SPATIAL AND TEMPORAL VARIABILITY OF INSHORE COD LANDINGS IN LABRADOR AND EASTERN NEWFOUNDLAND

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SPATIAL AND TEMPORAL VARIABILITY OF INSHORE COD LANDINGS IN LABRADOR AND EASTERN NEWFOUNDLAND

by

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ABSTRACT

The Newfoundland northern cod inshore fishery has been of great importance to both the Newfoundland economy and thousands of inshore fishermen. This fishery is associated with both spatial and temporal variations in landings. Various studies have been conducted to examine the relationships between landings and biological and oceanographical factors. However, these studies analyzed the relationships at an annual scale. Temporal and spatial variations in landings within a fishing season and among different geographical areas have not been formally investigated. No attempt has been made to forecast inshore cod landings thus far. This study, using the 1974-1991 data, examined the spatial and temporal variability and the relationships between temperature and the landing patterns in the inshore trap and gillnet fisheries. Several parametric and nonparametric forecast models of inshore landings were constructed and tested. Area, year and week effects and their interaction effects on inshore landings were identified and examined using ANOVA. Annual variation of the weekly landing patterns was found to be significantly influenced by water temperature. Significant spatial variation in weekly landing patterns was also found, probably due to the spatial difference of water temperature. Based on the jackknifed prediction sums of squares, probability density function (PDF) forecast models were shown to have some utility in forecasting inshore landings, particularly with respect to the inshore gillnet fishery.

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CHAPTER 1. INTRODUCTION

Marine fish is one of the most important renewable natural resources in the world. It provides an important source of protein and greatly supports the economic activities in many countries and regions. Effective management of the fisheries resource is essential for the optimal utilization of this resource and sustainable economic development. Today, however, over-fishing has compounded the seriousness of fisheries resource management in many parts of the world. In Canada, fisheries resource management is, in particular, facing a great challenge. Due to the dramatic decline of the northern cod stock for reasons that are still not clearly known, the Newfoundland northern cod fishery was forced to undertake a two-year moratorium program in 1992. This action has directly affected the Newfoundland economy and the livelihood of more than twenty thousand fishermen and plant workers. A better understanding of the factors influencing the cod fishery is urgently needed to better manage the resource.

The goal of this study is to examine the variability of the Newfoundland inshore cod fishery and gain a better understanding of the factors affecting this fishery. In this chapter, the concept of resource management and issues in fisheries resource management are addressed. Problems associated with the Newfoundland northern cod inshore fishery are then discussed. The specific objectives and the geographical area of this study are also described in this chapter.

1.1 THE CONCEPT OF FISHERIES RESOURCE MANAGEMENT

Ecological analysis, particularly the study of human-environment relationships, has been an important facet of geographical research since the 1900s. During the last several decades, it has been gaining increasing attention as a result of the growing concern over the environment (Mitchell 1989). Within the broad concept of ecological analysis, resource management emerges as a study concerning the decisions and policies toward the allocation and development of natural resources.

Because the concept of natural resources is closely linked with human needs, cultural perceptions, and technological capability (Zimmermann 1933), resource management is an integrating process of environmental, social, and economic considerations. It involves various steps such as inventory, assessment, analysis, goal formulation, legislation, and policy implementation. In this process, many factors from biophysical, social, economic, political, legal, technological and institutional perspectives need to be incorporated (Krueger and Mitchell 1977). Adding spatial and temporal components to these perspectives, the complex management issues could be illustrated in a three-dimensional diagram which emphasizes the importance and interactions of various perspectives, time periods, and spatial scales (Figure 1.1).

Fisheries resource management is a difficult problem in the field of resource management. Unlike other resources such as forests and agricultural systems which are stationary and have a clear jurisdiction, the fisheries resources are associated with high uncertainty and are common property in nature. These two particular problems, along

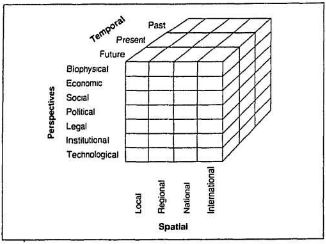


Figure 1.1 Dimensions of resource management.

Source: Krueger and Mitchell (1977)

with some other fisheries resource management issues, have been examined by analysts from biological, social, and economic science disciplines (*e.g.* Gordon 1954; Gulland 1973; Rothschild 1983). Sylvia (1991) grouped issues in fisheries resource management into four topics: the common property nature, resource uncertainty, resource demand and technology, and management process. Due to the common property nature of the resource, much confusion and many disputes on the criteria by which resources are allocated have occurred. The term "tragedy of the commons" (Hardin 1968) is well known: everybody's property is nobody's property. As a result, users tend to ignore the long term impacts of their activities on the resource. The high variability of the fisheries resource and the lack of understanding of the complex ecosystem have created difficulties for resource analysts in providing the much needed information for the political decision-makers (resource managers). The increasing demand on the resource and rapid development of the advance technologies have resulted in a more extensive and intensive exploitation of the fisheries resource. And yet, the effectiveness of the fisheries resource managers and analysts in dealing with these problems and developing information for management process is still far from satisfactory.

Mitchell (1989) suggested that the complexity of resource analysis requires an interdisciplinary approach; however, fisheries resource management continues to be dominated by biologists (Wooster 1988). Draper (1981) pointed out that relatively little research had been conducted by Canadian geographers on fisheries management issues, due to the discipline's lack of interest and research in fisheries in the past. Although attempts have been made to increase geographers' contribution to fisheries research (Mitchell and King 1984), there is still much room for improvement, especially in physical geography. Draper (1981) strongly argued that geographers have the opportunity to improve their performance in and contributions to fisheries analysis and management. In accordance with Mitchell's (1979) analysis of geographers' orientations to resource research, Draper (1981) suggested that geographers could make resource analysis contributions in at least four areas: studies of the fisheries resource (survey, mapping, demand and supply), studies of alternative allocation (spatial, temporal and functional) of the fisheries resource, studies of various variables affecting the fisheries resource allocation and development, and studies of the impact of fisheries resource allocation. Research in these areas will contribute towards a better understanding of the fisheries resource management issue.

1.2 THE NEWFOUNDLAND NORTHERN COD INSHORE FISHERY

The Newfoundland northern cod fishery has a long history. For many years, this resource has been utilized by fishermen from Newfoundland and other countries. However, because of the migratory nature of the northern cod stock, conflicts in the allocation and utilization of the resource exist among regions, provinces, and countries. The common property problem, along with a lack of understanding of the ecological system governing the northern cod stock, have made management of this fishery very difficult. Yet, effective management of this fish stock is particularly important as thousands of fishermen in Newfoundland depend on the fishery for their livelihood.

The inshore sector of the Newfoundland northern cod fishery, the inshore fishery, has been associated with a spatial and temporal variability in landings. It is not unusual that some areas report very good harvests while others suffer a bad year. Even within a particular area, landing could be very high one year but drop dramatically the next. Although the inshore cod fishery has existed for many years and effort has been made to study the inshore cod landings (*e.g.* Akenhead *et al.* 1982; Lear *et al.* 1986; Lilly and Davis undated; Pinhorn 1984), the spatial and temporal patterns of landing variation have not been formally investigated. Reasons for landing variability are even less known. Understanding the spatial and temporal variability in landings for the inshore fishery is one of the major problems facing resource managers in Newfoundland northern cod fisheries management. It is also an interesting research problem for resource analysts.

Spatial and temporal aspects of resource problems are important components in the dimensions of resource management. As resource analysts, we seek to understand the fundamental characteristics of natural resources and their allocation process. The status of resources and their changes over time and space are among the major concerns of resource analysts (Mitchell 1989). It is the intention of this study, through an examination of the variability in inshore cod landings of Labrador and eastern Newfoundland, to identify the spatial and temporal patterns in the inshore cod fishery and to explain these patterns, thereby providing useful information for the management of northern cod. Investigation of the biophysical (biological and environmental) variables which affect resource allocation and development is essential in understanding the ecosystem governing the northern cod stock. Accurate forecasts of inshore landings will provide managers with quantitative information for making management decisions. It is expected that such a study will make a contribution towards several important aspects of fisheries resource management, in particular, problem identification, resource allocation, and management strategy formulation.

1.3 OBJECTIVES

The overall purpose of this study is to examine the spatial and temporal patterns in inshore cod landings off the coast of Labrador and eastern Newfoundland, and to test factors which could explain variability in landings. This is accomplished through the analysis of the existing Department of Fisheries and Oceans (DFO) data on landings and other variables (temperature and cod biomass). Specifically, this study has the following objectives:

1) to identify the spatial and temporal patterns in landing variation. This includes identifying and documenting patterns by different gear types (trap and gillnet), at annual and weekly scales, and in different geographical areas (unit area);

2) to relate the spatial and temporal patterns in inshore landings to cod biomass and an environmental factor (temperature) that may have influence over the landing patterns, and to examine statistical relationships between landing patterns and these factors; and

3) to develop forecast models of inshore landings and to test them with the inshore landing data.

1.4 STUDY AREA

This study used landing data from the inshore cod fishery for the period between 1974 and 1991. The inshore fishery is defined as that involving fixed gear operated by vessels less than 65 feet in length (Lear *et al.* 1986). This fishery operates in two depth ranges by two vessel classes: vessels less than 35 feet in length mainly operate in shallow water with traps, gillnets, hooks and lines; vessels between 35 - 65 feet in length operate in deep water with gillnets. Although there are several types of gears used in the inshore fishery, trap and gillnet are the two principle gears, accounting for 76% c' the annual landings, on average, for the period of 1974 to 1991. Therefore, this study concentrated on these two gear types. Trap and gillnet were chosen also because they are deployed at different depths and catch different ages of fish. Traps are usually deployed at a depth of 20 meters and catch mostly younger fish, while gillnets are generally deployed at depths deeper than 180 meters and catch older fish (Lear *et al.* undated). This suggests that trap landings are likely affected by the abundance of younger age classes of cod and temperature of shallow water, and gillnet landings may have stronger relationships with older age classes and deep water temperature. Hence, it is useful to see the effects of these differences on the relationships between landing, cod biomass and temperature.

Although the inshore fishery operates in most of the NAFO (Northwest Atlantic Fisheries Organization) sub-divisions 2J, 3K and 3L, the focus of this study is on the coastal areas from southern Labrador to eastern Newfoundland (Figure 1.2). These areas (NAFO unit areas 2Ja, 2Jd, 2Jm, 3Ka, 3Kd, 3Kh, 3Ki, 3La, 3Lb, 3Lf, 3Lj and 3Lq) are adjacent to the coast and are the most important fishing grounds for the inshore fishery. Initial data analysis has indicated that these areas accounted for almost the entire landing by traps for the period of 1974-1991. In the gillnet fishery, although landings were reported in as many as 31 NAFO unit areas, landings from areas outside the coastal units

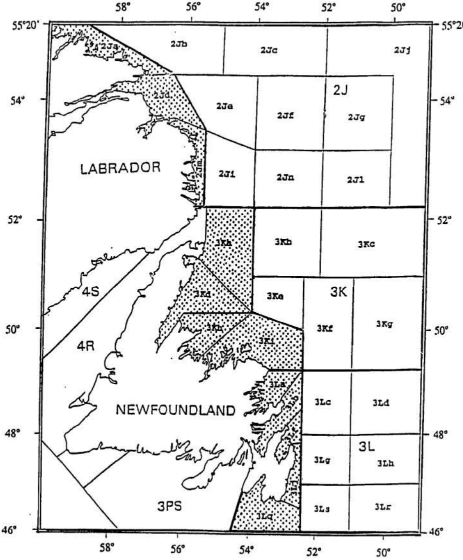


Figure 1.2 Map of NAFO unit areas. Shaded areas are covered in this study.

are very low, with the only exception of 3Lr (Virgin Rocks). 3Lr is a new fishing ground for the inshore gillnet fishery. The gillnet fishery by inshore fishermen in this area did not start until 1987. Catches in this area have been consistently good since then, however, the history of inshore fishery is relatively short, and this area is far away from the coast. It has therefore been excluded from this study.

1.5 SUMMARY

Issues in fisheries resource management are complex. Our knowledge about these issues are limited. As Mitchell (1989) suggested, analysis of resource problem may be pursued through various perspectives (biological, physical, sociological, economic, political, *etc.*). It should be noted, however, that achieving an in-depth knowledge about a perspective, even at one spatial and temporal scale, would require enormous effort (Draper 1981; Krueger and Mitchell 1977). Therefore, it is important to identify and define a research problem, and complete an investigation in time so that the results can be used in a management decision (Mitchell 1989). Aiming at the variability of the inshore cod fishery in Newfoundland, this study focuses on specific spatial and temporal patterns in inshore cod landings and the influencing factors. Research approach, study methodologies, and procedure of data analysis are presented and discussed in the following chapters.

CHAPTER 2. GENERAL APPROACH

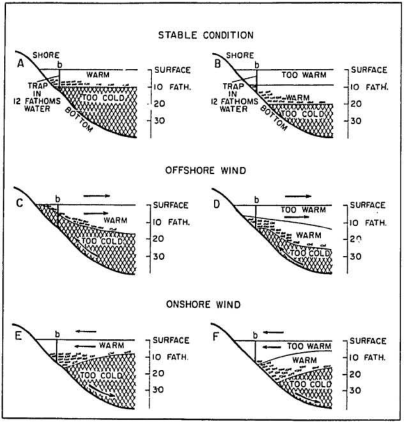
Preliminary discussions and formal meetings with the DFO scientists in St. John's to define the research problems and identify data availability began in the fall of 1991. An extensive review of literature on past studies on the northern coc' fishery, factors influencing the inshore landings, and fishery forecast models was carried out in order to formulate an approach to the research problems. In this chapter, findings and methods of these earlier studies are discussed and justifications are made for the present research. Following the literature review, an examination of data availability was carried out. A general approach was then formulated for this study based upon literature review and data availability.

2.1 LITERATURE REVIEW

The northern cod is defined as a stock (a group of fish in the same geographical area with the same migratory pattern) within NAFO Divisions 2J, 3K, and 3L (Pinhorn 1976). A major characteristic of this stock is an annual inshore-offshore migration cycle. In April to May, schools of spent cod begin to migrate from offshore to inshore. The main migration occurs in June. Cod remain in the inshore area until October when offshore migration begins (Lear and Green 1982). Due to this characteristic of the northern cod stock, the success of the inshore fishery depends upon the extent and duration of the inshore migration, and this in turn may depend upon various factors which could influence the movement, distribution, and availability of cod. Taking into account anthropogenic considerations, Lear *et al.* (1986) categorized factors influencing inshore landings into three broad groups: availability of fish, catchability of fish, and fishing effort. Availability refers to the quantity of fish available for the inshore fishery. This could be affected by biomass, offshore catch, temperature, capelin, *etc.*. Catchability depends on selectivity of gear and the distribution of fish, particularly the vertical distribution. Vertical distribution can be affected by the thickness of the water of suitable temperature and other environmental conditions (*e.g.* wind, cloud, and sunlight). Fishing effort can be affected by catch rate, labour disputes, market, and environmental conditions. For many years, fisheries scientists have been trying to understand the relationships between the influencing factors and landings (*e.g.* Akenhead *et al.* 1982; Lear *et al.* 1986; Pinhorn 1984; Templeman 1966; Templeman and Fleming 1956).

