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BORMICON

A Boreal Migration and Consumption model

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Part I

Background

Chapter 1

Introduction

Ólafur K. Pálsson

1.1 Historical review

Studies on the food and feeding of marine fishes have been part of fisheries research during this century and even longer. However, quantitative studies specifically aimed at multispecies analysis have been carried out only during one or two decades. In Icelandic waters feeding studies on fish have focused on the cod, and continuous studies have been carried out in this respect since 1980. Studies on the food of other fish species have been carried out sporadically and during limited periods of time (see [24] for references).

Some attempts have been undertaken to analyze the trophic interactions of cod and its prey species on a quantitative basis, in particular the interaction of cod and capelin the most important prey of Iceland cod ([14] and [16]). These studies have been mostly limited to the consumption by cod on the various prey species or groups. Attempts to combine consumption and growth, however, have not been successful.

In other cases species interaction has been verified without the direct inclusion of consumption, such as through the positive relationship between capelin stock size and cod growth ([44]) or the inverse relationship between cod stock size and shrimp recruitment ([40]). Based on these and some additional assumptions such as stock-recruitment and stock-growth dependence an extension of a cohort model has recently been developed ([43]).

1.2 The Multi Species Project

The multi species project was launched in 1992 and is terminating its last year in 1995 as far as sampling of data is concerned. The main objective of the project was broadly defined to increase knowledge and understanding in the field of marine biology and ecology in order to enhance the prospects for comprehensive mana-

gement in ecological context. Based on this objective intensive research activity has been carried out in feeding studies of fish, marine mammals and seabirds, as well as ecological studies of zooplankton and predator-prey interaction of capelin and zooplankton. Some experimental studies have been conducted on growth and food conversion of cod. The ultimate goal is to integrate the findings of the various research activities in a multi species model - the Bormicon model.

1.3 The Bormicon model

This model represents the most ambitious attempt to model species interaction in Icelandic waters so far. Flexibility is the basic concept of the model both in terms of predator and prey number as well as the modelling of species specific life history traits, such as migration, consumption, growth and sexual maturity, or the modelling of physical or ecological features such as oceanic currents or zooplanktonic abundance.

However, as clearly indicated by this report, this work is now in its very first phase to be followed by an intensive developmental and experimental work.

1.4 This report

The important species interactions of cod and capelin represent the essence of this report. It starts with a general description of the biology of predator and prey, a definition of subareas and a presentation of the construction and the mathematical outlines of the model (chapter 2-5). In chapters 6-12 more detailed descriptions of input variables are given for the predator and the prey. In the last sections results are presented, starting with single species output of growth or migrations of cod or capelin and, finally, the full model.

In additional reports detailed descriptions are given in a Bormicon User's Manual and a Bormicon Programmer's Manual.

1.5 The biological model

1.5.1 Principles

Given the above description of the ecosystem involved, it becomes clear that a model which is to take these effects into account will need to incorporate several essential issues.

Since the predation of one species by another is highly dependent on the length of the predator and the prey, the length of the species needs to be included in the model. Similarly, weight needs to be included since a starving fish will lose weight but hardly length.

The fact that growth of some fish species depends critically on the abundance of their prey ([14], [15], [44]) also needs to be accounted for.

The migratory patterns of the species involved vary depending on their maturity stage. Thus, the spawning migration of cod is totally different from the feeding migrations undertaken by immature fish. Drift of eggs and larvae can conveniently be considered in the same fashion as migration. This leads to a natural separation of each stock into different stages: 0-group, immature and mature fish.

1.5.2 Units: Length, age, maturity, season and area

The choice of basic units depends on the amount of disaggregation required to distinguish the most important features in the system. The choice of areas is quite complicated and is described in chapter 3.

The basic unit of time needs to take into account the speed of migration of the various species and the resulting effect on the overlap between predator and prey. Since the capelin migrate around half the country in only a few months, the time step is taken to be one month. This is somewhat coarse, but practical considerations (computational time and data) dictate a bound on how fine the time step can be taken.

Naturally, age is measured in years whenever age disaggregation is possible.

Since a number of processes, such as consumption, are largely length dependent, it is not enough to keep track of the number of fish at a given age, along with their mean length. Rather, the actual number of fish within each age-length cell needs to be tracked.

This leads to the definition of a model unit of fish as the number of individuals of a given species within an area in a certain month, all of the same age, in the same length group and of the same maturity stage.

1.5.3 Processes: Birth, death, migration, harvesting and consumption

The processes that need to be tracked in the Boreal model include migration, consumption, growth and mortality. It is clear that a model which incorporates all these factors on a fine spatial and temporal scale will need to be a simulation model.

Given a “homogeneous” group of fish with respect to age, length and maturity, these can conceptually be tracked in time as they migrate from one region to another, increase in age and prey on other stocks. The predation will result in a weight and length increase of the predator. Predation must also be reflected in a decrease in prey abundance.

1.5.4 Handling of unknown parameters and processes

There are a fairly large number of unknown parameters. In the first instance these need to be set at initial values which give results that can be demonstrated to more-or-less reflect results from catch data and surveys.

In particular, values of migration parameters are largely unknown, although the general migration structure is well established.

Given output from a single simulation, it is possible to obtain the areal distribution of each stock at any given point in time. Such results can be compared to survey distributions using any of a number of different techniques. Different values of unknown parameters can then be compared on the basis of how well the resulting simulations fit to the data at hand.

Thus, the model needs to be expanded from a simulation model for a fixed set of parameters to include the evaluation of a likelihood function which returns a measure of the goodness of the fit to the various data sets. This likelihood function must be sufficiently generally set up so as to potentially accommodate the time trend in yearclass abundance and the spatial distribution of yearclasses or total biomass.

There are a large number of other data sets available, all of which provide pieces in the jigsaw puzzle describing the ecosystem. Thus, stomach content data provide information on the prey distribution, predator-prey overlap and suitability of the prey for the predator. Samples for age include data on the length, sex, maturity and weight at age, which again contains information on e.g. growth. Ideally, the model output should be such that each of these puzzle pieces seem to fit into the picture.

The final step in the modelling exercise should be to include a maximization algorithm for maximizing the likelihood over some or all uncertain parameters. For flexibility this should be done in such a fashion as to allow any parameter to be estimated.

