector, by far the major groundfish landed consists of cod.

The models specified will be utilized for the offshore sectors representing: (1) the whole northwest Atlantic offshore groundfish fisheries; and (2) Canada's east coast offshore groundfish fisheries. These sectors are interrelated in that sector (2) is a subset of sector (1) and both are subject to ICNAF regulations. The list of variables for these sectors is given in Table XX.

2.1 Sector 1: The Northwest Atlantic Groundfish Fisheries.

The groundfish resources of the offshore northwest Atlantic will be divided into three major species: (1) cod; (2) redfish; and (3) flatfish or other groundfish. In the model it will be assumed that the groundfish resources of the northwest Atlantic are evenly distributed in the area, i.e., no attention will be paid to sub-areas; that international fishing effort is highly mobile; and that landings of

TABLE XX.

List of Variables

Sector 1: The Northwest Atlantic Groundfish Fisheries.

C_{11} = Total ICNAF offshore cod lands

C_{12} = Total ICNAF offshore redfish landings

C_{13} = Total ICNAF offshore other groundfish landings

E_{11} = ICNAF offshore fishing effort for cod

E_{12} = ICNAF offshore fishing effort for redfish

E_{13} = ICNAF offshore fishing effort for other groundfish

Sector 2: Canada's Offshore Groundfish.

C_{21} = Canadian east coast offshore cod landings

C_{22} = Canadian east coast offshore redfish landings

C_{23} = Canadian east coast offshore other groundfish
landings

E_{21} = Canadian east coast offshore fishing effort for
cod

E_{22} = Canadian east coast offshore fishing effort for
redfish

E_{23} = Canadian east coast offshore fishing effort for
other groundfish

the various species are proportional to fishing effort. This effort, as pointed out earlier, will be measured by the tonnage of ICNAF's groundfish fleet times the number of days fished.

2.2 Sector 2: Canada's East Coast Offshore Groundfish Fisheries.

In this sector, dealing with Canada's groundfish fisheries in the northwest Atlantic, resources will be divided into three main species; cod, redfish, and other groundfish. The same assumptions made for the international sector pertaining to area distribution of resources, fishing effort, and returns to effort will hold for Canada. Fishing effort here will again be measured by the tonnage of Canadian groundfish vessels times the number of days fished.

3. Estimation Results of Models.

In this section, the estimation results for the specified models will be analysed. Both models were used to specify equations for sectors 1 and 2, i.e., the northwest Atlantic fisheries and Canada's offshore groundfish fisheries. Attempts were made to model the inshore groundfish sector but results from the models were poor. The main reason for this is that the inshore sector is not distinct in a resource context since a considerable proportion of these resources consist of offshore stocks. As a result of

this, and problems with obtaining good measures or estimates of inshore fishing effort, this sector has traditionally been difficult to model.

3.1 Sector 1, ICNAF Northwest Atlantic Groundfish Fisheries.

The results obtained from the models were extremely good (Table XXI). The Houthakker-Taylor model, model II, gave the best results in terms of high R^2 , low standard errors, Durbin Watson statistics and goodness of fit (Figure 8). Although the Durbin Watson statistic is only a proxy when the regression contains lagged variables, the small number of observations (less than 30) precluded the use of the test suggested by Durbin in this case¹². However, since the Durbin Watson statistics were close to 2, autocorrelation was not considered a serious problem for the model. For the Gulland-Fox, model I, the Durbin Watson statistics were very low for all equations and indicative of positive first order autocorrelation. Various attempts were made to solve this problem, including trying other specifications and generalized

¹² This is the "h" test. See J. Durbin, "Testing for Serial Correlation in Least Square Regression where some of the Regressors are lagged Dependent Variables", Econometrica, Vol. 38, 1970, pp. 410-421.

TABLE XXI.

Results of Models I and II, ICNAF
Northwest Atlantic Fisheries by Major Species.

Model I. The Gulland-Fox Model

(7.2) Cod $\log \frac{C_{11t}}{E_{11t}} = 3.756 - .607E_{11t}$

(66.44) (-9.315)
((.056)) ((.065))

$R^2 = .83 \quad \bar{R}^2 = .82 \quad \text{S.E.E.} = .130 \quad \text{D.W.} = .499$

$E_{11}^* = (1.647)10^{11} \quad E_{11} = (1.666)10^{11} \quad (1968)$

(7.3) Redfish $\log \frac{C_{12t}}{E_{12t}} = 3.711 - 2.788 E_{12t}$

(71.02) (-9.35)
((.522)) ((.998))

$R^2 = .83 \quad \bar{R}^2 = .82 \quad \text{S.E.E.} = .129 \quad \text{D.W.} = .396$

$E_{12}^* = (.358)10^{11} \quad E_{12} = (.333)10^{11} \quad (1973)$

(7.4) Other Groundfish $\log \frac{C_{13t}}{E_{13t}} = 3.688 - .883 E_{13t}$

(86.98) (-11.175)
((.424)) ((.790))

$R^2 = .87 \quad \bar{R}^2 = .87 \quad \text{S.E.E.} = .116 \quad \text{D.W.} = .871$

$E_{13}^* = (1.132)10^{11} \quad E_{13} = (1.107)10^{11} \quad (1973)$

() = t-values
(()) = standard errors

Number of Observations, n = 20

E* = optimal effort
E = actual effort

TABLE XXI. Continued

Results of Models I and II, ICNAF
Northwest Atlantic Fisheries by Major Species.

Model II, The Houthakker-Taylor Model

$$(7.5) \quad \underline{\text{Cod}} \quad \frac{C_{11t}}{E_{11t}} = 436.473 + .999 \frac{C_{11t-1}}{E_{11t}} - 457.168 \frac{E_{11t-1}}{E_{11t}}$$

$$\begin{array}{ccc} (1.470) & (28.057) & (-1.576) \\ ((.296)) & ((.0356)) & ((.292)) \end{array}$$

$$R^2 = .98 \quad \bar{R}^2 = .98 \quad \text{S.E.E.} = 271.95 \quad \text{D.W.} = 1.89$$

$$\text{Structural Parameters } \delta = .048 \quad \beta = .050 \quad \gamma = 4.36 \quad \gamma^* = -10.46$$

$$(7.6) \quad \underline{\text{Redfish}} \quad \frac{C_{12t}}{E_{12t}} = 2411.06 + .992 \frac{C_{12t-1}}{E_{12t}} - 2603.265 \frac{E_{12t-1}}{E_{12t}}$$

$$\begin{array}{ccc} (3.965) & (11.263) & (-3.690) \\ ((.652)) & ((.088)) & ((.705)) \end{array}$$

$$R^2 = .89 \quad \bar{R}^2 = .87 \quad \text{S.E.E.} = 635.3 \quad \text{D.W.} = 1.49$$

$$\text{Structural Parameters } \delta = .079 \quad \beta = .087 \quad \gamma = 2.41 \quad \gamma^* = -23.79$$

$$(7.7) \quad \underline{\text{Other Groundfish}} \quad \frac{C_{13t}}{E_{13t}} = 1225.786 + .988 \frac{C_{13t-1}}{E_{13t}} - 1310.37 \frac{E_{13t-1}}{E_{13t}}$$

$$\begin{array}{ccc} (7.479) & (44.713) & (-7.227) \\ ((.163)) & ((.022)) & ((.181)) \end{array}$$

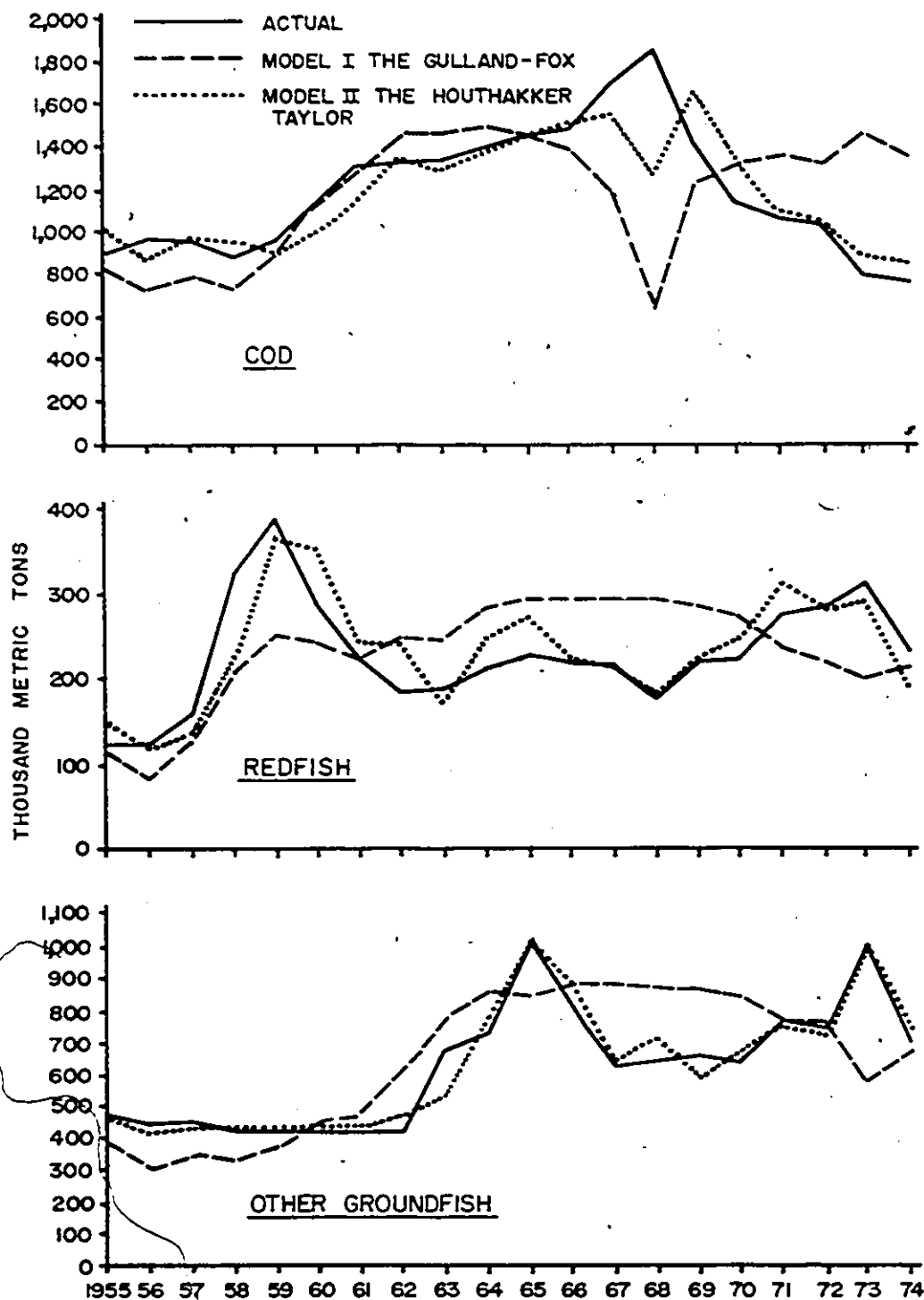
$$R^2 = .99 \quad \bar{R}^2 = .99 \quad \text{S.E.E.} = 174.6 \quad \text{D.W.} = 2.66$$

