Université d'Ottawa • University of Ottawa

Thesis

Master's Program in Systems Science
School of Graduate Studies
University of Ottawa

Assessing the dynamic status of fish resources in space and time

By: Qizhi Liu

Supervisor:Dr. Daniel E. Lane

0-612-66080-X

Abstract

The purpose of this thesis is to analyze the spatial-temporal dynamic status of Scotia-Fundy herring stocks in NAFO divisions 4WX in the Bay of Fundy region and the Scotian Shelf. This thesis uses an alternative method to examine the dynamic in-season status of fish movement in space and time over the fishing season. Two models are presented based on Bayesian uncertainty statistical theory. A working computer decision model is developed to estimate the weekly stock abundance by area. A simulation model is developed to examine the strategic plan of the fishery. A visualized computer application tool, MapTest has been developed to implement the above two models. This application uses OLE (object linked and embedded) techniques to present fishing data on a GIS (geographic information system) mapping system and link and embed to a Visual Basic application. Using MapTest, fishery scientists can estimate the stock abundance based on the available catch data and simulate the impact of alternative catch scenarios. This thesis used the MapTest application to analyze the catch and estimated abundance of the five spawning areas in the 4WX herring fishery and processed three estimated caches year analyses. The computer application developed and illustrated here provides valuable information to assist decision makers in managing the fishery in real on a spatial-temporal basis throughout the fishing year.

Table of contents

List of Figures

List of Tables

1. Introduction

1.1 Topic

The assessment of the abundance of fish in the ocean is a difficult and complex task. Fish are continually moving throughout their seasonal migrations about which marine scientists know surprising little detail. Added to this dynamic behavior, the lack of complete observation of underwater resources contributes to the problem. Finally, the year over year dynamics of birth, growth and death from natural and from fishing are poorly understood.

With these difficulties in mind, scientists endeavor to make stock abundance estimates using scientific survey data, information from commercial fisheries and general information about the marine ecosystem.

This thesis analyses the estimate of stock abundance by assuming that fish stocks move in well-determined spatial and temporal patterns during each annual period. This information forms the basis of the separated measures in each season toward making better stock estimates.

Specifically, this thesis examines the issue of assessing the status of fish resources that are dynamic in space and time as defined by the fishery grounds and the period of annual stock migration. Furthermore, a fish stock is often comprised of several discernable substocks that mix and interact throughout their joint migrations.

1.2 Problem definition

Currently there are standard methods that fisheries stock assessment scientists use to estimate stock abundance states. The virtual population analysis (VPA) model provides an annual aggregate measure of aggregate stock abundance by age. An alternative approach proposed by this thesis examines the dynamic in-season pattern of fish movement and fisheries intervention in space and time over the course of the fishing season. The spatial-temporal assessment for the status of fish resources is an independent estimate of stock abundance states that can be compared to the static annual VPA methodology estimates to provide more robust stock size estimates.

1.3 Motivation

For specific fisheries such as Scotia-Fundy herring, up-to-date data of weekly catch and ecosystem observations are available. In-season spatial-temporal analysis on this fishery has been previously developed (Storey, 1998). This thesis expands the earlier work and develops a computer-aided, visual decision support system based on the spatial-temporal dynamics of the herring fishery resources.

1.4 Objectives

The objective of this thesis is to develop an easy to use in-season decision support and simulation system for the case of Scotia Fundy herring stock in NAFO (North Atlantic Fisheries Organization) divisions 4WX. The system takes into account uncertainty and provides in-season estimates for stock size by area and time as a probability distribution. This system consists of (1) a working model for in-season operational planning and (2) a simulation model for strategic planning.

1.5 Outcomes

The thesis contributes two primary outcomes. One is the operational planning model of weekly decision support for setting exploitation limits based on estimates of the status of in-season spatial-temporal stock abundance. The second outcome is the strategic planning simulation model that examines the on-going status of the fishery under various management policies over time.

1.5.1 Operational planning model

The operational planning model is developed for aiding in-season, weekly decision making in the herring fishery. The model provides estimates for weekly stock abundance status by area in the form of probability distributions. These estimates are determined as a function of historical migration patterns, current catches, survey information and other ecosystem observations by area in each previous week. The visual model is designed to provide timely information in support of real-time decision making and fishing area protocols.

1.5.2 Strategic planning model

The strategic planning simulation model is aimed at examining the alternative stock and management hypotheses for strategic planning in the fishery. Management options can be explored by closing zones or restricting catches by zones for particular periods while exploring the impact the management measures have on stock abundance status. The simulation model allows comparison of alternative strategies and the net affect on catches, and stock status.

1.6 Plan of thesis

This thesis begins with the literature review of spatial-temporal model approaches using Bayesian analysis theory for estimating the uncertain status applied to the particular case of the 4WX Scotia-Fundy herring resource.

After the establishment of the spatial-temporal dynamic model, the methodology of partially observable Markov chain is used to analyze the fish stock and a visualized computer simulation tool, called MapTest, is introduced to perform the simulation and statistical analysis.

Using the visualized computer simulation application tool, MapTest, the analysis of catch, operational and strategic plans are described.

This final section of the thesis discusses some extensions of this research and recommendations for future work.

2. Literature review

This systems science thesis focuses on applying spatial-temporal modeling to a stochastically varying resource. As such, the important literature may be divided into three main areas:

1) Spatial-temporal modeling approaches, especially in the area of fish population dynamics.

2) Uncertainty and the description and presentation of stochastic systems analysis for decision making.

3) Application of the model to a particular case study, namely the Scotia-Fundy herring resource in NAFO divisions 4WX.

2.1 Spatial-temporal modeling

A remarkable characteristic of fin fish stocks is that they are highly dynamic in space and time over the course of their seasonal migrations. The success of commercial fisheries on these stocks exploits the regular pattern of stock movements over the course of the fishing season. While several spatial-temporal models have been developed to estimate or examine the on-going status of relatively sedentary marine species (e.g., scallops), there are relatively few fin fish models that track seasonal migrations toward estimating stock abundance.

Caddy (1970, 1975) developed a method using spatial analysis method to analyze the scallop population on the Georges Bank. In this method, he divided the scalloping grounds into areas of equal size and assumed that effort and population distributions were uniform only over these smaller localized areas.

Seijo, Caddy and Euan (1994) have developed a simulation package to model the space-time distribution of fishing intensity on sedentary stocks such as scallops. This package, called "SPATIAL", has three models that include a short-run spatial bio-economic model, a spatial dynamics model of population structure and a model to represent short and long-run spatial dynamics of fisheries as a result of interacting biological, economic, and geographic characteristics.

Lane (1989) developed a decision model of the intraseasonal decision making using a partially observable Markov decision process. This model is applied to the salmon freezer troller gear sector of the British Columbia commercial salmon fishing fleet. This fleet was the fastest growing and the most capital intensive component of the troll fleet. This model describes the seasonal stock abundance dynamics for Pacific salmon, which "runs" from ocean to freshwater. The state-to-observation function, the reward functional for the partially observable Markov decision process to reflect the uncertainty about actual stock abundance, and uncertainty in catchability are included to model in-season decisions by fishermen for selecting area and times to fish.

Allen and McGlade(1986) present a spatially defined multispecies model. Their primary interest is on how fishermen exploit the spatial distribution of stocks among fishing grounds, rather than the core stock dynamic process itself. This short-run decision making model is also addressed elsewhere in the literature by Bockstael and Opaluch, 1983; Eales, 1983; and Eales and Wilen, 1986.

MacCall (1990) presented a management oriented general model for the spatial distribution of stock range during periods of changing resource abundance.

Storey(1998) developed a spatial-temporal assessment approach for estimating the in-season status of the Scotia-Fundy herring stock in NAFO divisions 4WX. The estimations of the stock status are updated by the data from spatial-temporal migration dynamics of the fish, and observations from catches over the course of the season using the Bayesian updating method. A Markovian probability transition matrix is used to describe the stochastic core process of the herring stock movements by area and week.

Weekly catch observations were used in the Bayesian framework to update the expected distributional status of the herring stock. The spatial-temporally defined estimates were comparable to aggregate results but more significantly provided up-to-date stock status information for in-season harvest planning. This thesis builds on this approach and application by developing a decision support system for in-season decision making and a strategic simulation analysis for longer-term planning.

2.2 Uncertainty estimation

Uncertainty exists where the possible outcomes are known, but the probabilities associated with the outcomes are not known. Using Bayesian analysis theory for estimating the uncertain status of the fishery resource over the season is an effective means of combining prior information and repeated new information about the fish stock status in order to have the most up to date information with which to make the best decision.

The subjective Bayesian theory is the only one of the various approaches to modeling uncertainty so far to have been given an explicit and powerful theoretical justification (Howson and Urbach 1991).

Bayesian statistics provide the probability of a hypothesis or state (e.g., stock size) given the data (e.g., observations from catches, fishing surveys, etc.) and starting with an *a prior* view of the state and a reliability index of state to observation measures. The following paragraphs describe the basics of the Bayesian approach.

Let H = hypothesis (value of a parameter), e.g., stock size is "low"; and d = observation, e.g., catches are "good", then the Bayesian state updating equation may be written as:

$$P_r(H \mid d) = P_r(d \mid H) P_r(H)$$

where H_i (i = 1, 2, 3, ..., n) is the complete set of state possibilities or hypothesis events; d is an observation event that is preceded by a H_i state event opportunity; $P_r(H_i)$, the prior state probability, and $P_r(d \mid H_i)$, the observation selective reliability data are assumed to be known. Then we may write the updated probability of the state given the data observation by Bayes' Theorem as follows:

$$P_r(H_1 \mid d) = \frac{P_r(H_1) P_r(d \mid H_1)}{\sum_{i=1}^{n} P_r(H_i) P_r(d \mid H_i)}$$

Bayesian methods are the only statistics that allow the calculation of the probability of a hypothesis given the available data. In other words, they are accomplished by integrating the product of the prior distribution and the likelihood function, with a point estimate usually being the mean of the resulting distribution, which is called the posterior distribution. Bayesian methods summarize what is known about a parameter in the posterior distribution (Wade, 1997).

Fernandez, Ley and Steel (1998) developed a Bayesian Model of catch in a northwest Atlantic fishery. Their model deals with the issue of modeling daily catch of fishing boats in the Grand Bank fishing grounds. They propose a statistical model for daily catch per species of fish based on linear regression combined with a certain probability of zero catch. The Bayesian framework leads to exact small sample results, fully taking both parameter and model uncertainty into account.

Bayesian decision analysis offers a useful framework for helping to achieve a precautionary approach to managing developing fisheries. With little data on the resource, data and experience from ecologically similar fish populations (or prior information) can also be used to quantitatively evaluate alternative procedures for managing the resource and to provide management advice. McAllister and Kirkwood (1998) presented a Bayesian framework to evaluate fishery management procedures. They applied Bayesian decision analysis to a hypothetical developing fishery in which a logistic model was fitted to catch per unit effort data.

McAllister, Pikitch, Punt, and Hilborn(1994) used a Bayesian approach to model the sampling/importance resembling algorithm to improve estimates of policy performance indices. It extends the number of parameters that can be treated as uncertain, does not require deterministic assumptions about population dynamics, and can use any of the types of fishery assessment models and data. Application of the approach to New Zealand's western stock of hoki shows that the use of Bayesian prior information for parameters such as the constant of proportionality for acoustic survey abundance indices can enhance management advice by reducing uncertainty in current stock size estimates. It also suggests that a stochastic recruitment assumption can be more appropriate than that of historic recruitment.

Ellison(1996) uses Bayesian statistical inference to estimate ecologically meaningful parameters and provides an explicit expression of the amount of uncertainty in these parameter estimates. Since Bayesian inference requires the investigator to use pre-existing data to develop quantitative, probabilistic, and parameterized hypothesis, Bayesian hypothesis decision analysis inevitably will lead to testable predications, and permit the rapid development and refinement of applicable theory.

Patterson (1999) uses a Markov chain Monte Carlo approach to calculate Bayesian posterior distributions for critical parameters of a Norwegian spring-spawning herring stock assessment using an assessment model that incorporates catch-at-age, survey, and tag release and recapture observations.

In this thesis, the Bayesian approach is used to update current estimates of stock status in each spatial area of a fishery based on catch and other ecosystem observations about the stock. This in-season view of changing stock status is linked to stock seasonal spatial and temporal dynamics as the prior. In-season observations in space and time update the estimates of stock status.

2.3 Application

This thesis studies the case of 4WX commercial herring fishery that takes place along the Southern and Western Scotia shelf and into the Bay of Fundy (see map of fishing grounds in Figure 2.1).

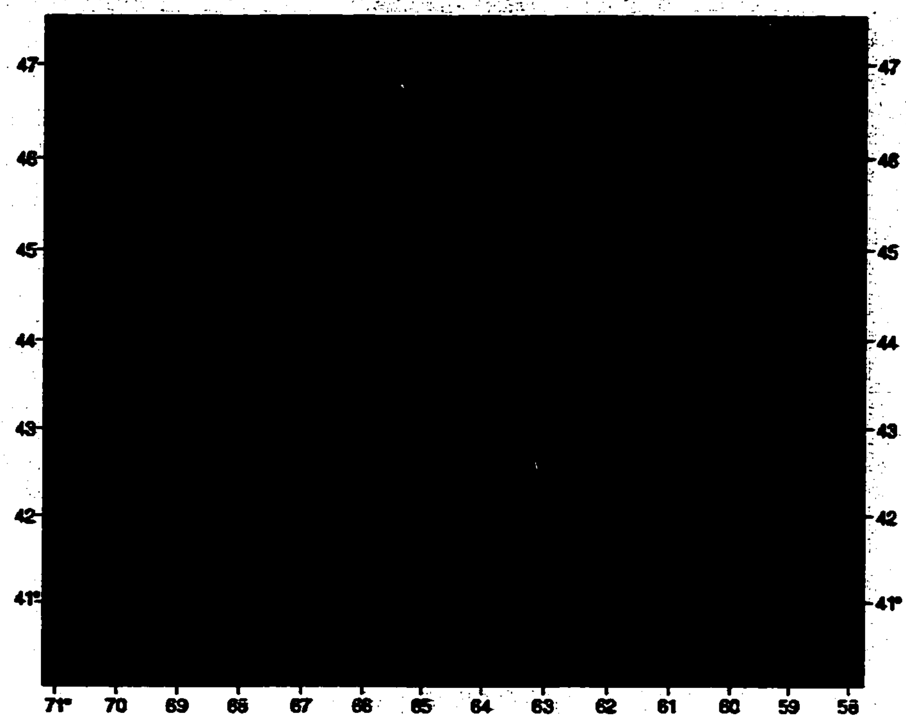


Figure 2.1 Map of Scotia-Fundy herring fishing grounds show the Gulf of Maine, the Bay of Fundy and the Scotia Shelf areas.

The Atlantic herring is one of the best known open sea fish on Canada's east coast. Spawning occurs along the Canadian Atlantic coast in any month between April and October, but it is concentrated between May and September. Most evidence shows that spring and fall spawners are biologically independent stock groups. Biochemical studies have recently shown that there are clear genetic differences between fall-spawning and spring-spawning herring.

A large stock of herring spawns off Southwest Nova Scotia in the fall. Spawning activity is concentrated on the Trinity Ledge and Lurcher Shoals near Yarmouth. After spawning, much of the adult stock migrates up to the Nova Scotia coast for winter in the area around Chedabucto Bay. In the spring, they migrate to the Bay of Fundy where they feed during the summer off the south and southwest coast of Nova Scotia before moving to the spawning grounds. Juvenile herring from this stock mix with Gulf of Maine juveniles to form large concentrations of "sardines" along the New Brunswick coast of the Bay of Fundy during summer, where they support a traditional weir fishery.

There are several sources of information that provide us with knowledge of herring stock structure. Tagging studies are a traditional method. Meristic studies compare the counts of some body parts, especially vertebrae, gill rakers and fin rays. These counts are different between fish from some stocks.

In Nova Scotia, inshore fishermen in Sidney Bight and Chedabucto Bay fish local spawning runs of herring. Purse seines in these areas fish overwintering herring. The winter seine fishery in Sydney Bight started from 1968 and reached a peak of 17,547 t in 1973, only to decline to less than 4,000t per year by the early 1980s. Catches are a mixture of overwintering herring from southwest Nova Scotia, the Gulf of St. Lawrence, and local Cape Breton stocks. The peak catch from the winter fishery off Chedabucto Bay was in the order of 50,000t in the early 1970s. More recently catches have varied between 10,000 and 20,000t per year. From tagging studies, the Chedabucto Bay fishery seems to be closely associated with the Southwest Nova Scotia stock and has been managed in conjunction with the southwest Nova Scotia fishery since 1974. The TAC (total allowable catch) for the fishery off the Chedabucto Bay is determined according to the management plan for the southwest Nova Scotia fishery.

Some of the largest Canadian herring fisheries are carried out when fish from several spawning populations are mixed together for feeding or migration. So it is impossible to predict exactly what portion of the TAC will be caught from any one population. For this reason, it's possible that small subpopulations contributing to a large fishery might accidentally bear much more than their relative share. This may result in the virtual elimination of these spawning populations and it may take many years before new stocks repopulate the abandoned spawning sites.

There is a considerable difference of sub-stock degrees within large herring stock complexes such as the Scotia-Fundy Atlantic herring stock due to individual spawning groups that follow well-defined migration routes. There is relatively little inter-annual variability in terms of time or space migration on these sub-stocks compared to many other commercial fin fish (Stephenson, 1991). The migration patterns of six spawning subgroups of the 4WX herring stock in the Bay of Fundy off Nova Scotia are relatively well-known by fishery scientists and the fishing industry (Stephenson et al, 1993). In addition, for this stock from annual VPA stock assessment estimates, e.g., estimates of the total stock size and proportions of spawning groups are also available (see Stephenson et al. 1995).

Furthermore, using a Bayesian updating procedure, the weekly estimation for total stock size for the years 1991-1995 and the estimation for the size of each spawning group was made by updating catch observation data (Storey, 1998).

Other techniques have been developed to estimate the abundance of herring stocks. Catch rates on spawning fisheries are being introduced to estimate the numbers of spawning fish. Acoustic surveys are also used to determine the abundance of herring over winter, when stocks are more concentrated. Surveys of the numbers of eggs deposited on spawning beds (larval abundance) permit back calculation of the number of parent fish.

The most challenging area of fishery research includes the understanding of recruitment variability. Acoustic surveys are being used to estimate the abundance of juveniles. But in order to predict accurately future variations in recruitment, more information about the relationships between herring (as a prey species) and other species (as predators) as well as the relationships with the environment are necessary. Detailed ecological research about these relationships continues (Canada 1984).

In this thesis the development and analysis of the spatial model using Bayesian updating is applied to the 4WX herring stock. This application takes into account the known dynamics and variability of the aggregate stock and its subcomponents.

3. Methodology

This section describes the modeling process for the spatial-temporal dynamics of the 4WX herring stock.

3.1 Spatial-temporal dynamic model

Analysis of herring stock scientific data suggests that there are 6 distinct geographical areas for Scotia-Fundy herring spawning (Stephenson et al., 1993). The spawning event occurs at different timing each year. The following methodology imports a probabilistic pattern of stock migration for each spawning group to take timing variability into account.

The fish stock can be looked at as a set of dynamic subsystems in different states of abundance throughout the course of the year, the spatial-temporal behavior of the subsystem is defined by the location and abundance of the spawning group during its particular seasonal migration behavior.

To describe the process of spatial-temporal dynamics of stock abundance from zone to zone and week to week, a transition model was developed to describe the week over week probability of transition from zone to zone in the fishery. This model takes account the range of the whole stock, the ranges of each of several distinct spawning groups, the migration patterns of the main wave of each spawning groups and the relationships between the up to five proportional migration wave patterns. A probability transition matrix is used to describe the weekly zone to zone migrations of the stock.

3.2 Observation process

To help solve management problems, an accurate estimation of the fish abundance in a population at a given time during the season is very important. One very useful guide for the observation of some species of fish is the regular catch of commercial fishing vessels. If, for example, the catch is larger than that of last year (all other things unchanged), this suggests that fish may be more abundant.

3.3 Markov chain

The abundance of the stock in each geographical zone is estimated by assigning qualitative levels of abundance measures to the stock: e.g., zero, low, medium, medium-high and high. The abundance level of the stock distributed across each zone in a given time period describes the state of the system.

For spawning groups that migrate along relatively specific routes each season, the state of abundance of the system during a period of time depends on the state of the system in the previous period, i.e. knowledge of how many fish there are in each location currently provides useful information about the state of the system in the next period. For this reason, the spatial-temporal model is established corresponding to the dynamics of the "core process", the changing population levels of the fish stock throughout the year. A Markov chain is ideally suited for describing the probabilistic population dynamics of this kind of dynamic system behavior.

The following defines the key notation of the partially observable Markov chain problem methodology (Lane 1989) also adopted for this thesis:

Let $K \in \{1, 2, \ldots 52\}$ denote the k^{th} week of the year, and let $z \in Z$ denote a geographical zone in the habitat of the fish with $|Z| = Nz$, the finite number of zones in the fishery.

Let X_k be a N_z-dimensional random variable whose components represent the population levels of the stock in the various zones at the end of the kth week. So $\{X_k\}$ describes the dynamics of the underlying process of the changing population levels of the fish stock throughout the year.

We define $P_{ijk} = P_r(X_k = j \mid X_{k-1} = i)$ to be the probability of moving from an abundance level vector of value i at the end of the (k-1)th week to an abundance level vector of j at the end of the kth week, where i and j are vectors of length N_X, which represent pair-wise discrete levels of stock abundance across all zones. Then the probability transition matrices, P_k, describe the non-stationary (i.e. weekly varying) process of stock abundance spatial-temporal dynamics from zone to zone and week to week throughout the season.

Since the population dynamic of the fish stock is only partially observable, an additional N_z-dimensional vector random variable, Y_k, is required to define the observation levels process. For example, catch statistics or other fishing observations (i.e. sampled with error) are only partially available, so actual catch statistics by zone and week are required to define the observation process. The components have values that represent the observations of stock abundance status such as discrete levels of the catch.

Let $$q_{jlk}(z) = P_r(Y_k = l \mid X_k = j), \quad z \in Z \tag{3.1}$$

define the state-to-observation function, a function of the state of the core process, which is the true population level. The state-to-observation function expresses the reliability of the observation with respect to the true state. It is assumed that this reliability does not depend on the period (week) of the observation. Thus we let $q_{jlk} = q_{jl}$ for all k. The stochastic matrices $Q(z)$ are also called signal matrices or reliability matrices. They describe the distribution of probabilities for the observation levels, Y_k, relative to the actual state of the system.

We define the sufficient statistic (Bertsekas 1976), π, as follows:

$$\pi_j(k) = \mathrm{P_r}(X_k = j \mid I_k), \quad j \in N \tag{3.2}$$

where $\pi_j(k)$ is the variable of the system state that defines the interaction between the partially observed actual population size and all the available historical information about it, $I_k = (Y_1, Y_2, \ldots Y_{k-1}, Y_k)$.

Using Bayes' formula, $\pi_j(k+1)$ is defined by the transfer function T_k as

$$T_k(\pi \mid I)_j = \pi_j(k+1) = \frac{q_{jlk} \sum_i p_{ijk} \pi_i(k)}{\sum_{i,j} q_{jlk} p_{ijk} \pi_i(k)} \tag{3.3}$$

for state vector indices i,j and weekly periods $k \in \{1,2,\ldots 52\}$. Let $\pi(0) \leftarrow \pi(52)$, which is the last week of the previous year, describe the initial probability distribution of the stock at the beginning of the year. The probabilities of initial abundance levels, $\pi_j(0)$, are assumed to be known through historical estimates or from research survey data.

The purpose of equation (3.3) is to use Bayes' Theorem and the core process Markovian dynamics to obtain information about the true level of abundance through the sufficient statistic. $\pi(k)$ is the probability distribution of the population abundance levels, which can also be computed by adding up all expectations for each period by zone. Estimates of abundance are updated for each period of k following reception of the latest observation set.

We also need to pay attention to the following different situations that both yield a zero catch observation: (1) No fishing effort - implies no catch and consequently no additional information on stock size. (2) a catch of no fish - when there has been effort expended and provides considerable information about abundance. Here the equation (3.3) is used only for zone-week combinations where there is non-zero catch data or there is reason to expect (from historical fishing observations) that fishing effort actually took place.

The following update equation is used to update population levels when there is no fishing. This situation involves only the core process. The probability transition matrices, P_k, is used as follows as a modification of (3.3):

$$T_k(\pi)_j = \pi_j(k+1) = \frac{\sum_i \pi_i(k) p_{ijk}}{\sum_j \sum_i \pi_i(k) p_{ijk}} \tag{3.4}$$

3.4 Estimation procedure

The Bayesian methods described above are used to update estimates of the stock size for the fishery of Scotia-Fundy herring. First, probability matrices, P_K, are determined to describe the process of spatial-temporal dynamics of stock abundance from zone to zone and week to week by considering the range for the size of both the whole stock and the relative ranges of every spawning groups, and their migration patterns for both of the main wave and each relative proportional waves. Secondly, the signal matrix is estimated from catch data over time. Catches from different spatial-temporal states during the year provide a sample distribution of catch signals with respect to past reported levels of abundance. Thirdly, the prior probability distribution should be initialized according to the population data that are available at the beginning of the season. Finally the historical catch observation data are included in each week to update the stock status in each area and week throughout the season.

3.5 Simulation and statistical analysis tools

Several computer software packages in programming, database and graphical display are used in this thesis to develop the MapTest tool. This software includes the spread sheet - *Microsoft Excel*, the Geographic Information System - *MapInfo Professional* and the programming language - *Microsoft Visual Basic* and under the support of OLE (Object Linking and Embedding).