As an example, eventually the spawning migration should result in a certain amount of eggs and 0-group fish, which “migrate” to the nursery areas. It is not clear how this particular process should be modelled, however. One possibility would be to use an estimation procedure, where the annual amount of eggs and/or egg mortality function is determined in such a fashion as to provide a recruitment series which fits well to the survey data.

As another example, the initial migration matrices need to be defined in a somewhat ad hoc manner, but there are certain components to the matrices, which can be determined using a least squares fit. Thus, if the major capelin spawning migration is described as a general clockwise migration of unknown speed, then it should be possible to estimate this single parameter.

Chapter 2

Definition of oceanic areas around Iceland: A proposal

Gunnar Stefánsson, Ólafur K. Pálsson, Jóhanna Erlingsdóttir
and Gunnar Pétursson

2.1 Introduction

The marine environment around Iceland is highly heterogeneous. Summary measures therefore need to be computed on an areal basis, which again requires some definition of areas. An areal split should reflect the bathymetry of the region, as well as the hydrography and the distribution, migration and interaction of the various fish species. Thus, different stocks of the same species should be allocated to different areas if there is otherwise a possibility of e.g. a consumption or fishery model otherwise disproportionately exploiting the stocks.

This paper considers various aspects of the bathymetry, hydrography, biology and general ecology of Icelandic water in order to consider the appropriate separation

of the waters into areas which can be used for the purpose of multispecies modelling. For simple consumption modelling, different stocks of the same species should be allocated to different areas, bathymetry, hydrography and chemistry should be as uniform as possible within each area and within each region the distribution and migration of each fish stock should be well defined.

As will be described in the various sections, the Icelandic region lies in the intersection of two ridges, which implies a natural separation of the surrounding area into four regions. Further considerations of the bathymetry and fish distribution imply a natural separation into the waters deeper and shallower than 500 meters. Further considerations of the distribution of various fish species and the extent of certain hydrographic conditions gives a separation into the regions given in figure 2.1.1. It will be shown in this paper that this separation satisfies the basic requirements laid out above.

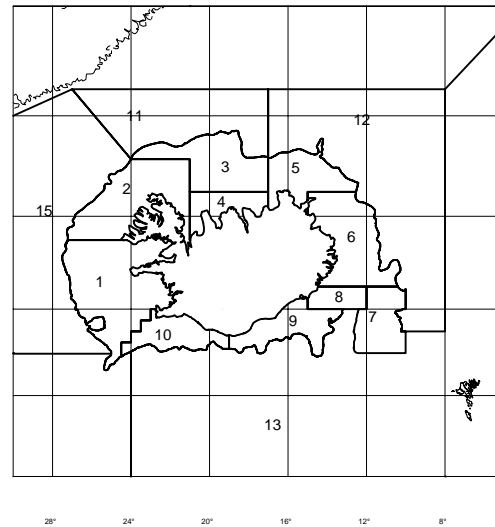


Figure 2.1.1: Suggested area definitions

2.2 Bathymetry

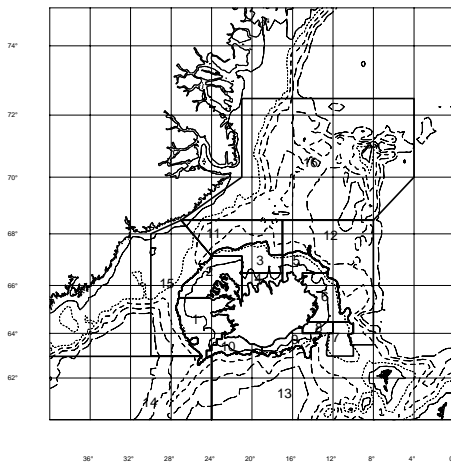


Figure 2.2.1: Global bottom topography.

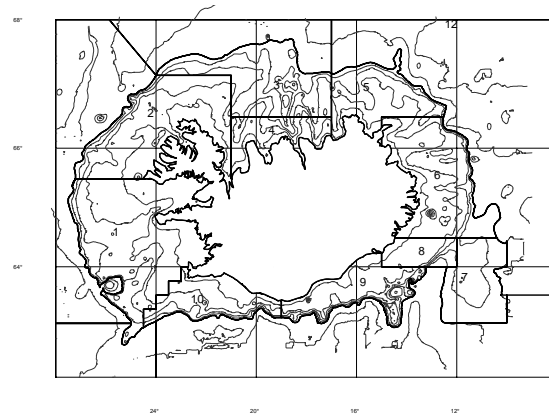


Figure 2.2.2: Local depth contours.

The global bottom topography in figure 2.2.1 is derived from a world depth database (? , 19xx) and local depth contours from the MRI database are given in figure 2.2.2. It is seen that the country is positioned on two ridges, the mid-Atlantic ridge going

roughly from the south-west Reykjanes ridge to the north-east Jan Mayen ridge and the Faroes-Greenland ridge going roughly south-east to north-west.

Variability in the Atlantic inflow causes considerable interannual differences in temperature and salinity in the various subareas. The coastal current, close to the shore, consists of relatively fresh water circling the island in a clockwise fashion [42].

It follows that considerations of the ridges involved would lead to a minimal split into 4 areas, along the ridges, since the ridges have considerable influence on the hydrography and biology of the regions. These considerations thus lead to the natural separation between the indicated areas 2 and 3 to the north-west, areas 10 and 1 in the south west, 5 and 6 in the north east and between areas 6 and 9 in the south east.

The depth contours in figure 2.2.2 show that the shelf falls off quite steeply in some areas, most notably off the south coast. This leads quite naturally to a further refinement of the 4 base areas, splitting each one into an on-shelf and off-shelf area. The precise definition of this split needs to be done in accordance with the behaviour of the various species, however.

Finally, the bathymetry clearly indicates area 7 to be an intermediate nature with respect to depth. It must also be regarded as specific with respect to hydrographic condition, mainly in view of the characteristic “overflow” of the Iceland-Faroes ridge.

2.3 Hydrography

The basic system of currents is given e.g. in [42] and is repeated here in figure 2.3.1. The figure clearly shows the flow of warm Atlantic water up to the south coast along with the coastal current.

Also seen is the cold low-salinity water originating from the north.

The importance of the oceanic ridges described in the previous section is clear from a consideration of this figure. Thus, for example, the Iceland-Faroes ridge is clearly important concerning the hydrography of the south-east region.