$$\text{Structural Parameters } \delta = .069 \quad \beta = .081 \quad \gamma = 1.226 \quad \gamma^* = -7.05$$

() t-values
(()) standard errors

n = 20

Figure 8 ESTIMATED AND ACTUAL LANDINGS MAJOR SPECIES,
NORTHWEST ATLANTIC, ICNAF AREAS



least squares¹³, without much success.

The results obtained from both models are interesting. For model I, the Gulland-Fox, the optimal effort E^* for the various species is given and compared with the highest actual effort E during the period the models were tested. The results indicate that optimal effort has been exceeded only for cod in 1968, while for the other species optimal and actual efforts were closest for 1973. In the latter cases, however, they were sufficiently close to indicate that exploitation was close to their MSY levels in 1973 but the MSY for cod was probably between the 1967 and 1968-levels¹⁴. These results, therefore, suggest that fishing effort should definitely have been reduced for cod, as

¹³ The Gulland-Fox model with the assumption of first order autocorrelation gave the following reduced form:

$$(1) \quad \log \frac{C_t}{E_t} = \alpha + \rho \log \frac{C_{t-1}}{E_{t-1}} - \beta E_t + \delta E_{t-1}. \quad \text{From which } \rho$$

was obtained and from this:

$$(2) \quad \log \frac{C_t}{E_t} - \rho \log \frac{C_{t-1}}{E_{t-1}} = \alpha - \beta(E_t - \rho E_{t-1}). \quad \text{This model}$$

was then tested empirically and although much better Durbin Watson statistics were obtained, the R^2 's were reduced considerably.

¹⁴ Unfortunately, estimates of MSY's from the Gulland-Fox model were so low that they were implausible and therefore omitted.

in fact occurred, but not necessarily for redfish and other groundfish.

The reduced form coefficients of model II, the Houthakker-Taylor, revealed that for all species the natural rate of growth of stock δ was less than β the stock adjustment due to fishing effort indicating that the underlying stocks of these species was declining. Judging from their differences, i.e., $\delta - \beta$, the rates of decline were highest for flatfish followed by redfish and cod. The declining stocks are also evident in the long run derivative estimates for fishing effort. The short term derivatives of fishing effort γ are all positive as expected but the long run derivatives γ^* are negative.

The findings of model II corroborate those of ICNAF scientists that the groundfish resources of the northwest Atlantic were exploited at levels higher than their reproductive capabilities can bear and that, as a result, fishing effort had to be reduced. Model I's findings did not support this for all species with the exception of cod but its results indicated that fishing effort was very close to optimal levels for the other species in 1973.

3.2 Sector 2, Canada's Offshore Groundfish Fisheries.

The models' results from Canada's offshore groundfish fisheries indicated that generally the Houthakker-Taylor model, model II, gave better results than model I, the

Gulland-Fox (Table XXII). This model had higher $\bar{R}^2$'s and lower standard errors, and better Durbin Watson statistics than the Gulland-Fox model. The fits given by both models (Figure 9) were good. The Gulland-Fox model again experienced low Durbin Watson statistics indicative of positive autocorrelation. The optimal effort E^* for the various species when compared with the highest level of effort indicated that cod was the only species where Canadian fishing effort exceeded optimal fishing effort. However, for redfish, the actual fishing effort in 1973 was close to the optimal effort indicating that there should be no increase in effort for that species.

The structural parameters of model II are given even though the estimates of δ and β pertain only to the stocks fished by Canadian fishing effort. As such, they are not relevant to the overall stock situation in the northwest Atlantic given in Sector 1, since Canadian effort is but a subset of the overall ICNAF fishing effort. Although this is the case, it is interesting to compare these results with those for Sector 1, ICNAF groundfish fisheries, for the species given from the standpoint of consistency. For cod the findings were consistent in that parameter estimates indicate that the population is increasing but seems close to a dynamic equilibrium, δ almost equal to β . However, for other groundfish, δ is greater than β implying that the

TABLE XXII.

Results of Models I and II,
Canada's Offshore Groundfish Fisheries by Major Species

Model I, The Gulland-Fox Model

(7.8) Cod $\frac{C_{21}}{E_{21}} = 2.739 - .861 E_{21}$

(50.09) (-9.24)
((-0.054)) ((.093))

$R^2 = .82 \quad \bar{R}^2 = .81 \quad S.E.E. = .158 \quad D.W. = .64$

$E_{21}^* = (1.161)10^9 \quad E_{21} = (1.221)10^9 \quad (1968)$

(7.9) Redfish $\log \frac{C_{22}}{E_{22}} = 2.641 - .6079 E_{22}$

(48.68) (-7.86)
((-0.054)) ((-.077))

$R^2 = .76 \quad \bar{R}^2 = .75 \quad S.E.E. = .179 \quad D.W. = .56$

$E_{22}^* = (1.645)10^9 \quad E_{22} = (1.673)10^9 \quad (1973)$

(7.10) Other Groundfish $\log \frac{C_{23}}{E_{23}} = 2.794 - .549 E_{23}$

(80.04) (-16.086)
((-0.035)) ((.032))

$R^2 = .93 \quad \bar{R}^2 = .93 \quad S.E.E. = 9.70 \quad D.W. = .59$

$E_{23}^* = (1.821)10^9 \quad E_{23} = (1.709)10^9 \quad (1968)$

() t statistics
(()) standard errors

Number of Observations, n = 21

E^* = optimal effort
 E = actual effort

TABLE XXII. Continued

Results of Models I and II,
Canada's Offshore Groundfish Fisheries by Major Species

Model II, The Houthakker-Taylor Model

$$(7.11) \text{ Cod} \quad \frac{C_{21}}{E_{21}} = 76.385 + 1.095 \frac{C_{21t-1}}{E_{21}} - 79.474 \frac{E_{21t-1}}{E_{21}}$$

$$\begin{array}{ccc} (2.11) & (25.8) & (-2.20) \\ ((.36)) & ((3.896)) & ((.036)) \end{array}$$

$$R^2 = .97 \quad \bar{R}^2 = .97 \quad \text{S.E.E.} = 41.65 \quad \text{D.W.} = 1.61$$

$$\text{Structural Parameters } \delta = .040 \quad \beta = .036 \quad \gamma = 7.63 \quad \gamma^* = 62.40$$

$$(7.12) \text{ Redfish} \quad \frac{C_{22}}{E_{22}} = 197.646 + .926 \frac{C_{22t-1}}{E_{22}} - 196.587 \frac{E_{22t-1}}{E_{22}}$$

$$\begin{array}{ccc} (3.93) & (15.39) & (-3.33) \\ ((5.02)) & ((-.060)) & ((5.89)) \end{array}$$

$$R^2 = .93 \quad \bar{R}^2 = .92 \quad \text{S.E.E.} = 67.26 \quad \text{D.W.} = 3.14$$

$$\text{Structural Parameters } \delta = -.005 \quad \beta = .064 \quad \gamma = 19.76 \quad \gamma^* = 1.67$$

$$(7.13) \text{ Other Groundfish} \quad \frac{C_{23}}{E_{23}} = 126.593 + 1.089 \frac{C_{23}}{E_{23}} - 146.84 \frac{E_{23t-1}}{E_{23}}$$