2.1.1 Factors Affecting Inshore Landings

Previous research has concentrated on three key factors affecting inshore landings: oceanographical conditions (chiefly temperature), cod biomass, and capelin abundance. Among these factors, hydrographical conditions were the focus of the earliest studies (Templeman 1966; Templeman and Fleming 1956, 1965; Templeman and May 1965). Templeman (1966) theorized that the shoreward movement of cod to Labrador and eastern Newfoundland coast was influenced by extremes of temperature. He hypothesized that temperature changes forced by wind would result in changes in the distribution and availability of cod inshore as illustrated in Figure 2.1.



A, C, E -- early season B, D, F -- middle and late season

Figure 2.1 Effects of water temperature changes on the inshore availability of cod under diffirent wind conditions.

Source: Templeman (1966).

Various studies have been conducted to test Templeman's theory. Sutcliffe *et al.* (1977) found that trends in cod catch were associated with trends in sea temperature in the Gulf of Maine. Sea surface temperature in July and August was inversely correlated with fish catch. Based upon past research addressing cod temperature ranges, Taggart and Frank (1987) summarized that cod catches in the Northwest Atlantic usually occurred within the temperature range of -1 to 8 °C. In an attempt to test Templeman's theory, Rose and Leggett (1988) reported that no catches were made when temperatures were outside the range of -0.5 to 8 °C along the north shore of the Gulf of St. Lawrence. They found that cod movement and catch in the inshore area were associated with coastal water mass advection caused by alongshore wind. Fréchet (1990) found large catches of cod were taken in water temperatures in the 3.9 - 5.3 °C range and in depth of 100 - 150 fathoms in the Gulf of St. Lawrence. He concluded that temperature and depth are important factors affecting cod distribution.

Since the late 1970s, as concerns over the interaction of cod and capelin arose (TGNIF 1987), studies have been conducted to include cod biomass and capelin abundance as influencing factors on inshore landing variability (Akenhead *et al.* 1982; Lear *et al.* 1986). The shoreward migration of cod suggests cod biomass could be a factor affecting inshore availability. The success of the inshore fishery could therefore be measured by the amount of cod in the population, the proportion of cod migrating inshore and the proportion of the inshore population caught in the inshore fishery (Pinhorn 1984). Using cohort analysis (Pope 1972), Pinhorn (1984) estimated that between 1961 and 1976 the rate of inshore exploitation averaged about 5% of the cod population.

Various studies have indicated that the inshore movement of cod is a feeding migration to take advantage of the concentration of capelin inshore (Pinhorn 1976; Lear *et al.* 1986). Therefore, capelin abundance, particularly the abundance of mature capelin moving inshore to spawn, could be another factor that affects the inshore catch. In a study of cod-capelin relationships using correlation analysis, Akenhead *et al.* (1982) found that neither trap landings nor total inshore landings were correlated with mature capelin biomass, cod biomass, or average temperature of June to September. However, they did find that mature capelin biomass and temperature were two significant factors influencing the cod inshore availability (expressed as trap landings divided by the cod biomass of ages 4-13). Due to the relatively short time period of data (8 years), Akenhead *et al.* (1982) stated that this finding should be considered preliminary.

Perhaps the most comprehensive study of factors influencing the availability of cod and inshore catch variations was conducted by Lear *et al.* (1986). This study included factors such as available biomass of cod, capelin abundance, temperature, and ice cover, and an attempt to relate these factors to inshore landings for various gear types. But Lear *et al.* (1986) cautioned that the biophysical attributes are likely to be interrelated among themselves, and hence regressing cod landings on these attributes might provide misleading results. To minimize the effects of interrelationships, Lear *et al.* (1986) used Principal Components Analysis (PCA) to extract patterns of interrelationships among inshore cod landings from various areas, and among landings and biophysical attributes. Interrelationships among areas and environmental attributes for various gear types were found. Although relationships between environmental features and catches were suggested, the extent to which the biophysical factors may affect the inshore landings was still not clear. The lack of inshore fishing effort data may have contributed to the difficulties in interpreting the relationships and reaching conclusive results (Lear *et al.* 1986).

Fishing effort no doubt influences catches. Rose (1992) argued, however, that the exploitation rate (the number of fish caught relative to the number in the stock) in the inshore fishery may not increase linearly with increasing effort because good fishing locations are limited in number, well known, and used seasonally on a regular basis, whereas new fishing locations may be less effective. Therefore the effect on exploitation rate of additional fixed gears deployed at less suitable sites or times is not likely to be great. In addition, there has never been any catch quota to restrict the inshore fishery. Rose's (1992) study concluded that in the trap fishery in 2J3KL and 3Pn4RS, nominal effort (number of traps deployed) and exploitation rate were not closely related; exploitation rate was largely determined independently of nominal effort. Inshore catches have been responding consistently to the overall abundance of fish. This suggests that variation of inshore fishing effort may have only a limited effect on landings.

2.1.2 Forecast Models

Previous studies on the northern cod inshore fishery have focused on the relationships between landings and biophysical factors. No attempt has been made to predict inshore landings. An accurate forecast of inshore cod landings would assist resource managers in formulating management plans and better prepare them to handle problems which might appear in the fishery. Difficulties in developing forecast models include the lack of inshore fishing effort data and the complexity of the relationships between landings and influencing factors. Although it is generally believed that inshore cod landing could be influenced by biological and environmental factors such as cod biomass and water temperature (Akenhead *et al.* 1982; Lear *et al.* 1986; Pinhorn 1984; Templeman 1966), the relationships between inshore landings and these factors may not be linear and may change over time.

In comparison, various forecast models have been developed for salmon fisheries, particularly on the west coast of Canada, and applied to forecast salmon return with some success. In addition to parametric approaches, typically the linear regression models in which stock size and/or catch per unit effort (CUPE) are often used as independent variables, Bayesian techniques (Fried and Hilborn 1988) and nonparametric approaches (Noakes 1989) have been utilized to develop forecasting models of salmon return. Based on Bayesian statistical theory, Fried and Hilborn (1988) developed a model for incorporating several independent estimates of total salmon run size from different forecast models into a "best" estimate of the salmon run size in Bristol Bay, Alaska. This model offers the resource managers a combined "best" estimate, rather than having to chose among various estimates. This approach was recommended for fisheries stock assessment problems by Hilborn and Walters (1991). They pointed out that although few papers using Bayesian estimation had appeared in fisheries research, Bayesian statistics would find a much wider use in fisheries in the near future.

In recent years, nonparametric approaches have been proposed to deal with the non-linearity in fishery data. One of these approaches, the probability density function (PDF) approach, has proven to be useful (Claytor *et al.* in press; Evans and Rice 1988; Noakes 1989; Rice and Evans 1988). The PDF approach allows the data to determine the relationships among variables instead of being constrained to specific functional relationships or assumptions (Noakes 1989). Such an approach is useful, especially in the case where there is little known about the functional relationships and where great variability in the relationships exists. Evans and Rice (1988) proposed this approach to overcome the problem of having to assume a functional relationship between stock size and recruitment in predicting recruitment. They suggested that the PDF approach may allow recruitment to be predicted more accurately than parametric approaches. Using the nonparametric probability density estimation technique to calculate total run size for Skeena River Sockeye salmon, Noakes (1989) demonstrated that it is a convenient and flexible framework for constructing forecasting models. Claytor *et al.* (in press) adopted this approach in forecasting Atlantic salmon returns, and agreed that the PDF forecast is a suitable method for incorporating uncertainty in biological advice.

2.1.3 Justification for this Study

Major factors influencing the inshore cod catch have been extensively studied. These factors include cod biomass, capelin abundance, and environmental conditions (chiefly temperature). Studies of the inshore cod landing variability were often based on large scale analysis. For example, when considering temporal variations, landings were summed over the year and the annual average value of temperature over summer was used to represent a physical index for the year (Akenhead *et al.* 1982; Lear *et al.* 1986). Existing data on landings are recorded on a daily basis. Analysis at a finer scale could be conducted to further examine the relationships between inshore landings and the influencing factors, and hence, provide a better insight to the understanding of factors affecting inshore landings. Lilly and Davis (undated) conducted a descriptive study of the landing variations within a year, but did not involve an analysis of the factors causing the variations. To date, landing variations within a year have not been formally investigated. Examination of the spatial and temporal (annual and within a year) variations and the influencing factors would be useful in understanding the variability of inshore landings.

In analyzing the relationships between landings and influencing factors, previous studies suggested several factors may affect inshore catch. A conceptual model has been formulated in this study to indicate the possible influences of these factors upon inshore catch (Figure 2.2). In this conceptual model, the amount of fish available for inshore migration mainly depends on cod biomass at the beginning of the year and catch by the

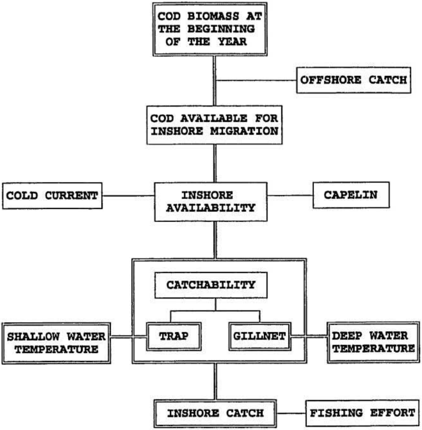


Figure 2.2 A conceptual model of the major factors possibly affecting inshore catch. A much simplified model is highlighted (double-line frame) and tested in this study.

offshore fishery from January 1 to the time when the inshore migration begins. A proportion of cod available for inshore migration will move inshore, depending upon various factors such as temperature and capelin abundance. Catchability of this inshore migrating portion of the stock varies for different gears and different age groups, and could be affected by temperature. Finally, the amount of fish caught will also be affected by fishing effort, which in turn is influenced by biophysical factors (Rose 1992) as well as socioeconomic factors such as labour disputes and markets. Because the focus of this study is on the biophysical factors, the human dimensions of the fishery are not included in this model but would certainly affect the fishery.

This conceptual model includes only some of the major factors that may affect inshore landings. While the ecosystem governing cod is complex, our understanding of the ecosystem, environmental influences, and species interactions is still very limited. Besides those factors included in the model, biophysical factors such as seal consumption of cod and water pollution are also thought to have effects on inshore catch. Limited by our knowledge and the availability of data, attention could only be focused on a few variables. In fact, no model can have all the attributes of the real world; models are by definition simplifications. Models of ecosystems are much simpler than the real system (Hall and Day 1977). Starfield *et al.* (1988) pointed out that no single model can sufficiently address the wide range of potential problems of renewable resources. A model is just a tool; a particular model works best for specific, limited purposes. In the analysis of the effects of major biophysical factors on inshore landings, this conceptual model illustrates the possible linkages for investigation. However, even in this simplified conceptual model, not all variables shown can be included in this study because of the limitation of resource, time, and data. To date, documented inshore effort data for the cod fishery is not available. Inshore capelin catch/effort data (for purse seine vessels and capelin traps) exist for only 9 years from 1983 to 1991 (Nakashima and Harnum 1992). Offshore catch by foreign countries may be substantial but are not accurately known. Therefore, a much simplified model (double-line framed in Figure 2.2) may be advisable. The value of this conceptual model is that it provides a clear direction to explore the possible relationships between landing patterns and influencing factors. It will also prove useful in building hypotheses and developing forecast models that can be tested with the landing data.

2.2 DATA SOURCES

A large amount of detailed data were obtained from DFO, St. John's, to allow for better exploration of the patterns in inshore landings and factors that may influence the patterns. The primary source of these data are the Purchase Slip Records. Other data include temperature profiles at Station 27, and cod biomass estimates from Virtual Population Analysis (VPA) carried out as part of the stock assessment exercise.

2.2.1 Inshore Landing Data

DFO regularly collects inshore cod landing data through Purchase Slip Records.

When fishermen make a sale, the buyer completes a purchase slip, and then forwards it to DFO, St. John's. The purchase slip contains information on the date of landing, amount of fish (in kilograms), vessel class, gear type, area of capture, port of landing, and home port. Inshore vessels are classified into two categories: vessels less than 35 feet in length and vessels between 35 and 65 feet in length. Landings are recorded by vessel classes and gear types. Exact locations of the inshore catch are not available, rather, location of capture is recorded as NAFO unit area (*e.g.* 2Ja, 2Jm, 3Kd, *etc.*). In addition to the Purchase Slip Records, DFO also estimates the amount of fish that is landed but not included in the Purchase Slip Records. These estimates are made on a monthly basis by gear types. Inshore landing data, however, do not include discards by fishermen due to regulation, technical limitation, and market conditions.

Inshore landing data exist since 1959. However, during the early years, landings were not strictly recorded for different gear types. Prior to 1974, landing data by gear are not considered to be reliable (S. Savory, Statistics and Systems Branch, DFO, St. John's, 1992. pers. comm.). To allow for separate analysis of landing variations for different gears, this study used a subset of the inshore landing data, covering a 18 year period from 1974 to 1991. During this period, because the daily landing records for earlier years were incomplete, monthly estimated landings accounted for approximately 80% of annual trap landing and 60% of annual gillnet landing between 1974 to 1980. The proportion of the monthly estimated landings has significantly declined to about 15% since 1981.

Accuracy of the date of landing in the DFO Purchase Slip Records is a concern. For unemployment insurance purpose, fishermen may attempt to spread landings over a period of time so that they can gain enough weeks of employment to qualify for unemployment insurance benefits. If this occurs, the date recorded in the purchase slips will not be the actual date of landing. However, information regarding the extent to which this misreporting occurs is not available thus far. This needs investigation, but it is beyond the scope of this study. In this study, the date indicated in the Purchase Slip Records is assumed to be correct.

2.2.2 Temperature Data

To monitor the ocean climate variation and to aid the analysis of environmental influences on fisheries, temperature data have been collected from standard oceanographic sections and one station on the eastern Newfoundland and Labrador shelves since about 1950 (Petrie *et al.* 1992). These sections and station include, from north to south, Hamilton Bank Section, White Bay Section, Bonavista Section, Grand Bank (47°N) Section, and Station 27 (Figure 2.3). The longest series and the most complete data sets are those from Station 27, located off Cape Spear, St. John's. Since 1946, temperature and salinity measurements at Station 27 have been routinely taken (Narayanan *et al.* 1992). Starting from 1959, temperature observations at standard depths of 0, 10, 20, 30, 50, 75, 100, 125, 150, and 175 meters, have been irregularly collected every year at an average of twice a month (Petrie *et al.* 1992). Temperature data sets from other

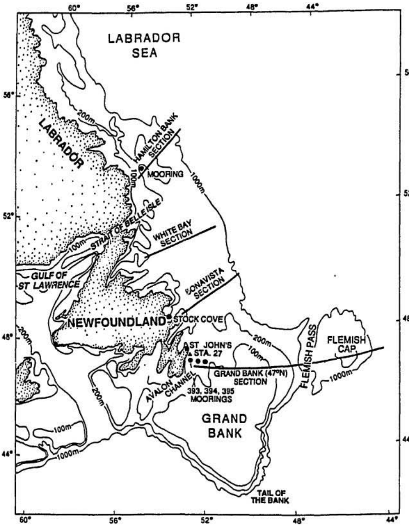


Figure 2.3 Locations of the oceanographical sections and station in Labrador and eastern Newfoundland shelves.

Source: Petrie *et al.* (1992)

oceanographic sections are either short in length or discontinuous.