The strength of the warm Atlantic inflow varies considerably from year to year as is seen for the month of August in figures 2.3.2, taken from 0-group survey reports. These are temperatures at 50m depth and the

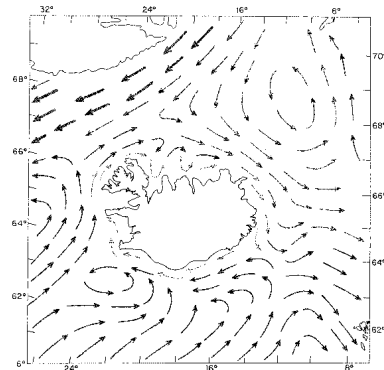


Figure 2.3.1: Ocean current regime

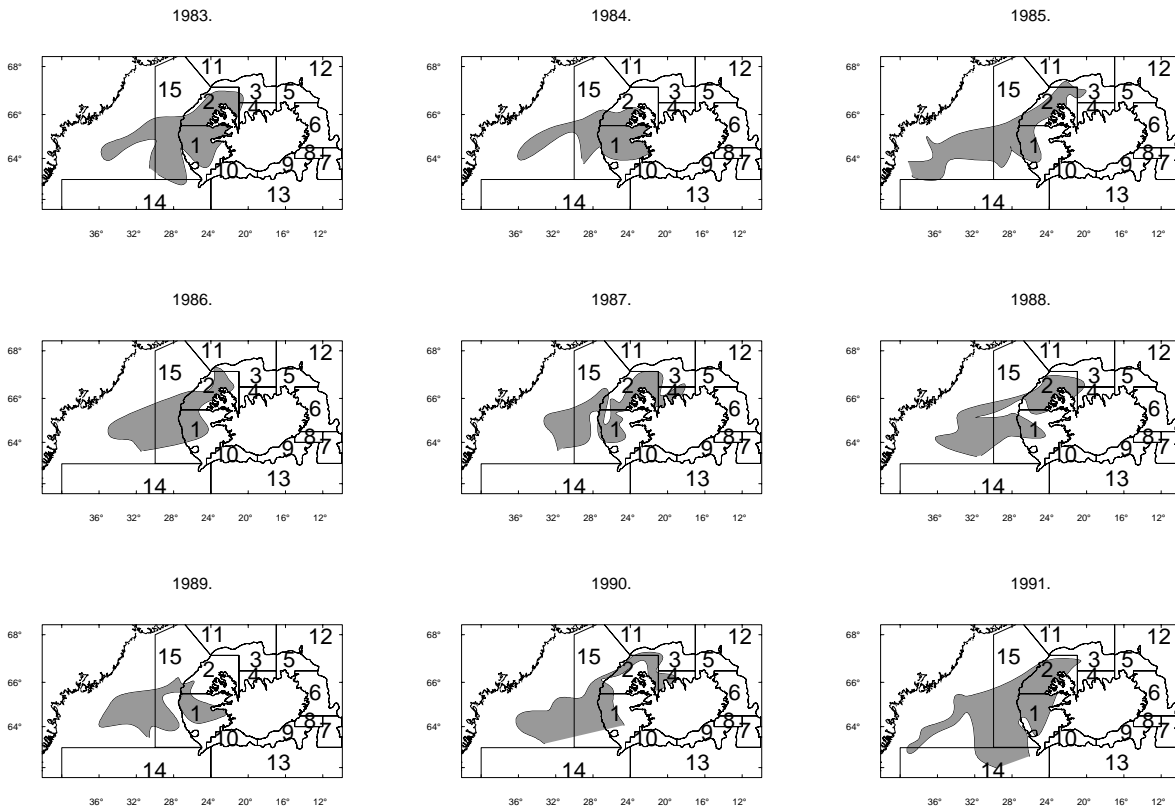


Figure 2.3.2: Temperature distribution. Shading denotes area with 6-7 C°.

main 6°C contour line is highlighted in the figures.

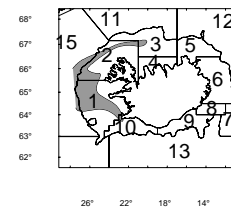
It is seen that the eastern part of the region is dominated by cold waters whereas the southern and western parts are dominated by the warm water inflow in all years. The northern part is quite variable, however, indicating that this part should be split up into finer areas.

Salinity may also be taken as an indicator of the inflow of atlantic water. Plots of salinity are given in figs 2.3.3, taken from 0-group survey reports. Much the same can be read from these as from the temperature plots.

Combining the hydrographical and bathymetrical considerations, it is seen that the southern part should be kept distinct from the rest, using the Reykjanes and Iceland-Faroe ridges as separators. The western part should also be kept separate from the rest, using the Iceland-Greenland ridge as a separator. The northern area should be split into at least two subareas, since the western half can be much warmer than the eastern part in some years.

Finer splits are clearly needed but will be defined by the biology.

50m depth May 1991.



50m depth May 1992.

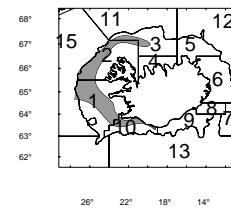


Figure 2.3.3: Salinity distribution. Shading denotes area with over 35 o/oo

2.4 Cod

The cod is the single most important predator and commercial species in the ecosystem. Any areal split thus needs to be set up in such a fashion as to accommodate the behaviour of the cod. Cod are mainly caught in the 0-500 m range. The 500m depth contour therefore serves the need for splitting the region into an on-shelf vs off-shelf part.

The cod spawn mainly off the western part of the south coast in April-May, although the spawning area extends along the west coast into Breidafjörður and along the south coast to the south eastern area. Furthermore, there is some spawning in other locations such as fjords along the north and the east coasts. This is seen in figure 2.4.1 where each point corresponds to a groundfish survey sample of at least 25 fish of which at least 50% are mature.

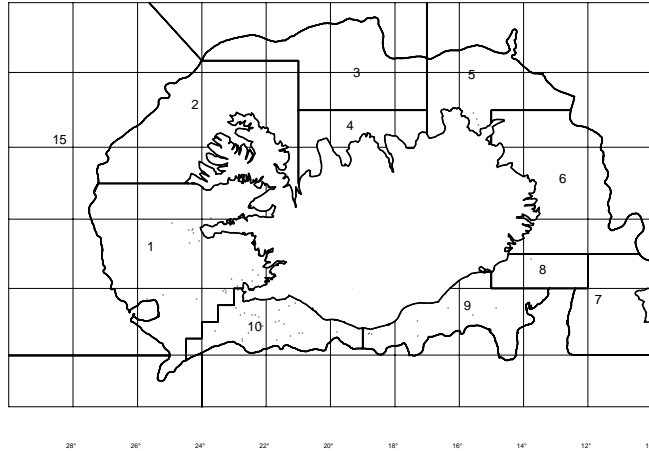


Figure 2.4.1: Cod spawning locations from groundfish survey

The major migration to the spawning grounds is in the reverse direction but there are also spawning migrations around the south-eastern part of the coast. After spawning the cod return, probably along the same route, to feeding grounds. The eggs and larvae of cod drift from the spawning area, north along the west coast to the nursery areas in the north.