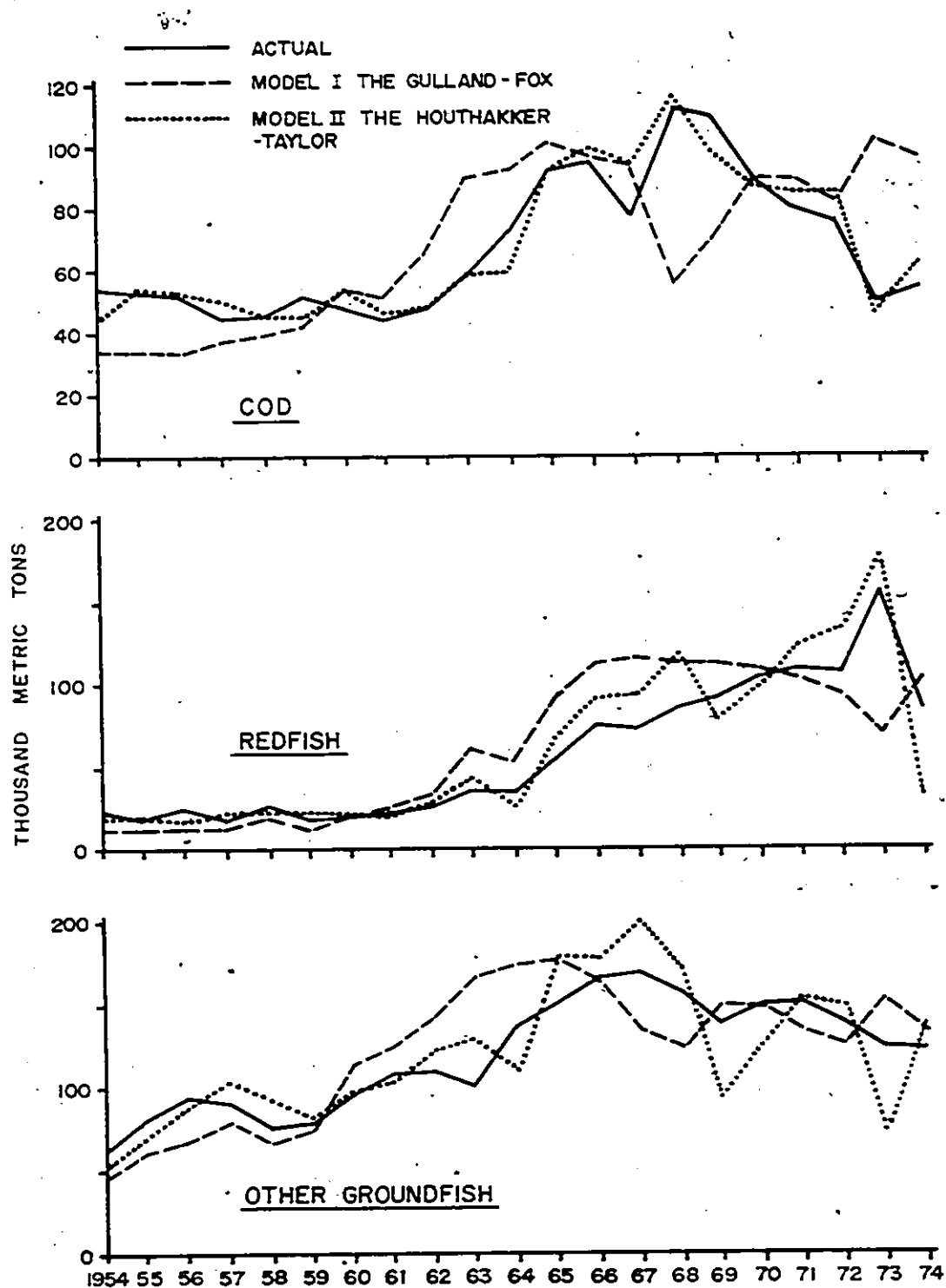
$$\begin{array}{ccc} (1.87) & (18.88) & (-2.04) \\ ((6.739)) & ((-.576)) & ((7.169)) \end{array}$$

$$R^2 = .95 \quad \bar{R}^2 = .95 \quad \text{S.E.E.} = 55.2 \quad \text{D.W.} = 1.07$$

$$\text{Structural Parameters } \delta = .160 \quad \beta = .070 \quad \gamma = 12.66 \quad \gamma^* = 20.10$$

$$n = 21$$

Figure 9 ESTIMATED AND ACTUAL LANDINGS MAJOR SPECIES,
CANADA'S OFFSHORE GROUNDFISH FISHERIES



population is increasing. The short and long term derivatives of effort, i.e., γ and γ^* support the population situation for cod and other groundfish in that they are both positive.

For redfish, δ is negative, indicating a negative natural rate of growth of the stock. This finding, which seems implausible, can be explained by the fact that redfish, unlike other groundfish species, is relatively slow growing and its abundance is very dependent on survival rates of previous year classes which in turn are affected by changes in ecological condition. As a result of this, a negative natural rate of growth, which was small and close to zero, is possible. The peculiar characteristics of redfish population growth however indicate that models which specifically take these into consideration, such as the Beverton-Holt mentioned in Chapter V, might be more pertinent than the models described in this thesis.

The results obtained from model II are in conflict with the overall ICNAF situation of declining rather than increasing groundfish populations. They indicate that Canadian fishing effort should increase for cod and other groundfish. Model I's results also support increasing fishing effort for other groundfish. A possible explanation for

the dichotomy between the overall ICNAF and the Canadian situation is that Canada's offshore groundfish fleet did not avail itself of many groundfish resources available to it with the result that there is some potential for increasing the fishing effort of this fleet.

4. A Comparative Analysis of the Models.

The empirical testing of models I and II indicated that the Houthakker-Taylor stock adjustment model gave superior results to the Gulland-Fox model in terms of statistical tests and goodness of fit. From an explanatory standpoint, the models supported the findings of ICNAF scientists for the northwest Atlantic groundfish fisheries.

As pointed out earlier, the acid test of models is their predictive capabilities. As a result, the models were tested by using them to make short-term predictions for the period 1975-1977. The results obtained were extremely poor for both models and were therefore not a significant test for comparing them. The main reason for this is that this period was a period of controlled exploitation while the models were based on a period of largely uncontrolled exploitation. Thus the models predictive results indicated that controlled exploitation brought about a structural change in the northwest Atlantic groundfish fisheries and in Canada's groundfish fisheries in the area. The major

factors responsible for this change will be treated in the next and final chapter which deals with a period of controlled exploitation.

CHAPTER VIII

POLICY IMPLICATIONS AND CONCLUSION

The previous chapters of this thesis dealt with the northwest Atlantic groundfish fisheries and Canada's east coast groundfish industry during the period of the early 1950's to 1974, a period of virtually uncontrolled exploitation. The effects of this type of exploitation conformed to the biological and economic theories and models of fisheries under uncontrolled exploitation: that is, they led eventually to overexploitation of the resources and to decreasing economic returns.

This chapter will be concerned with the problems of controlled exploitation since it will deal with the period from 1974, a period of controlled exploitation and jurisdictional changes. These latter changes were due to the large coastal states of Canada and the United States taking over management control for their 200 mile limits from ICNAF in 1977. The controlled exploitation was through the widespread use of quotas or TAC's to reduce fishing effort by ICNAF from 1974 to 1976 and since then by Canada¹. As a

¹ Although Canada took over management responsibility for its 200 mile Economic Zone on January 1, 1977, she honoured the ICNAF allocations imposed on her and other countries for that year. Thus, it was not until 1978 that Canada began to exercise effective control through her own allocation of the TAC's.

result, the chapter will concentrate on: resource management problems during the end of the ICNAF regime, i.e., the period 1974-1976; Canada's management problems for the 200 mile Economic Zone; and the strategy which Canada can pursue to solve some of the major economic problems facing Canada's east coast industry. Attempts will be made where possible to utilize the models, particularly the Houthakker-Taylor, for policy purposes. The chapter will end with a short conclusion on the major findings of the thesis from the models standpoint.

1. The End of ICNAF's Management Regime 1974-1976.

The period 1974-1976 is an important one to fisheries because of ICNAF's management measures to control exploitation and the economic problems caused by these measures to Canada's groundfish industry. A short analysis will therefore be made of the effectiveness of the ICNAF measures for resource management; and of their impact on Canada's groundfish industry.

1.1 ICNAF's Control Over Exploitation by TAC's.

During the period 1974-1976/77, ICNAF controlled the exploitation of the northwest Atlantic groundfish resources through TAC's on individual species and areas. The main objective of these measures continued to be biological; they were designed to reduce effort to levels which would

permit the rejuvenation of stocks. These TAC's were based on recommendations from ICNAF scientists and levels were established by negotiation and agreement of member nations. General concern for the state of the stocks led to a significant reduction in ICNAF's TAC's for groundfish species (Table XXIII).

The GAC for total groundfish species was reduced from 2,050 thousand metric tons in 1974 to 1,324 thousand metric tons in 1976 or by 35 percent. This TAC was reduced further to 970 thousand metric tons in 1977 since, as was pointed out earlier, this TAC was honoured by Canada.² The total groundfish landings from ICNAF areas declined from 1,743 thousand metric tons in 1974 to 1,309 thousand metric tons in 1976 or by 25 percent². The TAC's by major species were reduced considerably with this reduction being greatest for cod, followed by redfish and flatfish, reflecting the order of species needing most attention. As a result, cod landings declined from 791 thousand metric tons in 1974 to 525 thousand metric tons in 1976 or by 34 percent; redfish from 233 thousand metric tons to 179 thousand metric tons or by 23 percent; and flatfish from 719 thousand metric tons to

² Actual landings have been less than the TAC's because of quotas for countries by areas which have not been exploited by these countries. These have been referred to as "paper" quotas.

TABLE XXIII.

ICNAF's TAC's, Groundfish Landings by Major Species, and Total Groundfish Fishing Effort 1974-1976

	1974	1975	1976	1977	Percent Change 1974-1976
	('000 Metric Tons)				
<u>Cod</u>					
ICNAF TAC's	1,079	994	642	352	-41
Actual Landings	791	639	525	n.a.	-34
<u>Redfish</u>					
ICNAF TAC's	209	162	137	125	-34
Actual Landings	233	216	179	n.a.	-23
<u>Other Groundfish</u>					
ICNAF TAC's	762	693	545	492	-29
Actual Landings	719	710	605	n.a.	-16
<u>Total Groundfish</u>					
ICNAF TAC's	2,050	1,849	1,324	969	-35
Actual Landings	1,743	1,565	1,309	n.a.	-25
<u>No. of Groundfish Vessels</u>	1,537	1,455	795		-49
<u>Total Tonnage of Groundfish Vessels</u>	1,523,088	1,804,084	1,165,243		-24
<u>No. of Days Fished</u>	152,705	171,385	143,824		-06
<u>Fishing Effort 10¹¹</u>	2.3258	3.0919	1.6759		-28

n.a. not available.