Oceanographical conditions at Station 27 are considered to be representative of the inshore Labrador current (Narayanan *et al.* 1992). Petrie *et al.* (1988) found that the extent of cold intermediate layer (CIL) across the Newfoundland and Labrador Shelves was highly correlated with the annual and summer temperature at Station 27. Through the examination of ice cover, freshwater runoff and salinity, Myers *et al.* (1990) pointed out that the oceanography of the Labrador Shelf and Station 27 were closely related. The study by Petrie *et al.* (1992) strongly suggested considerable horizontal and vertical coherence of the temperature and salinity variability on the Newfoundland and Labrador shelves. All these studies have indicated that temperature anomalies at Station 27 can be used to represent the variability in the oceanographic conditions on the continental shelf off Newfoundland and southern Labrador (Narayanan *et al.* 1992).

Because the temperature data from Station 27 are representative and constitute the longest and most complete time series, various studies of the environmental influences on the Newfoundland fisheries have used these data for analysis. For instance, Akenhead *et al.* (1982) derived an index of water temperature in the inshore area of NAFO Divisions 2J3KL by summing the monthly water temperature at Station 27 from July to September. Lear *et al.* (1986) used the average temperature for June and July from 100 to 150 meters at Station 27 as an index to represent the conditions over the eastern Newfoundland and Labrador shelfs. In this study, temperature data from Station 27 are used to test the effects of water temperature on the northern cod inshore fishery.

2.2.3 Cod Biomass Estimates

Assessments of cod population biomass using VPA have been conducted since 1962 (Baird *et al.* 1991). Cod biomass estimates are used as basic information for providing scientific advice for the management of the northern cod fishery. Results from VPA have also been used in various studies related to the northern cod stock (Akenhead *et al.* 1982; Lear *et al.* 1986; Pinhorn 1984; Rose 1992). Data on cod biomass estimates at the beginning of the year were obtained from Baird *et al.* (1992). These data cover the period of 1962 to 1990.

2.3 SEQUENCE OF ANALYSES

In accordance with the objectives and considering data availability, this study first examined the spatial and temporal variability in inshore landings, then tested the relationship between landing and potentially influencing factors, and finally constructed and evaluated several parametric and nonparametric models for forecasting inshore landings. To meet these objectives, this study adopted a three stage strategy: (i) data exploration, (ii) hypothesis testing, and (iii) prediction (Figure 2.4). In the first step, a preliminary data visualization and exploration exercise was carried out on a short time period of disaggregated data for 1989 and 1990 to identify variables affecting the spatial and temporal variability in inshore landings, and to build hypotheses to be tested with the longer period data (the entire data set covering 1974-1991). In the second step, patterns in landings were identified and statistical relationships between landing patterns and the

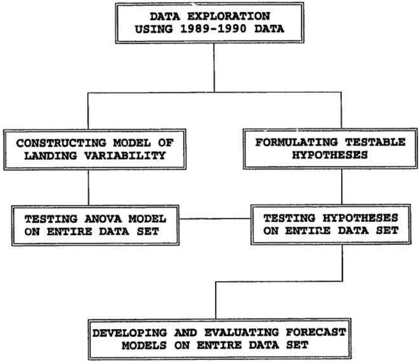


Figure 2.4 Logic flow of the approach adopted in this study.

influencing factors were tested. In particular, an ANOVA model of spatial and temporal variation in inshore landings was fitted to the inshore landing data; a linear relationship between weekly landing pattern and temperature was hypothesized and tested. Finally, using these relationships, forecast models for inshore landings were constructed and fitted to landing data and their predictive performance assessed. Both parametric and nonparametric models for pre-season and in-season forecasts were introduced and their predicting power evaluated using a jackknife procedure. Details of the methods are fully described in the following chapters.

CHAPTER 3. DATA VISUALIZATION AND EXPLORATION

The 1989 and 1990 cod purchase slip records were chosen for data visualization and exploration, as these two years' data are the most complete and clean data sets (D. Tilley, Statistics and Systems Branch, DFO, St. John's, 1992. pers. comm.). Preliminary findings from this exercise are discussed below and are used for analysis in the coming chapters.

3.1 PRELIMINARY FINDINGS

Initial examination of landing data showed a clear weekly cycle in landing variation; landings on weekends were low (Figure 3.1). Because of this, week was selected as the unit to examine for the temporal pattern (seasonal variation) within a year. Standardized weeks were used to number the weeks of the year beginning with week 1 from January 1-7 for each year. Monthly estimates of fish were evenly spread over each day of the month in order to minimize the effect on weekly pattern. Landings were then summed within each standardized week of the season to produce weekly landings. The effects of converting monthly estimates into weekly landings on the analyses of this study are discussed in chapters 4, 5 and 6 accordingly.

Visual inspection of the two years' data suggested variations among areas, years and weeks in inshore landings. Spatially, in the trap fishery, there was an increasing trend in landings from the north to the south (Figure 3.2). Temporally, landings started increasing in late May (around week 20), peaking in late July (around week 28).

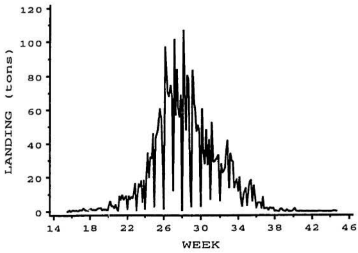


Figure 3.1 Daily landings from the trap fishery in 1989. A weekly cycle in landings is clearly evident.

Landings remained low after early September (around week 40) (Figure 3.3). While the two years data showed a general spatial pattern (increasing trend from the north to the south), a slight variation between the two years existed (*i.e.* suggestion of a year-area interaction effect). In the weekly pattern, there was approximately a 4 week shift in the phase of trap landings from 1989 to 1990, indicating that there may be a year-week interaction effect.

Monthly average temperature at the depth of 20 meters (where traps are normally deployed) also showed seasonal variation between years (Figure 3.4). Water temperature

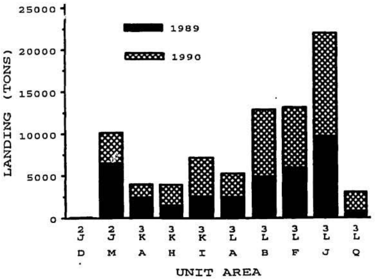


Figure 3.2 Trap landings by NAFO unit area in 1989 and 1990. Spatial variation is evident.

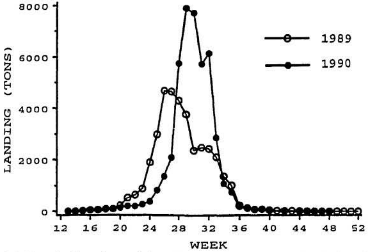


Figure 3.3 Trap landings by week in 1989 and 1990. A seasonal variation within a year and an annual variation between the two years are evident.

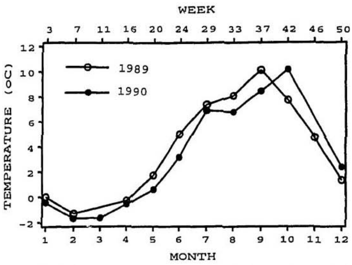


Figure 3.4 Monthly average temperature at the depth of 20 meters in 1989 and 1990. The later warm up of water temperature in 1990 was associated with a later start of the trap fishery in the same year.

in February and March were among the lowest in the year. Starting from April, temperature began to raise steadily. Temperature reached the maximum in September and October, before it started to decline in November. During the two years, temperature warmed up earlier in 1989 than in 1990. The change in water temperature was associated with the change in the weekly pattern in the trap landings shown in Figure 3.3.

In the gillnet fishery, the change of the weekly landing pattern (Figure 3.5) was also associated with a change in the seasonal temperature pattern from 1989 to 1990 (Figure 3.6). The relatively higher temperature in 1989 might have resulted in an earlier

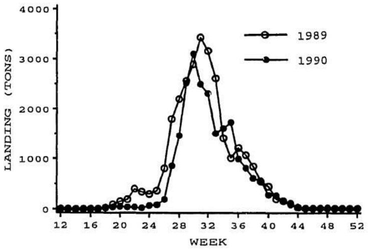


Figure 3.5 Gillnet landings by week in 1989 and 1990.

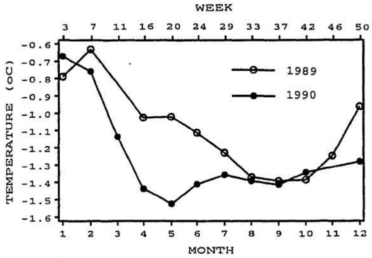


Figure 3.6 Monthly average temperature at the depth of 175 meters in 1989 and 1990. The relatively higher temperature in 1989 was associated with an earlier start of the gillnet fishery.

start of the fishery in the same year, although the effect does not appear to be as strong as in the trap fishery. These preliminary findings suggest the hypothesis that the weekly pattern in the inshore landing is related to the annual changes in water temperature, which is tested using the entire data set in Chapter 5.

Spatial differences in the timing of the fishery were also indicated in the two years data exploration. The weighted midpoint of the fishing season (weighted by weekly landings) changed from area to area (Figure 3.7). The fishing season became increasingly later from south (3L) to north (2J) in both years. This pattern may be related to water

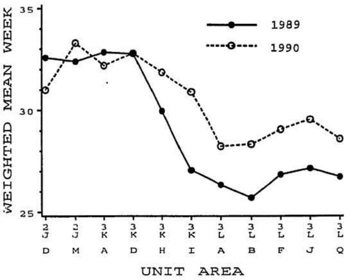


Figure 3.7 Weighted midpoint of the fishing season by NAFO unit area for trap and gillnet landings.

temperature since the seasonal warming is later in the north than in the south (Hachey 1961).

Preliminary findings from the data exploration exercise on the 1989-1990 landing data have shown that landing variations among areas, years, and weeks as well as interaction effects may exist. These temporal and spatial differences may be due to the annual and spatial variations of water temperature. These preliminary findings are further tested using the entire data set in Chapter 4 and 5.

CHAPTER 4. VARIATIONS IN INSHORE LANDINGS

The data exploration exercise on the 1989 and 1990 data indicated that area, year and week effects, as well as possibly interaction effects may exist in inshore landings. To examine this, a model of spatial and temporal variability of inshore landings was constructed and tested for significance on the entire data set (1974-1991).

4.1 METHODS

To test for significance of the area, year, and week effects, a multiplicative effect model of spatial and temporal variability of inshore cod landing was constructed. Multiplicative models may be more likely to capture the nature of the inshore landing variation than additive models. In a multiplicative model, landings for area *A* (area effect) are expressed as being always a percentage (say 10%) higher than those in area *B*, for example, while in an additive model landings in area *A* would be expressed as being always an absolute amount (say 10 tons) higher than those in area *B*, a less likely situation. The full model has three main effects, three first-order (two-way) interaction effects, and one second-order (three-way) interaction effect. It can be written as:

$$y_{ijk} = \mu\alpha_i\beta_j\gamma_k\delta_{ij}\theta_{ik}\lambda_{jk}\eta_{ijk} \qquad (4.1)$$

where y_{ijk} = landing for unit area i, year j and week k;

μ = mean over all landings;

α_i = effect of the unit area i;

β_j = effect of the year j;

γ_k = effect of the week k;

δ_{ij} = interaction effect of unit area i and year j;

θ_{ik} = interaction effect of unit area i and week k;

λ_{jk} = interaction effect of year j and week k;

η_{ijk} = interaction effect of unit area i, year j and week k.

Transforming the model into an additive linear model by taking logarithms, a log-linear ANOVA model was obtained:

$$logy_{ijk} = \log\mu + \log\alpha_i + \log\beta_j + \log\gamma_k + \log\delta_{ij} + \log\theta_{ik} + \log\lambda_{jk} + \log\eta_{ijk} \tag{4.2}$$

The model can be rewritten as:

$$L_{ijk} = M + U_i + Y_j + W_k + (UY)_{ij} + (UW)_{ik} + (YW)_{jk} + (UYW)_{ijk} \tag{4.3}$$

Because there is no error term, the three-way interaction $(UYW)_{ijk}$ mean square was used for significance test on the assumption that the area-year-week interaction effect is zero (Sokal and Rohlf 1981). The ANOVA model to be tested with the landing data then becomes:

$$L_{ijk} = M + U_i + Y_j + W_k + (UY)_{ij} + (UW)_{ik} + (YW)_{jk} + \epsilon_{ijk} \tag{4.4}$$

In order to focus analysis on the main fishing season, weeks that accounted for less than an average of 1% of the annual landing during the 18 years were eliminated from the analysis, thus, only 14 weeks (from week 22 to week 35) were used for the trap fishery and 22 weeks (from week 19 to week 40) for the gillnet fishery. Prior to log-transformation, a value of 0.5 (kg) was added to all weekly landings to avoid 0 landings. The ANOVA procedure provided in SAS (1990) was applied separately to the trap and gillnet fisheries to test the area, year and week effects as well as the two-way interaction effects. ANOVA is particularly useful in analyzing the effects of different classification variables (See Sokal and Rohlf 1981). In this study, ANOVA was used to access the extent of the effects due to classification variables (area, year, and week).

4.2 RESULTS

During the period from 1974 to 1991, spatial and temporal variations existed in inshore landings. Spatially, average annual landing of the trap fishery showed an increasing trend from the areas in the north (2J) to the areas in the south (3L) (Figure 4.1). In the gillnet fishery, this trend was not observed; instead, the highest average annual landing was found in the 3K area. Annual landings for the trap fishery showed an increasing trend for the period from 1974 to 1991, though landings dropped markedly in 1981 and 1987 (Figure 4.2). Landing data for the gillnet fishery showed that annual landings went up steadily until 1982, then began to decrease, and dropped dramatically in 1991. Inshore landing data also showed a seasonal pattern (Figure 4.3). The fishing

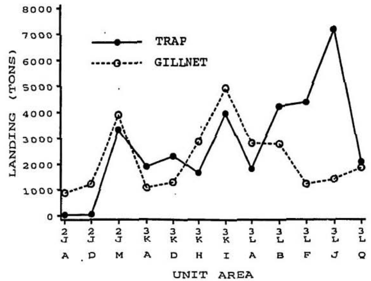


Figure 4.1 1974-1991 average annual landing for unit area from the trap and the gillnet fisheries.

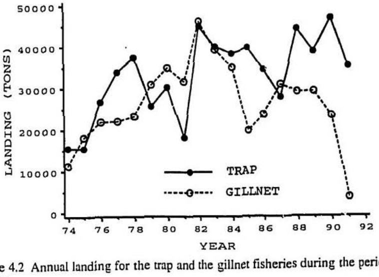


Figure 4.2 Annual landing for the trap and the gillnet fisheries during the period of 1974 to 1991.

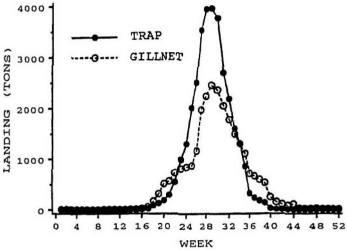


Figure 4.3 1974-1991 average weekly landing for the trap and the gillnet fisheries.

season peaked in week 29 - 31 (late July) for both the trap and the gillnet fisheries. The fishing season was, however, relatively short in the trap fishery compared to the gillnet fishery. In the trap fishery, average weekly landing did not rise significantly until week 18 and dropped to near 0 after week 40. The gillnet fishery started to report significant landings as early as week 16 and continued until week 45.

Statistical tests of the model of inshore landing variability using the ANOVA procedure showed that all main effects and two-way interaction effects were highly significant (p=0.0001) in the trap (Appendix B-1) and gillnet (Appendix B-2) fisheries.