(1) Microsoft Excel - MS Excel is a well-developed software tool and is powerful for dealing with large amounts of data (Microsoft, 1997). This thesis uses MS Excel to establish the database of historical catches in the 4WX commercial herring fishery. The database is based on the updated in-season catch by vessel-trips raw data available from 1989 to 1998. Table 3.1 is an example from MS Excel data file in 1993. In the table, each record (row) presents one trip of catch in a specific location. The terminology of the data fields has the following definitions:

(i) Catch – herring catch (t) by a single purse seine vessel at a specific location and week.
(ii) Zone – geographical area defined for management purposes.
(iii) Week – sequential week number during year (1 –52).

(iv) Lat_New – recorded logbook latitude where catch was made.

(v) Long_New – recorded logbook longitude where catch was made.

Appendix A – Herring fishing zones provides the zone definitions with descriptions of geographic location. Appendix B – Catch data set information contains the raw data on information on the herring catch logbook detail from which Table 3.1 is derived.

CATCH	ZONE	Week	Lat_New	Long_New
4	1	1	44.66667	66.66667
14	1	24	44.48611	66.60639
18.1	1	24	44.49917	66.5975
14	1	25	44.48333	66.57167
28.3	1	25	44.52861	66.5525
11	1	26	44.64333	66.63944
10.3	1	26	44.5	66.5
15.5	1	26	44.5	66.5
25.3	4	26	43.87333	66.6525
9.7	2	27	44.32056	66.37889
6.8	2	27	44.32083	66.37889
14.1	2	28	44.16667	66.33333
11.1	2	28	44.16667	66.33333
...	...	...	...	...

Table 3.1 MS Excel partial catch data file for 1993.

(2) MapInfo Professional - MapInfo is a Geographic Information System by MapInfo Corporation available for use in conjunction with OLE Microsoft software (MapInfo 1996). For this application of spatial-temporal fishery research, MapInfo is an excellent tool to provide visual images and analyses of the in-season status of the fishery. Figure 3.1 provides an example screen dump of the map display with marked locations of herring landings using MapInfo.

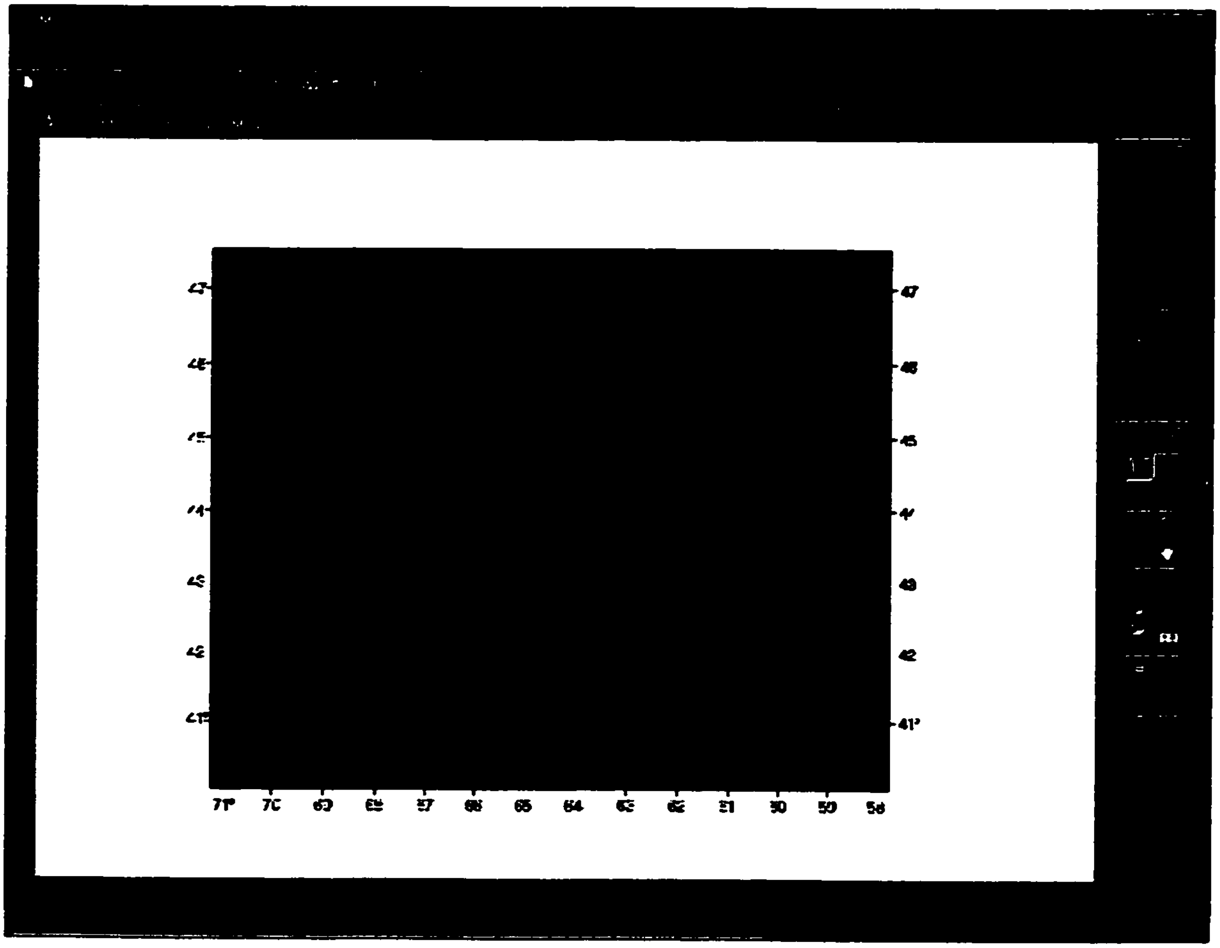


Fig 3.1 The catch data of 1991 is shown on the map by Map Info.

(3) Microsoft Visual Basic - In this thesis, MS Visual Basic (VB) is used to create an easy to use user interface to present the model results and to link the OLE components, Excel, and MapInfo. The VB model processes the source data from the MS Excel records files and controls the MapInfo routines to present the geographic simulation results within

the VB interface. An example of the VB interface with the MapInfo map and Excel purse seine catch location for week 24 of 1992 is shown in Figure 3.2.

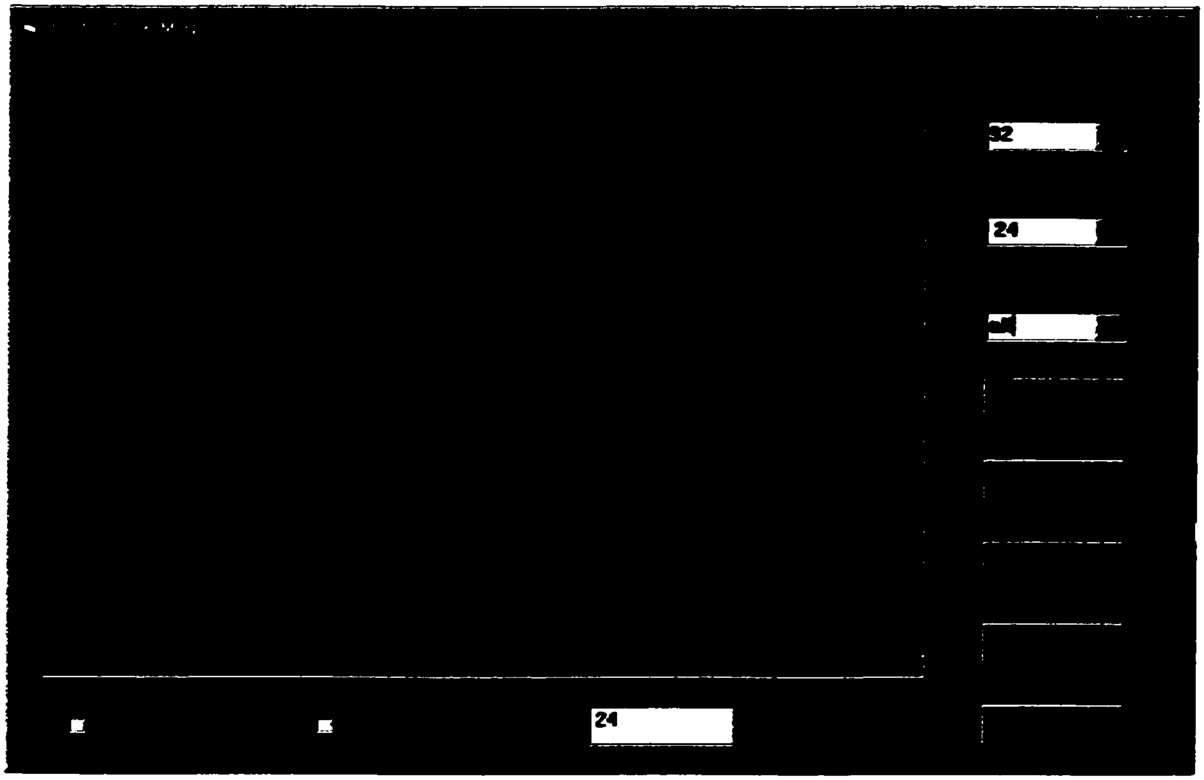


Fig 3.2. The VB interface shows the catch for week 24, 1992 at all zones.

3.6 Model structure and process

The detailed description of the computer application model contains the following three parts:

(1) Model Structure – design level explanation of the database and data handling, programming language, computer technique (i.e. OLE), and software packages (i.e. MapInfo, MS Excel), which are adopted in MapTest.

(2) Model output – explains the main features and results of MapTest.

(3) Model process – explain how to use MapTest to perform operational planning and strategic planning for the 4WX herring fishery.

3.6.1 Model structure

In 1992, Microsoft created Object Linking and Embedding (OLE) programming functions that allowed programmers to create applications that enabled one large document to consist of a variety of smaller documents, each created in a different application. A simple example of OLE is in a word processing package, an embedded spreadsheet can create a graph in a spreadsheet document.

The computer simulation tool (MapTest) developed in this thesis uses the OLE data connection technique to connect the MapInfo geographic display with the VB interface. OLE makes it possible for a VB application interface to contain files from MapInfo. Fig. 3.3 shows the OLE between VB and MapInfo, which is the illustration of the design of the MapTest product. OLE also applies to connecting data between the MS Excel spreadsheets and the MapInfo Interface. Fig 3.4 shows the OLE between Excel and MapInfo. OLE applied to data processing and presentation is the basis of the implementation of the visualized computer application that is MapTest.

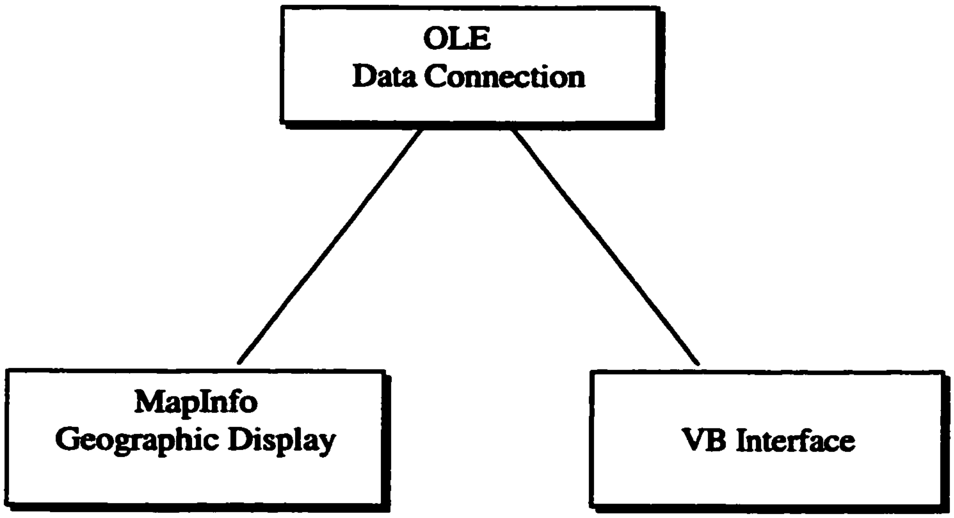


Fig. 3.3 OLE between MapInfo and VB Interface

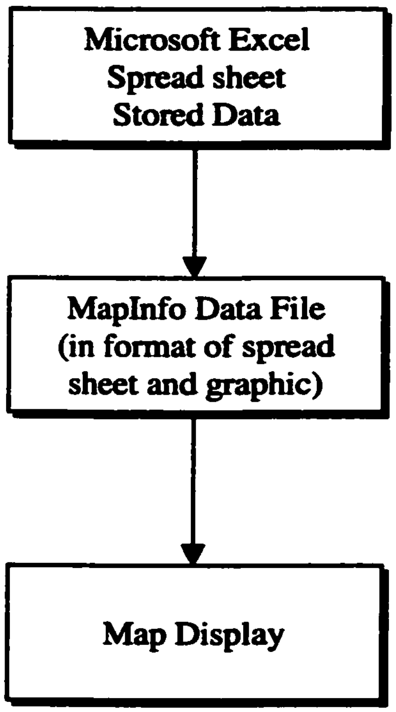


Fig 3.4 OLE between Excel data and MapInfo

Microsoft Visual Basic supports the use of OLE on compatible software such as MapInfo and Excel. In the VB program, using OLE by function call, the geographic presentation which is originally on MapInfo interface can be embedded onto VB GUI (Graphical User Interface). Different VB GUI can control different MapInfo geographic displays by different calls.

The database of this simulation application tool is stored in Microsoft Excel spreadsheets. Each year's data are contained in one table. MapInfo reads the Excel spreadsheet file and using OLE converts this data into a MapInfo data file. MapInfo data file can be displayed in standard spread sheet table format, as well as symbols displayed on a geographic map corresponding to map grid (latitude and longitude referenced) geographic locations. In MapTest, we use MapInfo data tables to store data and then display the geographic presentation on a visual map.

Besides MapInfo and Excel, Visual Basic plays an important role in this application tool. The computer program is developed using Microsoft Visual Basic V6.0 (Microsoft, 1998). Visual Basic is a powerful programming language in data application and database management. Its advanced GUI tools make it successful in developing user friendly, easy-to-use user level applications. Fig 3.5 shows the interface of the VB application in this thesis.

MapTest is an Object-Oriented Program that creates object at run time by input information to models in the application. In MapTest, each year of catch is saved in a MapInfo data file. At run time, one or two year(s) of data are selected depending on which model (operational planning model or strategic planning model) to be used by the user. Base on the selected year(s) of data and other input (i.e. the input TAC for estimated caches), an object is created by MapTest for this run to simulate operational planning and strategic planning. When the user select different input of year or TAC, an new object is created for the new estimation process.

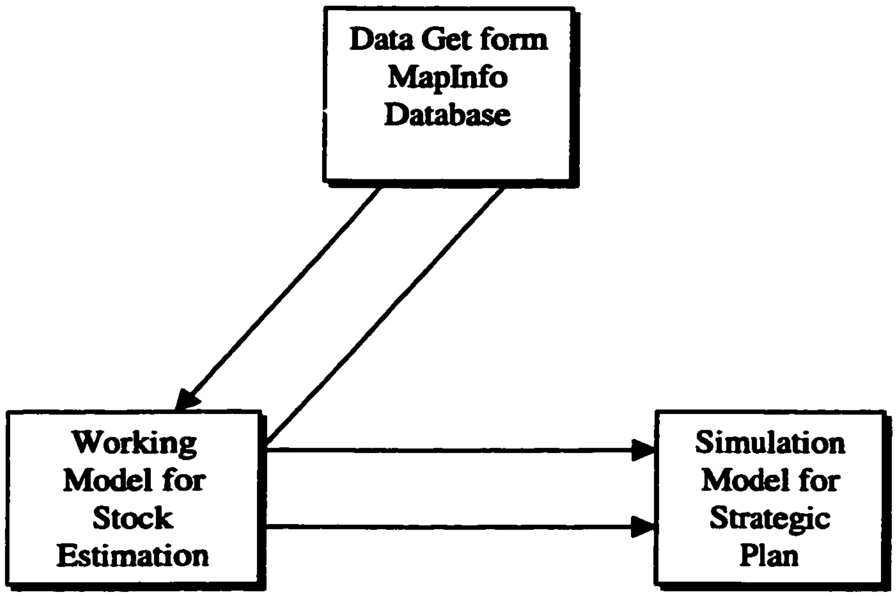


Fig. 3.5 The VB application interface

There are two models in this application: the working operational planning model and the strategic simulation model. The working model uses catch data from MapInfo to develop the Bayesian statistical estimations of stock abundance by week and by zone. The simulation model can use the result from the working model to simulate a projected year. The following sections describe the model output (3.6.2), and 3.6.3 describes the model process and how to use the application tool for planning in this fishery.

3.6.2 Model output

The VB GUIs in MapTest can be classified into catalogs. Catalogs are: The Main GUI, Catch Data Display GUI, State Set Up GUIs, Estimation GUIs, Simulation GUIs, Report GUIs and Help Information GUIs. From the Main GUI, users can obtain help and usage information. Users also can obtain information about zone definitions assigned for the MapTest 4WX herring application. From the Main GUI, users can display catch data or identify the states for estimation or simulation. MapTest will provide stock abundance estimates. The estimation can be reported in built-in graphs or tables. Estimated caches can be simulated after estimation and estimated caches reports are generated. Both the operational and simulation reports can be printed on a connected peripheral printing device. Fig 3.6 shows the GUIs developed in this application and their relations.

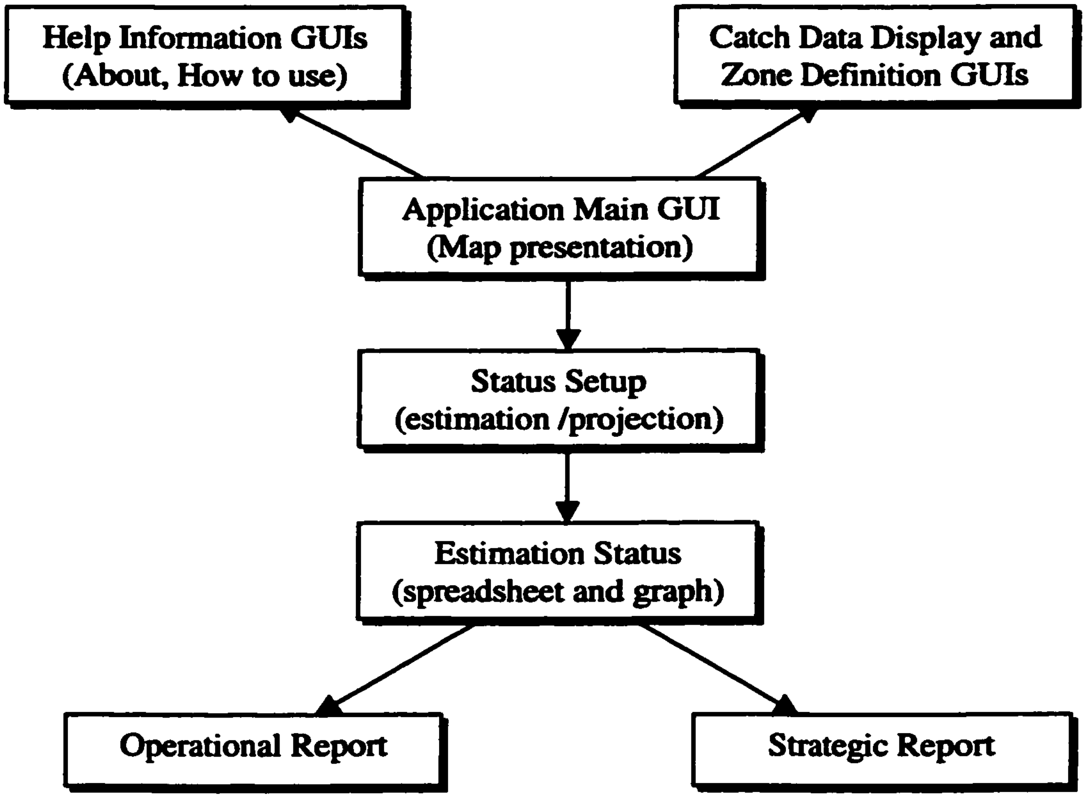


Fig. 3.6 GUIs in the MapTest application tool

3.6.3 Model process

MapTest is designed to be an object-oriented easy-to-use application tool for fishery analysis. This section intends to explain how to use MapTest to estimate stock abundance and project strategic simulation.

1. From the VB application start-up window (Main GUI, Fig. 3.2), users can obtain help information from the "Help" menu on the top-left of the Main GUI. From the "View" menu, users can select "Zone definition" to see the geographical definitions of different zones in this application. Zones locations are also shown directly on the visual map. For example, Fig. 3.7 shows the zone definition of Scots Bay, also known as Zone 8.

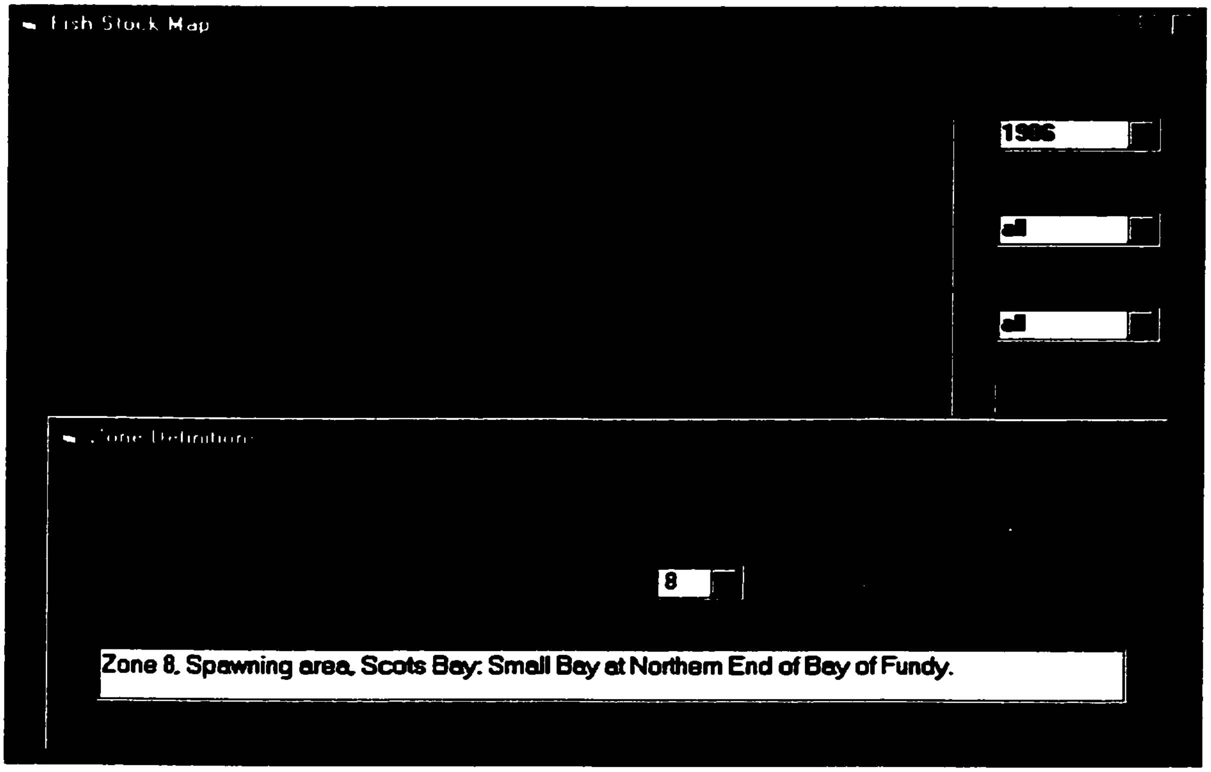


Fig. 3.7 Zone definition of Scots Bay

2. From the Main GUI, if a user selects year, week and zone, then selects "Display" or "Detail" in "View" menu, will display catch data on the map or in a spread sheet table. The data in spreadsheet can be sorted by zone, week or catch. The map also can display thematic bubble maps of catch classes by checking the "Thematic Map" box on main window. Fig. 3.8 shows the graph "Display" of catch data locations along with its accompanied "View – Detail" table of catches observations by locations for 1998.

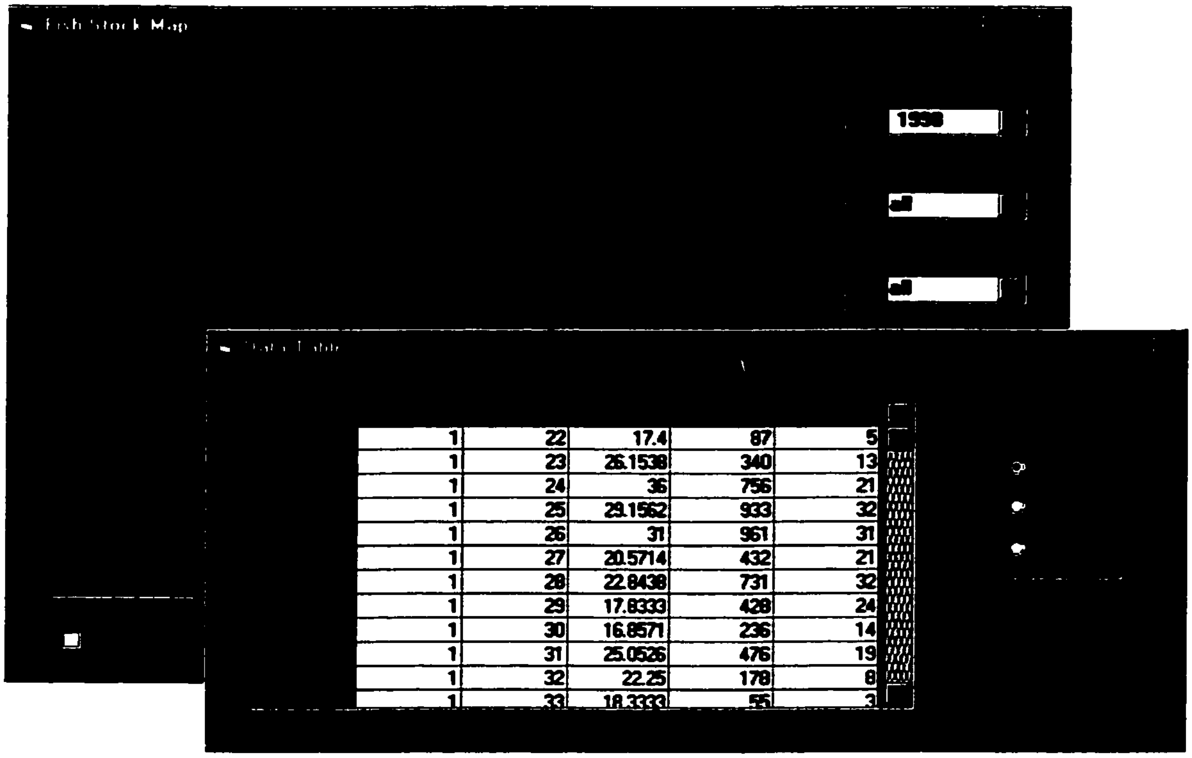


Fig. 3.8 Catch data in 1998

3. For illustration purposes, now we obtain the stock abundance estimation on Scots Bay in 1998. From the Main GUI, click the "Status" button, select "1998" as the year of interest and "8" as the zone in the pop-up Status GUI then click OK. Fig. 3.9 is the Status GUI that shows the observation matrices and the updated probability matrices. The Graph GUI in Fig 3.10 shows the stock estimate update week by week. The scaled stock levels in the Graph GUI are defined by the stock abundance in units of tonnes as shown in the table on the Graph GUI in Fig 3.10.