Sources: ICNAF, Statistical Bulletin, Vol. 26.
ICNAF, List of Fishing Vessels, 1976.

606 thousand metric tons or by 16 percent.

ICNAF's reduced TAC's exerted a significant impact on fishing effort. Although the number of countries exploiting the resources did not decline³, the number of groundfish vessels in the ICNAF fleet was reduced from 1,537 vessels, with a total tonnage of 1,523 thousand metric tons in 1974, to 785 vessels with a total tonnage of 1,165 thousand metric tons in 1976; and the number of days fished from 152.7 thousand to 143.8 thousand during the period. Since fishing effort has been measured by the total tonnage of the fleet times the days fished, this constituted a reduction in effort of 28 percent⁴. Effort had in fact increased by 33 percent between 1974 and 1975 but declined by 47 percent between 1975 and 1976.

The reduced TAC's and resulting effort changes caused economic problems for the fishing fleets of all ICNAF member nations. Although special concessions were given by ICNAF to Canada as a coastal state her TAC reductions caused severe economic problems to her east coast groundfish industry. These were responsible to a great extent for Canada actively pursuing jurisdictional responsibilities for the

3 ICNAF, Statistical Bulletin, Vol. 26, 1977, op.cit.

4 It is interesting to note that a 28 percent reduction in effort resulted in a 25 percent reduction in landings.

200 mile Economic Zone. This was done specifically at the continuing sessions of the Law of the Sea Conference and through bi-lateral negotiations with other countries⁵.

1.2 Crisis in Canada's Groundfish Industry 1974-1976.

Canada's allocation from ICNAF's TAC's for groundfish species were reduced from 408 thousand metric tons in 1974 to 268 thousand metric tons in 1976 (Table XXIV). These allocations did not cover all of Canada's fishing areas since they excluded Canada's territorial limits, i.e., the inshore fishing areas, and Canada's exclusive fishing zones of the Gulf of St. Lawrence and the Bay of Fundy. They, along with Newfoundland's trawler strikes in 1974 and 1975⁶, exerted an influence on Canada's groundfish landings. However, these landings increased during the period from 418 thousand metric tons, valued at \$59 million, in 1974 to 470 thousand metric tons, valued at \$63 million, in 1976.

The changes which took place in the fisheries were more pronounced in the offshore than in the inshore sectors.

⁵ Canada's strategy and its success has been treated by D.A. Pepper, "Men, Boats and Fish in the Northwest Atlantic: An Economic Evaluation", (unpublished Ph.D. thesis) submitted to the University of Wales, April, 1978.

⁶ The first trawler strike in 1974 has already been referred to. There was a second one in 1975 which lasted for about three months.

TABLE XXIV.

Groundfish Landings, Volume and Value,
Canada's East Coast Groundfish Fisheries,
and Fishing Effort 1974-1976

Landings	Inshore		Offshore		Total		ICNAF TAC Allocation
	Q	V	Q	V	Q	V	Q
(V '000 Constant 1971 \$, Q '000 Metric Tons)							
<u>1974</u>							
Cod	102.7	16,807	54.4	8,899	157.1	25,706	199
Redfish	1.8	153	85.4	7,430	87.2	7,583	40
Other Groundfish	52.3	7,763	121.6	18,037	173.9	25,800	168
Total	156.8	24,723	261.5	34,366	418.3	59,089	408
<u>1975</u>							
Cod	106.9	16,218	39.0	5,872	145.9	22,090	193
Redfish	2.7	194	100.2	8,502	102.9	8,696	89
Other Groundfish	53.7	6,769	118.3	17,136	171.0	23,905	187
Total	163.3	23,181	257.5	31,510	420.8	54,691	469
<u>1976</u>							
Cod	132.3	19,802	61.2	9,045	193.5	28,847	154
Redfish	2.6	252	87.1	7,430	89.7	7,682	103
Other Groundfish	55.4	7,727	131.0	18,547	186.5	26,274	173
Total	190.2	27,781	279.3	35,022	469.7	62,803	430
	No. of Vessels	Tonnage	No. of Days Fished	Estimated Effort 10 ⁶			
1974	335	87,642	38,436	3,368.61			
1975	291	87,499	38,820	3,396.71			
1976	302	90,351	38,015	3,434.69			

Sources: ICNAF, Statistical Bulletins and List of Fishing Vessels, op.cit.; Environment Canada, Statistical Review of Canadian Fisheries, 1955-1976, Vol. 9, op.cit.

In the inshore sector, landings increased from their lowest of 156 thousand metric tons, valued at \$25 million, in 1974 to 190 thousand metric tons, valued at \$28 million, in 1976. In the offshore sector, landings declined from 261 thousand metric tons, valued at \$34 million in 1974 to 257 thousand metric tons, valued at \$21 million in 1975, and increased to 279 thousand metric tons, valued at \$35 million in 1976.

Canada's offshore groundfish effort increased slightly by 2 percent between 1974 and 1976. This occurred mainly as a result of increased tonnage of the fleet from 87.6 thousand gross tons to 90.3 thousand gross tons since the number of vessels declined from 335 in 1974 to 302 in 1976, and the total number of days fished remained relatively stable. The decline in the number of vessels was due to the introduction of a licencing policy in 1975 which prevented any expansion in the offshore fleet. Thus, new vessels could only be for replacement purposes and criteria for replacement were established to ensure that the vessels built for replacement would not add to the capacity of the existing fleet.

The groundfish processing industry was affected by the reduced level of landings and raw material throughput for the period 1974-1976 in comparison with the level of throughput in the late 1960's. As a result of the changes, the value of groundfish food products remained stable in.

constant terms of \$160 million in 1974 and 1975 but increased to \$191 million in 1976⁷. This was close to the peak value of production in 1973, indicating increased prices for groundfish food products, since the volume of raw material inputs was about 13 percent less than the volume in 1973. There was, however, no reduction in plant capacity during the period; there were 638 plants in operation on the east coast in comparison with 611 in 1972⁸. The maintenance of and even increase in plant capacity during the period 1974-1976, when raw material inputs were at relatively low levels, was due to government measures to assist the industry during this period.

The decline in the level of landings, in 1974 and 1975 in particular, brought about economic problems in the industry in these two years and also in 1976. These were due to the detrimental effects of overcapacity in both the primary and secondary manufacturing sectors of the industry. As a result, Federal Government programs of assistance to the industry were introduced in 1974, namely working capital loans, inventory financing and product promotion which were

⁷ Environment Canada, Annual Statistical Review of Canadian Fisheries 1955-1976, Vol. 9, op.cit.

⁸ This information was obtained from the Industry Services Directorate, Fisheries and Marine Service, Department of Fisheries and the Environment, which carried out two survey studies on plant capacity levels in 1972 and 1976 respectively.

followed by deficiency payments to vessels and plants. In 1975, the Groundfish Rehabilitation Program was announced and a \$50 million fund established for long term measures for strengthening the industry⁹. Under these programs, the government allocated about \$130 million for the industry during the period 1974-1976¹⁰.

ICNAF quota restrictions brought to the fore management problems for Canada emanating from the overcapacity of the fishing fleet. Early in 1976, it became apparent that the groundfish fleet could take its quota allocations in nine months on the basis of traditional fishing patterns¹¹. Thus, there were prospects of a tie-up of the fleet for three months of the year and the adverse effects of this on plant operations and employment in the Atlantic regional economy. As a result, Canada was faced with the management problem of (1) how to spread out fishing effort during the year to prevent the tie-up of the fleet and processing plants; and (2) how to sub-allocate Canadian quotas amongst

9 These programs will not be treated in any detail in this study. For more details on them see Environment Canada, Policy for Canada's Commercial Fisheries, op.cit., pp. 47-50.

10 *ibid.*, p. 1.

11 Had it not been for the Newfoundland trawler strike in 1975 this problem would have occurred in that year.

her fleets on a rational basis. These problems led to Canada formulating annual fishing plans, the first of which was the 1977 Fishing Plan announced by the Minister of Fisheries on December 21, 1976. This plan, which had three main goals, will be treated in the next section dealing with the management implications of the 200 mile Economic Zone to Canada.

Canada's east coast groundfish industry faced serious economic problems during the period 1974-1976 as a result of ICNAF's controlled exploitation. Conditions in this industry were such that unless control was exercised by Canada over the exploitation of resources the industry would continue to be in dire straits. Canada's fishing industry therefore pressed for taking management responsibilities away from ICNAF. The result was that on June 4, 1976 the Minister of External Affairs announced that Canada would take over jurisdiction of the 200 mile limit on January 1, 1977. A new era in fisheries was about to begin. In the next section, the implications of this new era will be treated.