The model explained about 87% and 86% of the landing variations in the trap and gillnet fisheries respectively. In both fisheries, the unit area effect explained the most variation in landings, accounting for 57% of the landing variation in the trap fishery and a significant but smaller proportion of the variability in the gillnet fishery. Among the three main effects, the year effect had the lowest ANOVA sum of squares. The first order (two-way) interaction effects also explained a significant amount of the variation. The area-week interaction effect, in particular, contributed significantly to the ANOVA sum of squares of the model. It accounted for about 29% of the landing variation in the gillnet fishery and about 11% in the trap fishery.

These effects were examined in three-dimensional plots. In the trap fishery, different unit areas were associated with different weekly patterns (Figure 4.4). While areas in the north were observed to have increasing landings as weeks progressed, landings in the southern areas showed an increasing trend in early weeks and a declining trend in later weeks. In other words, the peak of the fishing season became increasingly later from south to north. This variation in weekly pattern accounted for the significant area-week interaction effect. Spatial differences in landings were also indicated as landings in the southern areas were generally higher than those in the north. The variation of weekly landing patterns shown in Figure 4.5 accounted for the year effect (main effect) and year-week interaction effect.

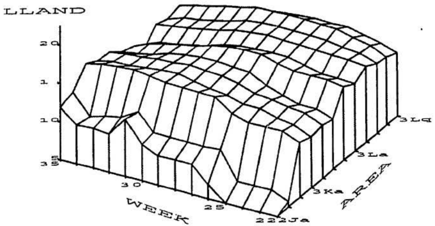


Figure 4.4 Illustration of the area-week interaction effect on trap landings. Different areas showed different weekly patterns. The peak of the fishery became increasingly later from the south to the north, indicating spatial variation in weekly pattern.

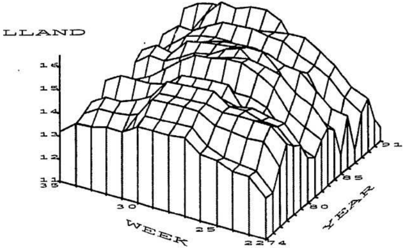


Figure 4.5 Illustration of the year-week interaction effect on trap landings. Weekly patterns varied from year to year, showing the presence of year-week interaction effect.

4.3 DISCUSSION

In the ANOVA model, area, year, and week have significant effects on inshore landings. Based on the partition of the ANOVA sum of squares, these three main effects accounted for a large proportion of the spatial and temporal variations in landing. The area effect could be a result of spatial variation in fishing effort and/or cod distributions. The week effect is likely determined by the timing of fish migration. The year effect might be a result of the biophysical factors such as cod biomass, capelin, and oceanographical conditions.

The treatment of monthly landing data (spreading the monthly estimates evenly over each day of a month), particularly for the period from 1974-1980 when monthly estimates accounted for a large portion of the annual landings, may affect the ANOVA statistics associated with the week effect to some degree. This is, however, unlikely to be problematic because the data after treatment still clearly illustrated the weekly landing variation (Figure 4.6). If the weekly landings for the earlier years were available as was the case in later years, it is possible that the year-week interaction effect would have accounted for less of the ANOVA sums of squares because the data treatment has caused less variation in weekly pattern in those years in which a large amount of the catch was estimated.

The significant interaction effects could have been caused by biological, environmental, socioeconomic and other factors. Data exploration suggested that the area-week and week-year variations were associated with water temperature (Figure 3.3 - 3.6).

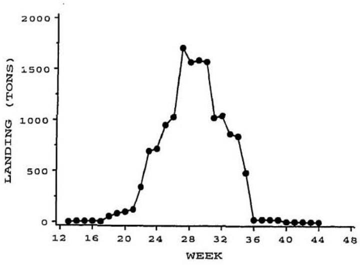


Figure 4.6 Weekly trap landings in 1974 (generated by spreading monthly landing evenly over each day of the month).

To examine the interaction effects more closely and to reveal the relationships between interaction effects and environmental factors, two hypotheses (related to year-week interaction and area-week interaction) are tested in the following chapter. The area-year interaction effect might be related to variations in the distribution of fish and fishing effort. A test of this hypothesis, however, would require information on the annual distribution of fish and fishing effort, which are unavailable at this time.

CHAPTER 5. TEMPERATURE AND TIMING OF THE FISHERY

Preliminary exploration of the 1989 - 1990 data suggested that weekly pattern may be related to temperature; early start of the fishery might be a result of the early warming of water temperature (Figure 3.3 - 3.6). Results from the test of the ANOVA model on the 1974-1991 landing data also indicated that significant area-week and year-week interaction effects existed in inshore landings. In this chapter, two hypotheses are tested to further examine the interaction effects and, more importantly, to reveal the statistical relationships between temperature and the timing of the fishery.

5.1 METHODS

Effects of temperature on catch have been previously studied (Fréchet 1990; Lear *et al.* 1986; Lear *et al.* undated; Rose and Leggett 1988; Sutcliffe *et al.* 1977; Templeman 1966). Studies on cod temperature ranges have indicated that cod catches occurred within the temperature range of -1 to 8 °C (Rose and Leggett 1988; Taggart and Frank 1987). Lear *et al.* (undated) stated that traps and gillnets are normally deployed at 12 fathoms (approximately 22 meters) and 100 fathoms or deeper (approximately 183 meters or deeper), respectively. Based upon the patterns found in the two years data and knowledge from these studies, a hypothesis related to the year-week interaction was constructed. This hypothesis stated that annual variation in weekly pattern for the trap fishery was mainly affected by temperature at the depth of 20 meters (depth at which traps are normally set) in the early and late season, since monthly average temperature at these times are close to the lower and upper limit of the suitable temperature range for cod (-1 °C and 8 °C respectively) (Figure 3.4). Higher temperature in the early season would result in an earlier start of the fishery, while in the late season it would result in an earlier end to the fishing season when temperature is above the upper limit of the suitable range. For the gillnet fishery, temperature at the depth of 175 meters in the late season does not reach the upper limit of the range (Figure 3.6), hence, only temperature in the early season was examined for an influence on weekly pattern for the gillnet fishery.

To test this hypothesis for the two fisheries, the weighted mean week (mean week of the fishing season weighted by weekly landings) for each year was calculated to represent the weighted midpoint of a fishing season. The weighted mean week was then used as an index of variation in weekly pattern. The average temperature at the depth of 20 meters in April, May, August, and September was used as temperature index for the trap fishery, and the average temperature at the depth of 175 meters in April and May was used for the gillnet fishery. Because observations of temperature were missing for some years, only 14 years of data for the trap fishery and 17 years for the gillnet fishery were available for this analysis. A linear regression model was fitted to the data to test the relationship between weighted mean week and temperature:

$$W = \alpha + \beta T + \epsilon \qquad (5.1)$$

where w = weighted mean week;

α = intercept;

β = slope;

T = average temperature of April, May, August and September at the depth of 20 meters for the trap fishery; average temperature of April and May at the depth of 175 meters for the gillnet fisheries;

ε = error term.

Preliminary data visualization and exploration on the 1989-1990 data also showed that the weighted mean week changed from area to area; earlier starts of fishing were observed for the southern areas (Figure 3.7). This led to a second hypothesis that weekly patterns are different among areas, and that fishing starts earlier in the southern areas. To some extent this hypothesis is an extension of the first one, since water in the northern areas warms up later than the southern areas due to the stronger influence by the cold arctic water during the period of March to May (Hachey 1961). To examine the variation of weekly patterns among areas and to test the hypothesis, the weighted mean week was calculated for each unit area and year. A general linear model of the spatial difference was applied to test this hypothesis. Tukey's HSD (Honestly Significant Difference) test for multiple comparisons of means provided in SAS (1990) was used to compare the differences between areas. This test is useful for comparing three or more means as it shows which means differ from which other means and provides confidence intervals. The general linear model can be written as:

$$w_i = \alpha + A_i + \varepsilon \qquad (5.2)$$

where w_i = weighted mean week of unit area i;

α = intercept;

A_i = area effect of unit area i;

ε = error term.

Finally, Model (5.1) and (5.2) were combined to examine the spatial and temporal variation of the weekly landing patterns:

$$w_i = \alpha + A_i + \beta T + \varepsilon \qquad (5.3)$$

5.2 RESULTS

Over the 18 years from 1974 to 1991, the weighted mean week varied from 27 to 32.5 for the trap fishery (Figure 5.1) and 28 to 34.5 for the gillnet fishery (Figure 5.2). A statistically significant fit of the linear model 5.1 was obtained for both trap and gillnet fisheries (Appendix B-3 and 4). The relationship between weighted mean week and water temperature was expressed as $W = 33.87 - 1.12T$ for the trap fishery, and $W = 26.47 - 3.58T$ for the gillnet fishery. The model explained 66% of the variance and was highly significant (p=0.0004) for trap landings. Although the model explained only 48% of the variance in the gillnet fishery, it was also significant (p=0.002). Based upon the results of these tests, the null hypothesis was rejected for both fisheries and the hypothesis that annual variation in weekly patterns is related to annual changes of temperature was

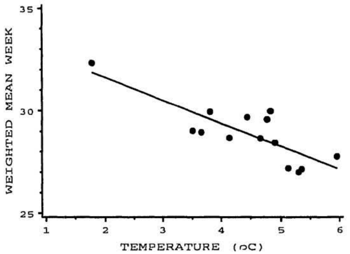


Figure 5.1 Relationship between weighted mean week and temperature in the trap fishery. A linear regression model obtained a significant fit to the data.

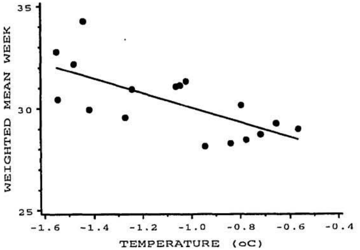


Figure 5.2 Relationship between weighted mean week and temperature in the gillnet fishery. A linear relationship was found to be significant.

supported. This finding is in agreement with the catch-temperature relationship proposed by past studies (Lear *et al.* undated; Rose and Leggett 1988; Taggart and Frank 1987; Templeman 1966).

In testing the spatial variation in the timing of the fishery, the general linear model 5.2 was found to be significant in both the trap and the gillnet fisheries (p=0.0001, Appendix B-5 and 6). The estimated weighted mean week gave a spatially coherent pattern, becoming progressively later from south to north (Figure 5.3). For example, in

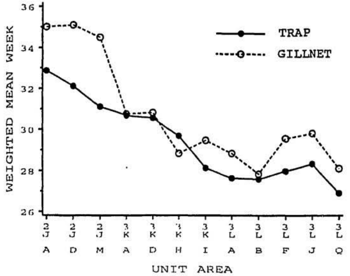


Figure 5.3 Estimated weighted mean week from the general linear model. It changed gradually from area to area in the trap fishery, but more abruptly in the gillnet fishery.

the gillnet fishery, the weighted mean week for areas in 2J was 5 or 6 weeks greater than areas in 3L, indicating that an average fishing season in 2J is 5 or 6 weeks later than in 3L.

Tukey's HSD test showed that at the 0.05 level, there were significant differences in weighted mean week among the areas for the two fisheries. While the difference in weighted mean week among the neighbouring areas in the trap fishery changed smoothly, this was not the case in the gillnet fishery. In the gillnet fishery, results from Tukey's test suggested that the unit areas in 2J formed a distinct region significantly different from all other unit areas. The unit areas in the south (all 3K and 3L areas excluding 3Ka and 3Kd) formed another region, and areas 3Ka and 3Kd were grouped in a third region. In the trap fishery, the timing of the fishery for neighbouring areas was not significantly different.

The model including both spatial and temporal variations of the landing pattern (Model 5.3) was also significant, explaining 79.5% of the variation in the trap fishery (p=0.0001) and 72.7% of the variation (p=0.0001) in the gillnet fishery (Appendix B-7 and 8). Spatial and temporal variations of the landing pattern was found to be predicted by: $w_i = 32.26 + A_i - 1.22T$ for the trap fishery, and $w_i = 24.33 + A_i - 3.50T$ for the gillnet fishery, where A_i, the estimated parameters for each unit area, are shown in Table 5.1.

Table 5.1. Estimated parameters for unit areas

	2Ja	2Jd	2Jm	3Ka	3Kd	3Kh	3Ki	3La	3Lb	3Lf	3Lj	3Lq
Trap	7.48	6.47	4.98	4.66	4.98	3.53	1.61	0.37	0.28	1.39	1.58	0.00
Gillnet	7.08	7.13	6.48	2.77	2.79	0.84	1.45	0.75	-0.21	1.51	1.70	0.00

5.3 DISCUSSION

In testing the hypothesis that the timing of the fishery is related to water temperature, a significant relationship between the weighted mean week and temperature was found in both the trap and the gillnet fisheries. The weighted mean week of the trap fishery was inversely correlated to the average temperature of April, May, August and September at the depth of 20 meters. In the gillnet fishery the weighted mean week was inversely correlated to the average temperature of April and May at the depth of 175 meters. In both cases, higher water temperature corresponds with a shifting of the weekly pattern towards an earlier fishery. These findings, in keeping with the catch-temperature relationships proposed by Templeman (1966) and following studies (Lear *et al.*, undated; Rose and Leggett, 1987; Taggart and Frank, 1987), extend understanding of the relationships between temperature and the variability in the spatial and temporal patterns in the landings of the northern cod inshore fishery.

In the trap fishery, the linear regression model 5.1 explained 66.2% of the variance while it explained only 48.3% in the gillnet fishery. The relatively low R^2 for the model for the gillnet fishery indicated that the relationship between weighted mean week and temperature was not as strong as in the trap fishery. Two possible explanations exist for this difference. First, traps are usually deployed at fixed locations in shallow water approximately at the depth of 20 meters, while the gillnet fishery is operated in various depths. Although gillnets are normally deployed in 180 meters and deeper water, they are also often deployed at the depth range of 50 - 80 meters (Lear *et al.* undated). Hence, using temperature at the depth of 175 meters as an index may not provide a good model fit to the landing data. Ideally, a separate analysis of shallow water gillnet and deep water gillnet should be undertaken. Unfortunately, data limitation prevents such an analysis -- the shallow water gillnet and deep water gillnet landings cannot be distinguished due to the lack of depth records for the catch (Lear *et al.* 1986).

A second explanation could be the mobility of gillnets. Because gillnets are non-fixed gear, fishing locations are more variable. Effects of temperature on landings may be reduced by fishermen setting their nets at various depths to avoid unfavourable water conditions. Rose and Leggett (1989) suggested that catch rate variation in the gillnet fishery is less affected by oceanographic conditions than that in the trap fishery because gillnets are deployed daily at varying locations which are considered to have higher fish density and more favourable environmental conditions.

In this study, weekly landings for years prior to 1981 were generated largely from monthly estimates. This may have some effects on the analysis. Although weighted mean week calculated could still represent the weighted midpoint of the fishery, the variation of the weighted mean week among years is less clear because of the broader scale of the monthly landings. If weekly landing data had accounted for a large portion of the total landing for the years prior to 1981, as in the case for later years, the relationship between temperature and timing of the fishery might be more significant and temperature may have accounted for more of the variance of the timing of the fishery.

In the trap fishery weighted mean week increased gradually from the southern areas to the northern areas, with no statistically significant difference between neighbouring areas. In the gillnet fishery, however, the change of the weighted mean week from area to area was so significant that three distinct regions could be identified. Areas in 2J formed a group characterized by a late fishery. Area 3Ka and 3Kd formed a second group, and the remaining areas formed a third group with an early fishery. The causes for this difference are not clear. Possibly, ice cover might be one of the causes; lengthy ice cover in the north may significantly delay the gillnet fishery. Further studies could investigate the effect of ice cover.