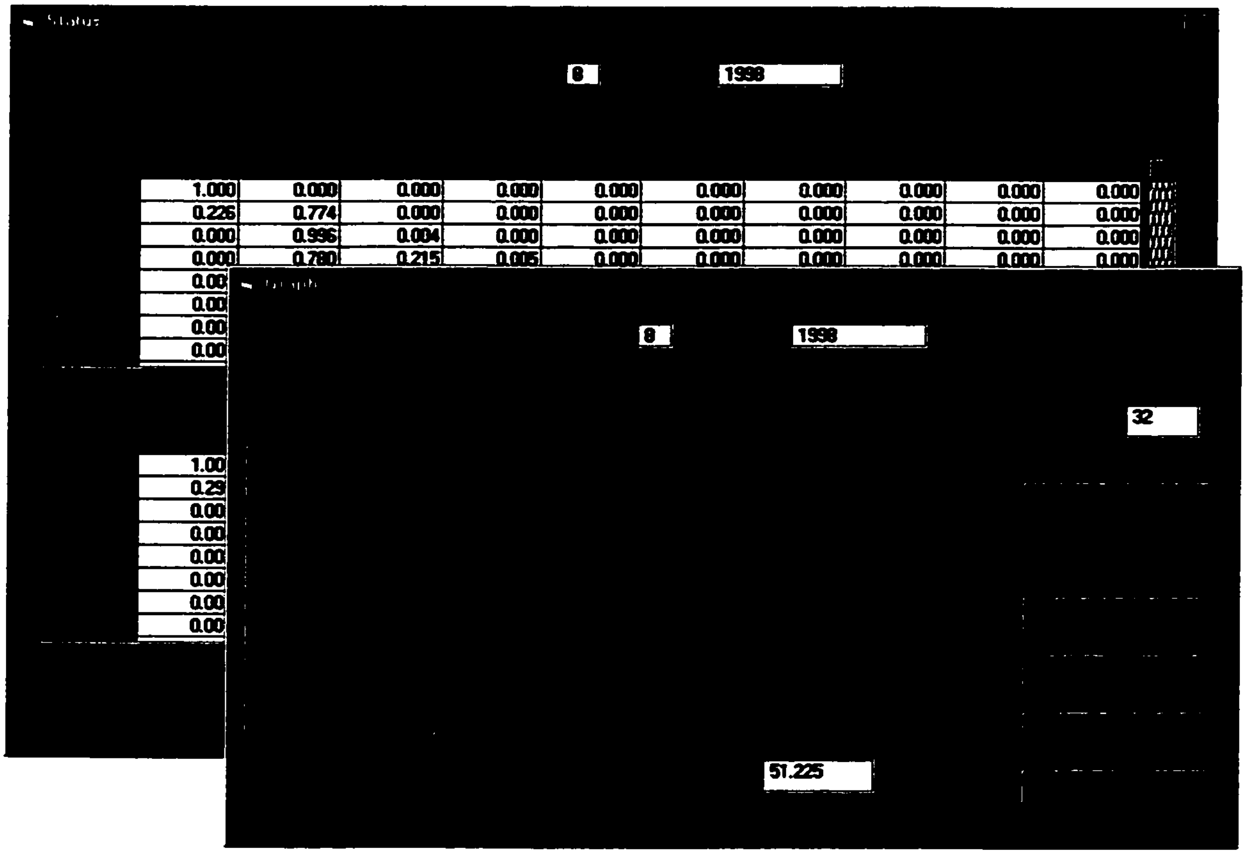


Fig. 3.9 Estimated stock abundance on Scots Bay in 1998

Appendix C provides an example of the Core Probability Transition Matrices used in MapTest for updating stock abundance estimates. Appendix D illustrates an example of Updated State Probability Transition Matrices.

4. From the Graph GUI, we can obtain the estimated stock abundance for year 1998 in Zone 8 by clicking the "Operational Report" button. Fig. 3.10 shows the operational week-by-week report of stock status in Zone 8, Scots Bay. The operational report can also be printed out.

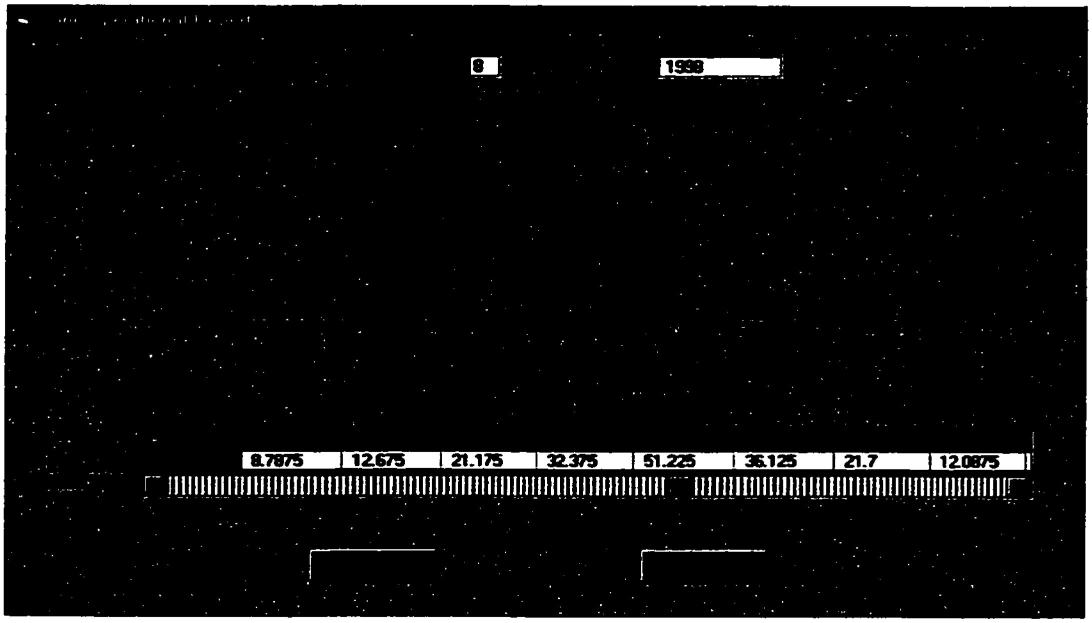


Fig.3.10 Operational report for Zone 8 in 1998

5. The strategic report information can be obtained from clicking the "Strategic Report" button on the Graph GUI. Fig. 3.11 displays the total expected adult stock of herring abundance in 1998 for Zone 8 spawning area (Scots Bay).

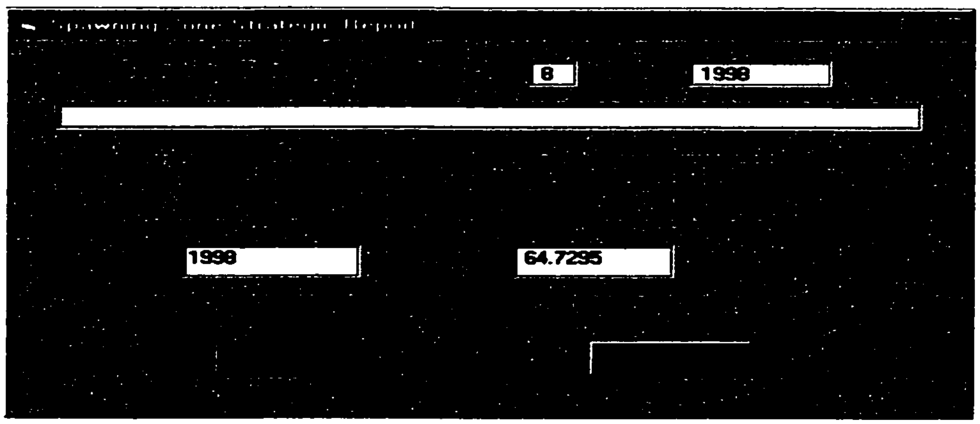


Fig. 3.11 Strategic report for Scots Bay in 1998

6. Now we describe a strategic simulation of a estimated caches year with a TAC of 100,000t. First, select "New Project" as the "Selected year" in the Main GUI, then click the "Start" button on the same GUI. From the pop-up Projection GUI, we set "100" as estimated caches year TAC and check the 1998 check box to select estimated caches year as 1998, i.e., 1998 data will be scaled to the target TAC of 100,000t (Fig. 3.12).

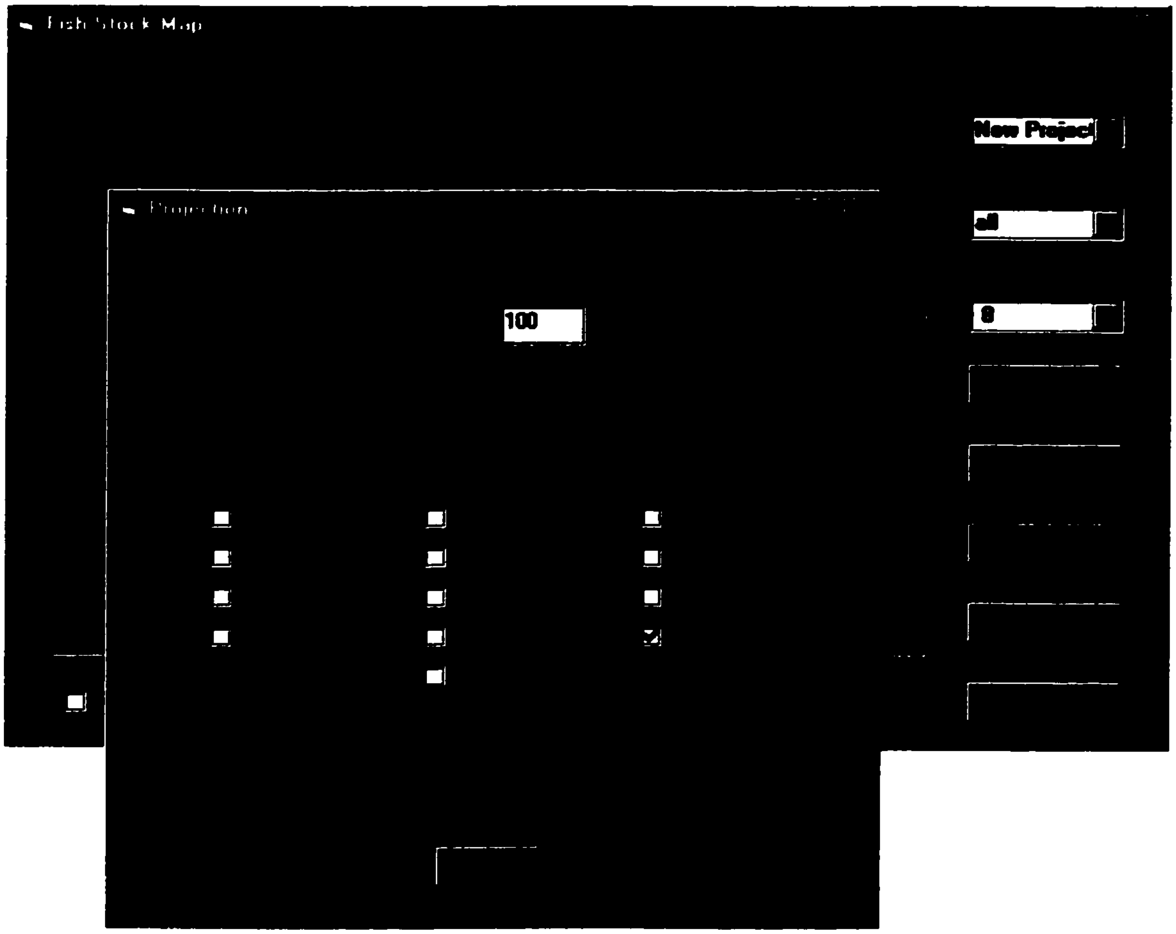


Fig. 3.12 Set up estimated caches year

7. To get the estimated stock abundance for the estimated caches year, click OK on the Projection GUI, then click "status" on the Main GUI. In the Status GUI, select Zone 8, leave the "Year" as "Projection", then click OK. We can get the estimated caches report and strategic report for the estimated caches year by repeating step 3 through 5 above.

In summary, the estimated caches simulation procedure includes a number of basic assumptions. These are:

1. Estimated caches allow users to change the total allowable catch (TAC) for a given historical year.
2. Purse seine records for the years selected (maximize of 2) are similarly adjusted to scale so that the present TAC is assumed caught.
3. Catch location from selected years are used to identify locations of catch by purse seines on the estimated caches year.

Appendix E – MapTest Object Diagram and Flowchart, presents the details of the model process.

4. Analysis and Results

The results of the analysis of the model presented in Chapter 3 above are comprised of two parts:

(1) Operational Planning Model Decision Support System - in-season updating and analysis that includes weekly reports on:

(i) catches to date(in the current season), including catch location from map graphics.

(ii) Bayes' update graph on the probability distribution of the estimated stock abundance by zone and week.

(2) Strategic planning simulation model - simulation of seasonal catch estimated caches for alternative TACs and fishery locations selected from historical data to explore the impacts on estimated abundance on the key herring spawning grounds.

4.1 Operational Planning Decision Support System

The 4WX management unit is known to contain a number of herring spawning areas separated, to various degrees, in space and time. Spawning units in close proximity, with similar spawning times, and which share a larval distribution area are considered part of the same complex - and undoubtedly have closer affinity than spawning units that are widely separated in space or time, and do not share a common larval distribution area. Some spawning areas are large and offshore, whereas others are small, and more localized, sometimes very near shore or in small embayments. The situation is complicated further by the fact that herring tend to migrate long distances, and to mix outside of the spawning period with members of other spawning groups.

For the purpose of this analysis, the in-season operational planning decision support system recognizes five separate herring spawning groups in 4WX. They are: Trinity Bank (zone 3), Lurcher Spawning Ground (zone 4), Seal Island (zone 6), German Bank (zone 7) and Scots Bay (zone 8). Table 4.1 gives the zone number and main spawning period dates for each spawning group.

Spawning Group	Trinity Bank	Lurcher	Seal Island	German Bank	Scots Bay
Zone Number	3	4	6	7	8
Week	33-39	33-39	34-40	35-41	28-35
Spawning Period	Aug15-Sept20	Aug15-Sept20	Aug20-Sept25	Aug30-Oct5	Jul15-Aug25

Table 4.1 The zone number and spawning period for the 4WX herring spawning groups.

In the decision support system, the in-season catch data are provided weekly. The purse seine herring catch events are given on the geographic map report of MapTest. Fig. 4.1 gives the geographic map presentation of catches that took place in 1998 over the entire fishing area.

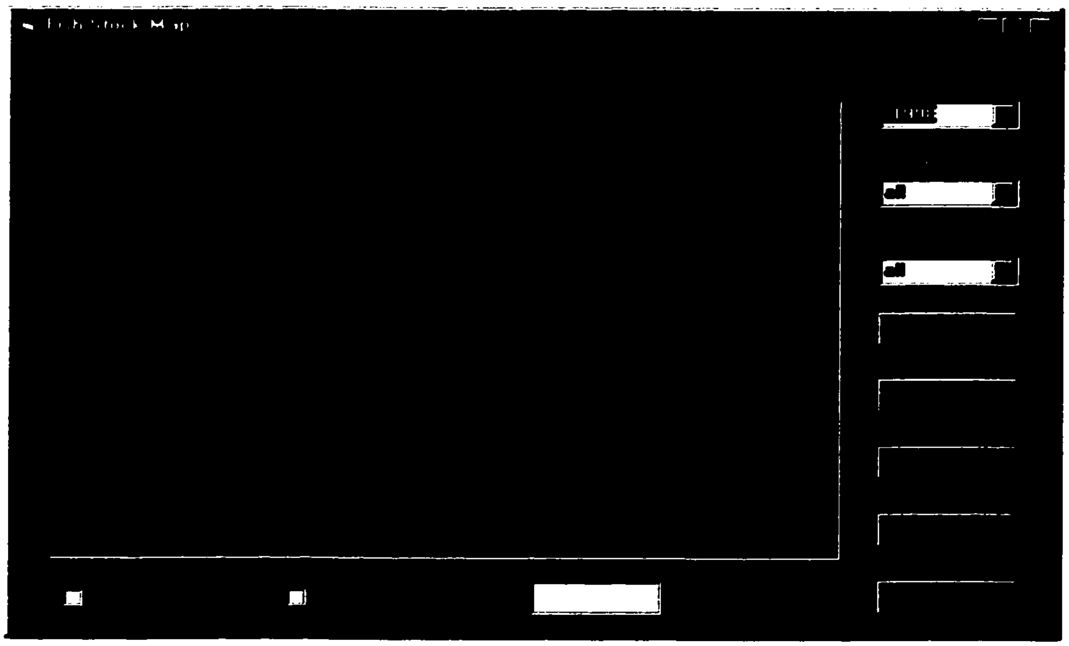


Fig. 4.1 Catches that took place in 1998

With the use of the MapTest software developed for this thesis, the analysis examines the spatial and temporal characteristics of the herring purse seine catches from 1986 to 1998 with special emphasis on timing and activity of spawning the spawning grounds where 4WX herring are known to annually congregate in a regular fashion. This behavior and the spatial-temporal analysis permits us to examine trends in stock dynamics over the period 1986 to 1998.

Table 4.2 gives the total catches of spawning period for the spawning groups from 1986-1998. Fig 4.2 shows the annual purse seine catches in graphic form. All catches in the table and the chart are in the units of 1000t of herring caught.

	Trinity Bank	Lurcher	Seal Island	German Bank	Scots Bay
1986	11.789	0	3.8115	10.5216	0.0363
1987	16.2929	0	5.6847	12.4371	3.5737
1988	12.1857	0	17.5821	17.5677	3.9042
1989	0.2612	0.0181	17.456	4.46525	5.9478
1990	0.299	0	19.3646	10.6991	8.8421
1991	3.198	0	13.0121	15.7398	6.1126
1992	0.133	0	10.9563	0.06	8.4101
1993	0.088	0	2.8584	0.039	5.3075
1994	0.49	0	1.1224	8.9848	8.9624
1995	0.152	0.1875	0.24666	16.66491	1.05025
1996	1.76	0	0.149	14.1975	8.9833
1997	0.341	0.599	0.235	11.694	3.409
1998	1.5757	0	0.0467	17.959	7.545

Table 4.2 Historical purse seine catches of herring on the designated spawning grounds from 1986-1998.

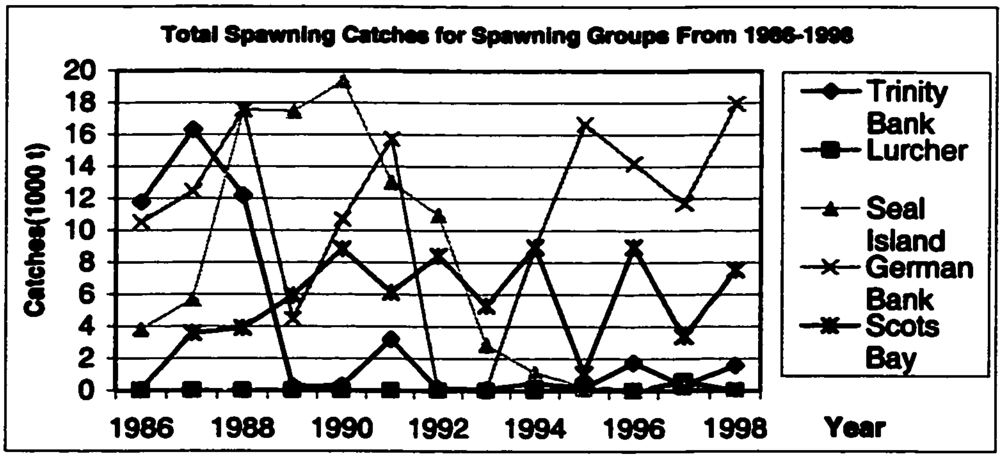


Fig. 4.2 Total Spawning Catches for Spawning Groups from 1986-1998

4.1.1 Analysis of Catches on Spawning Grounds

4.1.1.1 Scots Bay

Scots Bay is a small bay herring fishing ground at furthest northeastern end of the Bay of Fundy. The herring fishery zone number of Scots Bay is denoted as 8. In Scots Bay, herring spawn each year during week 28 through week 35, or from about July 15 to August 25. The zone definition map for zone 8, Scots Bay is shown in Fig 4.3.

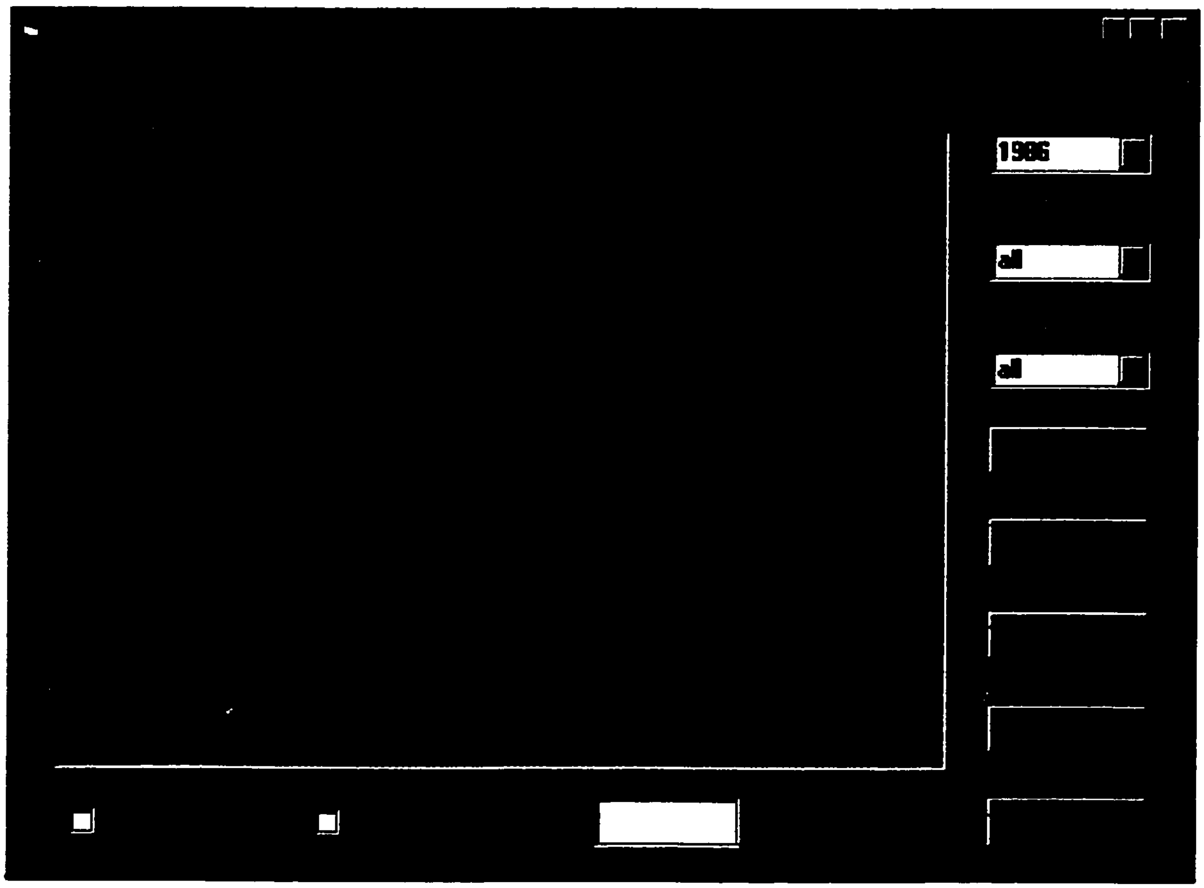


Fig. 4.3 Zone definition map for Scots Bay (zone 8)

Using MapTest, we note that the total catches of spawning herring in Scots Bay was negligible up to 1986, but then grew up to 6,000t by 1989. After that, the catches of Scots Bay spawners have stayed in the range from 5,000t to the high level of 9,000t with the exception of the very low year at 1,000t in 1995.