2. The 200 Mile Economic Zone for Canada, 1977 to 1985.

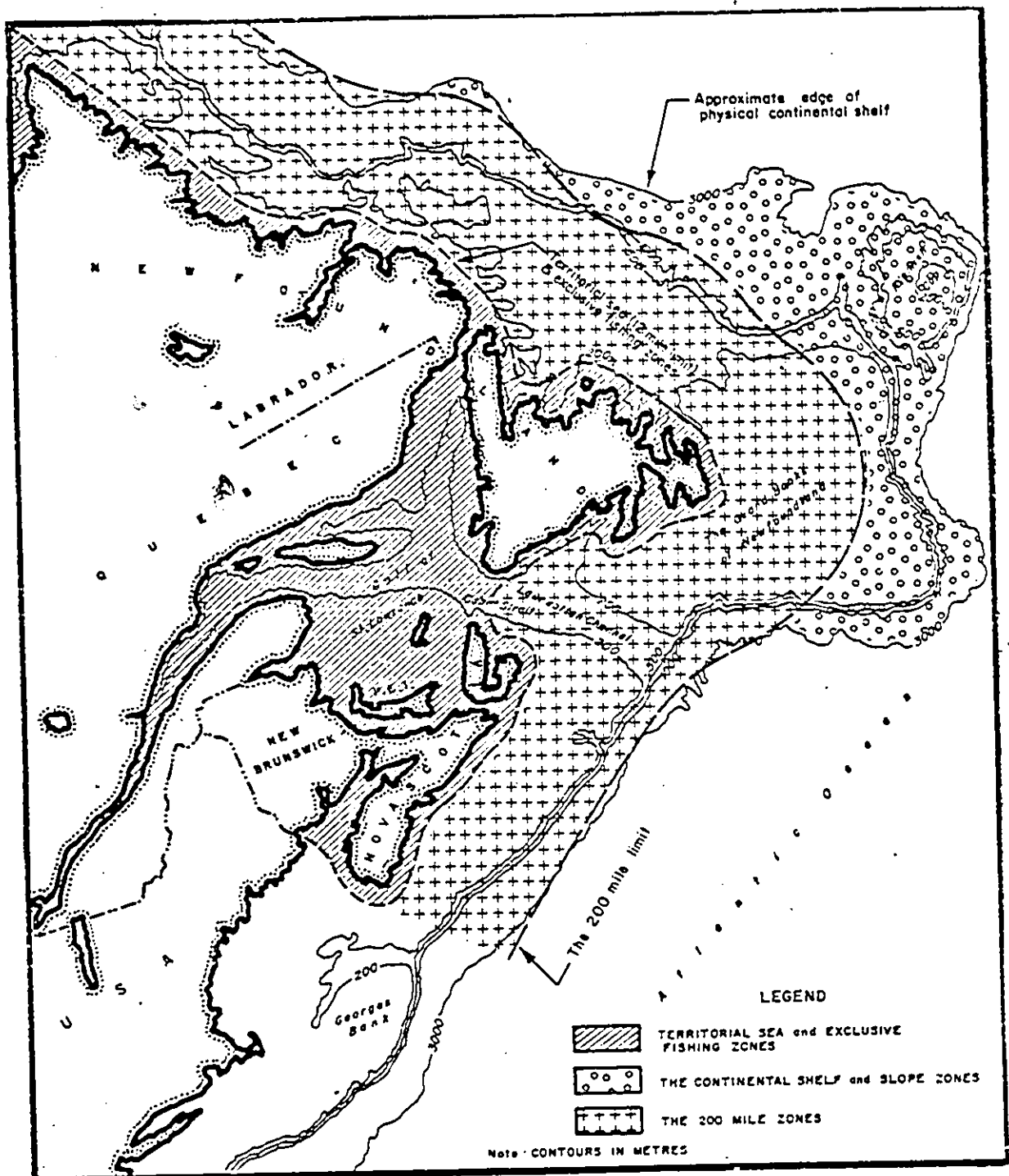
It was pointed out in Chapter III that effective management by Canada of its groundfish (and other) fisheries was not possible because of Canada not having control over international fishing effort. This was changed by Canada taking over management responsibility for the 200 mile limit off its coast on January 1, 1977. Thus, Canada now has coastal state management rights to the fisheries resources off its coast up to this limit (Figure 10). This vast area, covering about 250,000 square miles, contains, based on the level of landings for the period 1972-1976, over 60 percent of the total fisheries resources and 67 percent of the groundfish resources in the northwest Atlantic fishing areas covered by ICNAF sub areas 1-5 with which this thesis deals.

The importance of the 200 mile limit and the major reason why Canada assumed responsibility for this area is that it gives Canada the opportunity to manage the exploitation of the fisheries resources in this area to solve the economic problems of the industry¹². In this section, therefore, the main concern will be with the management strategy which Canada can pursue to attain the objective of a viable

¹² C.L. Mitchell, "The 200 Mile Limit: New Issues, Old Problems for Canada's East Coast Fisheries", Canadian Public Policy, IV: 2, Spring 1978.

Figure 12

THE 200 MILE LIMIT AND CANADA'S EXCLUSIVE FISHING
ZONES, NORTHWEST ATLANTIC FISHERIES



industry since without this viability the industry would continue to require considerable government assistance and support.

2.1 The Strategy for Development.

The strategy for the economic development of the fishing industry hinges on making the industry play the role of a leading sector in the Atlantic regional economy. In Chapter IV, the role of the leading sector was considered in a growth pole context in that the points of growth are by means of a propulsive industry. This propulsive industry has been described by Hirschman in terms of a leading sector theory¹³.

For fisheries to play the role of a leading sector in the Atlantic regional economy the following are necessary:

- (i) "an expanding volume and value of output in both the primary and secondary sectors of the industry;
- (ii) greater efficiencies in production in both sectors brought about by a better utilization of existing capacity, requiring some technological transformation; and

¹³ Hirschman, op.cit.

(iii) as a result of (i) and (ii), the generation of capital through industry profits to sustain momentum in the industry and in other supplementary industries associated with it"¹⁴.

The difficulties of Canada's east coast fishing industry meeting these requirements are apparent from this thesis. They can be summarized by the following: (a) resource constraints have made it difficult to bring about an expansion in the volume and value of output; (b) until there was control of entry, free entry brought about excess capacity, prevented efficiencies of production or dissipated the results of these efficiencies; and (c) because of (a) and (b), the fishing industry was unable to generate capital for its developmental needs, and to exert strong demand linkage effects on other industries. With the opportunities provided by the 200 mile Economic Zone and better management these can all change.

2.2 Canada's Management Objectives, Groundfish Fisheries.

Under ICNAF's management regime, the primary management objective was biological, i.e., to prevent overexploitation and protect threatened resources. For Canada, the

¹⁴ C.L. Mitchell, "The 200 Mile Limit: New Issues, Old Problems for Canada's East Coast Fisheries", op.cit., p. 176.

management principle is based on the "best use" concept which involves taking biological and socio-economic aspects into consideration.

Because of the structure of Canada's groundfish fisheries, their management requires two basic approaches; one for the offshore fisheries, and another for the inshore fisheries. In the inshore fisheries, where the majority of Canadian fishermen operate, the main concerns are with protecting inshore resources and improving economic returns to fishermen. In the international offshore fisheries, the main concerns are preventing overexploitation and bringing about a more efficient and stable allocation of Canadian fishing effort in relation to resource availability. In fact, Canada's declared management strategy for the 200 mile limit is based on her share of the resources in the area being determined by the catching capacity of her fleet, with the surplus to be shared amongst the foreign nations.

The major objectives for the management of Canada's groundfish fisheries for the 200 mile limit have been expressed in the 1977 fishing plan as follows:

- "(1) to avoid conflicts between local and mobile fleets over scarce fisheries resources,
- (2) to let fish stocks rebuild for bigger catches in the future,

(3) to stretch out the available resources, so as to keep the groundfish industry working all year round"¹⁵.

The management measures implemented by Canada to attain these objectives revolve around (a) controlling fishing effort in the offshore fisheries through licence limitation of Canada's offshore fleet; (b) overall quota allocation for Canada and the foreign nations, and (c) the encouragement of the exploitation of new species and areas.

Canada introduced in 1977 licencing for the foreign fleet and in 1978 charged licence and resource use fees. These fees were expected to raise about \$10 million in revenues. The foreign countries are also required to provide Canada with a detailed fishing plan every year indicating how they will utilize their fleets to take the quotas allocated to them by Canada. These measures are, therefore, designed as a means of controlling foreign fishing effort and of raising revenues from the foreign fleets operations.

The third measure, that of encouraging the exploitation of new species and new areas, was the direct result of the surplus fishing capacity of Canada's offshore fleet. In order for the fleet to operate on a year round basis it

¹⁵ Fisheries and Environment Canada, Fishermen's Special Bulletin, Ottawa: January 11, 1977, p. i.

was necessary for the fishing effort curtailed by quotas to be employed in areas or for species where Canada had quotas but which were not generally highly exploited by the Canadian fleet. These have been referred to respectively as non-traditional areas and non-traditional species. Measures to encourage their exploitation, mainly financial incentives, were established¹⁶.

Resource management, therefore, remains the major problem area for Canada under the 200 mile Economic Zone. It also offers the best prospects for fisheries development if it can succeed in meeting the objective of bringing about a viable industry. Because of its importance, the next section will discuss the use of the models as management tools in aiding to answer some of the major questions now facing Canada's fisheries management.

3. The Models as Management Tools.

The use of models as management tools hinges on their explanatory and predictive powers. However, since for reasons given earlier the models were inadequate for predictive purposes, their use for policy purposes will be based mainly on their explanatory powers. The models will

¹⁶ These incentives are to cover the additional costs to vessels for fishing in new areas, *ibid.*, pp. 9-11.

therefore be applied to some of the present short term management problems relating to fishing effort in the groundfish fisheries now under Canadian jurisdiction and control. The two main areas where the model's results are relevant are (1) with the reduced effort levels in Canada's 200 mile Economic Zone, how soon can the stocks rebound, and (2) what is the capacity of Canada's offshore groundfish fleet. Both of these are the two most important management questions faced by Canada at this time since the first will establish the total groundfish resources available in the northwest Atlantic, and the second will determine Canada's share of these resources, and the magnitude of resources available to the foreign countries.

3.1 Resource Projections: Rates of Recovery.

Projections have been made by Canadian scientists for the total landings of groundfish and other species in the northwest Atlantic areas within Canada's 200 mile limit and beyond (i.e., the Flemish Cap). These projections indicate that the TAC's for total groundfish in Canada's traditional groundfish fishery should increase by only 16 percent by 1985 and by 22 percent for all areas, i.e., traditional and non-traditional to Canada, over 1976 levels (Table XXV).

TABLE XXV.