CHAPTER 6. FORECASTING INSHORE LANDINGS

One of the objectives of this study was to construct forecast models to be tested with the inshore trap and gillnet landing data, and to evaluate the performance of the models. Prediction of inshore landings could provide useful information for the northern cod fisheries management and is a challenging problem for fisheries research. Development of forecast models is an essential step towards more accurate predictions. Unfortunately, as pointed out earlier in Chapter 2, the complexity, non-linearity, and uncertainty of the relationships between landings and the possible influencing factors, and lack of documented inshore fishing effort data have created difficulties for model development. Although no forecast models for the inshore fishery have been developed so far, models that have shown utility in other fisheries could be examined. The nonparametric approach, currently used in the salmon fishery in the west and east coasts of Canada (Claytor *et al.* in press; Noakes 1989), is attractive because of its ability to deal with non-linearity and uncertainty. This approach is examined for the data on cod landings and biomass in this study. In this chapter, various nonparametric models, as well as parametric models, are constructed and their performance evaluated.

6.1 METHODS

Six models were developed: (i) mean model, (ii) mean percentage model, (iii) temperature model, (iv) pre-season PDF model, (v) in-season PDF model, and (vi) combined model. Among these, the mean model and the pre-season PDF are pre-season forecast models, and the rest are in-season forecast models. Each is described in detail below. In making forecasts, a jackknife cross validation procedure (omitting each observation and using the remaining observations to predict the one omitted) was used. Model performance was evaluated by the jackknifed residual sum of squares (RSS).

6.1.1 Mean Model

The mean model (MEAN) is simply the arithmetic mean of the annual landings. Forecasts are made using the following formula:

$$X_t = \frac{1}{n}\sum_{i=1}^{n} X_i \qquad i \neq t \qquad (6.1)$$

where X_t = forecasted landing for year t;

X_i = annual landings for all years, excluding the one being forecasted.

Although MEAN mainly serves as a basic reference to compare the predictions of other models, it could also be used either independently, or with other models, to make forecasts (Noakes, 1989).

6.1.2 Logistic Models

Parametric models were developed using an empirical approach. Visual inspection of the weekly cumulative landing data expressed as a percentage of total landing of the year indicated that a logistic model might provide a suitable fit to the data (Figure 6.1). Consequently, a logistic model (PERCENT) was constructed as:

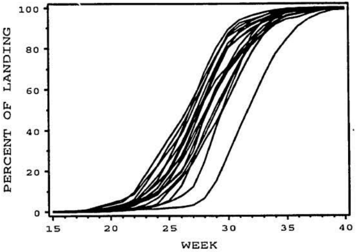


Figure 6.1 Cumulative percentage of trap landings by week from 1974 to 1991. The variation of the curves are deemed to be affected by water temperature.

$$Y=1-\frac{1}{1+\exp((week-m)/k)} \qquad (6.2)$$

where, Y = weekly cumulative landing expressed as a proportion of the total landings;

m = the median week at which Y equals to 0.5;

k = slope.

The parameters m and k were estimated using PROC NLIN within SAS (1990). The actual weekly cumulative landing (*landing to date*) divided by the predicted Y yields the forecast of total landing.

Testing of the hypothesis that a relationship exists between the weekly landing pattern and temperature showed that the median, or the weighted midpoint of a fishing season, *m*, is significantly affected by water temperature (Chapter 5). The relationship could be expressed as: $m = \alpha - \beta T$. Incorporating this relationship, the model (TEMP) was obtained:

$$Y = 1 - \frac{1}{1+\exp((week-(a-bT))/k)} \qquad (6.3)$$

where a, b, and k are parameters to be estimated;

T = temperature.

In Chapter 5, it was demonstrated that the average temperature of the April, May, August and September at the depth of 20 meters had a significant effect on the timing of the trap fishery. The timing of the gillnet fishery was associated with the average temperature of April and May at the depth of 175 meters. For the model to have predictive value, however, March temperature instead of temperature for later months was used, thus giving a lead time prior to the commencement of a fishing season and thereby making the predictions useful for management. To test the reliability of using March temperature as the temperature index in the model, an approximate randomization test technique (see Noreen 1989) was introduced. March temperature values for the years were randomly shuffled, resulting in a set of pseudo-temperature data. This procedure was repeated 200 times. Jackknifed prediction RSS from the model with randomized temperature values were then compared with the model using the correctly sequenced temperature values to assess the predictive value of using March temperature. The null hypothesis that the reduction in the prediction *RSS* using March temperature was in fact due to chance alone was tested by computing the significance level (see Noreen 1989):

$$p = \frac{n+1}{N+1} \qquad (6.4)$$

where p = significance level;

n = the number of times that the RSS for the shuffled data is lower or equal to the RSS for the unshuffled (correctly sequenced) data;

N = the number of shuffles.

6.1.3 PDF Models

Two PDF models (PRE-SEASON PDF and IN-SEASON PDF) were constructed following the procedures described by Noakes (1989). The PDF was obtained using a formula with a *Gaussian kernel:*

$$f(x) = \frac{1}{n}\sum_{i=1}^{n} \frac{1}{h_1 ... h_d (2\pi)^{\frac{d}{2}}} \prod_{j=1}^{d} \exp[-\frac{1}{2}(\frac{(x_j - x_{ij})}{h_j})^2] \qquad (6.5)$$

where n = the number of observations;

d = the number of dimensions, or variables, in the model;

x_j = the value of a variable for which PDF is estimated.

x_{ij} = the observed values of a variable;

h = smoothing parameter.

In addition to the Gaussian kernel, other kernels, such as the cauchy utilized by Evans and Rice (1988), could also be employed. Different kernels are unlikely to have significant effects on the determination of the value which has the maximum probability (Noakes 1989).

The objective of the PRE-SEASON PDF model was to use the historical data to construct the PDF, and then use this PDF to forecast landings f.r the year. This model provides forecasts before the fishing season begins. Models involving two variables (dimensions) were explored, since higher dimensions would require a much larger sample size than that which was available (Silverman 1986). Because cod biomass is considered to have a major effect on inshore landing (Akenhead *et al.* 1982; Lear *et al.* 1986; Pinhorn 1984), and because inshore catches have been directly and consistently responding to the cod abundance at a large scale (Rose 1992), two variables, cod biomass and annual landing, were selected to construct the joint PDF. Cod biomass of ages 4-7 at the beginning of the year from VPA (Baird *et al.* 1991) was used in forecasting trap landings, because inshore trap landings were mainly from fish in this range of age classes (Akenhead *et al.* 1982; Lear *et al.* 1986; Lear *et al.* undated). Akenhead *et al.* (1982) and Lear *et al.* (1986) used cod biomass of ages 4-7 when examining the relationships between inshore trap landings and cod biomass. For the model of gillnet landings, cod biomass of ages 4+ was used, as suggested by Lear *et al.* (1986).

IN-SEASON PDF could only be used after the fishing season started and some landing information was available. In the in-season PDF model, the model was then used to forecast the total landing based on the cumulative landing to date. Therefore, two variables, *landing to date* and *additional fish to be landed*, were considered. To avoid forecasting negative values for the *additional fish to be landed* and the lower (100 - α)% confidence limit, and to ensure that total landing would always be at least as large as *landing to date*, data were transformed to natural logarithms, as suggested by Noakes (1989). The forecast of the *additional fish to be landed* was then obtained using the anti-log of the maximum likelihood value, and added to the *landing to date* to yield the predicted value of total landing.

The key issue in the PDF model is the selection of the smoothing parameter *h*. Too large an *h* would result in oversmoothing. On the other hand, if *h* is too small, the PDF would be undersmoothed (Figure 6.2). In this study, smoothing parameters were

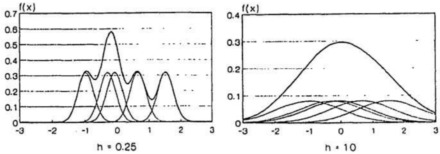


Figure 6.2 Effect of smoothing parameter *h* on the estimation of probability.
Source: Noakes (1989)

selected by maximizing the likelihood function in a jackknife cross validation procedure recommended by Noakes (1989):

$$L(h)=\prod_{i=1}^{n} f_i(x_i;h) \qquad h\geq 0 \qquad (6.6)$$

where, $f_i(x_i;h)$ is the estimated probability density at point x_i, using formula (6.5). To find the smoothing parameters, a grid search procedure was carried out. Various combinations of smoothing parameters were tried and their likelihood value were computed using formulas (6.5) and (6.6). Data were normalized by subtracting the mean and dividing by the standard deviation to rescale the variables and therefore decrease the instability and computational burden in estimating smoothing parameters. To reduce the effect of outliers on the estimation of smoothing parameters, a weighting procedure described by Noakes (1989) was used. Points within one standard deviation of the mean were given a weight of 1. Outside this range, points were assigned a weight inversely proportional to the distance from the mean.

6.1.4 Combined Model

PRE-SEASON PDF and IN-SEASON PDF were combined to form a combined in-season forecast model (COMBINED). This was obtained by weighting the pre-season and in-season forecasts with their confidence intervals as described by Noakes 1989:

$$F_c=(w\times F_i)+(1-w)\times F_p \qquad (6.7)$$

where F_c = combined forecast;

F_i = in-season forecast;

F_p = pre-season forecast;

w = weight, calculated using the confidence intervals with the following formula:

$$w = \frac{A}{A+B} \tag{6.8}$$

where A = the length of the (100 - α)% confidence interval for the pre-season forecast;

B = the length of the (100 - α)% confidence interval for the in-season forecast.

Confidence intervals were approximated by calculating the upper and lower values of the forecast such that each tail of the estimated probability distribution contained (α/2)% of the entire area of the probability distribution. A rectangular formula for finite integral (Murray 1968) was selected to calculate approximately the areas:

$$A = \int_a^b f(x)\,dx = h(y_0+y_1+y_2+\ldots+y_{n-1}) \tag{6.9}$$

where h = width of interval;

n = number of intervals between a and b;

$y_{0,1,2,\ldots,n-1}$ = probabilities at point 0, 1, 2,... n-1.

The choice of n (or h) is determined by the distance between a and b, required accuracy, and computation speed. As the number of intervals n increases, h will decrease, resulting in an increase in computation and accuracy. To calculate the upper and lower limits of the confidence interval, simply find the point that had (α/2)% of the total area below it as the lower limit, and the point that had $(\alpha/2)\%$ of the total area above it as the upper limit, using formula 6.9. The distance between the upper and lower limits produced the confidence interval. In this study, 90% confidence interval, as implemented by Noakes (1989), was used to produce the combined forecast though other confidence intervals could also be employed. As the season progresses, the in-season forecast will become more accurate and its confidence interval B will become smaller, resulting in progressively more weight being assigned to the in-season forecast.

6.2 RESULTS

During the period of 1974 to 1991, annual landings for the inshore trap fishery in areas covered in this study ranged from a low of 15,474 tons in 1975 to a high of 46,927 tons in 1990 (average 32,977 tons); estimated cod biomass of ages 4-7 (Baird *et al.* 1991) varied between 247,808 and 823,818 tons (Figure 6.3). For the gillnet fishery, landings ranged from an extreme low of 3,588 tons in 1991 to 46,149 tons in 1982 (average 26,331 tons); estimated ages 4+ biomass at the beginning of the year (Baird *et al.* 1991) ranged from 364,258 tons to 986,340 tons (Figure 6.4). Correlations between landing and cod biomass were not significant (p=0.05). This indicates that landing does not respond to cod biomass in a simple stationary, linear manner. Linear regression models may therefore not be suitable for making forecasts. Alternative parametric models and nonparametric models were developed and tested.

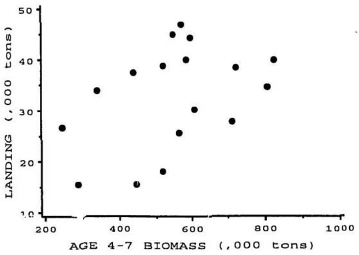


Figure 6.3 Relationship between inshore trap landings and cod biomass of ages 4-7 at the beginning of the year.

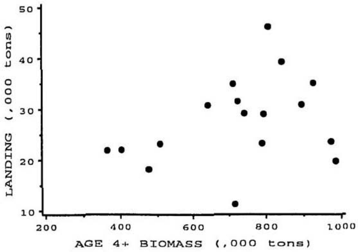


Figure 6.4 Relationship between inshore gillnet landings and cod biomass of ages 4+ at the beginning of the year.

6.2.1 Performance of the Logistic Models

The PERCENT model accounted for 96.2% of the variance (Appendix B-9). The TEMP model gave a better fit to the data by reducing the jackknifed prediction RSS from 2.336 to 0.862 (Appendix B-10). Forecasts were made by dividing the cumulative weekly landing by the predicted percentage. PERCENT and TEMP had a much higher RSS than MEAN during the early season, and did not perform better than MEAN until week 29 (early August) (Figure 6.5). Similarly, for gillnet landings neither PERCENT nor TEMP did better than MEAN before week 26 (mid-July) (Figure 6.6), but TEMP had a lower RSS than PERCENT through the entire season.

An approximate randomization test was applied to test the null hypothesis that the reduction in the RSS using March temperature data was due to chance alone. For the trap fishery, 7 of the 200 shuffles had a RSS value less than or equal to that obtained for the correctly sequenced data, implying that there is a p=0.04 that the observed reduction in RSS could be due to chance alone. Similarly, for the gillnet fishery, 1 shuffle out of the 200 was found to have a lower RSS, resulting in a p=0.01. The null hypothesis was therefore rejected at p=0.05. This suggests that March temperature in fact has predictive value.

6.2.2 Performance of the PDF and COMBINED models

In the PDF model, the first step was to select smoothing parameters using a maximum likelihood approach. Smoothing parameters (one for each dimension) that

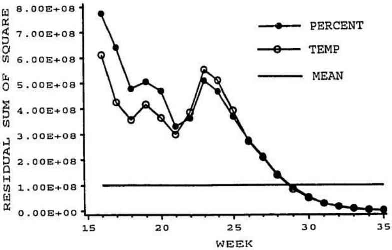


Figure 6.5 Performance of the PERCENT and TEMP models in comparison with the MEAN model in forecasting trap landings.