Besides the change of catches, the concentration of catches changed year by year as well. The distributions of spawning occurred in Scots Bay were mostly in the southeast part of the zone along the Nova Scotia shore except in 1998 when there were some catches made in the northwest part of the zone closer to the New Brunswick shore. The distributions of spawning were more spread out in Zone 8 before 1991. From 1992 to 1994, the catch distributions were very concentrated, and after 1995, the year the industry decided to halt the fishery after a poor survey result, the distribution of catches in Scot's Bay becomes more spread out. Although there is no full evidence to say that the halt year changed the concentration, it is a good sign for the fishery that the spawning populations are more decentralized after the halt in 1995. Fig 4.4 and Fig 4.5 show the spawning distributions of Scots Bay in 1993 and 1995.

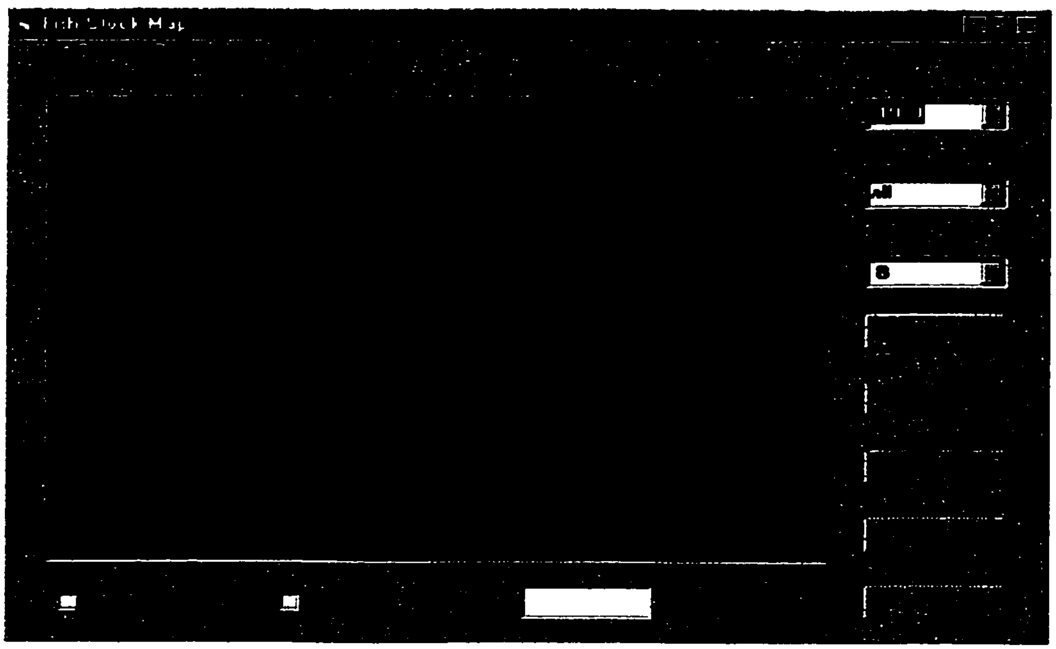


Fig 4.4 Spawning Distribution of Scots Bay in 1993

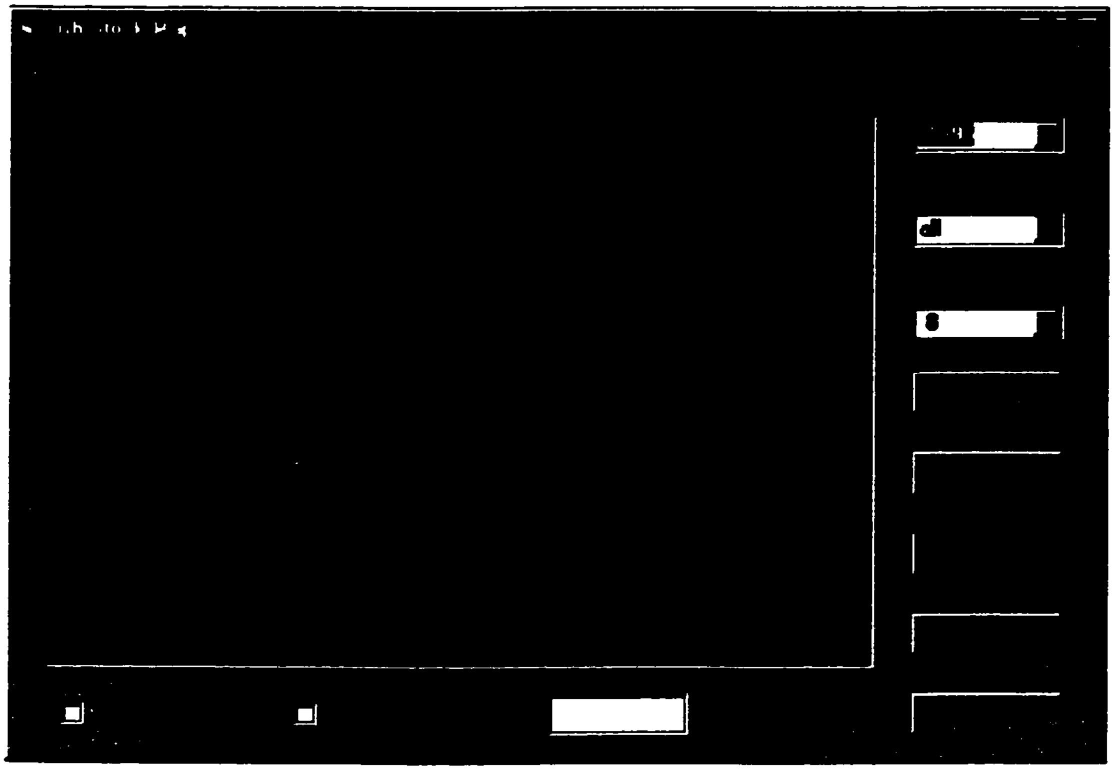


Fig. 4.5 Spawning Distribution of Scots Bay in 1995 (halt year in the fishery)

Implications for Scots Bay. As the first spawning ground of each season, Scots Bay typically bears the pressure of considerable purse seine fishing effort as the vessels move into the more lucrative herring roe market. From the above analysis using MapTest of the recent catch dynamics in Scots Bay, it is clear that unabated fishing here above 7,5000t annually could have long-term negative implications for this stock component. On the other hand, as evidence of the 1995 decision suggested by industry to not fish in Scots Bay attests, this stock component appears to bounce back quickly given the opportunity. The analysis suggests the annual catches in Scots Bay – and distributed throughout the zone - may be sustainable at levels of approximately 5,000t annually.

Further information about the incidence of spawning in Scots Bay, i.e., the number of multiple spawning "waves", the period of time spawners spend on the spawning grounds, and the ecosystem conditions that trigger the beginning and ending of the spawning event are key areas of investigation for herring scientists to explore.

4.1.1.2 Trinity Bank

Trinity Bank fishing ground is located to the south of Long Island, near the Nova Scotia Coast. Trinity Bank is located close to shore and within short distance of major landing and processing facilities in the Scotia-Fudy region. For this reason, i.e., low costs of catch, Trinity has always been an important herring fishing area in Scotia-Fundy. The herring fishery zone number in MapTest for Trinity Bank is zone 3. In Trinity Bank, the spawning event occurs each year during weeks 33 to 39 that is from August 15 to September 20. The zone definition map for zone 3 is shown in the MapTest Fig 4.6.

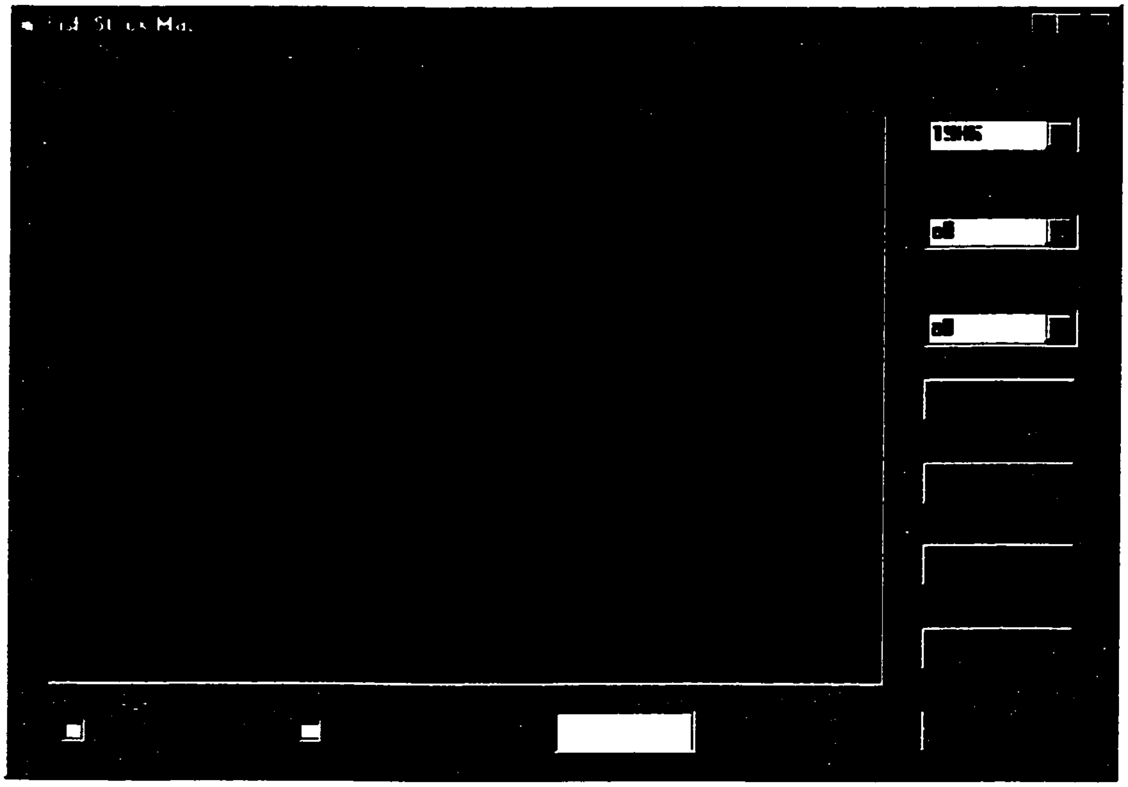


Fig. 4.6 Zone definition map for Trinity Bank

The size of catches for Trinity Bank was at the high level of 12,000t to 16,000t from 1986 to 1988. After 1988, the size of catches stayed at a stable negligible low level (primarily due to the mandatory closures of this spawning ground by management regulations) until 1998. In 1991 there was a small recovery of catches to 3,000t.

The distributions of catches in Trinity Bank were more concentrated in high level years from 1986-1988 and more dispersed in low level years after 1988. The catches occurred mainly in the center of the zone. Before 1992, more catches were found in the northwest corner of the zone. After 1992, more catches were found in the southern part of the zone. Fig. 4.7 and Fig. 4.8 show the purse seiner annual catch distribution on Trinity Bank in its high level year of 1986 and low level year of 1994.

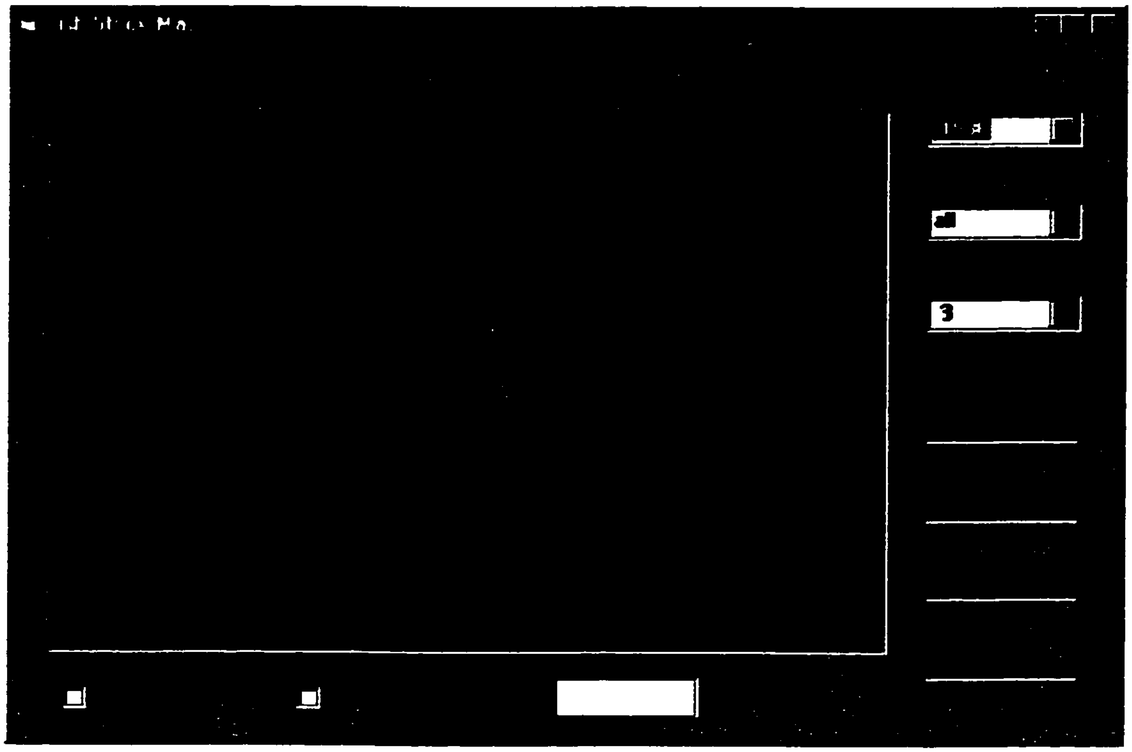


Fig. 4.7 Distribution of catches on spawning ground for Trinity Bank in 1986

Implications for Trinity Bank. The management intervention after 1987 to curtail fishing effort on Trinity spawners no doubt had the effect of sustaining this once large subpopulation of herring. The incidence of improving stock status of herring coming back to Trinity are evidence of the resilience of the stock and the benefits of the need to permit a period of reduced fishing to maintain stock abundance. However, the stock status on Trinity Bank has not yet returned to the historical highs of the 1980s and cautioned should be exercised not to apply undo fishing effort to this area through the continued use of closures to fishing during the spawning period.

Further information about the protracted spawning period on Trinity Bank as well as the number of multiple spawning "waves", the period of time spawners spend on the spawning grounds, and the ecosystem conditions that trigger the beginning and ending of the spawning event are key areas of investigation for herring scientists to explore.

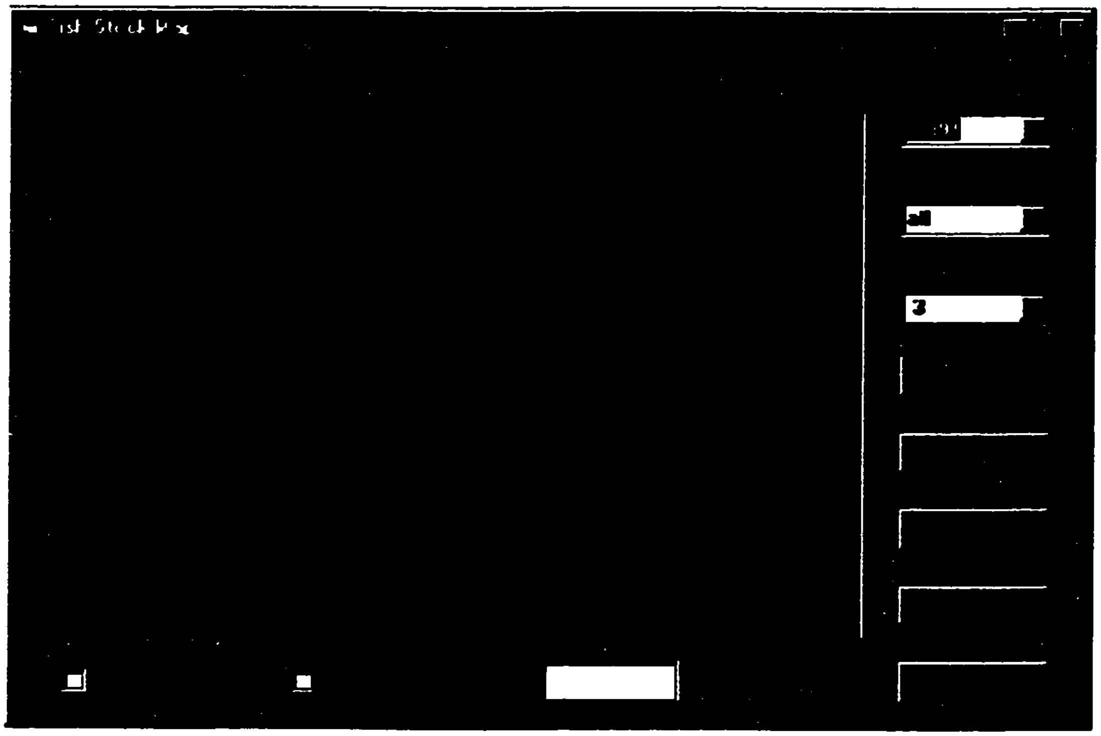


Fig. 4.8 Distribution of spawning catches for Trinity Bank in 1994

4.1.1.3 Lurcher

The Lurcher fishing ground is located adjacent and to the south of Trinity Bank. The herring fishery zone number of Lurcher herring spawning ground is zone 4. In Lurcher, the spawning occurs each year during weeks 33 through week 39 that is from August 15 to September 20, similar to that for Trinity Bank. The zone definition map for zone 4 is shown Fig 4.9.

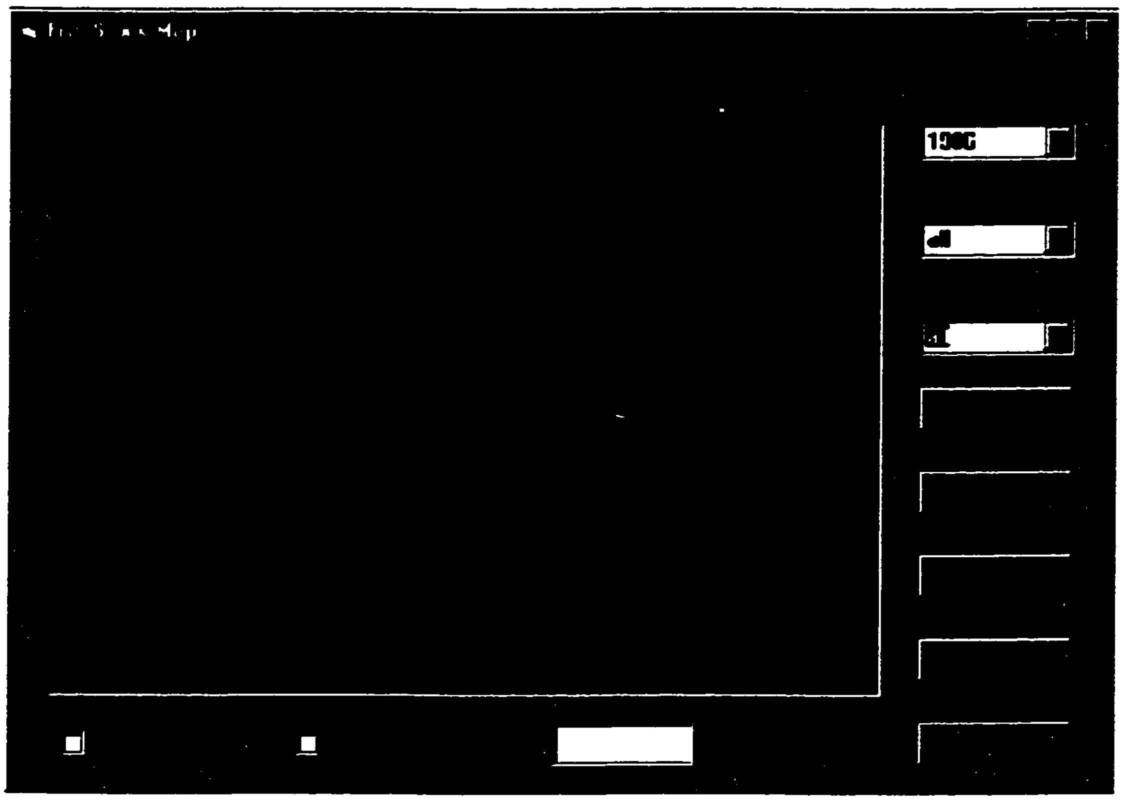


Fig. 4.9 Zone definition for the Lurcher Herring Spawning Ground

The size of catches in Lurcher was very low to nearly zero from 1986 to 1998 throughout the period under investigation. The spawning catches occurred almost in the southeast of the zone and the distributions were generally dispersed from year to year. The occurrences of spawning events in Lurcher fishing ground are continuously cycles of concentration-spread pattern. Each cycle is of three to five years of length and contains two to three years of spread (1986 to 1987, 1989 to 1991 and 1994 to 1996) and one to two years of concentration (1988, 1992 to 1993 and 1997). Fig 4.10 shows the distribution of spawning catches for Lurcher fishing Ground in 1997.

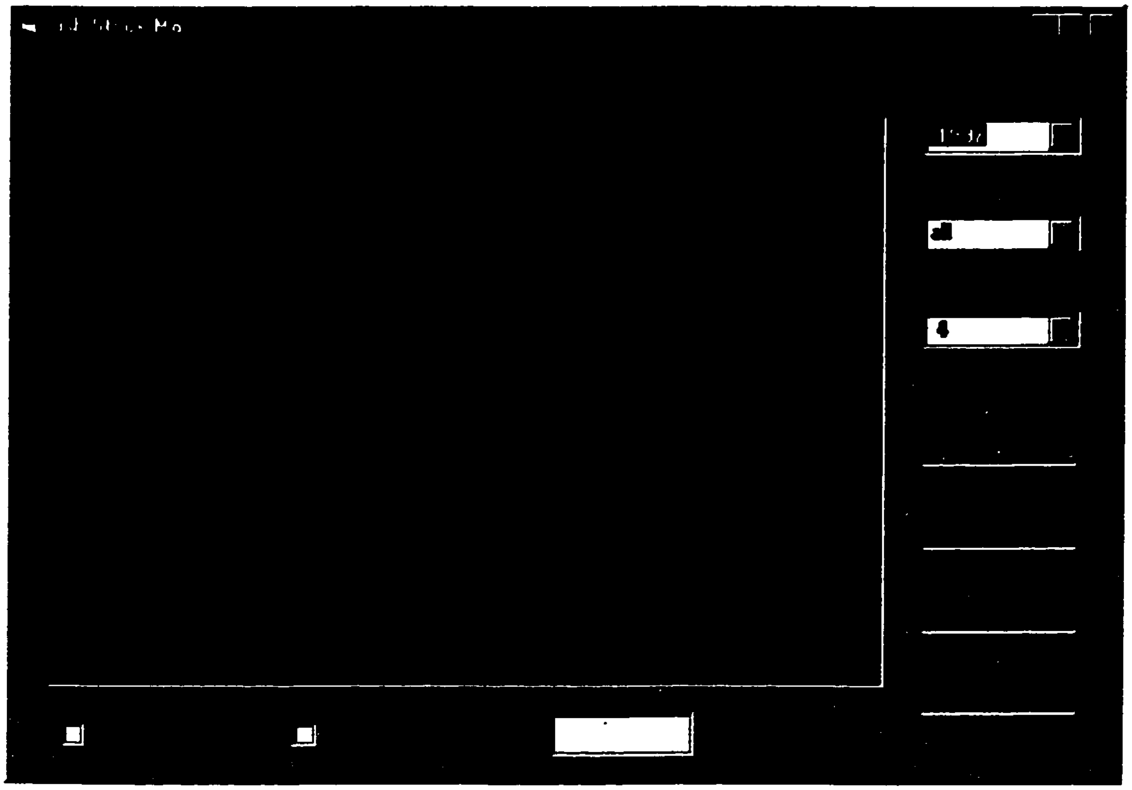


Fig.4.10 Distribution of spawning catches for Lurcher Fishing Ground in 1997

Implications for Lurcher. Lurcher has never evolved as a significant spawning ground for 4WX herring compared to the adjacent areas of Trinity Bank and German Bank. Accordingly, there may be some question about the definition of Lurcher as a separate and unique spawning area as opposed to a "spill over" spawning habitat for Trinity or German Bank herring. Further scientific research into substock definition is required to answer this question of Lurcher as a separate spawning group and its potential for sustainable harvest.

4.1.1.4 Seal Island

Seal Island is located off the southern tip of western Nova Scotia. The MapTest herring fishery zone number of Seal Island is 6. On the Seal Island fishing ground, spawning occurs annually during week 34 through week 40 that is approximately from August 20 to September 25. Fig. 4.11 shows the zone definition of Seal Island from MapTest.