Projected TAC's Major Groundfish Species,
Selected Years 1978-1985

	TAC's Allocations				Projected TAC's		Change 1976-1985
	1976*		1978*		1982	1985	
	Total TAC's	Canadian Share	Total TAC's	Canadian Share	Total TAC's	Total TAC's	
	('000 Metric Tons)						(Percent)
Cod	462	191	322	204	497	590	+28
Redfish	153	88	138	97	133	136	-11
Other Groundfish	218	156	220	166	234	242	+11
Total Traditional ¹	833	435	680	467	864	968	+16
Total Groundfish ²	981	462	881	538	1079	1193	+22

* Excluded presently unregulated groundfish species. Based on data presented in Table XXII, about 340 thousand metric tons of groundfish species has been excluded. Thus the projections account for 74 percent of total groundfish species.

1 There are TAC's for the areas within Canada's 200 mile Economic Zone, i.e., primarily ICNAF sub areas 2-4. Sub area 5 (George's Bank) is also included.

2 These include ICNAF sub areas 2-6.

Source: Department of Fisheries and the Environment, "Atlantic Coast Resource Prospects - 1978 to 1985", (Unpublished paper) Ottawa, December, 1977.

These projections have been made mainly¹⁷ on the basis of what is called the $F_{0.1}$ rule which states "that the optimal rate of fishing mortality is the one at which the marginal sustainable yield is equal to one-tenth the C.P.U.E. which would be enjoyed if the stock were lightly fished¹⁸". This rule, which owes its origin to Gulland, is based on the economists's static fisheries model and is really an application of marginal analysis in physical terms in that it attempts to equate the marginal catch with marginal effort¹⁹. The $F_{0.1}$ rule is considered a "safe bet" level of fishing²⁰ since it allows for stability, improved catch rates, and a margin of error. The improved catch rates are the result of the recovery rates of fish stocks.

The Houthakker-Taylor model, through its parameter estimates of δ and β , provides the information to indicate what impact changes in the level of fishing effort would have on the recovery rates of stocks. The model's results were therefore used to test whether they would agree with the projections made by the scientists. To do so, it was

¹⁷ In some cases they were made on an MSY basis.

¹⁸ G.R. Munro, "Canada and Fisheries Management with Extended Jurisdiction: A Preliminary View", in the Economic Impact of Extended Jurisdiction, op.cit., p. 39.

¹⁹ *ibid.*, p. 39.

²⁰ D.A. Pepper, op.cit.

assumed that: (1) the parameter estimate of δ (the natural rate of population growth) would remain constant at least in the short run but the percentage change in effort would affect the parameter estimate of β (the stock adjustment due to fishing effort) accordingly; and (2) the rate of growth in landings would be the same as the rate of growth in the underlying stock, i.e., $\delta - \beta$.

On the basis of these assumptions, a reduction in fishing effort of 25 percent from 1974 to 1976 (close to the actual reduction of 28 percent) would bring about increases in total groundfish landings of 9 percent by 1985 (Table XXVI). In 1977, Canada was able to obtain a reduction in overall ICNAF fishing effort by 40 percent of its 1972-1973 level²¹. This reduction would result in an average growth rate of 2.1 percent a year for total groundfish and would, if it had come into effect in 1976, increased landings by 21 percent by 1985. This, compared with the scientist's projections that landings would increase by 22 percent over their 1976 level, indicates that the 40 percent reduction in overall fishing effort would be sufficient to ensure the

21 At the ICNAF meetings in 1976, Canada was able to obtain agreement that total fishing effort would be reduced by 40 percent on the basis of a 40 percent reduction in the average number of days fished in 1972 and 1973. Although there is a different measure of fishing effort used in this thesis, this objective was accepted as realized in 1977.

TABLE XXVI.

Effort Reductions and Rates of Growth of Northwest Atlantic Groundfish Stocks and Landings, Houthakker-Taylor Model

	H-T Model Parameter Estimates		Effort Reductions on β			Rates of Growth of Stocks & Landings			Percentage Growth 1976-1985			
	δ	β	25%	(a)	(b)	(c)	(a)	(b)	(c)	(a)	(b)	(c)
Cod	.048	.050	.037	.037	.032	.030	.011	.016	.018	10.3	15.3	17.4
Redfish	.079	.087	.065	.065	.056	.052	.014	.023	.027	13.3	22.7	27.1
Other Groundfish	.069	.081	.061	.061	.053	.049	.008	.016	.020	7.4	15.3	19.5
Total*	.062	.069	.052	.052	.045	.041	.010	.017	.021	9.4	16.4	20.6

* This is a weighted average growth rate based on the proportion of major species landings in 1976.

level of landings projected for 1985.

This analysis serves mainly to demonstrate that the Houthakker-Taylor model provides data which can be used to give some idea of what reductions in the level of fishing effort, the management control variable, will be required to obtain desired levels of stock and landings growth. Thus, the management authority, in this case Canada, can control recovery through this means. Decisions have to be made however about whether it is better to have relatively high effort levels now, and thus have a low rate of recovery, or reduce effort levels substantially now, and have more rapid recovery in the future. These aspects, which depend mainly on economic factors, will not be considered in this thesis. Instead, the projected landings made by the scientists would be accepted as given. As a result of this the more important question to Canada is what is the capacity or fishing capability of its existing fleet.

3.2 Canada's Groundfish Fleet Capability.

Canada's offshore groundfish fleet capability is of importance from two standpoints: (1) its implications for the present existing surplus capacity and poor economic returns to vessel operations, and (2) it will give some idea of what Canada's offshore fleet can take if operated to full capacity and what, if any, would remain for foreign fleets. Although the models are limited in their use in answering

these questions, the Gulland-Fox model gives estimates of optimal fishing effort, and the Houthakker-Taylor of recovery rates. By combining these elements, with some economic analysis, they can shed some light on the future prospects for Canada's groundfish fisheries.

The main reason why Canada's offshore groundfish fleet was not efficiently utilized, leading to poor economic returns, was due to the resource constraints imposed by the TAC's. These resulted in a decrease in the average number of days fished per vessel in this fleet from 124 days in 1968-1971 to 115 days in 1974 but this increased to 126 days in 1976 mainly because there was a decrease in the number of vessels in the fleet. At this latter level, however, the fleet operated in the red since total costs were estimated to have exceeded total revenues by approximately 25 percent²². Thus, for the fleet to achieve a break even level and operate economically it must be more efficiently utilized.

The Gulland-Fox model estimates of optimal Canadian offshore groundfish fishing effort were 35 percent higher

²² This is based on average prices and average cost per pound of fish landed by selected groundfish vessels in Nova Scotia. See J.P. Charron, Costs and Earnings Studies of Selected Fishing Enterprises Nova Scotia 1975-1976, op. cit., Table 13(a), p. 29.

than 1976 levels of effort. Assuming that increases in effort levels would increase landings by the same amount, Canada's offshore groundfish fleet, fishing in traditional areas, has the capacity to take about 380 thousand metric tons, or 100 thousand metric tons more than the quantities landed in 1976. At this volume of landings, if there is no increase in the number of vessels, the average number of days fished per vessel would be 170 days. Over the years the Costs and Earnings studies have indicated that there is nearly a one to one ratio between the number of days spent at sea and decreases in costs per day at sea²³. Thus, this increase would reduce vessel costs per unit of output and make a significant contribution to improving the economic performance of vessels in the fleet.

The implications of Canada's offshore groundfish fleet's capability on future short term prospects for the east coast groundfish industry to 1985 can now be assessed. To do so, the following assumptions are made: (1) that Canada's offshore groundfish fleet would attain optimal effort levels of the Gulland-Fox model by 1980; (2) that landings would then increase once these optimal levels are

²³ The operations of large stern (155 ft) and side (141 ft) trawlers over a number of years showed that an 18 percent increase in days at sea resulted in a 17 percent decrease in cost per day at sea. J. Proskie and J.P. Charron, op.cit.

attained at the same rate as the stock recovery predicted by the scientists, (3) that inshore groundfish landings would increase by about 15 thousand metric tons a year²⁴; and (4) that average price trends for groundfish species by the inshore-offshore sectors for the period 1970-1976 will continue to 1985. The results using these assumptions are shown for the period 1980-1985 in Table XXVII.

The scenario which emerges shows that Canada's total groundfish landings could increase from 630 thousand metric tons valued at \$109 million in 1980 to 786 thousand valued at \$183 million by 1985. The surplus remaining for the foreign fleets was 167 thousand metric tons in 1980 and 182 thousand metric tons by 1985. Canada might, however, expand its fishing effort to take this surplus by that time. The magnitude of groundfish resources which will be available to Canada can solve the economic problems faced by the east coast groundfish industry providing there is little expansion in both the offshore fleet and plant processing capacity, and restrictions are imposed on entry of fishermen in the inshore groundfish fisheries. These are the main management

²⁴ This is based on the average increase in inshore landings between 1974 and 1976 which was slightly higher than 15 thousand metric tons a year. Although substantial increases in inshore landings have been reported for 1977 and 1978, it is thought that the increases projected might hold for the longer run, i.e., the period up to 1985.

TABLE XXVII.

Short Term Projections 1980-1985,
Canada's East Coast Groundfish Fisheries

	Offshore Fleet		Inshore Fleet		Total		Biological Projections Traditional Species*	Surplus for Foreign Fleet
	Q	V	Q	V	Q	V		
	(Q in '000 metric tons, V in \$'000 constant 1971 dollars)						000 metric tons	
1980	380	60,138	250	48,750	630	108,888	797	167
1981	395	65,965	265	55,544	660	121,509	828	168
1982	411	72,644	280	63,084	691	135,748	864	173
1983	427	79,934	295	71,449	722	151,383	896	174
1984	444	88,045	310	80,742	754	168,787	932	178
1985	461	92,246	325	90,967	786	183,213	968	182

* Table XXV.

challenges which Canada would be faced with in the years ahead.