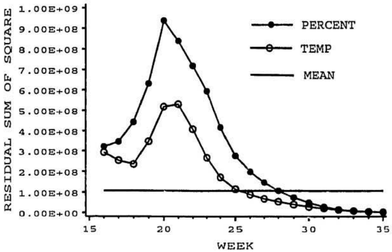


Figure 6.6 Performance of the PERCENT and TEMP models in comparison with the MEAN model in forecasting gillnet landings.

resulted in a jackknifed maximum likelihood $L(h)$ were selected. In the PRE-SEASON PDF model for trap landings, the smoothing parameters of 0.65 (biomass) and 0.40 (landing) maximized the likelihood (Figure 6.7). Based on the same approach, smoothing

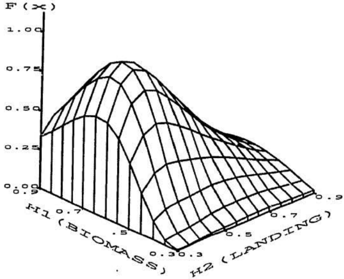
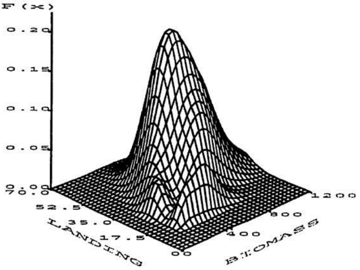


Figure 6.7 Estimated likelihood for various smoothing parameters.

parameters of 0.50 (biomass) and 0.65 (landing) were chosen for the gillnet fishery. These parameters were then used to compute the joint PDF for the two fisheries (Figure 6.8). Forecasting using these functions is straightforward: for a given biomass value, one can find a landing value which has the greatest probability density of occurring. For example, if we know this year's cod biomass (ages 4+) is 400,000 tons, from the PDF for the gillnet fishery we can determine that a landing of 21,500 tons has a maximum



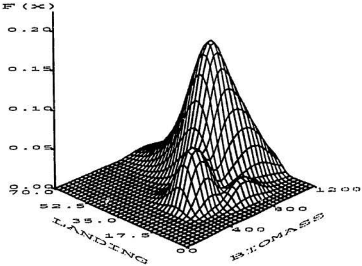


Figure 6.8 Three-dimensional displays of the probability density function estimated for trap (upper) and gillnet (lower) landings. Landing and biomass are in thousand tons.

probability (Figure 6.9). We would then choose 21,500 tons as the best forecast of gillnet

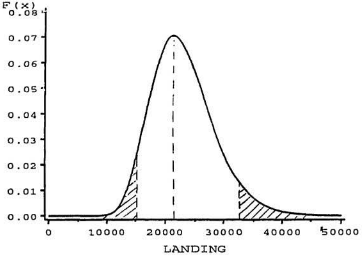


Figure 6.9 Probability density, "best" forecast, and 90% confidence interval of gillnet landing, based on a biomass of 400,000 tons.

landing for this year. By approximately calculating 5% of the entire distribution in each tail, we can obtain the lower and upper limits of the 90% confidence interval.

In IN-SEASON PDF, since forecasts were made on a weekly basis, smoothing parameters were estimated and selected for each week (Table 6.1). In the early season, forecast of total landing based on the weekly cumulative landing was less accurate than later in the season and the probability distributions tended to have longer tails. As the season progressed, the distribution narrowed, resulting in a smaller confidence interval. For instance, the PDF in week 20 was relatively flat and had long tails (Figure 6.10). By

Table 6.1 Estimated smoothing parameters for constructing IN-SEASON PDF. (h_1 for biomass, h_2 for landing)

Trap			Gillnet		
w	h_1	h_2	w	h_1	h_2
16	0.15	1.00	16	0.25	0.70
17	0.15	1.00	17	0.40	0.80
18	0.70	0.70	18	0.50	0.95
19	0.35	0.65	19	0.35	0.75
20	0.30	0.70	20	0.35	0.75
21	0.50	0.65	21	0.35	0.75
22	0.75	0.60	22	0.25	0.80
23	0.75	0.45	23	0.25	0.75
24	0.70	0.40	24	0.25	0.75
25	0.60	0.65	25	0.30	0.80
26	0.75	0.65	26	0.35	0.85
27	0.65	0.60	27	0.45	0.85
28	0.75	0.35	28	0.60	0.80
29	0.75	0.45	29	0.75	0.70
30	0.35	0.80	30	0.75	0.75
31	0.45	0.75	31	0.80	0.70
32	0.75	0.75	32	0.80	0.65
33	0.75	0.80	33	0.75	0.70
34	0.65	1.05	34	0.70	0.70
35	1.20	1.20	35	0.65	0.65

week 30, the probability density had become narrower (Figure 6.11). This occurs because in the later weeks there are more data available and the relationship between cumulative landing and total landing therefore becomes clearer.

The PDF models performed differently in the two fisheries. In the trap fishery, PRE-SEASON PDF had a higher jackknifed RSS than MEAN; IN-SEASON PDF did not perform any better than MEAN until week 28. The high RSS for the in-season PDF forecast also resulted in the poor performance of COMBINED (Figure 6.12).

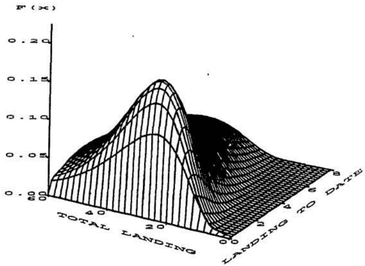


Figure 6.10 Probability density for week 20 for gillnet landings. Long tails are evident as the relationship between cumulative landing and total landing was not clear.

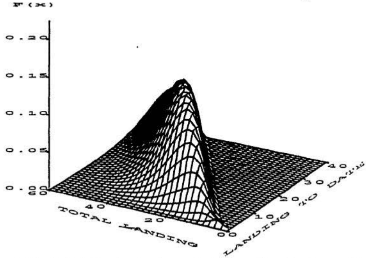


Figure 6.11 Probability density for week 30 for gillnet landings. The distribution narrows as the relationship between cumulative landing and total landing became clearer.

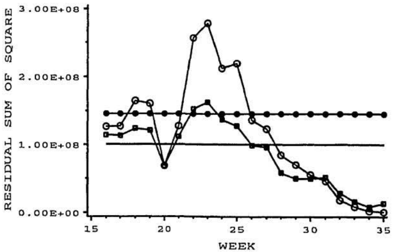


Figure 6.12 Comparison of PRE-SEASON PDF (—•—), IN-SEASON PDF (—o—), COMBINED (—▪—) and MEAN (——) in forecasting trap landings, based on the jackknifed residual sum of squares.

COMBINED gained significant reduction in the RSS compared to both PRE-SEASON PDF and IN-SEASON PDF, but still did no better than MEAN before week 28. To examine whether using MEAN as the pre-season forecast (Noakes 1989) could improve the combined forecast, PRE-SEASON PDF was replaced by MEAN. The confidence interval of the MEAN forecast was calculated using the estimated standard deviation. The outcome did not show any improvement in RSS (Figure 6.13).

For the gillnet fishery, the PDF models appeared to be useful. Both PRE-SEASON PDF and IN-SEASON PDF had a much lower RSS than MEAN (Figure 6.14).

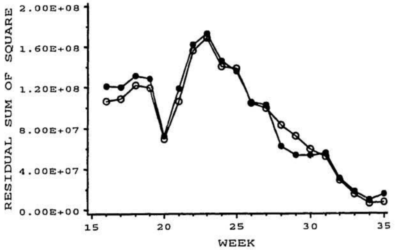


Figure 6.13 Comparison of the two COMBINED models using PRE-SEASON PDF and IN-SEASON PDF (—●—), and MEAN and IN-SEASON PDF (—○—) in forecasting trap landings.

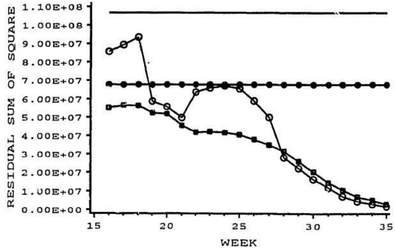


Figure 6.14 Comparison of PRE-SEASON PDF (—●—), IN-SEASON PDF (—○—), COMBINED (—■—) and MEAN (——) in forecasting gillnet landings, based on the jackknifed residual sum of squares.

IN-SEASON PDF had a slightly higher RSS than PRE-SEASON PDF for the first three weeks, but as the season progressed, the RSS for IN-SEASON PDF declined. Among all the models, COMBINED provided the most accurate forecast over almost the entire season. Even during the early season, the RSS for COMBINED was about 50% lower than MEAN. Table 6.2 illustrates the pre-season and in-season forecasts, their associated 90% confidence intervals, the weight, and the combined forecast, using the 1989 data as an example.

6.3 DISCUSSION

Several models for forecasting the inshore cod landings have been presented and their predictive power compared based on the jackknifed prediction sum of squares. In both fisheries, PERCENT had the highest RSS at the early season, although the model fitted the landing data reasonably well over the entire season, especially in the case of the trap fishery. The reason for this is not difficult to understand. In the early weeks, because the percentage of landing (Y) is very small, a small amount of error in Y could result in a large error in the prediction of the total landing since the latter is calculated by dividing the landing to date by the predicted Y. For example, if the cumulative landing to week 20 in a particular year is 2,000 tons accounting for 4% of the annual landing (50,000 tons), and the predicted value of the proportional landing to that week is 5%, this 1% difference would lead to a 10,000 tons residual in forecast (50,000 - 2,000/0.05). This is a intrinsic problem with the PERCENT method. Between PERCENT

Table 6.2 The combined in-season forecasts of 1989 gillnet landing

		PRE-SEASON			IN-SEASON				
Week	Landing	Pred.	Lo90%	Hi90%	Pred.	Lo90%	Hi90%	W	Final
16	29182	32100	16800	57400	23818	11418	62618	0.44	28437
17	29182	32100	16800	57400	24121	11621	63121	0.44	28583
18	29182	32100	16800	57400	24246	10746	59746	0.45	28541
19	29182	32100	16800	57400	24438	13338	60938	0.46	28573
20	29182	32100	16800	57400	23889	13389	63089	0.45	28408
21	29182	32100	16800	57400	23583	13483	61383	0.46	28193
22	29182	32100	16800	57400	23783	13783	62083	0.46	28302
23	29182	32100	16800	57400	23431	13531	60531	0.46	28082
24	29182	32100	16800	57400	22528	13028	61028	0.46	27714
25	29182	32100	16800	57400	22094	12994	58694	0.47	27393
26	29182	32100	16800	57400	22201	13501	56301	0.49	27281
27	29182	32100	16800	57400	22303	14303	54903	0.50	27202
28	29182	32100	16800	57400	22318	15218	53018	0.52	27034
29	29182	32100	16800	57400	22675	16675	45975	0.58	26626
30	29182	32100	16800	57400	23794	18394	42994	0.62	26928
31	29182	32100	16800	57400	25757	20857	39057	0.69	27720
32	29182	32100	16800	57400	27051	23151	38751	0.72	28452
33	29182	32100	16800	57400	28188	24988	37188	0.77	29092
34	29182	32100	16800	57400	28222	25622	36422	0.79	29037
35	29182	32100	16800	57400	28067	26067	33667	0.84	28703

Landing -- actual landing   Pred. -- prediction   Lo90% -- lower limit of the 90% confidence interval   Hi90% -- higher limit of the 90 confidence interval
W -- weight   Final -- final forecast

and TEMP, TEMP had a lower RSS during the early weeks in the trap fishery, suggesting that early landings can be more accurately predicted by incorporating March temperature into the model. In the gillnet fishery, TEMP also did better than PERCENT. However, because of the high RSS, it is unlikely that the logistic model, with or without temperature, would have much utility in forecasting inshore landings.

The PDF model provided more accurate forecasts of gillnet landings, but it was not better than the MEAN model early in the season (before week 28) in the trap fishery. The relatively poor performance for the PDF model in both pre-season and in-season forecast of trap landings indicated that the relationships between landing and biomass and landing to date and total landing were less clear than in the gillnet landings. For example, cod biomass of age 4+ was approximately 450,000 tons in 1974 and 1978, but landings for these two years were quite different. Landing in 1978 was more than 100% higher than in 1974 when a landing of only 15,494 tons was recorded (Figure 6.3). Similar situations were also found for 1975 and 1976 (biomass approximately 280,000 tons), and 1981 and 1989 (biomass approximately 520,000 tons). As a result, probability density functions estimated from the data contained two peaks for cod biomass of less than 600,000 tons (Figure 6.8). Because the forecast was made by choosing the landing value with the highest probability, only one peak (the peak with a higher probability) was considered (Figure 6.15). This resulted in a forecast of 39,800 tons for 1974, much higher than the actual landing. The large residual in the 1974 forecast in turn produced a large RSS.

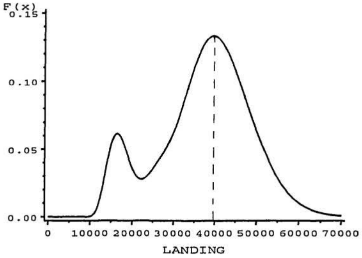


Figure 6.15 Probability density function for trap landings, based on a cod biomass of 450,000. Two peaks were presented in the distribution.

The residual sum of squares could be reduced if some consideration was also given to other peaks within the probability distribution. One possible approach is to weight all potential landing values by their probability, with more weight given to landings with higher probability. This approach is similar to the method utilized by Evans and Rice (1988). If such an approach is adapted, the forecast will not necessarily be the value with the highest probability. Instead, it will be the landing value where 50% of the cumulative probability of the entire distribution is found (Figure 6.16). Forecasts made by this procedure are more moderate than choosing the landing with the highest

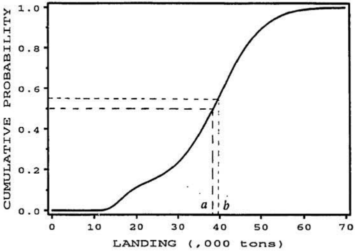


Figure 6.16 Cumulative probability of trap landings based on a biomass of 450,000 tons. Notice that landing value at the point of 50% cumulative probability (*a*) is different from the point with the highest probability (*b*).

probability, and may be more suitable in dealing with probability distributions with more than one peak.

While the PDF model provided a much more accurate forecast of gillnet landings than the MEAN model, the COMBINED model was able to further reduce the RSS. Noakes (1989) noted that combining different models rather than using a single forecasting model normally leads to improved accuracy and precision (lower RSS), because the COMBINED model tends to utilize the relative strengths of each model. The power of the COMBINED model, with different weights assigned to the pre-season and in-season forecasts according to their confidence intervals, was further demonstrated in this study. COMBINED provided better forecasts of gillnet landing than either of the two component models separately. Although it was not the case for trap landing, COMBINED still showed the ability of exploiting the strengths of each individual model. The combined forecast model, therefore, has utility as a forecast model for inshore gillnet landings. The utility of the PDF model in the trap fishery is discussed in Chapter 7.

It should be pointed out that the in-season forecasts (PERCENT, TEMP, IN-SEASON PDF, and COMBINED) are based upon information on weekly landings. The fact that weekly landings prior to 1981 were mainly generated from monthly estimates may have some effect on the forecasts. The influence, however, tends to be minor because forecasts are made using cumulative weekly landings instead of weekly landings. In fact, cumulative landing at the week that ends a month is exactly the same as the cumulative landing at that month. Therefore, the treatment of the data is not likely to significantly affect the performance of the in-season forecast models.

CHAPTER 7. CONCLUSIONS

In Chapters 1 - 6, the variability of inshore cod landings and the effect of temperature have been examined. Various forecast models were developed and tested. This study has quantitatively described the spatial and temporal variation in the inshore landing data. It has also demonstrated a strong relationship between temperature and the timing of the fishery. Comparison of various forecast models indicated that the COMBINED model utilizing PRE-SEASON PDF and IN-SEASON PDF has utility for predicting inshore gillnet landing. This chapter addresses the implications this study has for northern cod fishery management and research.

7.1 IMPLICATIONS FOR FISHERIES MANAGEMENT

The spatial and temporal variability of inshore cod landings in Labrador and eastern Newfoundland has been examined using an ANOVA model. Although area, year, and week were three main effects determining spatial and temporal variation in landing, their interaction effects were also significant. Weekly patterns in landing varied from year to year, and area to area. Spatial patterns also changed annually. In general, weekly landings started to increase at week 15 (late April), peaked at week 29 (late July), and approached zero after week 40 (mid-September) for the trap fishery and week 45 (mid-October) for the gillnet fishery (Figure 4.3). The weighted mean week, an index calculated to represent the midpoint of a fishing season, varied by as much as 7 weeks from year to year (Figure 5.1 and 5.2), and from area to area (Figure 5.3). Thus, the high season of the fishery could have a spatial and temporal difference of more than a month. Incorporating such information into northern cod fishery management could be useful. In particular, managers could take into account annual and spatial variations of the weekly landing pattern, and be prepared for the earlier arrival and prolonged delay of the inshore fishery when making decisions on fish processing, marketing, and spatial distribution of fishing effort.