The 0-group survey provides information on the distribution and abundance of 0-group cod. Sample plots are given in figure 2.4.2. These figures clearly illustrate the variation in the location and extent of the 0-group distribution.

It is seen that in “good” years such as 1983 and 1984, the distribution of 0-group cod is quite extensive. This is completely different from the low-abundance in 1986, where not only is the abundance low, but also the extent of the distribution area.

It is further seen that the location of the young is quite different in 1983 and 1984, illustrating the importance of initial hydrographical conditions, such as the strength of the Atlantic inflow, on the final locations of the 0-group.

2.5 Shrimp

The extent of the offshore shrimp (*Pandalus borealis*) fishery is indicated in figure 2.5.1. The figure gives those locations where more than 5 tows have been taken with shrimp trawl.

The fishery is conducted along the slope of the continental shelf from depth of

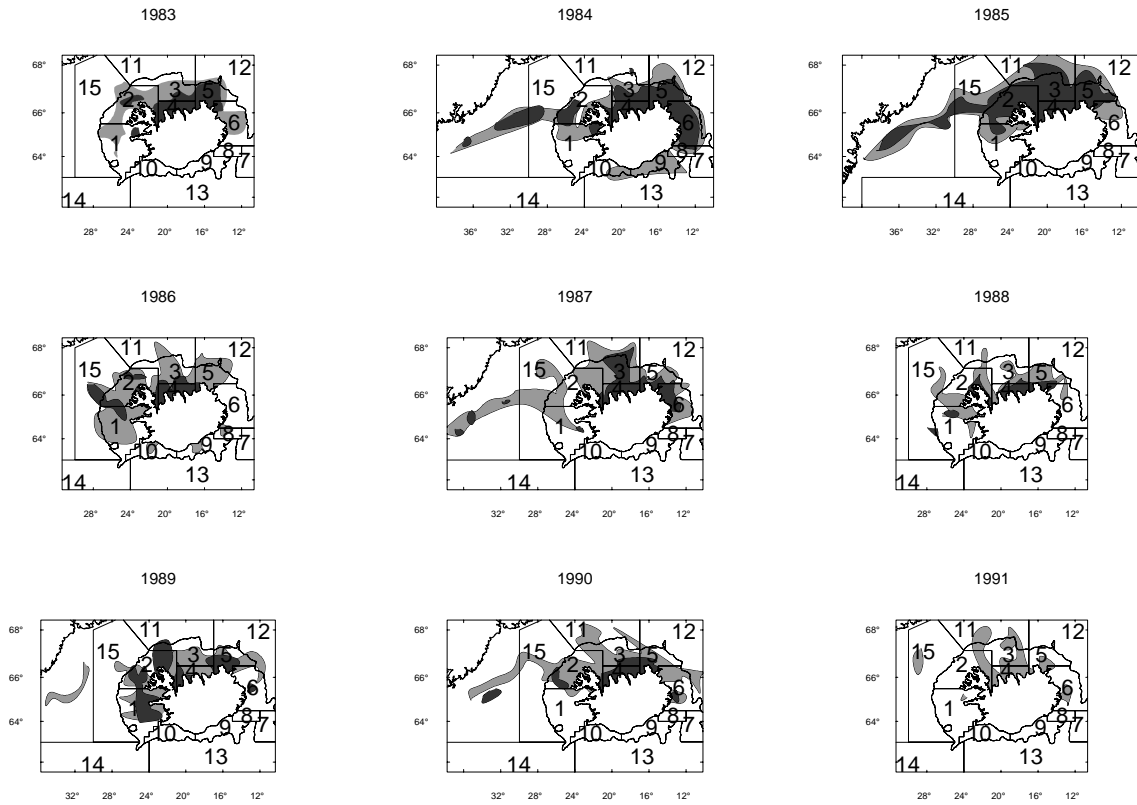


Figure 2.4.2: Distribution of 0-group cod in August.

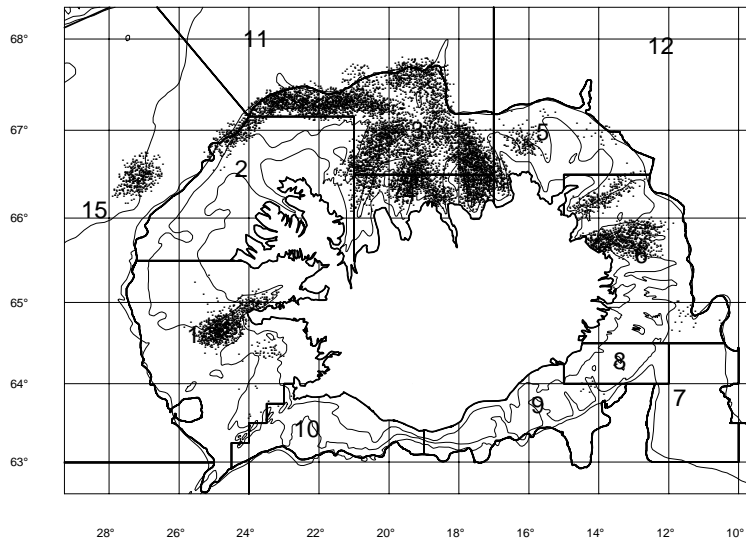


Figure 2.5.1: Offshore *Pandalus borealis* fishing grounds.

approximately 200 m down to 700 m, although the main fishery is in the depth range 300-500 m.

The shrimp constitutes rather important food for cod [14] and there are several indications that the cod may considerably affect the mortality of pandalid shrimp in Icelandic waters [41].

2.6 Greenland halibut

The extent of the trawl fishery for Greenland halibut is indicated in figure 2.6.1. The Greenland halibut is a deep water species and the fishery extends down to depths of approximately 1500 m.