4. Conclusion.

The effects of man's exploitation of fisheries resources have been rather difficult to assess. The main reason for this is that the underlying resource, the fish population, is not known neither are its growth rates or natural mortality. Biologists have attempted models of this exploitation based on factors which are known and measurable, namely, catch and fishing effort data, but these models have concentrated on physical factors. However, fisheries exploitation takes place for economic reasons with the result that economic variables, such as (a) costs of fishing operations and (b) prices and revenues, are important. This thesis concentrated on biological models but their impact on the economic theory and models of fisheries was discussed.

The most popular biological models are (1) the steady state model associated with Schaefer, and (2) the Gulland-Fox exponential model. The Schaefer model assumes that the underlying population is in a steady state or in ecological equilibrium whereby subtractions from that population caused by natural mortality, predation and man's fishing effort are balanced by additions to the population caused by the natural rate of reproduction. It is known, however, that populations

are generally in transient rather than in steady states as a result of man's exploitation. Because of this, an attempt was made to develop a stock adjustment model of fisheries which would allow for the population attaining its ecological equilibrium over time.

Houthakker and Taylor have recently developed a stock adjustment model for demand which has received considerable attention and which seemed especially *à propos* to fisheries since it dealt with a similar situation where an important variable was unknown, namely the stock. The model was therefore adapted to fisheries starting out with the biological model of fisheries population dynamics, and ending up with a reduced form formulation which contained catch and effort variables. Two versions of the Houthakker-Taylor model were discussed: (1) the continuous, and (2) the discrete. The discrete time version permitted a simpler estimation of the structural parameters than the continuous and was therefore used in the thesis.

The Houthakker-Taylor model was tested by comparing the results with the Gulland-Fox model which was used as an alternative to the Schaefer logistic model and proved superior to this model when tested empirically. The two models, i.e., the Houthakker-Taylor and the Gulland-Fox were then used to specify equations for two sectors: sector 1, the northwest Atlantic ICNAF groundfish fisheries; and

sector 2, Canada's offshore groundfish fisheries. The results indicated that the Houthakker-Taylor model was superior to the Gulland-Fox in terms of the standard statistical tests for comparing models. It was not possible, however, to judge the models on the basis of their predictive capabilities. This was because there were significant structural changes brought about by extensive control measures by ICNAF on fisheries exploitation in the northwest Atlantic from 1974 onwards; and by jurisdictional changes with Canada and the United States taking over management control from ICNAF in 1977. The results obtained from the Houthakker-Taylor model augur well for its application in fisheries; it provides a means of estimating the growth rates of stocks and the impact of fishing effort on these.

REFERENCES

Anderson, L., "Optimum Economic Yield of a Fishery Given a Variable Price of Output", Journal of the Fisheries Research Board of Canada, Vol. 30, 1973.

Beddington, J.R., Watts, C.M.K. and Wright, W.D.G., "Optimal Cropping of Self Reproducible Natural Resources", Econometrica, Vol. 43, No. 4, July, 1975.

Bell, F.W., E.W. Carlson, and F.V. Waugh, "Production from the Sea", a paper presented at the U.S. National Marine Fisheries Service Workshop on discussions and research and Ocean Fishery Management, November 5-6, 1970.

Blackwood, C.M., "Fish Processing Capability of Plants in the Atlantic Region", Proceedings Government Industry Meeting on the Utilization of Atlantic Marine Resources, Ottawa: Environment Canada, 1974.

Brewer, K.J., "The Canadian East Coast Groundfish Industry", (unpublished Ph.D. thesis), McGill University, 1972.

Brox, O., "Resettlement in Newfoundland: Some Sociological Comments", Viewpoints on Communities in Crisis, edited by Skolnik, St. John's: Institute of Social and Economic Research, Memorial University of Newfoundland, 1968.

Burt, O.R., and R.G. Cummings, "Production and Investment in Natural Resource Industries", A.E.R., September, 1970.

Carlson, E.W., "Bio-economic Model of a Fishery", Working Paper No. 2, Division of Economic Research, Bureau of Commercial Fisheries, March, 1969.

Carlson, E.W., "Theoretical and Empirical Explorations in the Economics of Marine Resources", (unpublished Ph.D. thesis), Boston College, 1971.

Charron, J.P., Costs and Earnings of Selected Fishing Enterprises Nova Scotia, (annuals) Ottawa: Fisheries and Marine Service, Department of the Environment.

Christ, C.F., Econometric Models and Methods, New York: John Wiley and Sons Inc., 1966.

Clark, C.W., "Economical Optimal Policy for the Utilization of Biologically Renewable Resources", Mathematical Biosciences, 12, 1971.

Clark, C.W., "Dynamics of Commercially Exploited Natural Animal Populations", Mathematical Biosciences, 12, 1972.

Clark, C.W., and Munro, G.R., "The Economics of Fishing and Modern Capital Theory", Journal of Environmental Economics and Management, 2, 1975.

Clark, C.W., Mathematical Bioeconomics: The Optimal Management of Renewable Resources, New York: John Wiley and Sons, 1976.

Clark, C.W., "Control Theory in Fisheries Economics: Frill or Fundamental", The Economic Impact of Extended Jurisdiction, edited by L.G. Anderson, Ann Arbor, Michigan: Ann Arbor Science Publishers Inc., 1977.

Copes, P., Fisheries Development in Newfoundland, a report commissioned by the Department of Regional Economic Expansion, Ottawa: 1967.

Copes, P., "The Backward-Bending Supply Curve of the Fishing Industry", Scottish Journal of Political Economy, Vol. 17, 1970.

Copes, P., "Factor Rents, Sole Ownership and the Optimum Level of Fisheries Exploitation", The Manchester School of Economic and Social Studies, Vol. 40, 1972.

Copes, P., "International Fishery - Resource Management: A Position for Canada", (unpublished paper), Simon Fraser University, Burnaby, British Columbia, 1972.

Copes, P., The Resettlement of Fishing Communities in Newfoundland, Canadian Council on Rural Development, April, 1972.

Copes, P., "Canada's Atlantic Coast Fisheries: Policy Development and the Impact of Extended Jurisdiction" Canadian Public Policy, IV: 2, Spring, 1978.

Crutchfield, J.A., and A. Zellner, Economic Aspects of the Pacific Coast Halibut Industry, Washington: Fishery Industrial Research 1, U.S. Department of the Interior, 1962.

Dagum, C., "On Methods and Purposes in Econometric Model Building", Z. Nationalökonomie, No. 4, 1968.

Dagum, C., "Review of H.S. Houthakker and L.D. Taylor, Consumer Demand in the United States", El. Trimestre Económico, Vol. 24, November, 147, 1970.

Dagum, C., "Un Modèle économétrique de l'offre et de la demande de produits énergétiques: Etude d'un cas concret, Le Mexique", Economies et Sociétés, Tome V. No. 8, Août, 1971.

Dagum, C., "Scheme for a Methodology of Research in Economics", a paper presented at the Fourth International Conference on the Unity of the Sciences, New York, November 27-30, 1975.

Department of Finance, Economic Review, Ottawa: The Queen's Printer, April, 1975.

Dhrymes, P.J., et al, "Criteria for Evaluation of Econometric Models", Annals of Economic and Social Measurement, Vol. 1, No. 3, July, 1972.

Durbin, J., "Testing for Serial Correlation in Least Squares Regression are Lagged Dependent Variables", Econometrica, Vol. 38, 1970.

Environment Canada, Annual Statistical Review of Canadian Fisheries, Vols. 1-9, Ottawa.

Environment Canada, Policy for Canada's Commercial Fisheries, Ottawa: May, 1976.

F.A.O., The Fish Resources of the Ocean, compiled and edited by J.A. Gulland, London: The Whitefriars Press Limited, 1971.

Fisheries and the Environment Canada, Fishermen's Special Bulletin, January 11, 1977.

Fisheries and the Environment Canada, "Atlantic Coast Resource Prospects - 1978 to 1985", (unpublished paper) Ottawa, December 1977.

Fox, W.W., "An Exponential Yield Model for Optimizing Exploited Fish Populations", Transactions American Fisheries Society, No. 99, 1970.

Friedman, M., Essays in Positive Economics, Chicago: University of Chicago Press, 1953.

Fullenbaum, R.F. and E.W. Carlson, F.W. Bell, "Economics of Production from Natural Resources: Comment", A.E.R., June, 1971.

Gadd, A., and H.O.A. Wold, "The Janus Quotient, A Measure for the Accuracy of Prediction", Econometric Model Building, Essays in Causal Chain Approach, edited by H.O.A. Wold, Amsterdam: North Holland Publishing Company, 1964.

Gates, J.M. and Norton, V.J., The Benefits of Fisheries Regulation: A Case Study of the New England Yellowtail Flounder Fishery, University of Rhode Island Marine Technical Report No. 1, Kingston, Rhode Island: 1974.

Gorbet, F.W., "Econometric Models: Some Comments on Their Use in Policy Analysis", Bank of Canada Review, Ottawa: October, 1973.

Gordon, H. Scott, "An Economic Approach to the Optimum Utilization of Fishery Resources", Journal of the Fisheries Research Board, Vol. X, September, 1953.

Gordon, H. Scott, "The Economic Theory of a Common Property Resource: The Fishery", Journal of Political Economy, No. 62, 1954.

Gulland, J.A., "Fishing and the Stocks of Fish at Iceland", Fisheries Investigation (series 2). U.K. Ministry of Agriculture and Fisheries, 1961.

Hannesson, R., Economics of Fisheries: Some Problems of Efficiency, Lund Economic Studies, Lund, Sweden: 1974.

Higgins, B., "Growth Pole Policy in Canada", Growth Centres in Regional Economic Development, edited by N.M. Hansen, New York: The Free Press, 1972.

Higgins, B., "Development Poles: Do they Exist", Research Paper No. 7503, Faculty of Social Sciences, University of Ottawa.