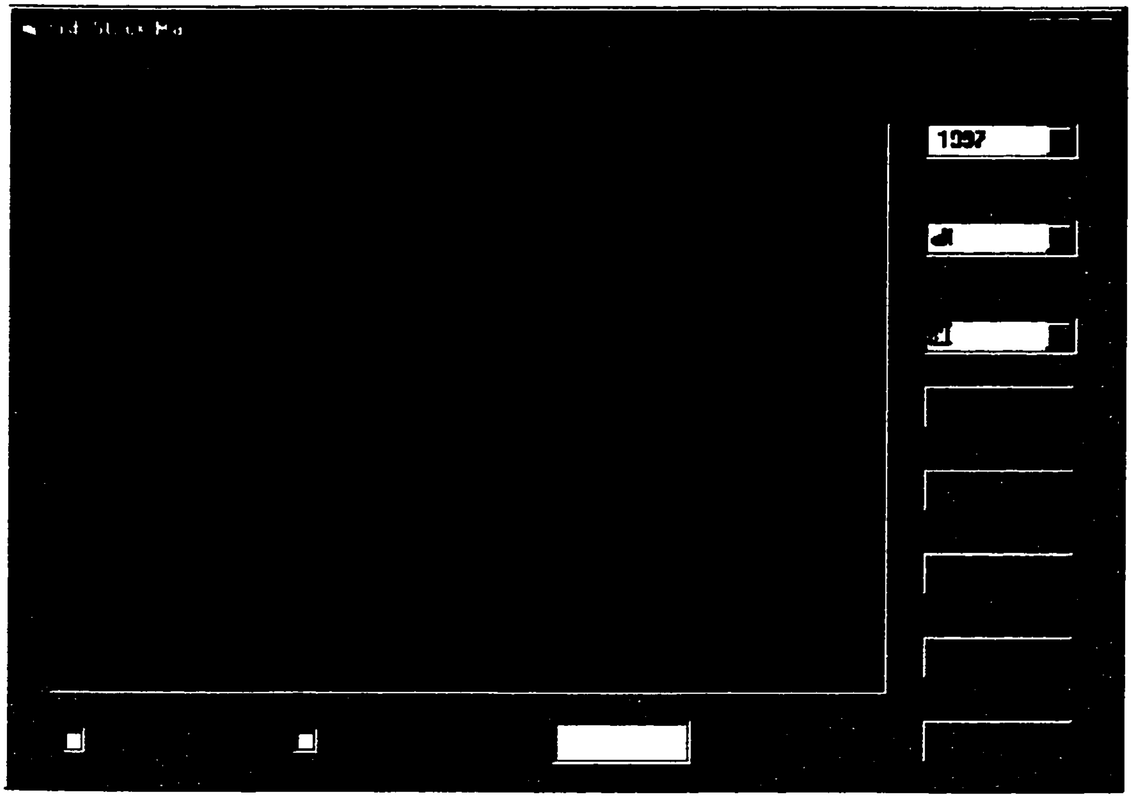


Fig. 4.11 Zone 6, definition for the Seal Island spawning group

The catches for Seal Island in 1986 were at 3,800t. Subsequently catches went up from 1986 to the peak in 1990 at 19,000t, then fell off dramatically to negligible levels after 1995. The period of high catches corresponded to the later stages of good markets and prices for herring roe in Japan coupled with Seal Island's good proximity (and lower costs of production) to processing plants in southwest Nova Scotia.

Generally the catch of Seal Island has been located to the west of the zone and adjacent to German Bank. Since there is some connection between the change of catches for these two zones, proximity may suggest that there exists "one big spawning area of German Bank and Seal Island" together. The distributions of Seal Island catches were generally dispersed in the west part of the zone. In 1994, the concentration was to west with substantial catches in the east off Cape Sable Island. After 1994, the catches fell off and distributions of low catches were recorded mainly in the west of the zone adjacent to German Bank. Fig. 4.12 and Fig. 4.13 give the catches distributions for the highest year of 1990 and a lower year of 1994.

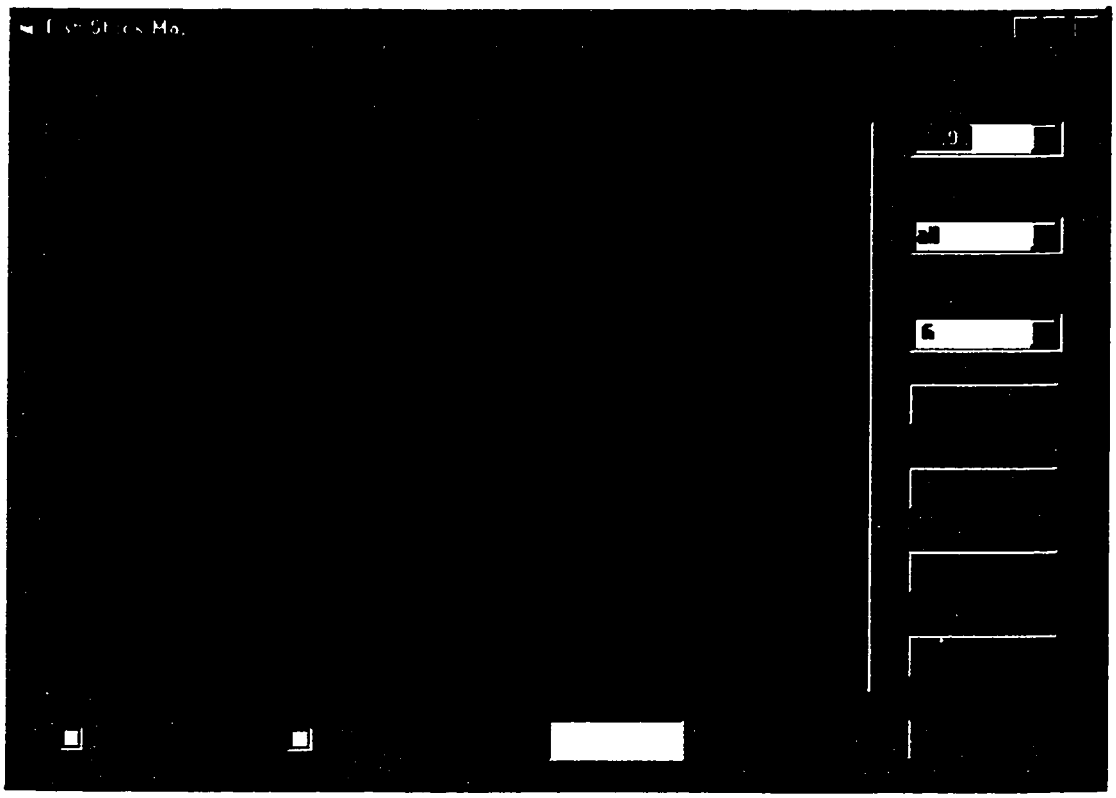


Fig 4.12 Catches distribution for Seal Island at the highest year of 1990

Fig. 4.13 Catches distribution for Seal Island in 1994

Implications for Seal Island. The rapid decline in Seal Island catches remains an enigma among 4WX herring spawning groups. Although the argument that the proximity to German Bank and the somewhat compensatory increases in catches there has gained favor, there is still the possibility that the high Seal Island catches at the end of the 1980s and early 1990s may have damaged the spawning capacity of the Seal Island group.

As before, more information about the spawning period on Seal Island, the number of multiple spawning “waves”, the period of time spawners spend on those spawning grounds, and the ecosystem conditions (e.g., water temperature, salinity) affecting this location with respect to the triggers of the spawning event are key areas of investigation for furthering our understanding of the Seal Island herring group.

4.1.1.5 German Bank

German Bank Fishing Ground is the fishing ground to the southwest of Nova Scotia adjacent to Seal Island to the east and Lurcher to the north. The MapTest herring fishery zone number for German Bank is 7. In the German Bank fishing ground, the spawning occurs each year during week 35 through week 41 that is from August 30 to October 5 and is the latest spawning group of the 4WX herring population complex. The zone definition map of German Bank is shown in Fig. 4.14.

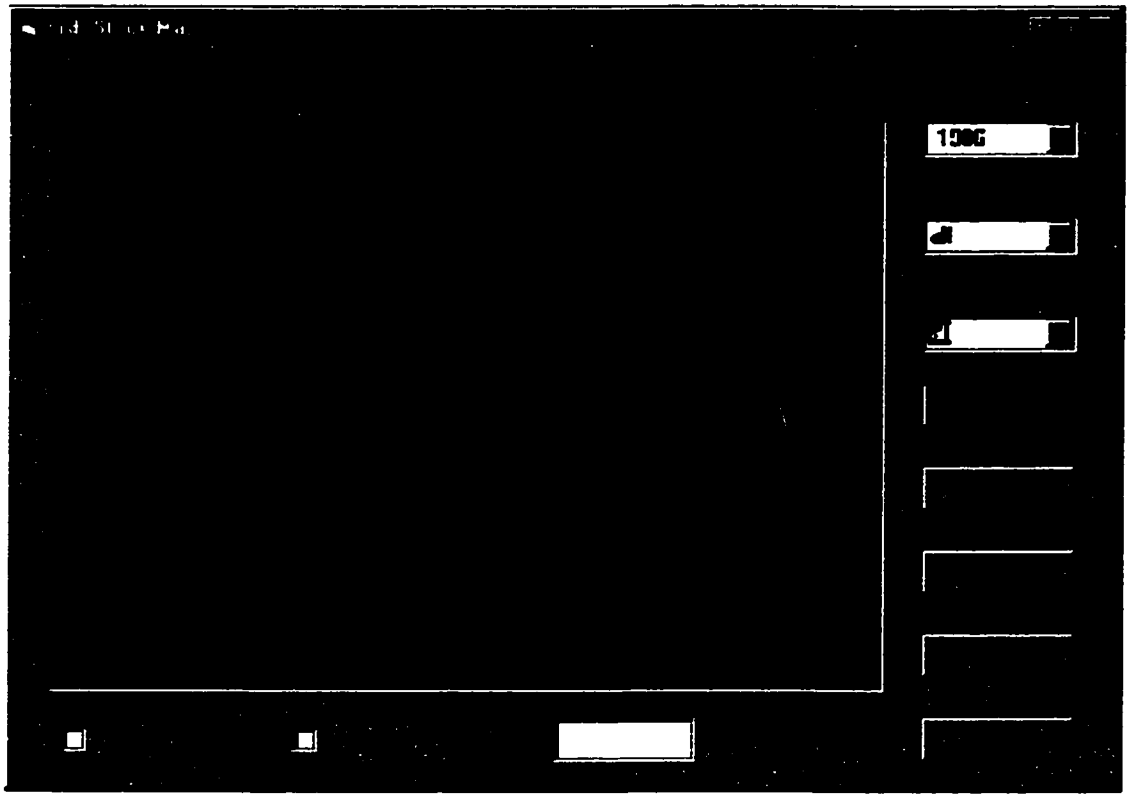


Fig. 4.14 Zone definition for German Bank

The size of annual purse seine catches in German Bank have changed erratically over the time period 1986 to 1998 in the range between negligible catches to more than 15,000t in cycles of 2 to 4 years (see also Fig. 4.2). The change of catches in Seal Island and German

Bank may be compensatory. For instance, in 1989, the catches in Seal Island were at its high level of 17,000t when that of German Bank was on the low level of 4,000t. But after 1993, the catches of German Bank grew up to high level while Seal Island catches declined toward lower sustained levels. This may more support the hypothesis of "one big spawning area of German Bank and seal Island" (see also 4.1.1.4).

The distributions of catches were normal and to the east adjacent to Seal Island from 1986 to 1988. In 1989 there were two disjoint concentrations of low catches: east as normal; west in deep water. This shift was back to normal in 1990 with few catches to the west. In 1991, catches were higher and dispersed east and south toward Southwest Grounds. In 1992 and 1993, catches were at negligible levels and concentrated west and south. In 1994, catches were heavily concentrated and this trend continued in 1995. In 1996, westerly concentration continued with some catches along the forefront of the Southwest Grounds. In 1997 and 1998 catches were heavily concentrated in the west as were catches in 1995. Fig. 4.15 and Fig 4.16 show the distribution of catch locations in 1991 and 1995 on German Bank.

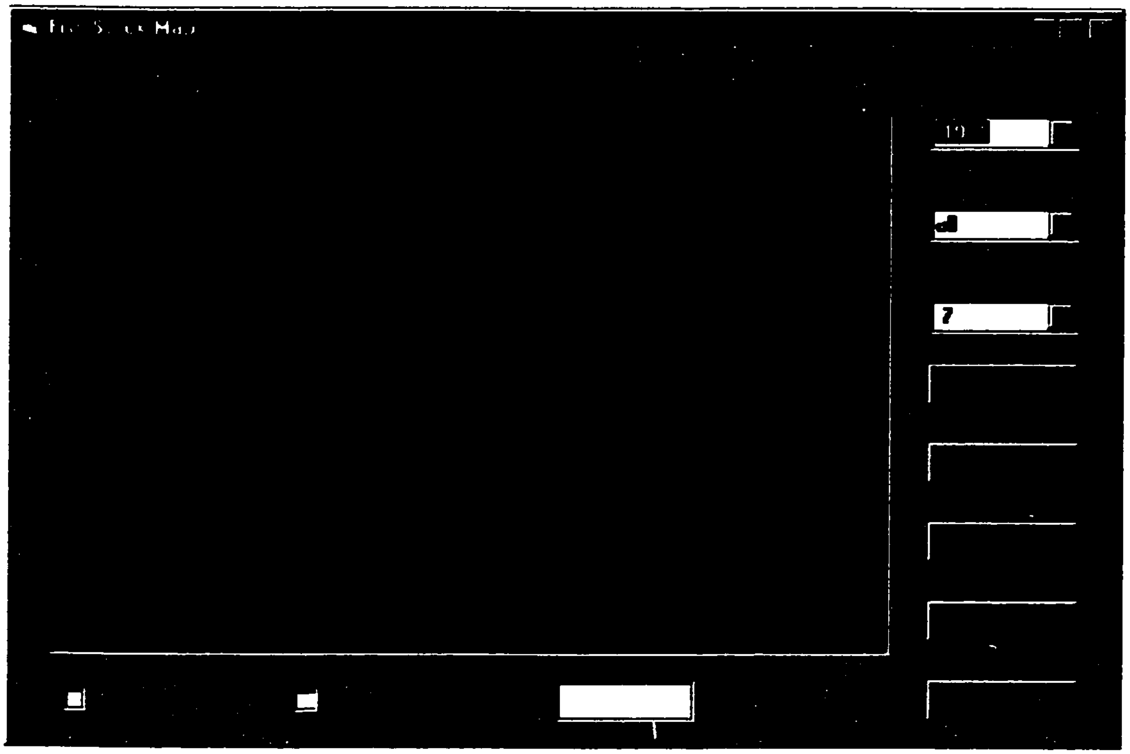


Fig. 4.15 Catches distribution of German Bank in 1991

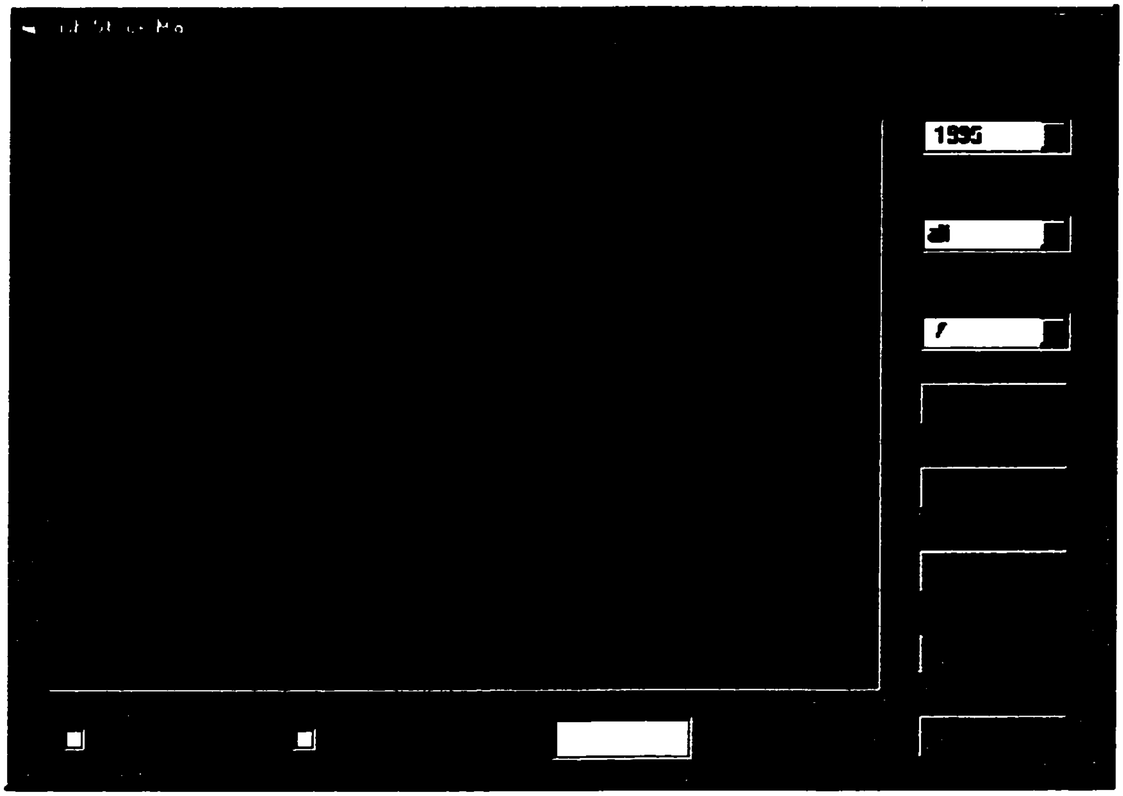


Fig. 4.16 Catches distribution for German Bank in 1995

Implications for German Bank. German Bank has become the most important herring spawning area in recent years and is an area that purse seines rely on at the end of their fishing season to reach their catch quotas. The connections between Seal Island and the decline observed there, and German Bank increases remains an open issue. Taken by itself, the status of the German Bank component is promising. As such, it is likely to be an area of primary exploitation for years to come.

Information about spawning dynamics on German Bank including the number of multiple spawning "waves", the period of time spawners spend on those spawning grounds, and the ecosystem conditions (e.g., water temperature, salinity) affecting this location are ongoing areas of scientific investigation.

4.1.2 Estimated Abundance

The estimated abundance of the weekly herring stock is carried out by the Bayesian updating scheme described in Chapter 3. Observation data comes from purse seine commercial catches by week/zone to update the state of the stock. The expected result for the in-season data updating for the MapTest operational planning model is detailed in a graphical presentation and weekly operational report that is a reference for within season (e.g., weekly) decision making in the herring fishery, especially on the spawning grounds.

Table 4.3 gives the total expected abundance for the spawning groups from 1986-1998 using the Bayesian algorithm. All abundance estimates in the table are in units of 1000t. Fig 4.17 and Fig. 4.18 show the expected abundance in graphical in line and stacked bar charts.

	Trinity Bank	Lurcher Fishing Ground	Seal Island	German Bank	Scots Bay
1986	67.533	27.592	54.079	69.282	40.367
1987	68.196	27.592	55.892	72.098	52.65
1988	68.575	27.592	56.575	72.978	43.454
1989	47.146	27.925	59.475	72.361	55.558
1990	50.221	27.592	57.779	73.058	54.967
1991	60.179	27.592	58.596	72.432	52.838
1992	44.201	27.592	57.858	69.778	54.917
1993	45.404	27.592	56.463	68.056	55.829
1994	48.696	27.592	52.521	69.132	55.396
1995	48.208	27.7	40.563	81.956	45.45
1996	44.275	27.592	50.167	106.432	56.092
1997	61.246	28.142	44.708	81.237	52.35
1998	57.517	27.592	45.95	83.132	65.383

Table 4.3 Total expected abundance for the five spawning groups from 1986-1998

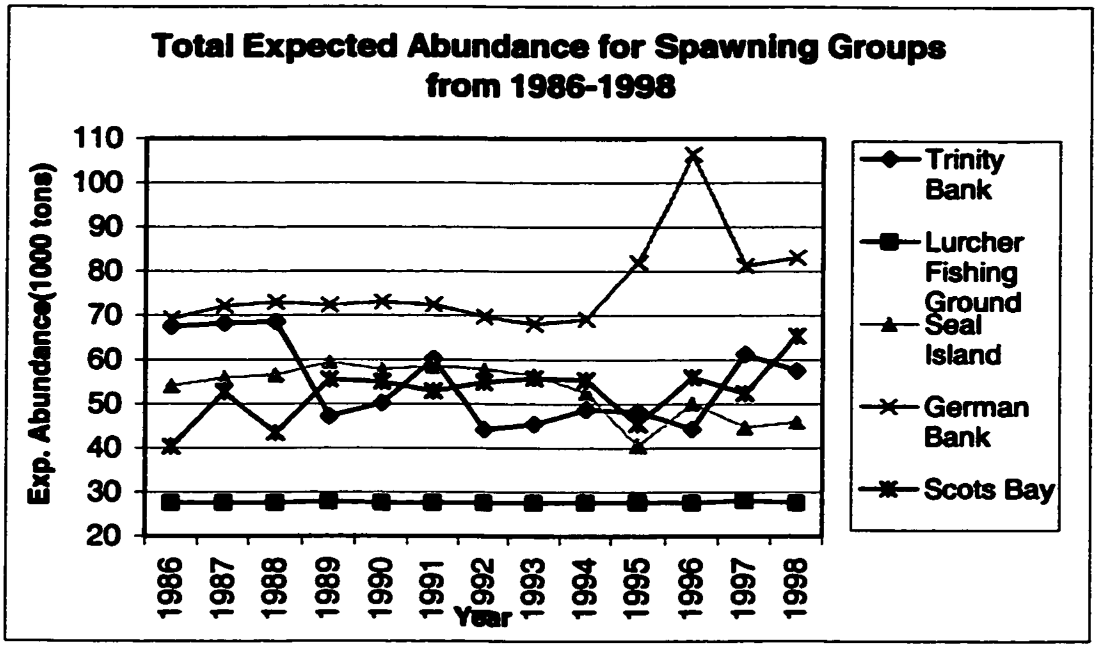


Fig. 4.17 Total Expected Abundance for Spawning Groups from 1986-1998

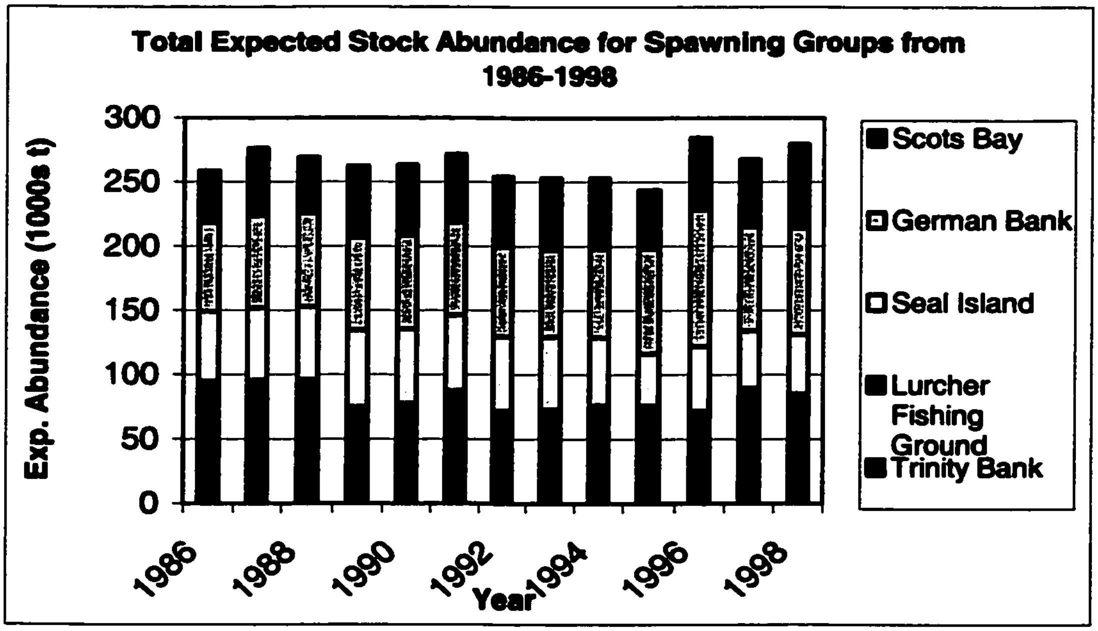


Fig. 4.18 Total Expected Stock Abundance for Spawning Groups from 1986-1998

More detailed analysis of spatial-temporal spawning events for the five spawning groups including graphic and geographical presentations are as follows: Fig 4.19 and Fig. 4.20 show the proportion for the five spawning groups in 1986 and in 1998. The comparison of Fig 4.19 with Fig 4.20 reveals that except for Lurcher which keeps a stable portion of around 10% in the total abundance, the other four spawning groups all experience significant relative changes. Trinity Bank and Seal Island have lower portion in 1998 than 1986 and Scots Bay and German Bank increased their portion from 1986 to 1998.

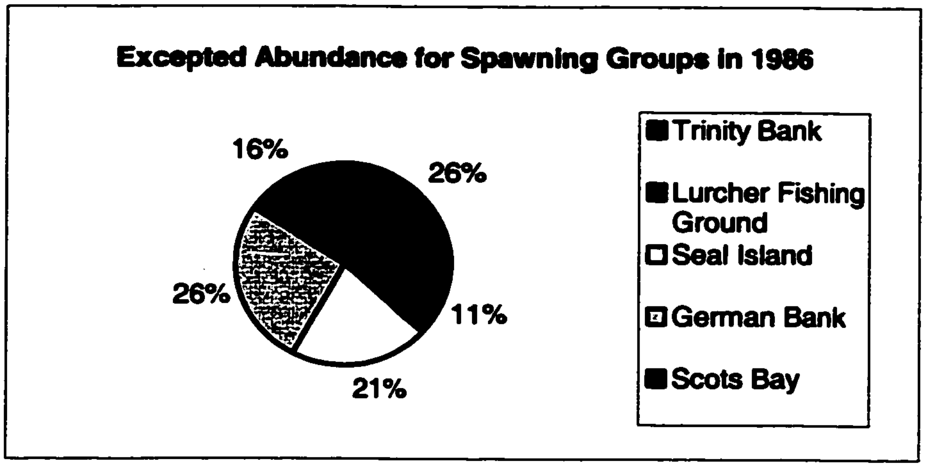


Fig. 4.19 Expected abundance for spawning groups in 1986

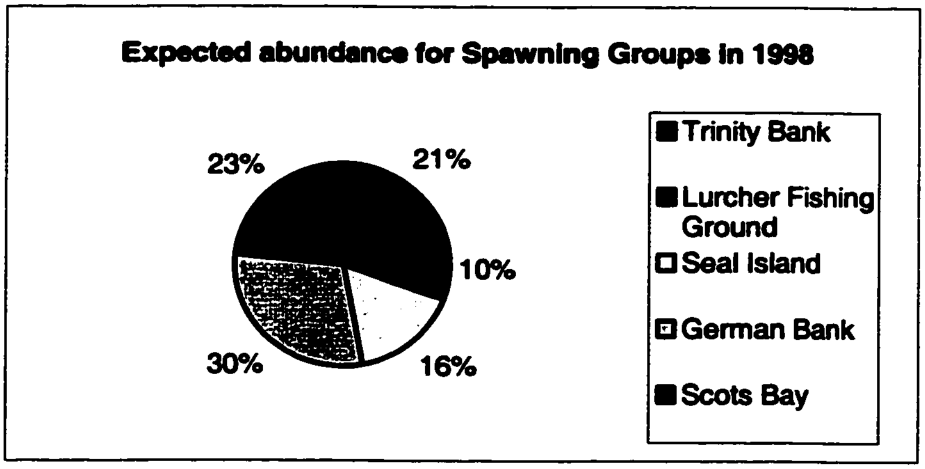


Fig. 4.20 Expected abundance for spawning groups in 1998

4.1.2.1 Scots Bay Fishing Ground

In Scots Bay (MapTest zone 8), spawning occurs each year as noted previously during week 28 through week 35 (that is, from July 15 to August 25). The Bayesian weekly update graph on stock status in year 1998 for zone 8 is provided in Fig 4.21.