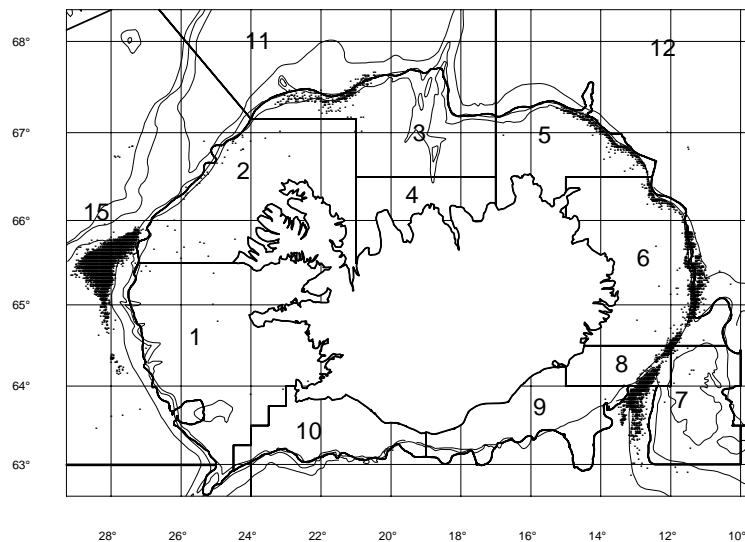


Figure 2.6.1: Locations of Greenland halibut catches.

It is seen that the main fishing areas are separated into a western area and an eastern one. Between the two areas a strip appears where smaller Greenland halibut are found.

The main (western) area is considerably offshore, quite distinct from the cod area above 500m.

The “strip”, however, appears to be close to the 500m contour. This is seen in figure 2.6.1 which shows the 400, 500 and 800m depth contours along with the locations of catches of Greenland halibut of over xxx kg.

Thus, Greenland halibut appear roughly in a semicircle around the country. This sets the additional requirement to the area definition that an offshore strip is needed.

To explicitly specify the Greenland halibut distribution, the offshore strip should be defined by depth contours of about 400m and 800m. However, the cod dictates that the 500m contour needs to be used as a separator. It follows that either the

number of areas must be considerably increased, or some compromising split must be used.

The approach taken is to use larger areas. Firstly, the cod-based 500m contours are used inshore. Secondly, the offshore areas to the north are elongated to the north, quite a bit further than the extent of the Greenland halibut distribution. This is not a problem in terms of the Greenland halibut, since the extended area will not lead to confounding between different food or behaviour. The area extension is needed for capelin, however (see below).

These figures indicate that although the fishery and distributional information for Greenland halibut can be classified into the various Bormicon areas, the present definition of areas is lacking in terms of providing an appropriate definition of the strip off the northern coast which contains Greenland halibut.

2.7 Capelin

The capelin (*Mallotus villosus*) migrates from feeding grounds towards the Jan Mayen area towards the western part of north coast, eastwards along the north coast, southwards parallel to the east coast, ending up in the spawning area off the western part of the south coast. This pattern is described in detail in chapter 9 of this book.

The precise migrational pattern is somewhat variable in time and space. It is seen that the basic Bormicon areas will not be able to completely reflect the distribution of capelin, since the distributional pattern can be quite different, yet the same abundance may be present within each region. It is equally clear, however, that the basic clockwise migration, can be captured by the Bormicon areas, as can the principle of overlap between capelin and cod.

For migration modelling, the areas should ideally not be so small as to allow the capelin to pass through them in a very short time step. For this reason, areas 11 and 12 are extended outwards. There is less interaction between capelin and predator stocks within this area than once the capelin is into shallower waters where it encounters the cod. For this reason, the areas are kept fairly large, allowing for orderly migration through them, (but yet keeping the likely most important predation outside them).

2.8 Nephrops

The Nephrops fishery takes place in the several deeps off the southern coast. This is clearly seen in figure 2.8.1, where each point indicates a single tow using a nephrops trawl (using only locations with repeated registrations).

The fishing area can be viewed as two principal distinct eastern and western fishing areas along the south coast.

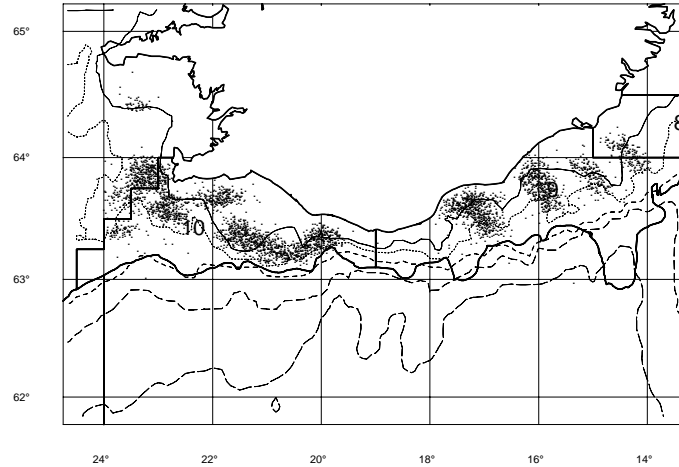


Figure 2.8.1: *Nephrops norvegicus* fishing grounds.

This indicates that the shallow portion of the southern part should be separated into two parts, an eastern and western part, and this is the main reason for the separation between areas 9 and 10.

2.9 Survey data

The groundfish survey abundance and depth is available by species, year and area. In particular, these can be aggregated by statistical rectangle and subrectangle as defined in figure 2.9.1.

Notably, the groundfish survey is primarily designed for cod and hence only covers the grounds down to 500m depth, i.e. Bormicon areas 1-10, which are also indicated in the same figure.

In the following analysis the abundance by station of cod, haddock, saithe, redfish, catfish, Greenland halibut, plaice, herring, capelin and shrimp are used. As a first smoothing step, the data are aggregated within subrectangle, so that the data becomes the number of fish by species, year and rectangle.

The analysis commences by standardising each measurement so that the mean is zero and the variance becomes one. This basically enforces the same sort of unit for all the different species.

In order to define “similar” subrectangles, some index of similarity or correlation needs to be computed between pairs of subrectangles. The different (standardised) abundance measurements within each subrectangle are therefore arranged as measurements on that subrectangle. For each pair of subrectangles the correlation between the pair is computed and a matrix of correlations constructed.