The significant relationship found between water temperature and the timing of the fishery may also be of benefit in the management of the northern cod fishery. Although various factors, including social-economic and biophysical ones, may affect the timing of the fishery, this study has demonstrated a statistically significant relationship between temperature and the timing of the fishery. Temperature in early season (April and May) could be used as an indicator of the expected seasonal pattern in trap and gillnet landings, though trap landings could also be affected by temperature in late season (August and September). This finding provides a better understanding of the factors affecting the timing of the fishery. Using the relationship with temperature, managers would have insight into the expected timing of the fishery.

Temperature data from Station 27 have been widely used in many research studies in the northwest Atlantic. The importance of these data was further demonstrated in this study. Weekly or even daily temperature data, rather than the current monthly data, if available, would be useful in further studies.

Another principle finding of this study for northern cod fisheries management is the forecast of inshore landings. This study has compared the predictive ability of several forecast models for inshore cod landings, using jackknifed prediction sums of squares. The logistic model is not likely to be of any use in forecasting inshore landings due to its high residual sum of squares. By contrast, the pre-season PDF and the combined forecast models, of the forms proposed by Noakes (1989), proved to be useful in forecasting inshore cod landings. The pre-season PDF can be used to make prediction before a fishing season starts, given a cod biomass at the beginning of the year. Its application, however, does not end here. The ability of obtaining a cumulative probability of all possible landings using the PDF may interest managers even more. A simple plot of the cumulative probability is both meaningful and easy to understand (Figure 7.1). For example, given a cod biomass of 400,000 tons at the beginning of the year, there is an 80% chance that gillnet landing will be less than or equal to 27,200 tons, and an 80% chance that it will be greater than or equal to 18,000 tons. Information provided in this way could greatly assist managers in decision making, as they are advised of the uncertainty and the possibility associated with the forecast.

Based upon the results of this study, it is recommended that the PDF model and combined model be considered for providing pre-season and in-season forecasts of gillnet landings in the inshore cod fishery. With regard to trap landings, none of the models examined in this study showed outstanding advantages over the MEAN model. Therefore, investigation of alternative forecast models is needed. In considering alternative models, it is worthy to note that in this study only one factor was included in the PDF model (cod

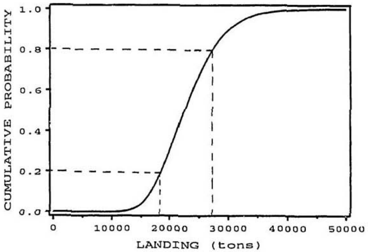


Figure 7.1 Cumulative probability of gillnet landings, given a cod biomass of 400,000 tons at the beginning of the year. Dash lines show landings with a cumulative probability of 0.2 and 0.8 respectively.

biomass in PRE-SEASON PDF and cumulative landing in IN-SEASON PDF). Since trap catch rate is more affected by environmental conditions than that of gillnet (Rose and Leggett 1989), incorporating environmental conditions such as temperature into the PDF model may improve the accuracy of the forecasts. However, increasing the dimensions of the PDF model from two to three means that the sample size must increase from 19 years to 67 years to ensure that the relative mean square error is less than 0.1 (Silverman 1986). Data limitation currently prevents the development of the PDF model with more than two dimensions. Further research could investigate replacing biomass with temperature in the model; however, it seems that such a forecast would not be robust with respect to the current condition of low cod biomass.

7.2 IMPLICATIONS FOR RESOURCE ANALYSIS

As discussed earlier in Chapter 1, resource management is a complex decision making process. Information from different perspectives, such as social, economic, and biophysical considerations, must be incorporated when making management decisions. The role of a resource analyst is to provide information and understanding to assist managers in formulating policies. Because resource issues are closely linked to many factors, and the interactions of these factors are complicated, it is important to focus analysis on a few key variables within a specific time frame. In northern cod fishery management, there are many issues that need to be addressed. Jurisdiction, institutional arrangement, social impacts, economic efficiency, inshore-offshore relationships, and stock assessment are just a few of them. Choosing a workable research topic is then a very important first step. In identifying research problems, this study focused attention on the variability of inshore cod landings and explanatory variables within a much simplified system governing the northern cod inshore fishery. For example, when examining the factors affecting the timing of the fishery, a key environmental factor, temperature, was chosen to be tested for significance, although other factors such as ice condition, capelin abundance, labour dispute, market, and even other fisheries may have an effect on the timing of the fishery. In forecasting inshore landings, only temperature and cod biomass at the beginning of the year were used as variables for making predictions.

Prior to this study, landing variations within a year and among different geographical areas had not been formally investigated and no attempt had been made to forecast inshore landings. This study has examined the spatial and temporal variability of inshore cod landings and tested several forecast models, however, more research is needed to improve our knowledge of the complex ecosystem governing the northern cod fishery. The relationships between landing patterns and possible influencing factors might be examined at various spatial and temporal scales. Factors other than temperature, including biological, social and economic that were not examined in this study, might also be explored for influences on landing variations. Other forecast models for inshore landings could be developed and tested. In considering forecast models this study has suggested that in a situation where the relationships between a dependent variable and the independent variables are not clear or are often non-linear, a nonparametric approach may have advantages over the competing parametric models. Therefore, nonparametric approaches, including the PDF model proposed by Evans and Rice (1988) and Noakes (1989), and Bayesian probability theory (Fried and Hilborn 1988; Hilborn and Walters 1991) might be further explored in future studies. Because of its ability in dealing with uncertainty, applications of the nonparametric method could also be sought in studies of other fisheries or resource sector problems (forest management, for example).

Resource management continues to be an important area of study in geography;

however, few geographers have addressed fisheries resource management issues, leaving a void in this area. Of the limited studies by geographers on fisheries, most studies have examined the issues from social, institutional, or political angles (McCalla 1978; Mitchell 1976; Mitchell and Huntley 1977; Mitchell and King 1984; O'Riordan 1977). While studies on fisheries issues from these aspects should be continued, research on the physical component of fisheries resource management by physical geographers are equally valuable. Marcus (1979) insisted that physical geographers have the opportunity and ability to make important contributions to resource analysis, especially in improving our understanding of the natural processes and the interactions occurring in the complex ecosystems.

Toward an understanding of natural processes and ecosystems, geographers have made considerable contributions which include studies regarding landforms, water systems, climates, vegetation and wildlife (Mitchell 1989). With respect to the fisheries, the complex ecosystems governing the fisheries resource remain an important area for geographers to demonstrate their skills and abilities. Using quantitative techniques, this study has addressed the effects of physical environment on the fisheries. Future research could also be pursued with the use of geographical techniques such as GIS and remote sensing and knowledge of climatology. By exploring the physical component as well as the social and economic components of fisheries resource management issues, we can expect more contributions from Canadian geographers on fisheries research in the future.

REFERENCES

Akenhead, S. A., J. Carscadden, H. Lear, G. R. Lilly, and R. Wells. 1982. Cod-capelin interactions off northeast Newfoundland and Labrador. Can. Spec. Publ. Fish. Aquat. Sci. 59: 141-148.

Baird, J. W., C. A. Bishop, and E. F. Murphy. 1991. An assessment of the cod stock in NAFO Divisions 2J3KL. CAFSAC Res. Doc. 91/53: 84p.

Claytor, R. R., G. A. Nielsen, and P. A. Shelton, (in press). Using jackknife and Monte Carlo simulation experiments to evaluate forecast models for Atlantic salmon (*Salmo salar*). Can. J. Fish. Aquat. Sci. Spec. Publ.

Draper, D. 1981. Oceans exploitation: efficiency and equity questions in fisheries management. In Mitchell, B. and W. R. D. Sewell (ed.), Canadian resource policies: problems and prospects. Methuen, Toronto.

Evans, G. T. and J. C. Rice, 1988. Predicting recruitment from stock size without the mediation of a functional relationship. J. Cons. Int. Explor. Mer. 44: 111-122.

Fréchet, A. 1990. Catchability variations of cod in the marginal ice zone. Can. J. Fish. Aquat. Sci. 47: 1678-1683.

Fried, S. M. and R. Hilborn, 1988. Inseason Forecasting of Bristol Bay, Alaska, sockeye salmon (*Oncorhynchus nerka*) abundance using Bayesian probability theory. Can. J. Fish. Aquat. Sci. 45: 850-855.

Gordon, H. S. 1954. The economic theory of a common-property resource: the fishery. J. Pol. Econ. 62: 124-142.

Gulland, J. A. 1974. The management of marine fisheries. Scientica, Bristol.

Hachey, H. B. 1961. Oceanography and Canadian Atlantic Waters. Bull. Fish. Res. Board Can. 134: 120p.

Hall, C. A. S. and J. W. Day, Jr. 1977. System and models: terms and basic principles. In Hall, C. A. S. and J. W. Day, Jr. (ed.), Ecosystem modelling in theory and practice. Wiley & Sons, New York.

Hardin, G. 1968. The tragedy of the commons. Science, 162: 1243-1248.

Hilborn, R. and C. Walter, 1991. Quantitative fisheries stock assessment. Chapman and Hall, New York and London.

Holling, C. S. (ed.) 1978. Adaptive environmental assessment and management. Wiley & Sons, New York.

Krueger, R. R. and B. Mitchell. 1977. Managing Canada's renewable resources. Methuen, Toronto.

Lear, W. H., J. W. Baird, J. C. Rice, J. E. Carscadden, G. R. Lilly, and S. A. Akenhead. 1986. An examination of factors affecting catch in the inshore cod fishery of Labrador and eastern Newfoundland. Can. Tech. Rep. Fish. Aquat. Sci. 1469: iv + 71 p.

Lear, W. H., B. A. Bishop, and P. R. Hood, undated. Trap cod: some facts about unpredictable catches and small fish. Department of Fisheries and Oceans, St. John's.

Lear, W. H. and J. M. Green. 1982. Migration of the "Northern" Atlantic cod and the mechanisms involved. In Mccleave, J. D. *et al.* (ed.) Mechanisms of migration in fishes. Plenum Press, New York and London.

Lilly, G. R. and D. J. Davis, undated. Observations on spatial and temporal patterns in Landings of Atlantic cod (*gadus morhua*) from the inshore fishery of Labrador and eastern Newfoundland.

MacCall, A. D. 1990. Dynamic geography of marine fish population. Univ. of Washington Press, Seattle and London.

Marcus, M. G. 1979. Coming full circle: physical geography in the twentieth century. Annals Asso. Amer. Geog. 69: 521-32.

McCalla, R. J. (ed.) 1978. Marine studies and coastal zone management. St. Mary's Univ. Occas. Pap. in Geog. No. 2, Halifax.

Mitchell, B. 1976. Politics, fish, and international resource management: the British-Icelandic cod war. The Geog. Rev. 66: 127-138.

Mitchell, B. 1979 (2nd ed. 1989). Geography and resource analysis. Wiley & Sons, New York.

Mitchell, B. and Huntley, H. M. 1977. An analysis of criticisms of international fishery organizations with reference to three agencies associated with the Canadian west coast fishery. J. Env. Managem. 5: 47-73.

Mitchell, B. and P. King, 1984. Resource conflict, policy change and practice in Canadian fisheries management. Geoforum, 15(3): 419-432.

Murray, R. S. 1968. Mathematical handbook for formula and tables. McGraw-Hill, New York and Toronto.

Myers, R. A., S. A. Akenhead, and K. Drinkwater, 1990. The influence of ice-melt and Hudson Bay runoff on the salinity of the inner Newfoundland Shelf. Atmosphere-Ocean, 28: 241-256.

Nakashima, B. S. and R. W. Harnum, 1992. The 1991 inshore capelin fishery in NAFO Div. 3K. CAFSAC Res. Doc. 92/56.

Narayanan, S., S. Prinsenberg, and E. B. Colbourne, 1992. Overview of environmental conditions in NAFO Divisions 2J+3KL in 1991. NAFO SCR. Doc. 92/6, Serial No. N2039.

Noakes, D. J. 1989. A nonparametric approach to generating inseason forecasts of salmon returns. Can. J. Fish. Aquat. Sci. 46: 2046-2055.

Noreen, E. W. 1989. Computer intensive methods for testing hypothesis. Wiley & Sons, New York.

O'Riordan, T. 1977. Resource management in a global commons. In Ellis, D. V. (ed.) Pacific salmon management for people. West. Geog. Series Vol 13.

Petrie, B., S. Akenhead, J. Lazier, and J. Loder, 1988. The cold intermediate layer on the Labrador and Northeast Newfoundland Shelves, 1978-1986. NAFO Sci. Coun. Stu. 12: 57-69.

Petrie, B., J. W. Loder, J. Lazier, and S. Akenhead, 1992. Temperature and salinity variability on the eastern Newfoundland Shelf: the residual field. Atmosphere-Ocean 30(1): 120-139.

Pinhorn, A. T. (ed.) 1976. Living marine resources of Newfoundland - Labrador: status and potential. Bull. Fish. Res. Board Can. 194: 64p.

Pinhorn, A. T. 1984. Inshore exploitation of Atlantic cod, *gadus morhua*, in Labrador and eastern Newfoundland waters. J. Northw. Atl. Fish. Sci. 5: 79-84.

Pope, J. G. 1972. An investigation of the accuracy of virtual population analysis using cohort analysis. ICNAF Res. Bull. 9: 65-74.

Rice, J. C. and G. T. Evans, 1988. Tools for embracing uncertainty in the management of the cod fishery of NAFO divisions 2J+3KL. J. Cons. Int. Explor. Mer. 45: 73-81.

Rose, G. A. 1992. Indices of total biomass in the "Northern" and Gulf of St. Lawrence Atlantic cod (*gadus morhua*) stocks derived from time series analysis of fixed gear (trap) catches. Can. J. Fish. Aquat. Sci. 49: 202-209.

Rose, G. A. and W. C. Leggett, 1988. Atmosphere-ocean coupling and Atlantic cod migrations: effects of wind-forced variations in sea temperatures and current on nearshore distributions and catch rates of *Gadus morhua*. Can. J. Fish. Aquat. Sci. 45: 1234-1243.

Rose, G. A. and W. C. Leggett, 1989. Predicting variability in catch-per-effort in Atlantic cod, *Gadus morhua*, trap and gillnet fisheries. J. Fish Biol. 35 (Supplement A): 155-161.

Rothschild, B. J. (ed.) 1983. Global fisheries. Springer-Verlag, New York.

SAS, 1990. SAS/Stat user's guide. SAS institute Inc. Cary, USA.

Silverman, B. W. 1986. Density estimation for statistics and data analysis. Chapman and Hall, London, New York.

Silvert, W. 1981. Principles of ecosystem modelling. In Longhurst, A. R. (ed.) Analysis of Marine ecosystem. Academic Press, London.

Sokal, R. R. and F. J. Rohlf, 1981. Biometry (2nd ed.). Freeman, San Francisco.

Starfield, A. M., P. A. Shelton, J. G. Field, R. J. M. Crawford, and M. J. Armstron, 1988. Note on a modelling schema for renewable resource problems. S. Afr. J. Mar. Sci. 7: 299-303.

Sutcliffe, W. H. Jr., K. Drinkwater, and B. S. Muir. 1977. Correlations of fish catch and environmental factors in the Gulf of Maine. J. Fish. Res. Board Can. 34: 19-30.