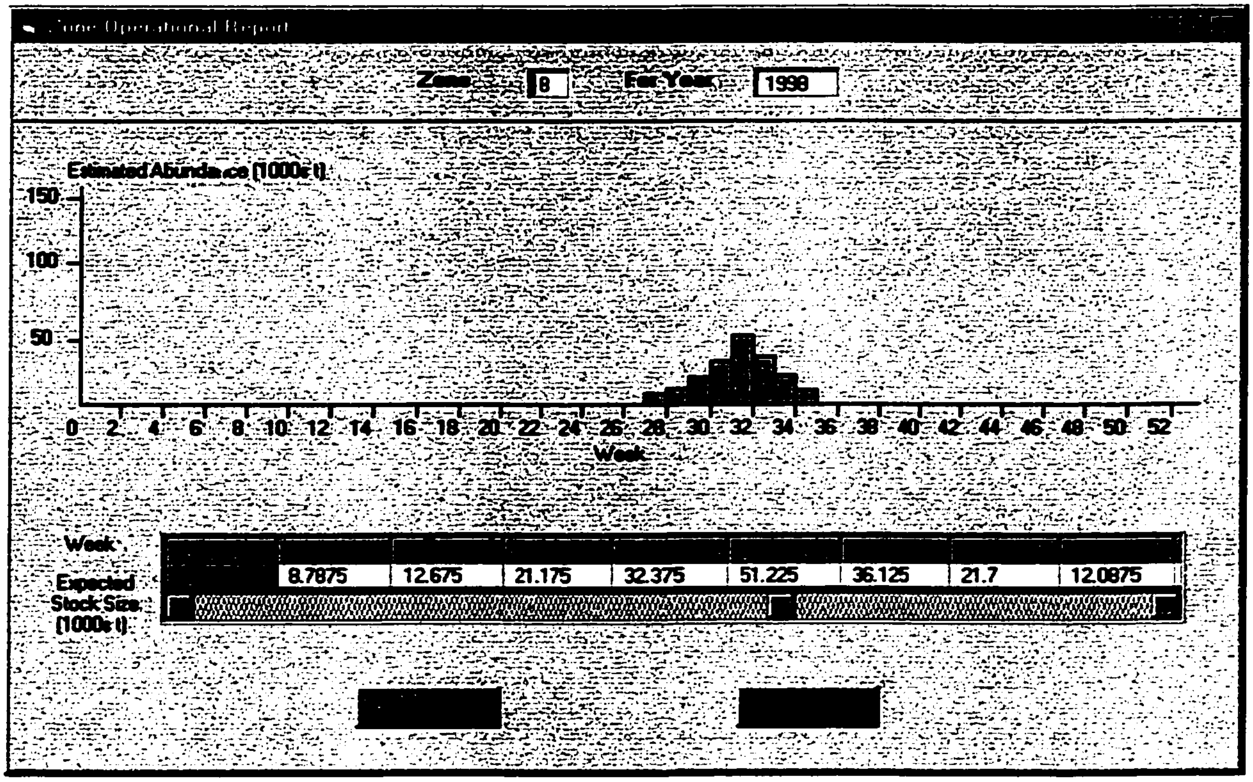


Fig. 4 .21 Expected Abundance for Scots Bay in 1998.

The total spawning abundance of Scots Bay was at approximately 40,000t in 1986. From 1987 to 1989, Scots Bay spawners increased, declined, then increased again at a rate of about 10,000t per year. From 1989 to 1994, the spawning abundance remained at about 53,000t per year. In 1995, the abundance declined by 10,000t and then returned to about

56,000t in 1996. Then after a small decline of 5,000t in 1997, the spawning abundance of Scots Bays reached its highest level of 65,000t in 1998. Table 4.4 and Fig. 4.22 provides the detailed weekly spawning abundance from year 1986 to year1998 for Scots Bay. The last column in Table 4.4 is the expected abundance from the MapTest operational planning report. This estimated is the sum of the expected stock size over all spawning weeks in the spawning period divided by 3 to account for estimated time spent on the spawning grounds by successive waves of herring spawners.

	28	29	30	31	32	33	34	35	Exp.
1986	12.063	12.575	15.875	21.625	21.913	15.625	12.8	8.625	40.367
1987	12.063	12.725	21.3	32.5	35.775	21.5	13.4	8.6875	52.65
1988	8.7875	12.625	21.188	25.35	24.375	16.5	12.9	8.6375	43.454
1989	8.7875	12.625	21.188	32.45	34.8	28.425	16.3	12.1	55.558
1990	10.913	12.7	21.25	32.5	35.775	28.888	14.1	8.775	54.967
1991	8.7875	12.675	19.975	31.7	35.375	27.325	13.925	8.75	52.838
1992	8.7875	12.55	21.075	32.4	37.725	29.188	14.238	8.7875	54.917
1993	8.7875	12.55	20.95	32.35	35.7	28.875	17.188	11.088	55.829
1994	8.7875	12.675	21.225	32.45	35.788	28.9	17.225	9.1375	55.396
1995	8.7875	12.55	21.075	25.238	24.288	22.238	13.475	8.7	45.45
1996	8.7875	12.55	21.025	33.9	36.35	29.1	17.4	9.1625	56.092
1997	8.7875	12.55	15.825	28.975	33.963	28.013	16.825	12.113	52.35
1998	8.7875	12.675	21.175	32.375	51.225	36.125	21.7	12.088	65.383

Table 4.4 Weekly spawning abundance for Scots Bay from 1986 to 1998.

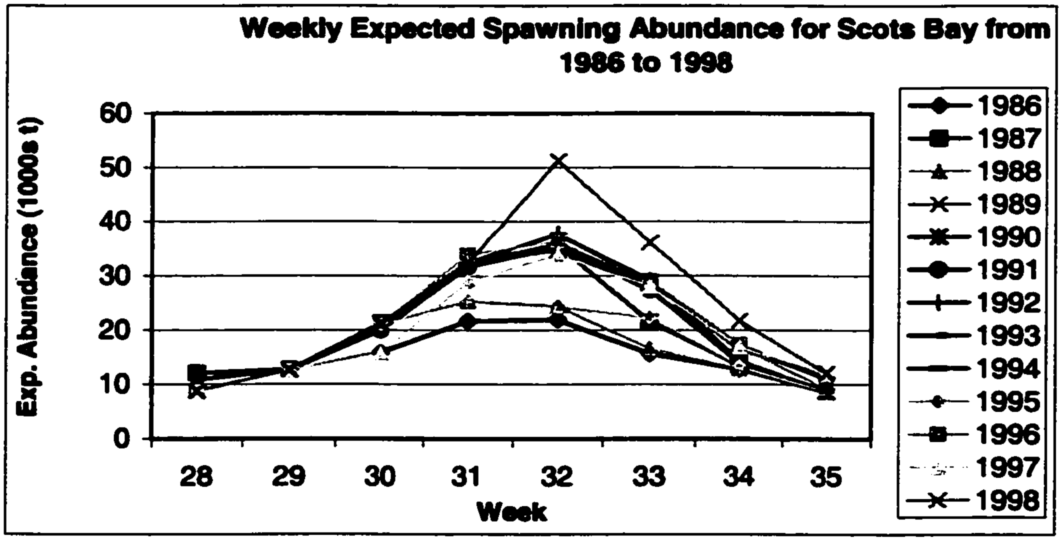


Fig. 4.22 Weekly spawning abundance for Scots Bay from 1986 to 1998.

Analysis of Scots Bay Spawner Population Estimates. The regular pattern of spawning timing in Scots Bay is typical of the regular spawning event across all 4WX spawning substocks. We note that peak spawning occurs between weeks 31 and 33. In periods of relatively low spawning, the peak period is smoothed out across these weeks. In contrast, relatively higher abundance is synonymous with a more pronounced peak spawning event typically at week 32. This information is valuable to planners for projecting overall spawning activity from surveys and catches early in the spawning event, i.e., in weeks 29 through 30. For example, a flat signal over this period may indicate that fishing effort should be curtailed in the latter periods.

4.1.2.2 Trinity Bank

As noted previously, Trinity Bank (MapTest zone 3) spawning occurs during week 33 to 39 that is from August 15 to September 20. The Bayes weekly update graphs on stock status in year 1998 for zone 3 are provided in Fig 4.23.

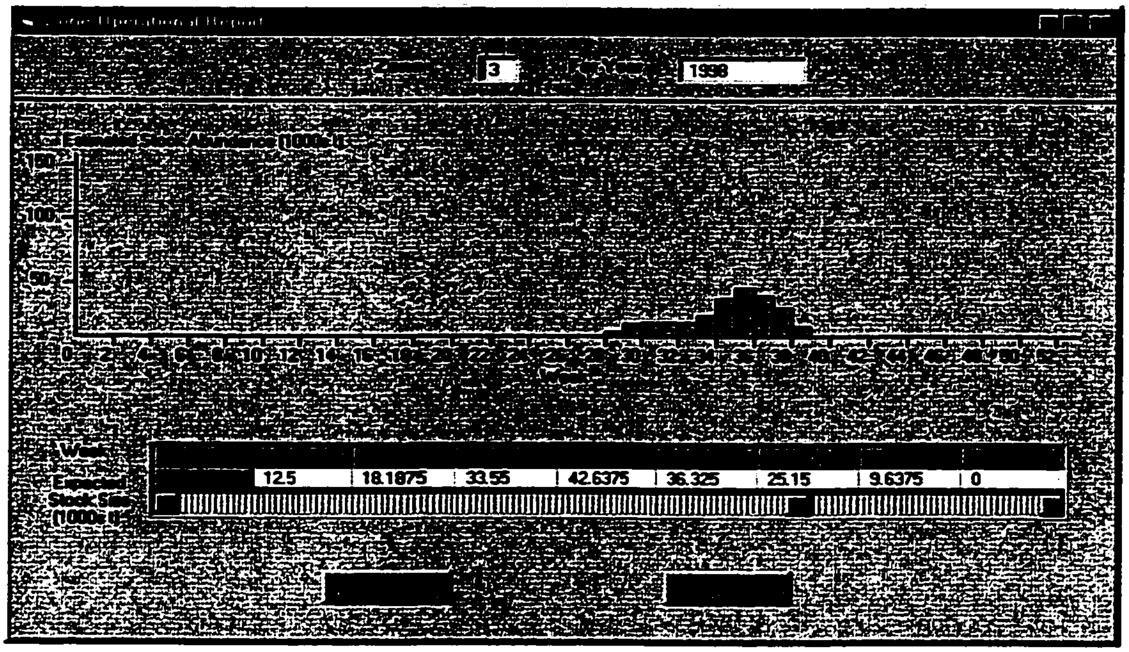


Fig. 4 .23 Expected Abundance for Trinity Bank in 1998.

The abundance of spawning in Trinity Bank is estimated at the highest level of 60,000-70,000t per year from 1986 to 1988. In 1989, there was a decline of more than 20,000t. After a recovery in 1990 and 1991 to about 60,000t, there was another decline in 1992. From 1992 to 1996, the abundance estimates are in the range of 43,000t to 48,000t.

From 1997, the spawning abundance in Trinity Bank recovered somewhat to the levels of 1987 and 1991 near 60,000t. Table 4.5 and Fig. 4.24 provide detailed weekly spawning abundance estimates from 1986 to 1998 for Trinity Bank.

	33	34	35	36	37	38	39	Exp.
1986	12.413	23.775	38.675	48.138	39.888	27.413	12.3	67.533
1987	12.413	23.775	39.4	49.038	40.463	28	11.5	68.196
1988	12.413	23.775	39.4	49.038	40.463	28	12.638	68.575
1989	9.35	17.4	25.188	38	26.575	15.838	9.0875	47.146
1990	12.413	24.6	31.175	34.038	24.175	15.213	9.05	50.221
1991	12.075	24.463	39.15	40.825	35.8	18.938	9.2875	60.179
1992	12.413	18.225	25.79	30.313	22.175	14.663	9.025	44.201
1993	9.35	17.4	25.188	29.938	28.725	16.5	9.1125	45.404
1994	9.35	17.4	25.188	38	26.575	20.175	9.4	48.696
1995	9.35	17.4	25.188	29.938	33.888	19.5	9.3625	48.208
1996	9.35	17.4	25.188	29.938	21.988	17.95	11.013	44.275
1997	9.35	23.213	38.063	45.763	37.975	19.45	9.925	61.246
1998	9.35	17.4	32.9	42.175	36.1	25	9.625	57.517

Table 4.5 Weekly spawning abundance from year 1986 to year1998 for Trinity Bank.

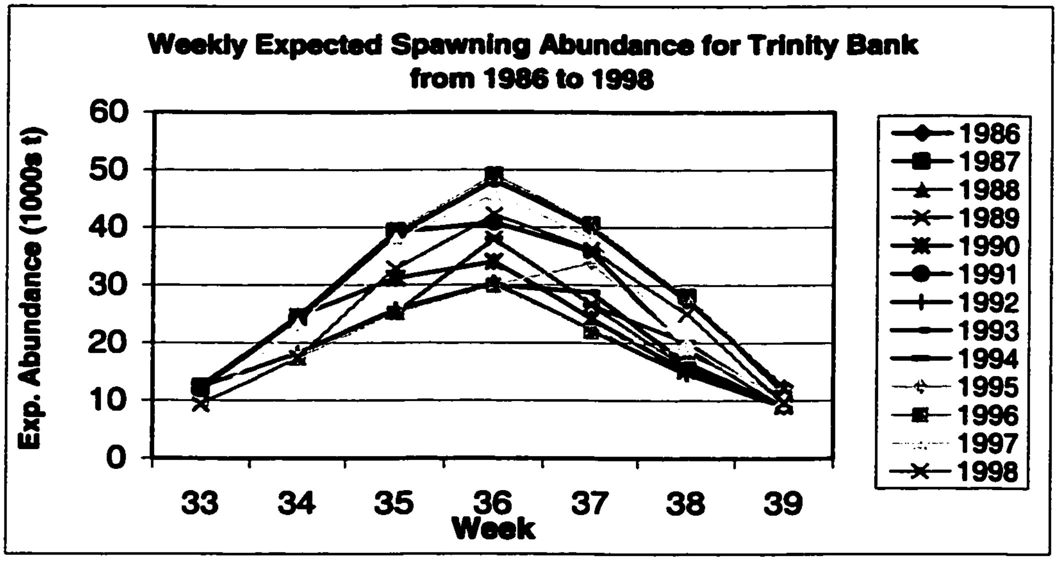


Fig. 4.24 Weekly spawning abundance from year 1986 to year1998 for Trinity Bank

Analysis of Trinity Bank Spawner Population Estimates. In Trinity Bank, the spawning events in the years of high estimated abundance (1986 to 1988) and recovering years (1991, 1997 and 1998) are more concentrated than the years of lower relative abundance estimates (1989 and 1992 to 1996).

In general, however, the abundance of spawners in Trinity Bank remains stable with a well-defined peak over several years at week 36. It would appear that the abundance of spawners might be recovering in Trinity Bank in the recent period from 1997 to 1998. Continuation of the Trinity Bank spawning closures regulation may further sustain this substock toward realizing its long run potential.

4.1.2.3 Lurcher Fishing Ground

On the Lurcher fishing ground (MapTest zone 4) spawning occurs each year during week 33 through week 39 that is from August 15 to September 20. The Bayes weekly updated abundance estimates for Lurcher are illustrated in Fig 4.25, the graph of stock status in 1998 for zone 4. In Figure 4.25 we note the appearance of appreciable herring abundance in weeks 22 through 31 in advance of the Lurcher spawning period. Herring found in Lurcher at this time are in feeding aggregations in transit to other spawning zones, e.g., Scots Bay. These herring do not supply the herring roe market and are in premature spawning condition that occurs in zones other than Lurcher.

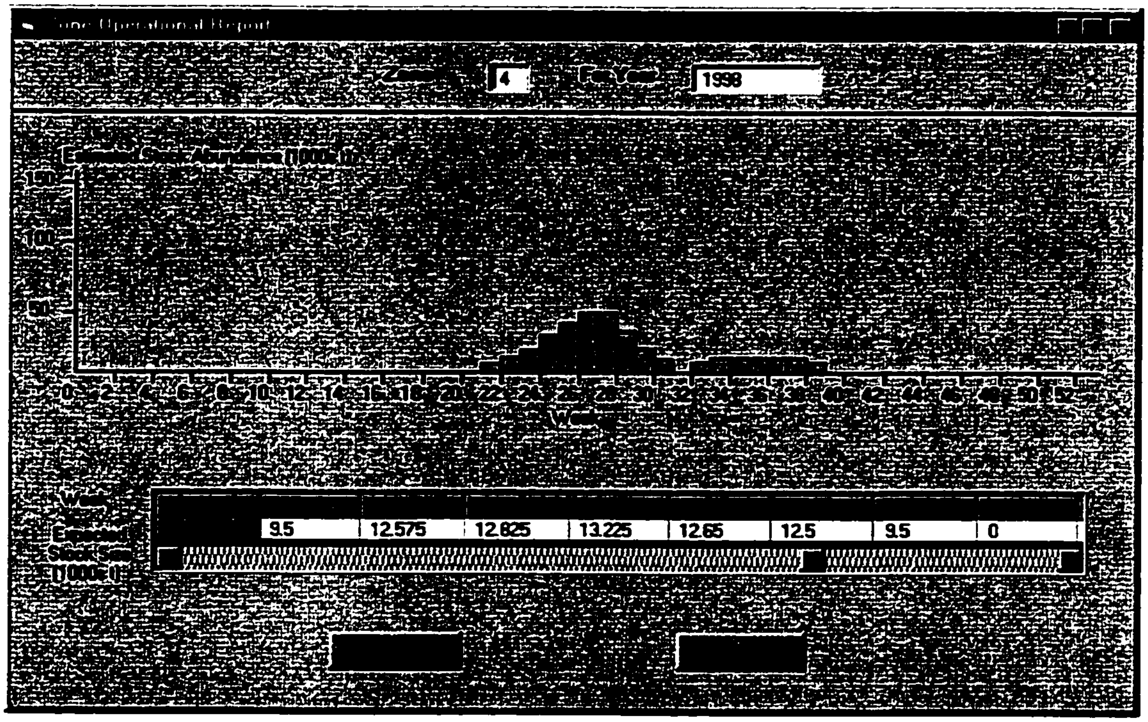


Fig. 4 .25 Expected Abundance for Lurcher Fishing Ground in 1998.

The spawning abundance is very stable in zone 4 from year to year at the level of about 27,000t per year. The weekly expected spawning abundance for the Lurcher Fishing Ground from 1986 to 1998 is given in Table 4.6 and Fig 4.26.

	33	34	35	36	37	38	39	Exp.
1986	9.5	12.575	12.825	13.225	12.65	12.5	9.5	27.592
1987	9.5	12.575	12.825	13.225	12.65	12.5	9.5	27.592
1988	9.5	12.575	12.825	13.225	12.65	12.5	9.5	27.592
1989	9.5	12.575	12.825	14.075	12.8	12.5	9.5	27.925
1990	9.5	12.575	12.825	13.225	12.65	12.5	9.5	27.592
1991	9.5	12.575	12.825	13.225	12.65	12.5	9.5	27.592
1992	9.5	12.575	12.825	13.225	12.65	12.5	9.5	27.592
1993	9.5	12.575	12.825	13.225	12.65	12.5	9.5	27.592
1994	9.5	12.575	12.825	13.225	12.65	12.5	9.5	27.592
1995	9.5	12.575	12.825	13.25	12.65	12.5	9.8	27.7
1996	9.5	12.575	12.825	13.225	12.65	12.5	9.5	27.592
1997	9.5	12.675	13.425	13.775	12.75	12.5	9.8	28.142
1998	9.5	12.575	12.825	13.225	12.65	12.5	9.5	27.592

Table 4.6 Weekly spawning abundance from year 1986 to year1998 for Lurcher

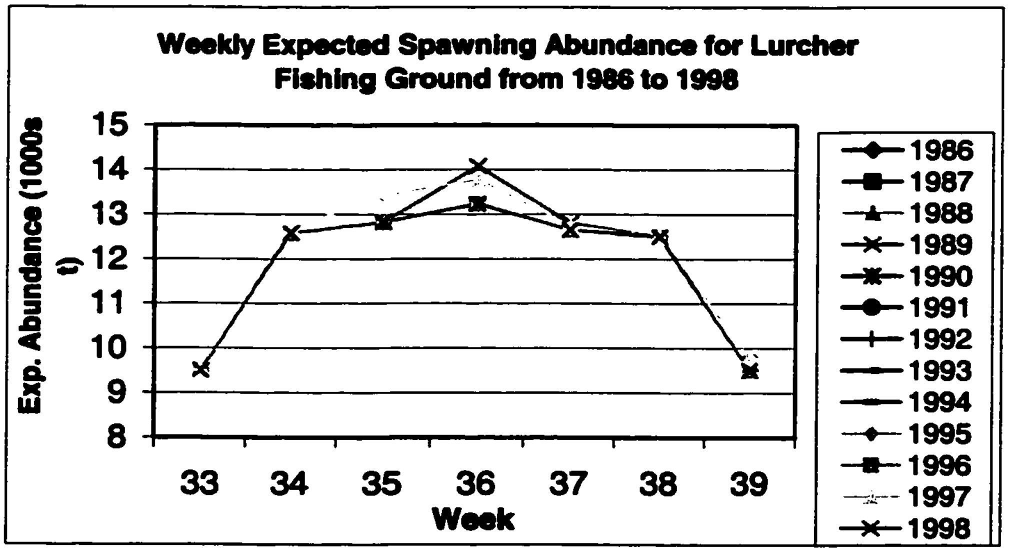


Fig. 4.26 Weekly spawning abundance from year 1986 to year1998 for Lurcher

Analysis of Lurcher Spawner Population Estimates. As a relatively small spawning component, the Lurcher grounds exhibits a stable and flat incidence of herring spawner estimates of abundance with a flat peak over the spawning period. Further information in the form of catches or pre-catch survey data at the outset of the spawning period would appear to enough to provide the data needed to project the extent of spawning abundance in Lurcher.

4.1.2.4 Seal Island Fishing Ground

In the Seal Island fishing ground (MapTest zone 6), the spawning was said to occur each year during week 34 through week 40 that is from August 20 to September 25. The Bayes weekly update graph on the estimates of spawning stock size for 1998 for zone 6 is provided in Fig 4.27. In Figure 4.27 we note the appearance of lower levels of herring abundance in weeks 26 through 31 prior to the more significant Seal Island spawning event. As for Lurcher, herring are found in Seal island waters during this time as they transit to other spawning zones, e.g., Scots Bay.

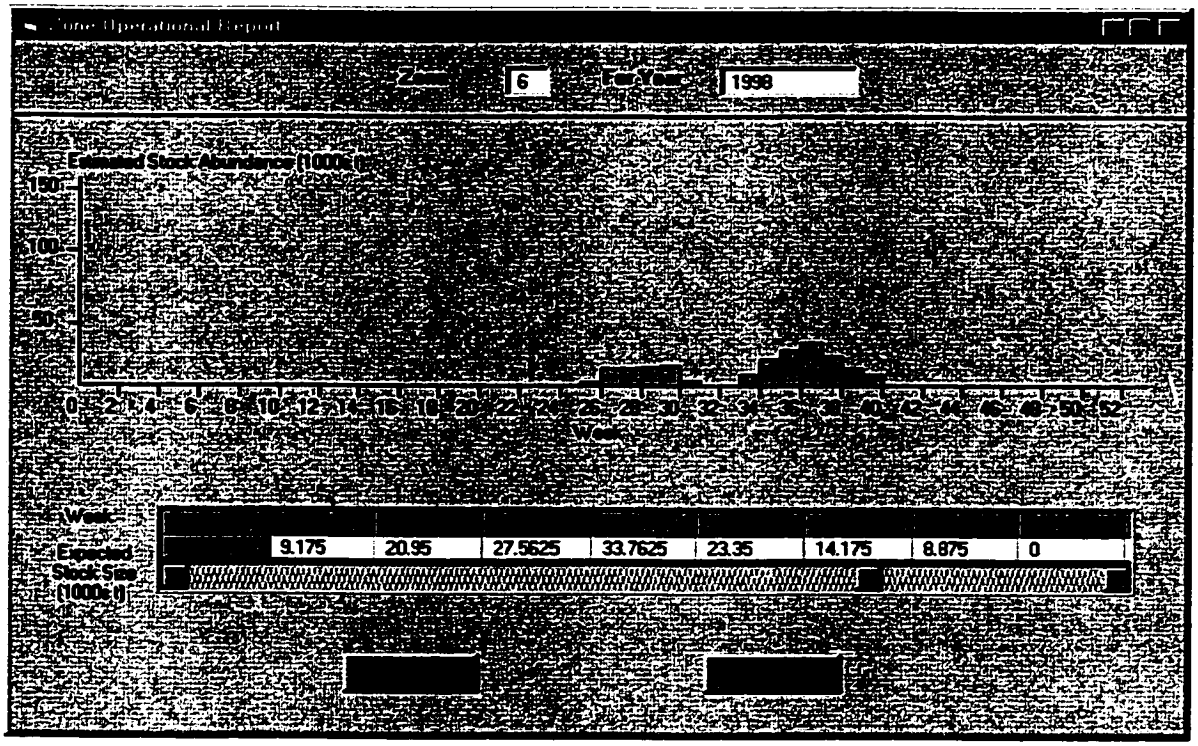


Fig. 4 .27 Expected Abundance for Seal Island in 1998.