The correlation matrix is then used as input to a cluster analysis. These simila-

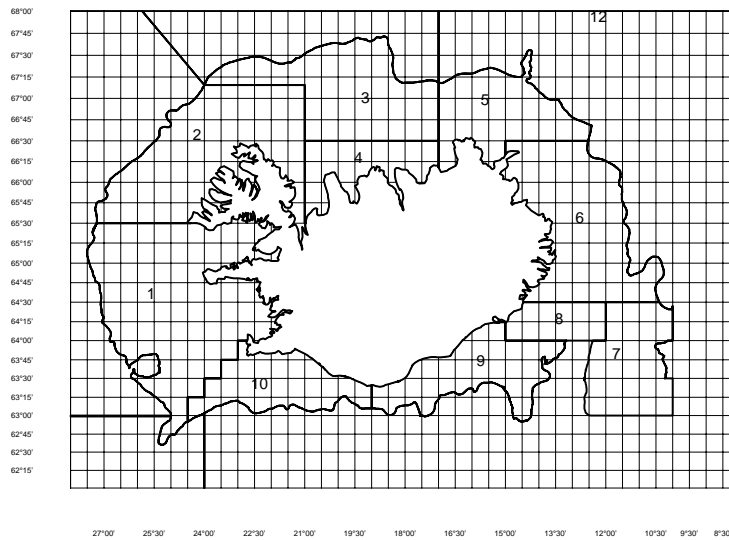


Figure 2.9.1: Statistical rectangles and subrectangles.

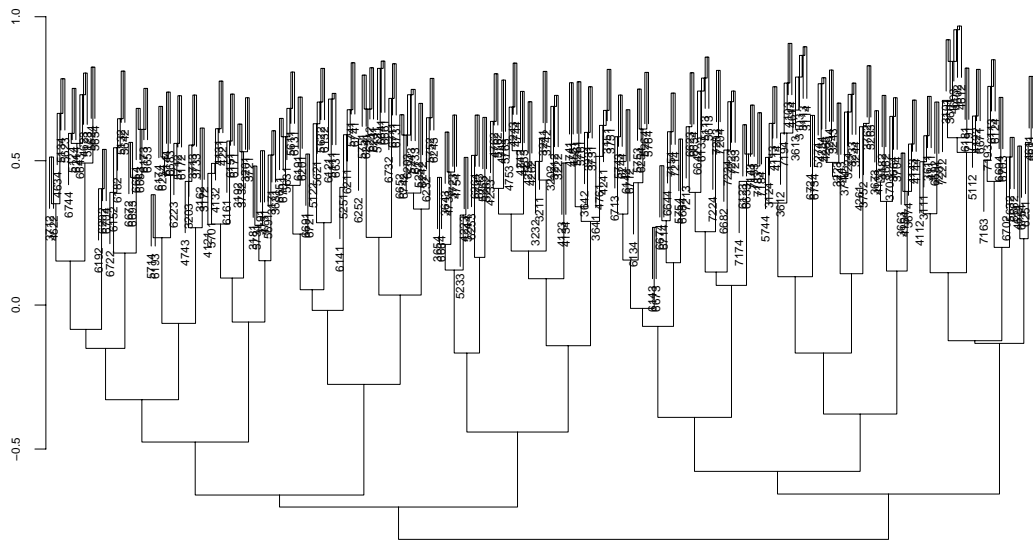


Figure 2.9.2: Dendrogram.

rity index computations result in the tree given in fig 2.9.2.

Grouping subrectangles by using the tree to define 10 regions results in the plot given in fig 2.9.3. Naturally, there is no constraint that the areas need to be continuous and therefore each one may be in several pieces.

These new strata are defined by their similarity and may therefore be called “similar” strata.

The same figure also gives the Bormicon strata. It is seen that there is indeed some consistency in how the similar strata relate to the Bormicon strata, but this relationship is in no way definite.

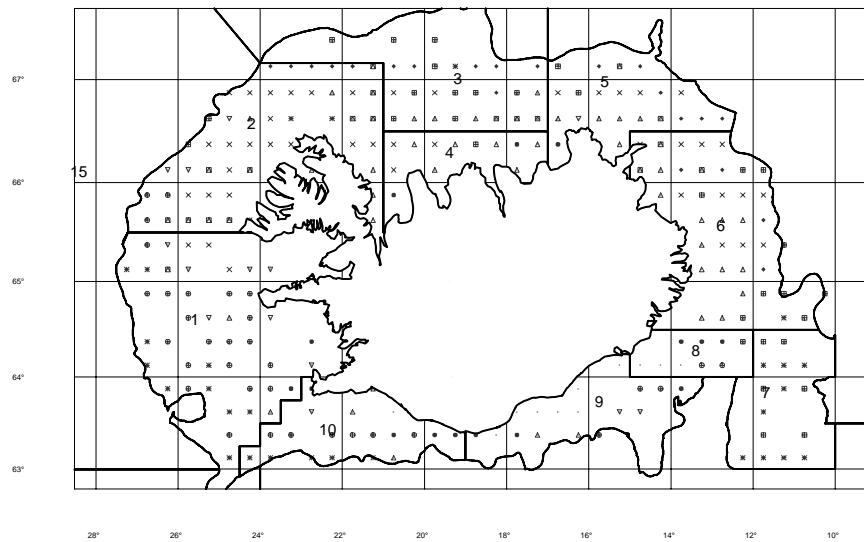


Figure 2.9.3: Areas from similarity index analysis.

2.10 Conclusions: Area definitions

The above considerations can now be combined into a single figure, where the ridges form a basic separation of the region and the 500m contour is used to define the extent of the cod. The offshore pandalrus distribution and fishery off the north coast along with the Greenland halibut migration and fishery off the north and east coasts and the redfish fishery off the west coast are defined to occur within two areas outside the 500m contour off the north coast. The Greenland halibut spawning area is a separate region which can be taken as the same as the region which contains the western part of the offshore Oceanic *S. mentella* fishery. The two stocks of nephrops require the split of the southern area into two subareas. The northern area is split into east-west subareas based on the pandalrus distribution and the hydrography of the region.

The resulting split is shown in figure 3.1.1 and it is seen from the previous section that this split is in reasonable accordance with analytical results based purely on survey data for the different species.

Since these areas are to be used for multispecies modelling in the Bormicon model as outlined in chapter 4, they will be referred to as the Bormicon strata.

Part II

The Model

Chapter 3

Mathematical model

Halldór Narfi Stefánsson

3.1 Introduction

This chapter describes Bormicon from a rather abstract point of view, with emphasis on its flexibility and constraints.