Hirschman, A.O., The Strategy of Economic Development, New Haven: Yale University Press, 1965.

Houthakker, H.S. and L.D. Taylor, Consumer Demand in the United States 1929-1970, Cambridge, Massachusetts: Harvard University Press, Second Edition, 1970.

The International Commission for the Northwest Atlantic Fisheries, Statistical Bulletin, (annuals), Dartmouth, Nova Scotia.

The International Commission for the Northwest Atlantic Fisheries, List of Fishing Vessels and Summary of Fishing Effort in the ICNAF Convention Area, (tri-annual) Dartmouth, Nova Scotia.

The International Commission for the Northwest Atlantic Fisheries, "Report of the Working Group on Joint Biological and Economic Assessment of Conservation Actions", Annual Proceedings, Vol. 17, Dartmouth, Nova Scotia, 1968.

The International Commission for the Northwest Atlantic Fisheries, Convention Article VIII, Dartmouth, Nova Scotia, 1949.

Isard, W., Introduction to Regional Science, Englewood Cliffs, N.J.: Prentice-Hall, Inc., 1975.

Intrilligator, M.D., Mathematical Optimization and Economic Theory, Englewood Cliffs, N.J.: Prentice-Hall, Inc., 1971.

John, J., Atlantic Coast Groundfish Marketing, a background study for the Department of Regional Economic Expansion, Ottawa, June, 1970.

Johnston, J., Econometric Methods, Second Edition, New York: McGraw Hill, 1960.

Koopmans, T.C., Three Essays on the State of Economic Science, Toronto: McGraw Hill Book Company Incorporated, 1957.

Levitt, K., "A Macro Economic Analysis of the Structure of the Economy of the Atlantic Provinces, 1960", a paper presented to the Canadian Economic Association Meeting at York University, June, 1969.

Levitt, K., Input-Output Study of the Atlantic Provinces 1965, Ottawa: Statistics Canada, 1975.

REFERENCES

197

Lotka, A.J., The Elements of Physical Biology, Baltimore: Williams and Wilkins, 1928.

Mitchell, C.L., and D.B. McEachern, Development in the Atlantic Coast Herring Fishery and Fish Meal Industry, Canadian Fisheries Reports No. 16, Ottawa: Department of Fisheries and Forestry, 1970.

Mitchell, C.L., and H.C. Frick, Government Programs of Assistance for Fishing Craft Construction in Canada, Canadian Fisheries Reports No. 14, Ottawa: Department of Fisheries and Forestry, 1970.

Mitchell, C.L., "The 200 Mile Limit: New Issues, Old Problems for Canada's East Coast Fisheries: Canadian Public Policy, IV: 2, Spring 1978.

Noelzel, B.G., A Report on the Economics of Polish Factory Trawlers, Working Paper No. 9, Division of Economic Research, U.S. Bureau of Commercial Fisheries, February, 1969.

OECD, Review of Fisheries in OECD Member Countries, (Annuals), Paris.

OECD, Financial Support to the Fishing Industry, Paris: 1971.

Paulaha, D., "A General Economic Model of Commercial Fisheries", (unpublished Ph.D. thesis) University of Washington, 1970.

Pearl, R., Studies in Human Biology, Baltimore: Wilkins and Wilkins, 1924.

Pepper, D.A., "Men, Boats and Fish in the Northwest Atlantic: An Economic Evaluation", (unpublished Ph.D. thesis), submitted to the University of Wales, April, 1968.

Proskie, J. and Charron, J.P., Costs and Earnings of Selected Fishing Enterprises Atlantic Provinces, (annuals to 1969) Ottawa: Department of Fisheries and the Environment.

Perroux, F., "Note sur la nation de pôle de croissance", Economie Appliquée, January-June, 1953.

Plourde, C.G., "A Simple Model of Replenishable Natural Resource Exploitation", A.E.R., September, 1970

Quirk, J.P., and V.L. Smith, "Dynamic Economic Models of Fishing", Economics of Fisheries Management: A Symposium, edited by A. Scott, Vancouver: Institute of Animal Resource Ecology, University of British Columbia, 1970

The Research and Productivity Council, Onsite and Data Analysis of East Coast Fish Processing Plants, (unpublished report), Fredericton, New Brunswick, 1977.

Ricker, W.E., Computation and Interpretation of Biological Statistics of Fish Populations, Ottawa: Fisheries and Marine Service, Department of Environment, 1975.

The Royal Commission Canada's Economic Prospects Study, The Commercial Fisheries of Canada, Ottawa: The Queen's Printer, 1956

Sancho, N.G.F., and Mitchell, C.L., "Economic Optimization in Controlled Fisheries", Mathematical Biosciences, 27, 1975.

Sancho, N.G.F., and Mitchell, C.L., "Optimal Fishing Effort of Canada's Offshore Groundfish Fisheries - An Application of Economic Optimization Techniques", Mathematical Biosciences, 34, 1977

Schäfer, M.B., "Fisheries Dynamics and the Concept of Maximum Equilibrium Catch", Proceedings, Gulf and Caribbean Fisheries Institute, Sixth Annual Session, November 1953.

Scott, A.D., "The Fishery, the Objectives of Sole Ownership", Journal of Political Economy, Vol. 63, 1955.

Smith, V.L., "Economics of Production from Natural Resources", A.E.R., Vol. 58, 1968.

Statistics Canada, Fisheries Statistics of Canada, Ottawa.

Statistics Canada, Fish Products Industry, (Annuals, Cat. 32-216), Ottawa,

Stojkovic, George, "Market Models for Agricultural Products", Econometric Model Building: Essays on the Causal Chain Approach, edited by H.O.A. Wold, Amsterdam: North Holland Publishing Co., 1964.

Templeman, W., Marine Resources of Newfoundland,
Ottawa: Fisheries Research Board of Canada, 1966.

Theil, H., Economic Forecast and Policy, Amsterdam:
North Holland Publishing Company, 1961.

Turvey, R., "Optimization and Suboptimization in
Fishery Regulation", A.E.R., Vol. 54, 1964.

Verhulst, P.F., "Notice sur la Loi que la population
suit dans son accroissement", Correspondence Mathématique
et physique publiée par A. Quételet, Brussels: X(1838)

Volterra, V., "Variazioni e fluttuazioni del numero
d'individui in specie animali conviventi", Mem. Acad. Lincei
2, 1926.

APPENDIX I

THE SINGLE RESOURCE MODEL: THE CASE OF DECREASING MARGINAL PHYSICAL PRODUCTIVITY

In Chapter V the logistic model was derived by assuming that the catch was a constant proportion of fishing effort and the fish population or stock. It was pointed out that the catch could be assumed to be a decreasing marginal rate as a result of crowding and stock externalities. That is:

$$(i.1) \quad Ex = rE^\alpha X \quad 0 < \alpha < 1 \quad \text{and}$$

$$(i.2) \quad rE^\alpha X = aX - bX^2, \quad (a, b > 0)$$

In this case, the catch function becomes:

$$(i.3) \quad C = Ex = \frac{a(a-rE^\alpha)}{b} - \frac{(a-rE^\alpha)^2}{b}$$
$$= \frac{arE^\alpha - r^2E^{2\alpha}}{b} \quad \text{which can be expressed}$$

as:

$$(i.4) \quad C = \beta_1 E^\alpha - \beta_2 E^{2\alpha} \quad \text{where}$$

$$\beta_1 = \frac{ar}{b}$$

$$\beta_2 = \frac{r^2}{b}$$

Fishing effort reaches a maximum where $\frac{dC}{dE} = 0$.

Differentiating (i.3) results in:

$$(i.5) \quad \frac{dC}{dE} = \frac{\alpha ar E^{\alpha-1} - 2\alpha r^2 E^{2\alpha-1}}{b} = 0$$

hence:

$$(i.6) \quad E^* = \left[\frac{a}{2r} \right]^{\frac{1}{\alpha}}$$

Substituting optimal effort in equation (i.2), the MSY population is obtained:

$$(i.7) \quad X^* = \frac{a}{2b}$$

It can be shown from (i.5) that the second order condition for a maximum is satisfied since α is positive and less than 1.

ABSTRACT OF
Stock Adjustment Models,
Canada's East Coast Groundfish Fisheries.¹

The problems associated with modelling the exploitation of fisheries resources are studied in this thesis in the context of ICNAF's northwest Atlantic groundfish fisheries and Canada's groundfish fisheries in the ICNAF area for the period from the early 1950's to 1974.

Fisheries exploitation has been difficult to model since the underlying resource, the fish population, is not known neither are its growth rates or natural mortality. Biologists, however, have developed models of fisheries exploitation based on catch and effort statistics to try and estimate the population and the effects of fishing effort on its growth. The most popular biological model used for this purpose is the steady state logistic model applied to fisheries by Schaefer. An alternative to this model, which has provided the main foundations for economic models, is the Gulland-Fox exponential model.

It is known, however, that fish populations are in transient rather than steady states with the result that the Houthakker-Taylor stock adjustment model was adapted for fisheries. This model was tested by comparing its results with the Gulland-Fox model which was more *à propos* to the

¹ C.L. Mitchell, (Unpublished Doctoral Dissertation), University of Ottawa, 1978.

ABSTRACT

data and gave better results than the Schaefer logistic.

The results obtained indicated that the Houthakker-Taylor model was superior to the Gulland-Fox and therefore the traditional biological models. It explained rather well the significant changes in the northwest Atlantic groundfish fisheries and in Canada's offshore groundfish fisheries during the period in question. This was a period of largely uncontrolled exploitation, the results of which conformed to the bio-economic theories that this would lead to biological overexploitation and to decreasing economic returns. The model's results were not useful in a predictive sense for the period after 1974, a period characterized by controlled exploitation. However, its performance augurs well for its use in fisheries.