The total abundance of Seal Island herring spawners from 1986 to 1993 are relatively stable and in the range of 50,000t to 54,000t. In 1994, there was a small decline to

48,000t, then down to 36,000t in 1995. In 1996, the total abundance estimate recovered to the level of 1994.From 1997, the abundance estimates were at a low level of 41,000 to 42,000t. The weekly expected spawning abundance for Seal Island from 1986 to 1998 is given in Table 4.7 and Fig 4.28.

	34	35	36	37	38	39	40	Exp.
1986	12.125	21.775	33.5125	37.525	32.7	15.6375	8.9625	54.079
1987	12.125	23.338	36.025	39.8	27.2125	18.1	11.075	55.892
1988	12.125	21.775	34.9375	39.3125	33.6125	15.875	12.088	56.575
1989	12.125	23.338	36.025	39.8	33.775	21.225	12.138	59.475
1990	11.113	21.475	34.825	39.2375	33.5125	21.0375	12.138	57.779
1991	12.125	23.338	36.025	39.8	32.6	20.75	11.15	58.596
1992	11.113	22.95	35.7625	39.725	33.675	21.075	9.275	57.858
1993	12.125	21.775	33.5125	38.6	33.175	20.925	9.275	56.463
1994	11.113	21.475	33.3	37.475	25.725	17.425	11.05	52.521
1995	9.175	16.7	24.075	26.95	19.1375	13.5875	12.063	40.563
1996	9.175	16.7	31.2625	41.5625	27.6875	15.175	8.9375	50.167
1997	12	17.175	24.525	33.875	23.5	14.175	8.875	44.708
1998	9.175	20.95	27.5625	33.7625	23.35	14.175	8.875	45.95

Table 4.7 Weekly spawning abundance for Seal Island from 1986 to 1998

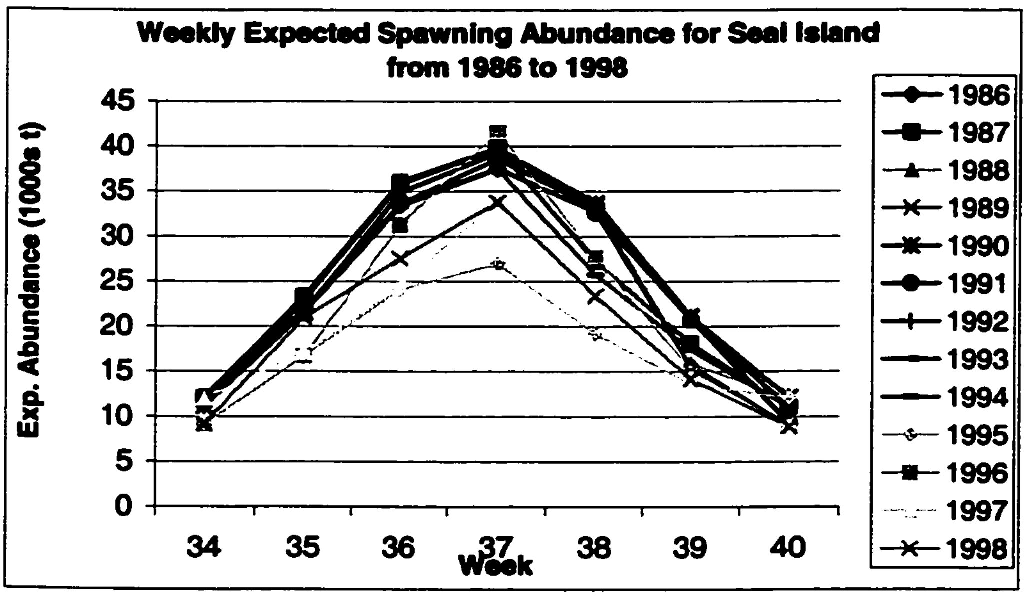


Fig. 4.28 Weekly spawning abundance for Seal Island from 1986 to 1998

Analysis of the Seal Island Spawner Population Estimates. As noted previously, this substock has exhibited a substantial decline in catches. Similarly, imputed from catch observations, the estimate of weekly spawner abundance shows a decline although the form of the weekly abundance pattern is stable. We note that simultaneously, the peak of abundance tends to flatten out as the estimates of abundance declines. Anticipating spawning abundance at Seal Island can be made from the size of catches and surveys compared to past data in years of higher abundance.

4.1.2.5 German Bank Fishing Ground

On German Bank (MapTest zone 7) spawning occurs each year during week 35 through week 41 that is from August 30 to October 5. The Bayes update of weekly abundance of German Bank spawners graphs for 1998 are provided in Fig 4.29. In Figure 4.29 we note the appearance of appreciable herring throughout weeks 19 through 31 well before the German Bank spawning period. As before these herring in feeding aggregations and in transit to other spawning zones, e.g., Scots Bay. These herring may be caught on German Bank at this earlier time period as fish for the bait or shore processed fillet markets.

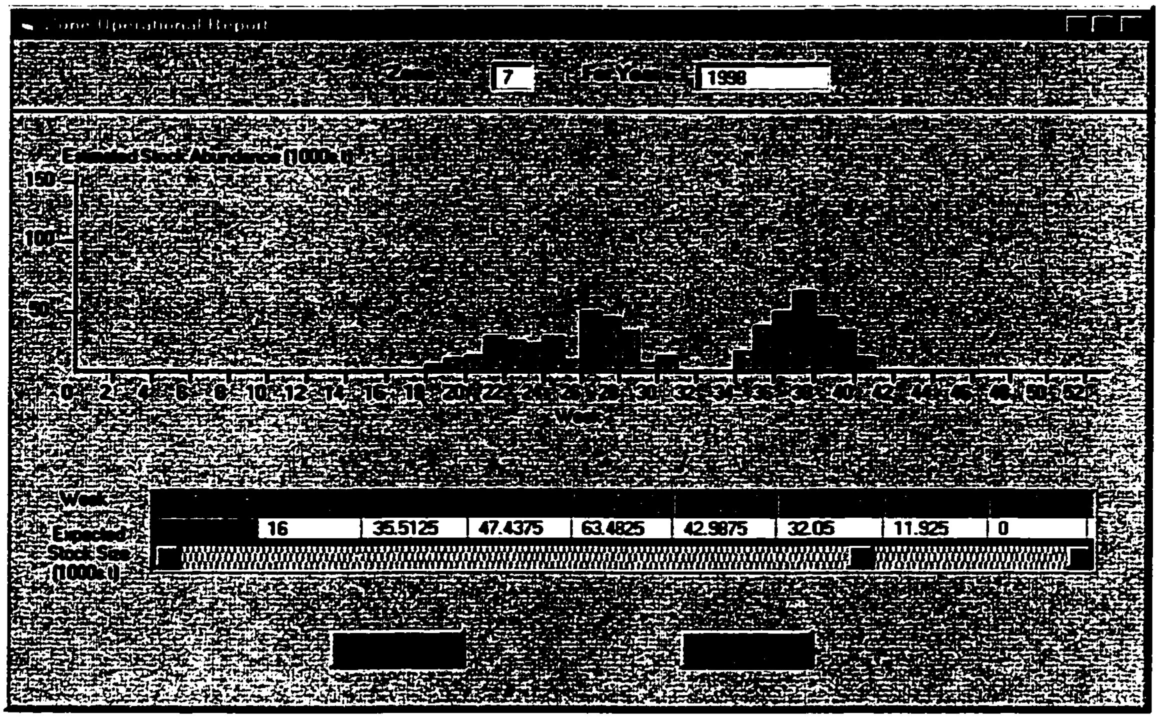


Fig. 4.29 Expected Abundance for German Bank in 1998.

The total abundance of German Bank remained at a stable level of about 70,000t per year before 1994. From 1995, it increased tremendously and reached its highest estimated level at more than 100,000t in 1996. In 1997 the abundance estimates of German bank spawners fell back to the level of 1995 of about 80,000t and remained at this same level in 1998. The weekly expected spawning abundance for German Bank from year 1986 to 1998 is given in Table 4.8 and Fig 4.30.

	35	36	37	38	39	40	41	Exp.
1986	14.3125	34.775	45.5	49.208	37.313	17.225	9.513	69.282
1987	14.3125	34.775	47.013	49.958	34.538	23.375	12.33	72.098
1988	14.3125	34.8625	47.525	49.895	39.05	24.338	8.95	72.978
1989	10.1875	33.675	47.125	50.145	39.213	24.413	12.33	72.361
1990	14.3125	34.775	47.013	48.335	38.438	24	12.3	73.058
1991	16.2375	35.3125	46.85	49.833	39.088	17.775	12.2	72.432
1992	10.1875	33.675	45.7	55.76	36.36	18.05	9.6	69.778
1993	10.1875	31.875	47.9	53.82	33.435	17.325	9.625	68.056
1994	10.1875	33.6125	47.025	50.17	39.163	17.775	9.463	69.132
1995	10.1875	38.875	62.688	57.405	41.788	26.075	8.85	81.956
1996	16	35.5125	47.438	63.483	73.175	61.5	22.19	106.43
1997	16	35.275	46.913	62.96	43.325	26.85	12.39	81.237
1998	16	35.5125	47.438	63.483	42.988	32.05	11.93	83.132

Table 4.8 Weekly spawning abundance for German Bank from 1986 to 1998

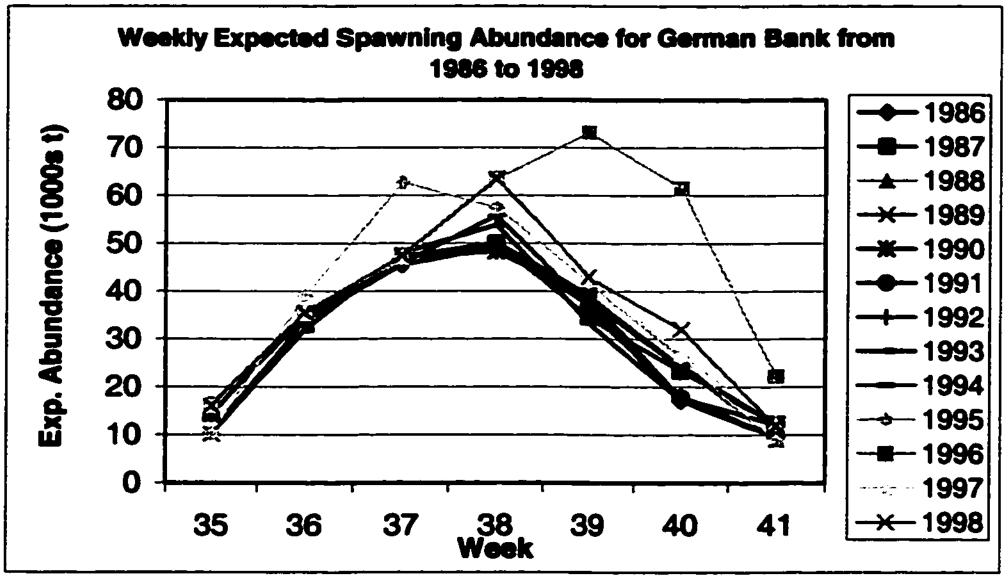


Fig. 4.30 Weekly spawning abundance for German Bank from 1986 to 1998

Analysis of the German Bank Spawner Population Estimates. Fig 4.30 points out the shifting peak in spawner estimates that may occur in this herring substock. The three highest estimates in 1996, 1995, and 1998 each has different weeks of highest spawner abundance (i.e., weeks 39, 38, 37 respectively). This observation makes it more difficult to project German Bank spawner abundance over the course of whole spawning event. Accordingly, extensive surveying and catch monitoring on German Bank may be necessary to obtain a complete picture of spawner abundance in each year.

4.2 Strategic Planning

The strategic planning simulation model is developed to enable managers to test and examine the potential impacts of various stock and catch scenarios using one or two combined historical years as the underlying status of the stock. The associated historical harvesting strategies (i.e., catches by location) are used to project the impact of variable total annual 4WX herring purse seine catches during one future harvest year.

The harvest simulation model allows users to select the level of the TAC for the estimated caches year. Catches from historical years are weighted to determine estimated caches year catches at the historical locations. The simulation model may use the aggregate result of annual VPA estimates to determine the TAC level and then compare with the weekly updated results for the projected year from the MapTest in-season spatial-temporal operational planning model to provide the insight into the expected spatial-temporal impacts on the fishery management.

The following examples present three pairs of estimated caches year analyses to illustrate the strategic planning model.

(1) One year estimated caches using 1986 at different TACs

(2) One year estimated caches of 1998 at different TACs

(3) Two years estimated caches of 1986 and 1998 at different TACs

4.2.1 One Year Estimated Caches using 1986 at Different TACs

For estimated caches year 1986, Fig. 4.31 shows the strategic catches for each spawning group at TAC of 100,000t and 75,000t. Fig 4.32 shows the estimated abundance for the estimated caches year based on 1986 catch locations at TACs of 100,000t and 75,000t.

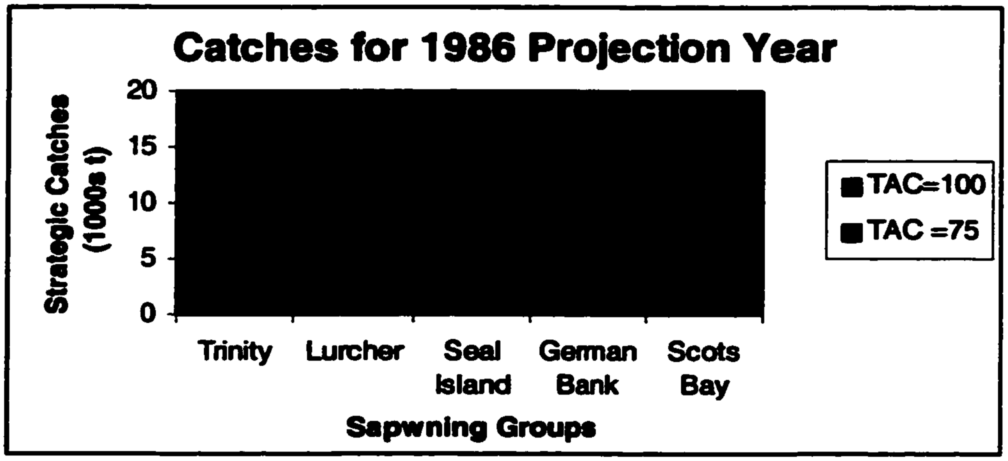


Fig. 4.31 Catches for 1986 estimated caches year at TAC of 100,000 and 75,000t

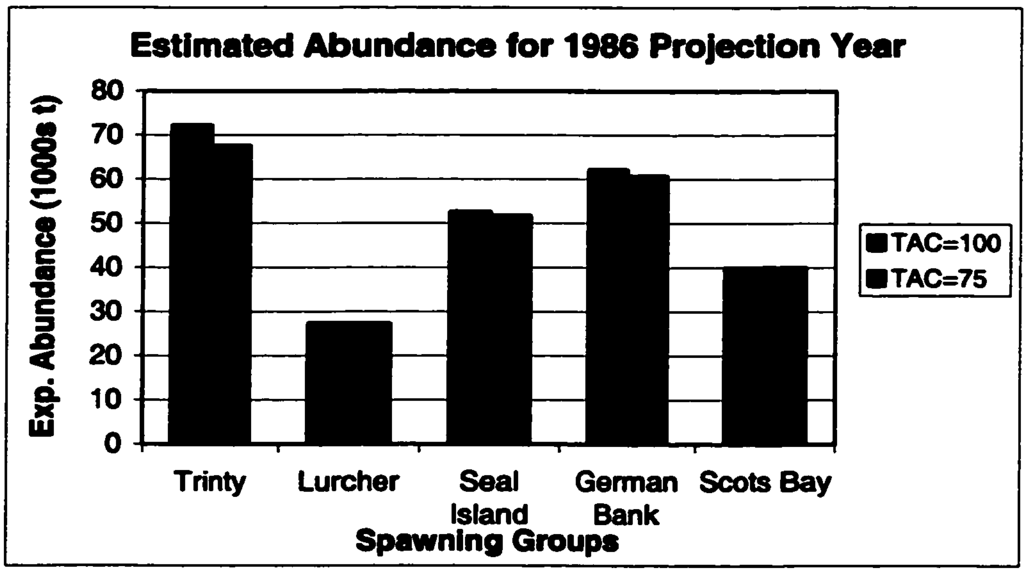


Fig. 4.32 Estimated Abundance for 1986 estimated caches year

In Fig 4.31, the catches for Lurcher and Scots Bay are less than 1,000t and not shown on the chart. Fig 4.31 provides us the information that in the estimated caches year of 1986, all spawning groups follow a same rule. The rule is that the catches for different estimated caches TACs are on the scale of the TACs, i.e., for every spawning group, the rate of catches for 100,000t TAC over 75,000t TAC are the same as the rate of 100,000t over 75,000t.

The catches scale for different spawning groups in Fig. 4.31 match those of Table 4.2 which are the historical pause seine catches. Table 4.2 also shows that in 1986, the catches of Lurcher and Scots Bay are very small and our estimated caches proves this.

From Fig. 4.31 and Fig. 4.32 we could find that if TAC estimated caches is lower, then the estimated abundance is lower, too.

4.2.2 One Year Estimated Caches of 1998 at Different TACs

For estimated caches year 1998, Fig. 4.33 shows the strategic catches for each spawning group at alternate TACs of 100,000t and 75,000t. Fig 4.34 shows the estimated abundance for estimated caches year based on 1998 catch locations at TACs of 100,000t and 75,000t.

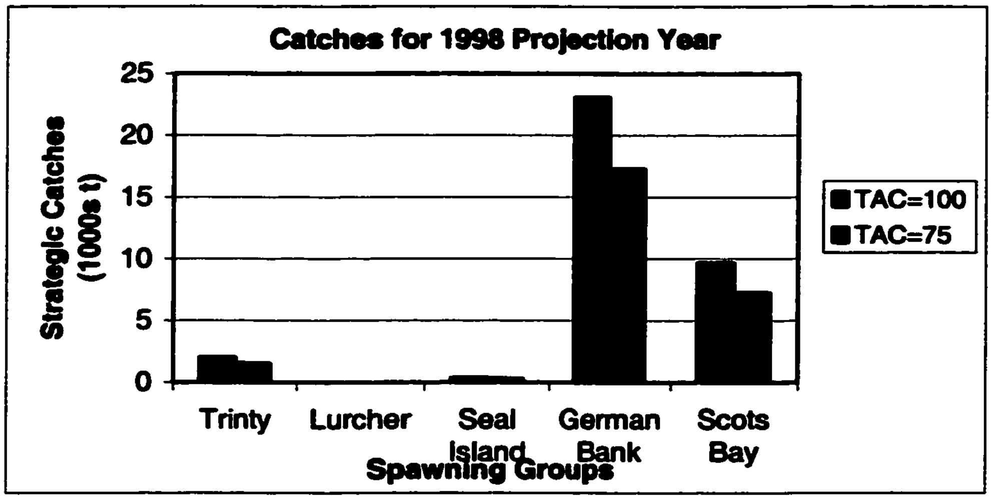


Fig. 4.33 Catches for 1998 estimated caches year at TAC of 100,000 and 75,000t

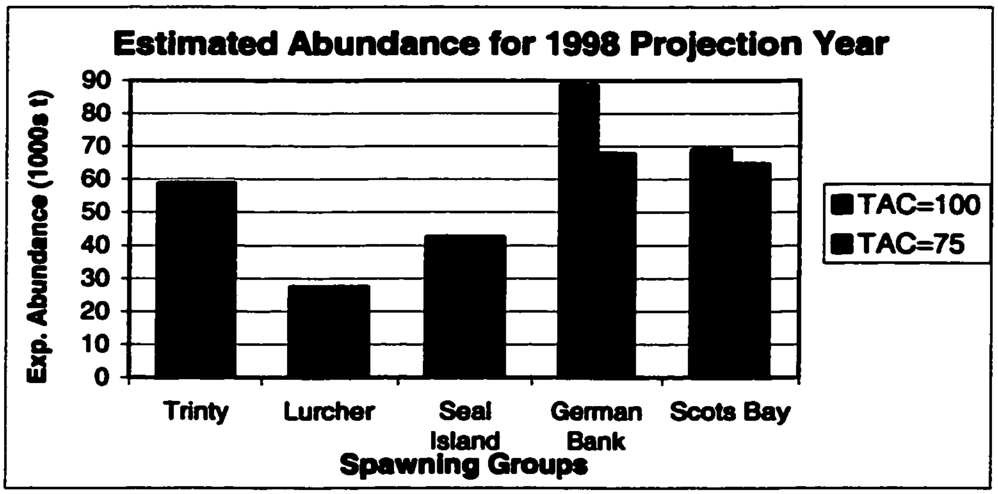


Fig. 4.34 Estimated Abundance for 1998 estimated caches year

In Fig 4.33, the catches for Lurcher is too small to be shown on the chart. Fig 4.31 provides us the information that in the estimated caches year of 1998, all spawning groups follow a same rule as they are in estimated caches year 1986. The catches for different estimated caches TACs are on the scale of the TACs, i.e., for every spawning group, the rate of catches for 100,000t TAC over 75,000t TAC are the same as the rate of 100,000t over 75,000t.

The catches scale for different spawning groups in Fig. 4.33 match those of Table 4.2 which are the historical pause seine catches. Table 4.2 also shows that in 1998, the catches of Lurcher and Seal Island are very small and our estimated caches proves this. And in 1998, the historical pause seine catch for Scots Bay is recovered. This is also shown in Fig. 4.33.

From Fig. 4.33 and Fig. 4.34 we could find that if TAC estimated caches is lower, then the estimated abundance is lower, too.

4.2.3 Two Years Estimated Caches of 1986 and 1998 at Different TACs

For two estimated caches years of 1986 + 1998, Fig. 4.35 shows the strategic catches for each spawning group at TAC of 100,000t and 75,000t. Fig 4.36 shows the estimated abundance for two estimated caches years of 1986 + 1998 at TAC of 100,000t and 75,000t.

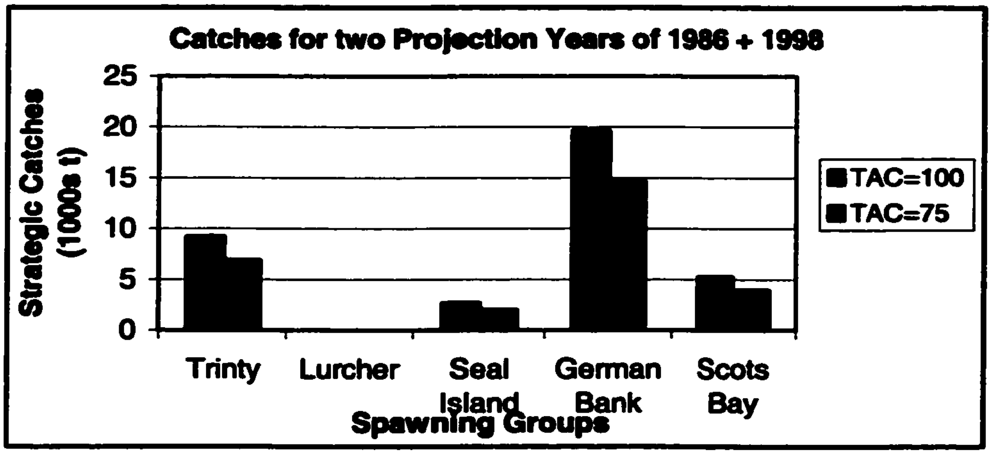


Fig. 4.35 Catches for two estimated caches years of 1986 + 1998

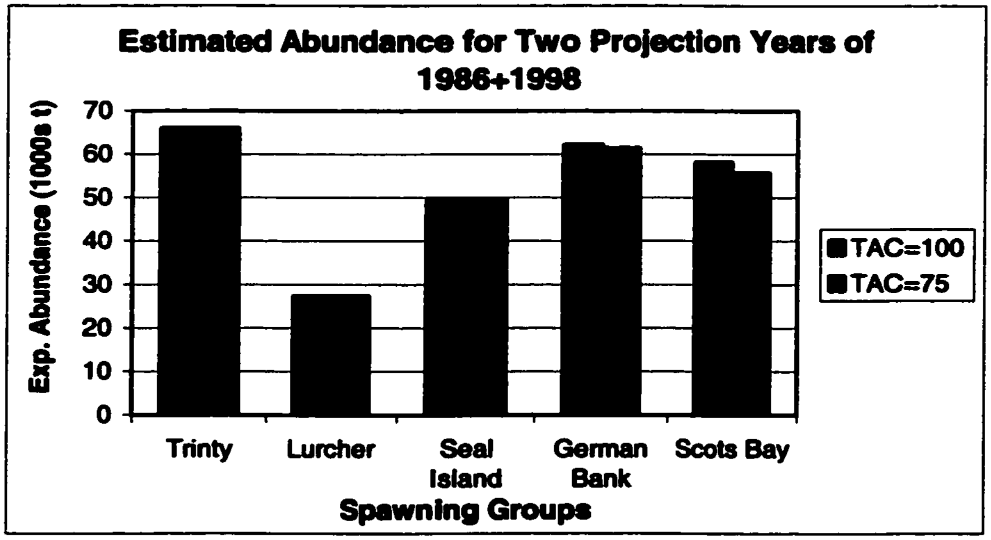


Fig. 4.36 Estimated Abundance for two estimated caches years of 1986 + 1998

In Fig 4.35, the catches for Lurcher are too small to be shown on the chart. Fig 4.33 provides us the information that in the estimated caches year of 1986 + 1998, all spawning groups follow the same rule as the single estimated caches year. The catches for different estimated caches TACs are on the scale of the TACs, i.e., for every spawning group, the rate of catches for 100,000t TAC over 75,000t TAC are the same as the rate of 100,000t over 75,000t.