From that point of view, Bormicon is an area-based first stage Markovian simulation model since only the last status and read-in data are used in the calculations, not the entire history, and the calculations are done for several areas at once.

3.1.1 Division of time and area

In a simulation model like Bormicon it necessary to make certain uniformity assumptions regarding time, area and the stocks involved. The time intervals have to be small enough for the assumption of uniformity in behavior within each period to be valid, and likewise do the areas need to be small enough for the assumption that every population is evenly distributed within each of them and the environmental conditions to stay approximately the same on each time interval to be valid. Of course this may require a fine division of time and area, thus creating practical problems concerning efficiency and availability of input data.

In order to accommodate these needs and maintain flexibility, the division of the calendar year into smaller steps is not hard coded. Instead, information on the division of the calendar year into smaller time steps is read from file and they may, in particular, be of unequal length, say a fortnight in periods of rapid change and two months in the stable ones.

The definitions of the areas are as well not hard coded, their number, sizes and environmental conditions are all read from file.

3.1.2 Division of stock

For the purpose of modeling, each stock should be split into sub-stocks with the same dynamics and behavioral patterns, i.e. patterns of migration, food selection, growth etc. This may be acquired by dividing the population into a mature and an immature part, or even splitting the mature part into male and female. But since it is known that some species change e.g. their migration pattern as they grow older, further division may be needed than just by maturity and sex.

The Bormicon program accommodates these needs by focusing on the behavior of sub-stocks and allowing the population of one sub-stock to move to another. This can happen in two ways:

- Due to age. The oldest age group of one sub-stock can move to another sub-stock.
- Due to maturation. An algorithm is used to calculate the proportion of a sub-stock that moves to another sub-stock.

The stock abundance in numbers by age group is needed in order to acquire the year class strength. And to obtain reasonable length distributions, the abundance numbers are needed by length. Therefore, abundance numbers and mean weights are kept by age and length for each of the sub-stocks.

3.1.3 Entities in the model

Instead of having the stocks enter the model as entities of their own, sub-stocks are the main part of the model and have the dynamics later to be described. By introducing the movements between them explained above, one gains the equivalence of the concept of a stock.

Fleet is another group in the model. A fleet predate in the same way as the predating sub-stocks, it has its suitability for the preys and catches them.

“Other food” is another group of preys (in addition to the sub-stocks that are eaten). They have no dynamics, just a read-in amount on each area and each time step. This approach allows the predators to have a certain suitability for it, and allows more than one kind of “other food” to be included.

3.1.4 Discussion

It might have served our purposes in some instances to keep just the mean length of each age group, and the standard deviation in the length distribution, assuming it is normally distributed. That could significantly reduce the computations needed, but on the other hand, that would put further restrictions on the model, and it is not obvious how that might e.g. affect the growth of the species.

3.1.5 Example

Depending on behaviour, a stock might be split into sub-stocks as:

Immature \rightarrow Mature

or even:

3-6 years immature \rightarrow 5-6 years mature.

\downarrow

7-8 years immature \rightarrow 7-14 years mature.

If, in the former case, the sub-stocks existed on areas 1-3, the stock size and mean weights would be kept as in figure 3.1.1.

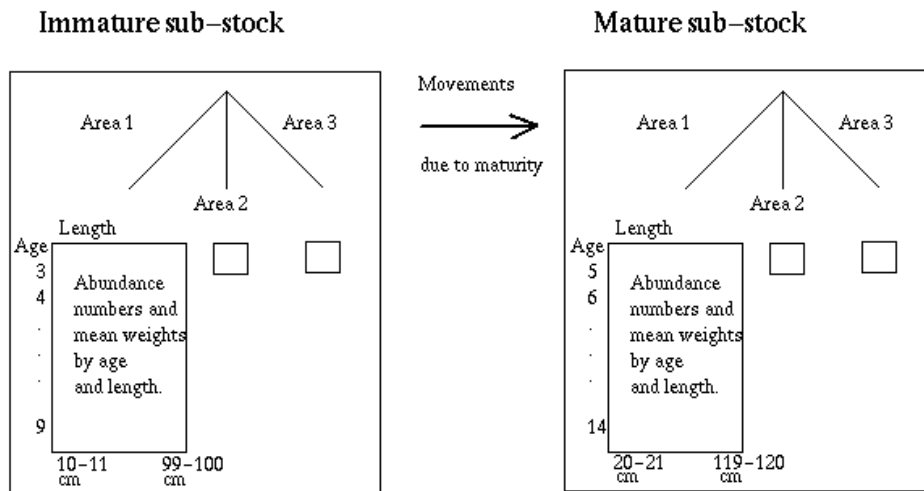


Figure 3.1.1: An example of the division of a stock into sub-stocks.

3.2 The simulation

In this section, the calculations done on each time step are explained briefly.

The simulation of a single time step consists of the steps shown in figure 3.2.1.

The calculations done separately for each area are shown in figure 3.2.2 where other update consist of the steps shown in figure 3.2.3

It is not necessary for all the sub-stocks to behave this way. The sub-stocks may or may not do the following:

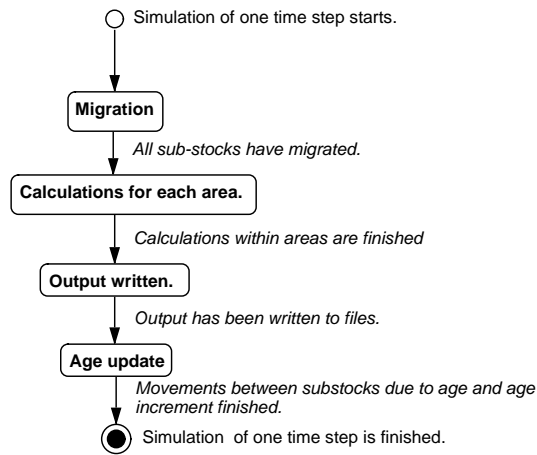


Figure 3.2.1: The simulation of one time step.