Sylvia, G. 1991. Concepts in fisheries management: interdisciplinary gestalts and socioeconomic policy models. Society and Nature Resource, 5: 115-133.

Taggart, C. T. and K. T. Frank. 1987. Coastal upwelling and *Oikopleura* occurrence ("slub"): a model and potential application to inshore fisheries. Can. J. Fish. Aquat. Sci. 44: 1729-1736.

Templeman, W. 1966. Marine resources of Newfoundland. Bull. Fish. Res. Board Can. 154:170p.

Templeman, W. and A. M. Fleming, 1956. The Bonavista longlining experiment, 1950 - 1953. Bull. Fish. Res. Board Can. 109: 55p.

Templeman, W. and A. M. Fleming, 1965. Cod and low temperature in St. Mary's Bay, Newfoundland. ICNAF Spec. Publ. 6: 131-135.

Templeman, W. and A. W. May, 1965. Research vessel catches of cod in the Hamilton Inlet Bank area in relation to depth and temperature. Int. Comm. Northw. Atl. Fish. Spec. Publ. 6: 149-165.

TGNIF (The Task Group on Newfoundland Inshore Fisheries), 1987. A study of trends of cod stocks off Newfoundland and factors influencing their abundance and availability to the inshore fishery. Report to the minister of fisheries, Canada.

Wooster, W. S. (ed.) 1988. Fishery science and management. Springer-Verlag, New York.

Zimmermann, E. W. 1933. World resources and industries. Harper and Brothers, New York.

APPENDIX A: SAS Code for Performing PDF Forecast

```
/*************************************************************
* SAS code for forecast using PDF approach described by     *
* Noakes(1989).  Cod biomass and landing are the variables *
* for constructing the joint probability.                  *
* X. Chen, Dec. 1992.                                      *
*************************************************************/

/*******************
* input date files *
*******************/
filename in '/home/chen/data/landing.dat';
filename in1 '/home/chen/data/biomass.dat';

data land;
infile in;
input year 1-2 section 3-4 area $ 5 vessel 6 gear 7-8 unit $
30-33 week 34-35 landing 40-49 .3;
if gear ne 61 or year=91 then delete;
else if unit='2J A' or unit='2J D' or unit='2J M' or unit='3K
A' or unit='3K D' or unit='3K H' or unit='3K I' or unit='3L A'
or unit='3L B' or unit='3L F' or unit='3L J' or unit='3L Q';

proc sort;
by year;

data landing;
set land;
by year;
if first.year then link init;
land+landing;
if last.year then output;
return;
init: land=0;
return;
keep year land;

data bio;
infile in1;
input yr a3-a14 sum;
if yr>1973;
year=yr-1900;
bio=sum-a3;
keep year bio;
```

```
/*********************
* log-transformation *
*********************/
data d;
merge landing bio;
by year;
lland=log(land);
lbio=log(bio);
same=1;
keep same year lbio land lland;

proc datasets;
delete land landing bio;

/******************************************************
* The following loop is used for estimating smoothing *
* parameters using a jackknife procedure              *
******************************************************/
%macro estimate;
%do i=74 %to 90;

data d1;
set d;
if year ne &i;  *eliminate the year being estimated;

/***********************
* normalizing the data *
***********************/
proc means;
var lbio lland;
by same;
output out=d2 mean=meanx meany std=sx sy;

data d3;
merge d1 d2;
by same;
normx=(lbio-meanx)/sx;
normy=(lland-meany)/sy;
keep same meanx meany sx sy normx normy;

data d4;
set d;
if year=&i;
same=1;

/***********************************
* assign weight to each data point *
***********************************/
```

```
data d5;
merge d3 d4;
by same;
x=(lbio-meanx)/sx;
y=(lland-meany)/sy;
if abs(x) <= 1 then weightx=1;
if abs(x) > 1 then weightx=1/abs(x);
if abs(y) <= 1 then weighty=1;
if abs(y) > 1 then weighty=1/abs(y);
keep year x y normx normy weightx weighty;

/*******************************************************
* estimating probability using various h (increment=0.05) *
*******************************************************/

data d6;
set d5;
do hx=0.1 to 0.5 by 0.05;
do hy=0.1 to 0.5 by 0.05;
p=(exp(-0.5*((x-normx)*hx)**2))*(exp(-0.5*(y-normy)/hy)**2));
output;
end;
end;

proc sort;
by hx hy;

data d7;
set d6;
by hx hy;
if first.hy then link init;
psum+p;
f=psum/(16*hx*hy*3.14159**2);
if last.hy then output;
return;
init: psum=0;
return;

data _null_;
set d7;
file 'smooth.par' mod;
put year 1-2 hx 22-25 .2 hy 28-31 .2  f 38-48 .8  weightx
50-55 .4 weighty 57-62 .4;

%end;
%mend estimate;
%estimate;
```

```
proc datasets;
delete d1 d2 d3 d4 d5 d6 d7;

/**********************************************
* searching for h with the greatest probability *
**********************************************/
data d8;
infile 'smooth.par';
input year hx hy f weightx weighty;
same=1;
fw=f**(weightx*weighty);
keep same hx hy fw;

proc sort;
by hx hy;

data d9;
set d8;
by hx hy;
if first.hy then lfx=1;
retain lfx;
lfx=lfx*fw;
if last.hy then output;
return;
keep same hx hy lfx;

proc sort;
by same lfx;

data d10;
set d9;
by same;
if last.same then output;
keep same hx hy;

proc print;     * -- best smoothing parameters;


/****************************************************
* The following loop produces landing forecasts using *
* a jackknife procedure                               *
****************************************************/
data d11;
merge d d10;
by same;

%macro prob;
%do i=74 %to 90;
```

```
data d12;
set d11;
if year ne &i;    * -- eliminate the year being forecasted;

proc means;
var lbio lland;
by same;
output out=d13 mean=meanx meany std=sx sy;

data d14;
merge d12 d13;
by same;
normx=(lbio-meanx)/sx;
normy=(lland-meany)/sy;
keep year same meanx meany sx sy normx normy;

proc sort;
by year;

data d15;
set d11;
if year=&i;
drop year lland;

data d16;
set d15;
do year=74 to 90;
do  forecast=1,  100  to  100000  by  100;      *  --  forecast
increment;
lland=log(forecast);
output;
end;
end;
drop forecast;

/*****************************************
* estimate probability using the known h *
*****************************************/
data d17;
merge d14 d16;
by year;
if year=&i then delete;
x=(lbio-meanx)/sx;
y=(lland-meany)/sy;
fxy=1/((((x-normx)/hx)**2+1)*(((y-normy)/hy)**2+1));

proc sort;
by lland;
```

```
data d18;
set d17;
by lland;
if first.lland then link init;
fxysum+fxy;
fxyfin=fxysum/(16*hx*hy*3.14159**2);
if last.lland then output;
return;
init: fxysum=0;
return;
drop hx hy fxy fxysum;

/**************************************************
* calculate the area of the probability density    *
* distribution to estimate the confidence interval *
**************************************************/
data d19;
set d18;
subarea=fxyfin*100;     *interval=100;
sum+subarea;
drop fxyfin subarea land;

data d20;
set d19;
by same;
area=sum;
if last.same then output;
keep same area;

data d21;
merge d19 d20;
by same;
difflow=abs(sum-0.05*area);     * -- 90% lower limit;
diffup=abs(sum-0.95*area);      * -- 90% upper limit;

proc sort;
by same difflow;

data d22;
set d21;
by same difflow;
low=exp(lland);
if first.same then output;       * -- extract the lower limit;
keep same low;

proc sort data=d21;
by same diffup;
```

```
data d23;
set d21;
by same diffup;
up=exp(lland);
if first.same then output;     * -- extract the upper limit;
keep same up;

proc sort data=d18;
by same fxyfin;

data d24;
set d18;
by same fxyfin;
pred=exp(lland);
if last.same then output;   * -- landing forecast;
keep same pred land;

data d25;
merge d22 d23 d24;
by same;
year=&i;

/*****************************************************
* output file containing actual landing, forecast and *
* confidence interval                                  *
*****************************************************/
 data _null_;
set d25;
file 'forecast.dat' mod;
put land 1-10 .3 pred 12-20 .3 low 22-30 .3 up 32-40 .3 year
42-43;

%end;
%mend prob;
%prob;

run;
endsas;
```

APPENDIX B: Statistical Summaries

Appendix B-1 Statistical summary of the ANOVA model on the trap landing data

Dependent Variable: LLAND

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	592	59180.597197	99.967225	27.16	0.0001
Error	2431	8948.578382	3.681028		
Corrected Total	3023	68129.175579			

R-Square	C.V.	Root MSE	LLAND Mean
0.868653	21.05985	1.9186005	9.1102294

Source	DF	Anova SS	Mean Square	F Value	Pr > F
YEAR	17	2705.316012	159.136236	43.23	0.0001
WEEK	13	3918.026400	301.386646	81.88	0.0001
UNIT	11	38880.044843	3534.549531	960.21	0.0001
YEAR*WEEK	221	3155.824388	14.279748	3.88	0.0001
UNIT*WEEK	143	6717.743022	46.977224	12.76	0.0001
YEAR*UNIT	187	3803.642533	20.340334	5.53	0.0001

Appendix B-2 Statistical summary of the ANOVA model on the gillnet landing data

Dependent Variable: LLAND

Source F	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	824	56762.886005	68.886998	29.25	0.0001
Error	3927	9249.503984	2.355361		
Corrected Total	4751	66012.389989			

R-Square	C.V.	Root MSE	LLAND Mean
0.859882	16.36734	1.5347187	9.3767134

Source F	DF	Anova SS	Mean Square	F Value	Pr > F
YEAR	17	5405.496396	317.970376	135.00	0.0001
WEEK	21	15002.832011	714.420572	303.32	0.0001
UNIT	11	15394.382221	1399.489293	594.17	0.0001
YEAR*WEEK	357	2799.847286	7.842709	3.33	0.0001
UNIT*WEEK	231	15192.541919	65.768580	27.92	0.0001
YEAR*UNIT	187	2967.786171	15.870514	6.74	0.0001

Appendix B-3 Statistical summary of Model 5.1 tested in the trap fishery

Model: MODEL1
Dependent Variable: MWEEK

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	1	17.44264	17.44264	23.550	0.0004
Error	12	8.88795	0.74066		
C Total	13	26.33059			

Root MSE	0.86062	R-square	0.6624
Dep Mean	28.88725	Adj R-sq	0.6343
C.V.	2.97923		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob > |T|
INTERCEP	1	33.872570	1.05273510	32.176	0.0001
AVE_TEMP	1	-1.121396	0.23108045	-4.853	0.0004

Appendix B-4 Statistical summary of Model 5.1 tested in the gillnet fishery.

Model: MODEL1
Dependent Variable: MWEEK

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	1	22.27048	22.27048	14.012	0.0020
Error	15	23.84148	1.58943		
C Total	16	46.11196			

Root MSE	1.26073	R-square	0.4830
Dep Mean	30.33577	Adj R-sq	0.4485
C.V.	4.15591		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob > |T|
INTERCEP	1	26.468519	1.07743803	24.566	0.0001
TEMP4_5	1	-3.576345	0.95542291	-3.743	0.0020

Appendix B-5 Statistical results of the general linear model 5.2 fitted to the trap landing data

Dependent Variable: MWEEK

Source F	DF	Sum of Squares	Mean Square	F Value	Pr >
Model	11	1085.0258204	98.6387109	25.58	0.0001
Error	198	763.3970865	3.8555408		
Corrected Total	209	1848.4229069			

R-Square	C.V.	Root MSE	MWEEK Mean
0.587001	6.652453	1.9635531	29.516228

Source F	DF	Type I SS	Mean Square	F Value	Pr >
UNIT	11	1085.0258204	98.6387109	25.58	0.0001

Source F	DF	Type III SS	Mean Square	F Value	Pr >
UNIT	11	1085.0258204	98.6387109	25.58	0.0001

Appendix B-6 Statistical results of the general linear model 5.2 fitting to the gillnet landing data

Dependent Variable: MWEEK

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	1377.3227052	125.2111550	27.94	0.0001
Error	203	909.6635745	4.4811014		
Corrected Total	214	2286.9862797			

R-Square	C.V.	Root MSE	MWEEK Mean
0.602244	6.904892	2.1168612	30.657410

Source	DF	Type I SS	Mean Square	F Value	Pr > F
UNIT	11	1377.3227052	125.2111550	27.94	0.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
UNIT	11	1377.3227052	125.2111550	27.94	0.0001

Appendix B-7 Statistical results of Model 5.3 fitted to the trap fishery data

General Linear Models Procedure

Dependent Variable: MWEEK

Source F	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	12	1076.9693440	89.7474453	48.05	0.0001
Error	149	278.3116092	1.8678631		
Corrected Total	161	1355.2809532			

R-Square	C.V.	Root MSE	MWEEK Mean
0.794647	4.593598	1.3666979	29.752228

Source F	DF	Type I SS	Mean Square	F Value	Pr > F
UNIT	11	853.89558563	77.62687142	41.56	0.0001
AVE_TEMP	1	223.07375840	223.07375840	119.43	0.0001

Source F	DF	Type III SS	Mean Square	F Value	Pr > F
UNIT	11	902.67795746	82.06163250	43.93	0.0001
AVE_TEMP	1	223.07375840	223.07375840	119.43	0.0001

Appendix B-8 Statistical results of Model 5.3 fitted to the gillnet fishery data

General Linear Models Procedure

Dependent Variable: MWEEK

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	12	1585.8508743	132.1542395	42.20	0.0001
Error	190	594.9736176	3.1314401		
Corrected Total	202	2180.8244919			

R-Square	C.V.	Root MSE	MWEEK Mean
0.727180	5.750205	1.7695875	30.774340

Source	DF	Type I SS	Mean Square	F Value	Pr > F
UNIT	11	1331.5897566	121.0536142	38.66	0.0001
TEMP4_5	1	254.2611177	254.2611177	81.20	0.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
UNIT	11	1342.5434255	122.0494023	38.98	0.0001
TEMP4_5	1	254.2611177	254.2611177	81.20	0.0001

Appendix B-9 Statistical summary of the logistic model PERCENT fitted to weekly cumulative landings for the trap fishery

Non-Linear Least Squares Summary Statistics
Dependent Variable CUMPER

Source	DF	Sum of Squares	Mean Square
Regression	2	140.97619065	70.48809532
Residual	348	2.33626157	0.00671340
Uncorrected Total	350	143.31245222	
(Corrected Total)	349	61.13707030	

Parameter	Estimate	Asymptotic Std. Error	Asymptotic 95 % Confidence Interval Lower	Upper
M	28.37939544	0.07753011007	28.226906713	28.531884177
K	2.08894401	0.06830580534	1.954597944	2.223290086

Appendix B-10 Statistical summary of the logistic model TEMP fitted to temperature and weekly cumulative landings for the trap fishery

Non-Linear Least Squares Summary Statistics
Dependent Variable CUMPER

Source	DF	Sum of Squares	Mean Square
Regression	3	142.45089797	47.48363266
Residual	347	0.85155425	0.00248287
Uncorrected Total	350	143.31245222	
(Corrected Total)	349	61.13707030	

Parameter	Estimate	Asymptotic Std. Error	Asymptotic 95 % Confidence Interval Lower	Asymptotic 95 % Confidence Interval Upper
A	33.39380100	0.20964927297	32.981451875	33.806150124
B	1.12915686	0.04601871755	1.038644851	1.219668878
K	1.97147692	0.04035421813	1.892106140	2.050847702