The catches for different spawning groups in Fig. 4.33 show the co-effect of both the two estimated caches years of 1986 and 1998. For an example, the estimated caches catches for Scots Bay is very low in 1986 and is relatively high in 1998 and provides us a mid-level estimated caches catch in estimated caches year 1986 + 1998. From Table 4.2, the level of catches for Scots Bay in 1986 and 1998 can be proved.

From Fig. 4.35 and Fig. 4.36 we could find that if TAC estimated caches is lower, then the estimated abundance is lower, too.

5. Conclusions and Extensions

This thesis uses a Bayes' updating method to analyze the dynamics of the 4WX herring in-season spatial-temporal stock status based on an extensive data set of commercial catches by purse seines. The thesis presents a form of a visualized computer application tool, MapTest that is developed for this specific fishery research application. MapTest is conceived as a planning tool to assist managers in this fishery in weekly exploitation decision making as well as for projecting and exploring longer term impact of alternative annual exploitation policies.

5.1 Conclusions

Using the Bayes' updating method based on the weekly catch data from the 4WX commercial herring fishery, the weekly estimates of abundance for each zone can be provided. Weekly estimates for individual zone abundance can be aggregated to produce total spawning stock size estimates for the whole fishery that facilitate the within season management of the fishery as well as allowing comparison to the standard aggregated population estimates in space and time.

During the course of model development, analysis and application, several issues were identified. These are described below.

(1) Model insensitivity. Herring spawning stock abundance estimates are subject to change over time and to changes in catch observations. The independence of the probability transition matrices of the model across zones and the relatively low number of stock states (10) does not permit the zone to zone linkages that exist in practice through the zonal migration patterns of the substocks. As well, a finer grid of states would increase the ability of the model to react to finer input changes albeit at a cost of increased parameterization.

(2) Geographical adjacency and the assumption of separate substocks. Trinity Bank, Seal Island and German Bank are three zones that are adjacent. The year-over-year changes of catches among these zones probably have some compensatory inter-connection especially at the edges of the adjacent three zones. For example, before 1991 when catches of Seal Island were very high, those of Trinity Bank and German Bank were at low levels; after 1994, the catches of German Bank rebounded but Trinity Bank and Seal Island simultaneous declined. Further refinement in stock definition perhaps through genetic testing and a better understanding of the environmental triggers for herring spawning is required to deal with this general issue. This information for instance may conclude that the adjacent areas form "one big spawning area of Seal Island and German Bank".

(3) Visual computer system modeling. The computer application tool developed in this thesis, MapTest, using VB and MapInfo was very useful and beneficial to users who understand and are familiar with the fishery of Scotia-Fundy region, i.e., fisheries scientists and managers. It provides the fishery scientists with an efficient visual tool to perform high speed and analyses and exploratory simulation based on the available information of catch data. This system also helps to reduce the complexity and difficulty at a cost of greater data needs for fishery research. Using this VB application in connection with OLE, the 4WX in-season spatial-temporal catch data of herring can be displayed on a map as well as in spreadsheets. Visual Basic is a most suitable language to develop this type of application. Moreover, VB is effective at designing applications with a graphical user interface (GUI). Visual Basic also has advantage of database management, it supports SQL (Structured Query Language) to store, retrieve and query the fish data. Another benefit from VB for this application is it supports OLE thereby enabling ease of use of multiple information sources and output, e.g., spreadsheets, word processors (for report writing). MapInfo is likewise compatible with OLE to VB, which makes it possible to ship data from MapInfo to the VB GUI interface. MapInfo itself supports data conversion from MS Excel enable us to create an Excel database and embed into a MapInfo data file and for displaying data as symbols on a defined scale map.

5.2 Extensions

With the high rate of development of information technology, more and more information are transported via the Internet. Internet publishing is a fast, economic and effective way for information sharing. Modeling of the type that have gone into the development and presentation of MapTest can be setup for multiple remote users on the Internet using object-oriented language advancements. Java is a good O-O (object-oriented) language that can create Java Applet to run applications on Internet browsers like MapTest. Java is also good at front stage software design and can provide advanced GUI like Visual Basic. If this application can be shipped to Java, it can be more widely used and available for further development and exploratory analysis.

6. Bibliography

Berger, James O.. 1980., *Statistical Decision Theory, Foundations, Concepts, and Methods*, Springer-Verlag New York Inc., 1980.

Caddy, J. F. 1970. A method of surveying scallop populations from a submersible. *Journal Fisheries Research Board of Canada*, 27: 535-549.

Caddy, J. F. 1975. A spatial model for exploited shellfish. *Journal Fisheries Research Board of Canada*, **32**: 1305-1328.

Canada 1984. *Underwater World - Atlantic Herring*. Communications Directorate, DFO,Ottawa, DFO/1366, UW/16.

Ellison, Aaron M. 1996. An introduction to Bayesian inference for ecological research and environmental decision-making. *Ecological Applications*, 6(4), 1996, pp. 1036-1046.

Fernandez, Carmen, Ley, Eduardo and Steel, Mark F.J. 1998. Bayesian Modeling of Catch in a Northwest Atlantic Fishery. *Version, July 22,1998.*

Groebner, David F. and Shannon, Patrick W., *Business Statistics, A Decision-making Approach*, Third Edition, Merrill publishing Company, 1989.

Hilborn, Ray and Walters, Carl J. 1992. *Quantitative Fisheries stock assessment - Choice, Dynamics & Uncertainty.* Chapman and Hall, New York 1992.

Howson, Colin and Urbach, Peter. 1991. Bayesian reasoning in science. *Nature.* Vol 350, 4 April 1991.

Lane, D. 1989. A partially observable model of decision making by fishermen. *Operations Research*, 37: 240-254.

Lane, D. and Kaufmann,B. 1993. Bioeconomic impacts of TAC adjustment strategies: A model applied to Northern Cod, in *Risk Evaluation and Biological Reference Points for fisheries Management* by S. Smith, J.J.Hunt and D. Rivard (ed.), Canadian Special Publication of Fisheries and Aquatic Sciences 120, 387-402.

Lane, D. and Stephenson, R.L. 1993. Management of the 4 WX Atlantic Herring (Clupea harengus) Fishery: An Evaluation of Recent Events, in *Canadian Journal of Fisheries and Aquatic Sciences,*50: 2742-2757 .

MacCall 1990 Dynamic geography of marine populations. *University of Washington Press, Seattle Washington.* P153.

MapInfo Professional, MapInfo Corporation, 1996.

MapInfo Professional Reference Guide, MapInfo Corporation, 1996.

MapInfo Professional User's Guide, MapInfo Corporation, 1996.

McAllister, Murdoch K., Pikitch, Ellen K, Punt, Andre E. and Hilborn, Ray. A Bayesian approach to stock assessment and harvest decisions using the sampling/importance resampling algorithm. 1994. *Canadian Journal of Fisheries and Aquatic Sciences.* Vol. 51, 1994. 2673-2687.

McAllister, M.K. and Kirkwood, G.P. 1998. Using Bayesian decision analysis to help achieve a precautionary approach for managing developing fisheries. 1998. *Canadian Journal of Fisheries and Aquatic Sciences.* Vol. 55, 1998. 2642-2661.

Microsoft Excel, Microsoft Corporation, 1997.

Microsoft Visual Basic V6.0 , Microsoft Corporation, 1998.

Patterson, K.R. 1999. Evaluating uncertainty in harvest control law catches using Bayesian Markov chain Monte Carol virtual population analysis with adaptive rejection sampling and including structural uncertainty. *Canadian Journal of Fisheries and Aquatic Sciences.* Vol. 56, 1999. 208-219.

Raiffa, Howard. *Decision Analysis: Introductory Lectures on Choices under Uncertainty.* Reading, mass.: Addison-Welsley, 1968.

Seijo, J.C., Caddy, J.F. and Euan, J. 1994. *Spatial, Space-time dynamics in marine fisheries-a bio-economic software package for sedentary species,* in FAO Computerized information series, fisheries. Food and Agriculture Organization of the united nations, Rome.

Siler, Brian and Spotts Teff. *Using Visual Basic 6, Special Edition,* QUE, 1998.

Stephenson, R.L.1990. Stock discreteness in Atlantic herring: a review of arguments for and against in Proceedings of the International Herring Symposium, Anchorage, Alaska, October 23-25, 1990. (9th Lowell Wakefield Fisheries Symp.)by V. Wespestad, J. Collie, E. Collie (ed.). University of Alaska, Fairbanks.

Stephenson, R.L., Power,M.J., Sochasky,J.B., Buerkle,U., Fife,F.J., Melvin,G.D 1993. *Biological Evaluation of the 1992 4WX Herring Fishery.* DFO Atlantic Fisheries Research Document 93/76 .

Stephenson, R.L., Power,M.J., Sochasky,J.B., Fife,F.J., Melvin,G.D 1994. *Evaluation of the 1993 4WX Herring Fishery.* DFO Atlantic Fisheries Research Document 94/84

Stephenson, R.L., Power,M.J., Sochasky,J.B., Fife,F.J., Melvin,G.D., Gavaris,S., Iles,T.D. and Page, F. 1995. *Evaluation of the stock status of 4WX Herring.* DFOAtlantic Fisheries Research Document 95/83.

Storey, S. 1998. Spatial-Temporal Fish Stock Assessment, *Master=s Thesis, School of Graduate Studies, University of Ottawa..*

Wade, P. R. The Advantages of Using Bayesian Analysis Methods in Marine Conservation, National Marine Mammal Laboratory, Seattle, USA., 1997.

Winkler, R. L. *Introduction to Bayesian Interface and Decision,* New York: Holt, Rinehart and Winston, 1972.

Appendix A. Herring fishing zones

The following table provides the zone definition with descriptions of geographic location.

Zone Number	Name	Description
1	Grand Manan	Island off N.B. Shore
2	Long Island	Island off Western N.S.
3	Trinity Fishing Ground	South of Long Island, near N.S.Coast
4	Lurcher Fishing Ground	South of Trinity
5	Gannet, Dry Ledge	Fishing Ground South of Lurcher
6	Seal Island	Island off Southern Tip of N.S.
7	German Bank	Fishing Ground Southwest of N.S.
8	Scots Bay	Small Bay at Northern End of Bay of Fundy
9	Chedabucto	Fishing Ground Adjacent to East Coast of N.S. and Cape Breton
10	Coastal	Fishing Ground Along Coast of N.B.
11	Southwest Grounds	Fishing Ground South of N.S.
12	Diffuse	Fish are Feeding, Diffuse Throughout the Region
13	Yankee Bank	Fishing Ground Between N.S., N.B.__between Scots Bay, Grand Manan
14	Georges Bank	Northwest Grounds Canada Portion
15	Liverpool	Fishing Ground Between Halifax, Seal Island
16	Browns Bank	
17		
18	Halifax	Fishing Ground off Halifax Harbour
19	Shelburne	
20		
21		
22		
23	Sydney Bight	
24	Others	All Other Fishing Grounds out of Zone 1 to 23

Appendix B. Catch Data Set Information

Data adopted in this thesis and MapTest is from St. Andrew Biological Station on individual purse seines catch logbook data from 1986-1998. Acknowledge with thanks for DFO 4WX Herring Science Team for use of data.

The following table provides the information of catch records for year 1986 to 1998 that used by this thesis and MapTest.

Year	Records
1986	2315
1987	2722
1988	3112
1989	2614
1990	3078
1991	2989
1992	2181
1993	1096
1994	2157
1995	1128
1996	1242
1997	1591
1998	2556

Appendix C. Core Herring State Probability Vectors

The following table is the example of core herring state probability matrices that is Zone 7, German Bank in 1998.

	1	2	3	4	5	6	7	8	9	10
1	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
3	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
4	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
5	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
6	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
7	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
8	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
9	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
10	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
11	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
12	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
13	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
14	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
15	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
16	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
17	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
18	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
19	0.420	0.578	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000
20	0.264	0.566	0.144	0.025	0.002	0.000	0.000	0.000	0.000	0.000
21	0.289	0.363	0.241	0.093	0.008	0.006	0.000	0.000	0.000	0.000
22	0.224	0.323	0.239	0.157	0.041	0.15	0.002	0.000	0.000	0.000
23	0.278	0.371	0.27	0.071	0.01	0.000	0.000	0.000	0.000	0.000
24	0.151	0.564	0.247	0.032	0.006	0.000	0.000	0.000	0.000	0.000
25	0.171	0.461	0.212	0.099	0.044	0.013	0.000	0.000	0.000	0.000
26	0.572	0.029	0.127	0.162	0.091	0.019	0.001	0.000	0.000	0.000
27	0.493	0.01	0.062	0.107	0.129	0.165	0.028	0.006	0.000	0.000
28	0.409	0.017	0.241	0.182	0.071	0.063	0.014	0.004	0.000	0.000
29	0.478	0.154	0.284	0.069	0.010	0.005	0.000	0.000	0.000	0.000
30	0.424	0.464	0.095	0.011	0.004	0.001	0.000	0.000	0.000	0.000
31	0.603	0.371	0.026	0.000	0.000	0.000	0.000	0.000	0.000	0.000
32	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
33	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
34	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
35	0.194	0.728	0.078	0.000	0.000	0.000	0.000	0.000	0.000	0.000

36	0.000	0.349	0.346	0.215	0.069	0.021	0.000	0.000	0.000	0.000
37	0.000	0.067	0.293	0.369	0.213	0.057	0.001	0.000	0.000	0.000
38	0.000	0.031	0.256	0.396	0.208	0.093	0.016	0.000	0.000	0.000
39	0.000	0.125	0.366	0.333	0.144	0.031	0.001	0.000	0.000	0.000
40	0.000	0.598	0.369	0.032	0.002	0.000	0.000	0.000	0.000	0.000
41	0.187	0.744	0.007	0.000	0.000	0.000	0.000	0.000	0.000	0.000
42	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
43	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
44	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
45	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
46	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
47	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
48	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
49	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
50	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
51	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
52	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

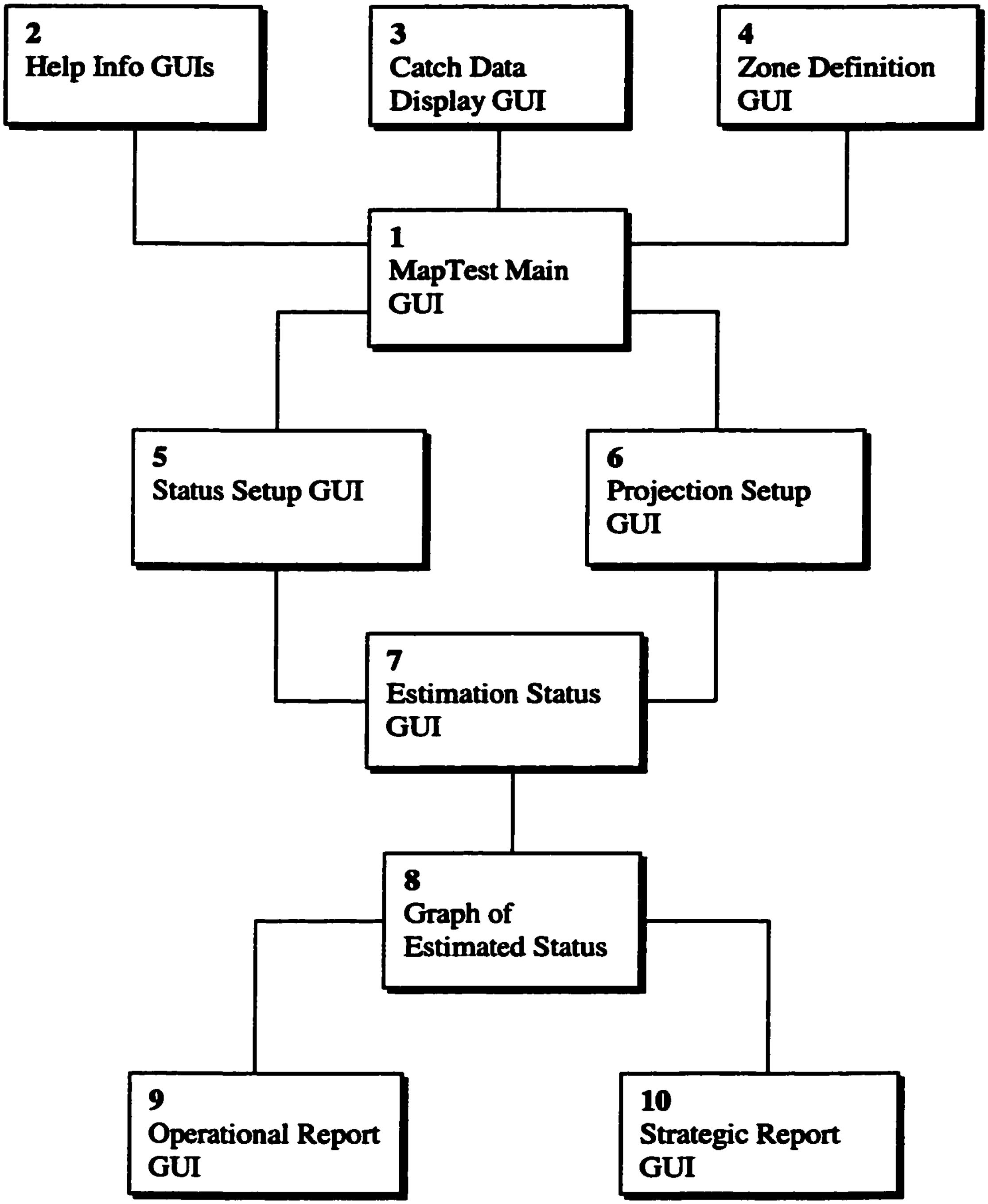
Appendix D. Updated Herring State Probability Vectors

The following table is the example of updated herring state probability matrices that is Zone 7, German Bank in 1998.

	1	2	3	4	5	6	7	8	9	10
1	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
3	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
4	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
5	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
6	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
7	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
8	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
9	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
10	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
11	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
12	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
13	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
14	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
15	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
16	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
17	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
18	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
19	0.512	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
20	0.368	0.487	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000
21	0.437	0.545	0.077	0.010	0.000	0.000	0.000	0.000	0.000	0.000
22	0.122	0.380	0.140	0.040	0.002	0.001	0.000	0.000	0.000	0.000
23	0.143	0.353	0.392	0.129	0.003	0.001	0.000	0.000	0.000	0.000
24	0.073	0.383	0.418	0.055	0.001	0.000	0.000	0.000	0.000	0.000
25	0.022	0.545	0.359	0.023	0.000	0.000	0.000	0.000	0.000	0.000
26	0.811	0.468	0.403	0.100	0.006	0.002	0.000	0.000	0.000	0.000
27	0.183	0.028	0.069	0.065	0.022	0.004	0.000	0.000	0.000	0.000
28	0.071	0.029	0.348	0.319	0.048	0.061	0.011	0.002	0.000	0.000
29	0.073	0.023	0.628	0.252	0.012	0.011	0.002	0.001	0.000	0.000
30	0.540	0.118	0.651	0.085	0.002	0.001	0.000	0.000	0.000	0.000
31	0.152	0.408	0.046	0.004	0.001	0.000	0.000	0.000	0.000	0.000
32	1.000	0.750	0.098	0.000	0.000	0.000	0.000	0.000	0.000	0.000
33	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
34	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
35	0.036	0.806	0.158	0.000	0.000	0.000	0.000	0.000	0.000	0.000
36	0.000	0.287	0.523	0.177	0.010	0.003	0.000	0.000	0.000	0.000

37	0.000	0.066	0.528	0.362	0.035	0.009	0.000	0.000	0.000	0.000
38	0.000	0.019	0.282	0.435	0.207	0.056	0.002	0.000	0.000	0.000
39	0.000	0.107	0.589	0.286	0.015	0.003	0.000	0.000	0.000	0.000
40	0.000	0.477	0.294	0.202	0.025	0.002	0.000	0.000	0.000	0.000
41	0.187	0.744	0.070	0.000	0.000	0.000	0.000	0.000	0.000	0.000
42	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
43	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
44	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
45	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
46	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
47	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
48	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
49	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
50	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
51	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
52	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

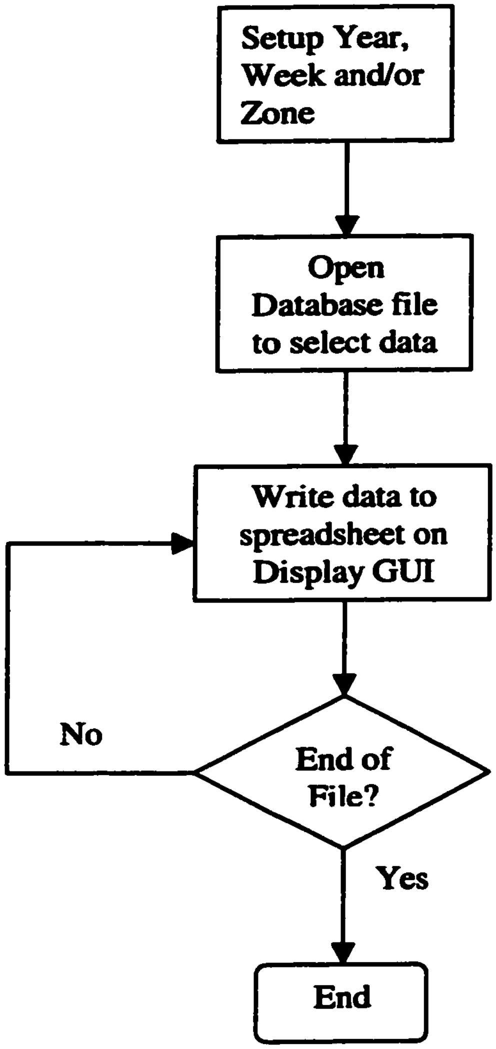
Appendix E. MapTest object diagram



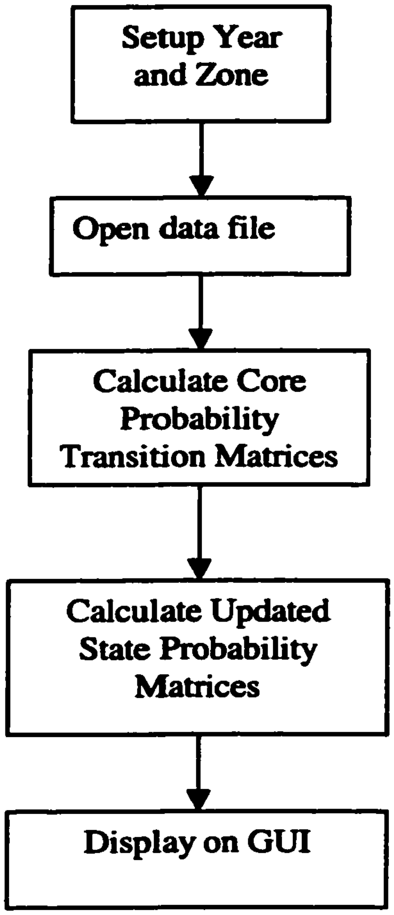
1. MapTest Main GUI (Fig. 3.2) The main interface GUI of MapTest application. All functionality of the MapTest application starts from here.

2. Help Info GUIs. Contains two GUIs: "About" and "How To". Can be triggered from the "Help" menu in the main GUI.

3. Catch Data Display GUI (Fig. 3.8) By selecting the "Year", "Week", "Zone" information on the Main GUI, then click "Start", the catch will be shown up week by week by selected year-week(s)-and zone(s). If select "Display" from the "View" menu, the pop up GUI will show the data table. The following is the flowchart of Display.



4. Zone Definition GUI (Fig. 3.7). From "View" menu in Main GUI, select "Zone Definition", then pop up the Zone Definition GUI. This GUI can provide the zone definitions and the highlighted locations on the Main GUI.
5. Status Setup GUI. From the main GUI, click "Status" button, then pop up the Status Setup GUI. This is used to set up the year, week and zone information for the estimation.
6. Projection Setup GUI (Fig. 3.12). From the main GUI, select "New Project" from the "Select Year" list, then click the "Start" button, the Projection GUI will pop up for setting up the information of estimated caches year(s).
7. Estimation Status GUI (Fig. 3.9). Both Status Setup GUI (5) and Projection Setup GUI (6) lead to Estimation Status GUI. The following is the flowchart of Estimation Status.



8. Graph GUI (Fig. 3.9). By clicking the "Graph" button on the Estimation Status GUI (7), the Graph GUI pops up. The left side of the Graph GUI shows the chart of scaled stock abundance in 10 levels from 1 to 10 which stands for the abundance of different scales from 0 to greater then 300. This GUI can show stock abundance in detailed graphical stock levels and in tons for the individual weeks.

9. Operational Report GUI (Fig. 3.10). From the Graph GUI (8), if click "Operational Report" button, the Operational Report GUI pops up. The Operational Report GUI provides the information of estimated stock abundance in graph and amount (in unit of 1000t) for all weeks in the selected year.

10. Strategic Report GUI (Fig. 3.11). From the Graph GUI (8), if click "Strategic Report" button, the Strategic Report GUI pops up. The Strategic Report GUI provides the information of the total expected abundance in specified year and zone. If the selected zone is not a spawning area, there is information showing in the GUI to indicate the applicable spawning areas.