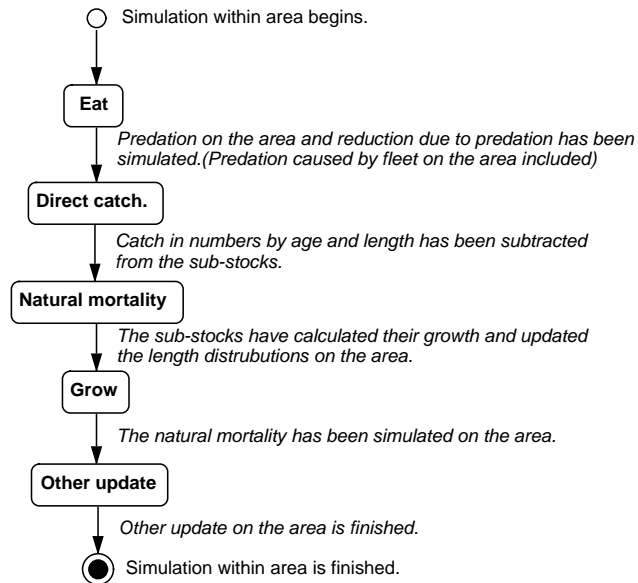


Figure 3.2.2: The simulation of one area on a single time step.

- migrate
- eat
- grow
- be eaten
- be caught
- become mature
- move to another sub-stock at maximum age

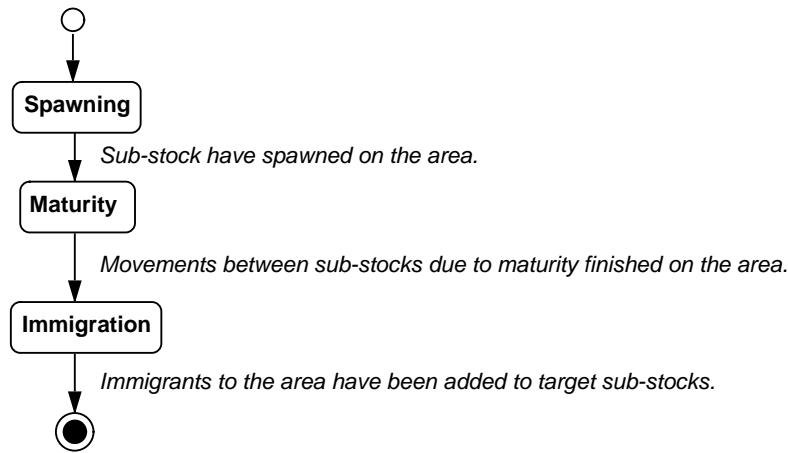


Figure 3.2.3: Other update on one area on a single time step.

- receive immigrants
- spawn

In the following lines, the restrictions put on the events in the flow diagrams above are explained and in the next part a further discussion follows, with examples of implementation.

3.2.1 Migration

The migration a sub-stock undertakes on a given time step is described with a matrix $A_t = (a_{ij})_{j=1, \dots, n}^{i=1, \dots, n}$, where a_{ij} is the proportion of the population of the sub-stock that moves from area j to area i and n is the number of areas. Hence, if $u = (u_1, \dots, u_n)$ are abundance numbers by area for an age-length group in the sub-stock, the area distribution after the migration has taken place, is $A_t u$.

3.2.2 Eating

The eating is assumed to be only dependent on the length of predator and prey, not their age. Eventually, the amount a predator eats on each area is calculated in biomass units, per length group of prey and its abundance numbers are reduced accordingly.

3.2.3 Growth

The growth of a sub-stock on a time step, which may depend on the eating of a predator on that time step, is given as two rectangular matrices for each area, $G = (g_{ij})_{j=1, \dots, m}^{i=1, \dots, l}$ and $W = (w_{ij})_{j=1, \dots, m}^{i=1, \dots, l}$ where l is the number of length groups of the sub-stock and $m \leq l$. Then g_{ij} is the proportion of the population in length group i

that moves up j length groups, w_{ij} its change in mean weight and m the maximum growth, measured in number of length groups.

3.2.4 Natural mortality

Natural mortality on each time step is currently given as one number for each age group of the sub-stock,

$$N_{a,t+1} = e^{-\Delta t M_a} N_{a,t},$$

where M_a is the natural mortality of the age group.

3.2.5 Maturity

The maturity is given as a proportion (p_{al}) of each age-length group of an (immature) sub-stock that becomes mature and moves therefore to the (mature) sub-stock(s) on the time step and area in question.

3.2.6 Age update

All the age groups are shifted upwards in age, except for the oldest. If it is to move to another sub-stock, it does so, else its age is unchanged and the age group next to is added to it.

3.2.7 Spawning

Spawning takes place on predefined areas and results in spawning mortality and weight loss.

3.2.8 Immigration and recruitment

Immigrants can be added to a sub-stock. This way, immigration from areas outside the scope of the simulation is accounted for and it is, furthermore, possible to keep recruitment outside the model by introducing the recruits as immigrants.

3.2.9 Discussion

The assumption that eating is only length dependent can be made less restrictive by dividing a stock in, say, two parts, young and old, and letting the sub-stock consisting of the young move to the sub-stock of the elder ones at its maximum age.

There are two instances where the Markovian property might seem a limitation of the model, in the growth and maturity and in the migration.

- One might want to connect the growth on consecutive time steps together to reduce the risk of too much or too little growth per year. However, this is mainly a problem if the length groups are too large, so a substantial proportion

of the population does not increase in length on each time step and the ones that increase their length of, say, one length group, should not do so on the next time step.

One might want to connect together maturity and growth, e.g. by letting the probability of maturity increase with weight increase in the previous months. However, only the weight and length increase on the last time step are available.

- Considering a hypothetical example of a stock that undertakes a long spawning migration southwards and returns northwards afterwards, the problem resulting from not keeping history becomes evident. If the populations going north and south cross, they cannot be distinguished because of the first stage Markovian property and some of the population going north is sent back south again, and vice versa. In this case, one would want to split the stock in two and keep the population going south separate from the postspawners.

3.3 Details of events

3.3.1 Migration

The migration is fully described by the migration matrices, but they have somehow to be created. This problem can become severe as the number of areas increases. Looking at the 10 bormicon areas on the continental shelf surrounding Iceland and considering only the possible movements between adjacent areas, there are possible 26 nonzero figures in a migration matrix. And if the size of the time step forces allowing movements over many areas, this number will increase. As is, the migration matrices are read in at the beginning, but another approach would be to parameterize them in some way, so they could also be more easily adjusted.

3.3.2 Eating

The main rule in the eating is that the predators may never eat more of a prey than exists of it on that area. Therefore, the predators' consumption of their preys is calculated and later adjusted to ensure that this condition is fulfilled. Due to the Markovian property, this can happen if the time steps are too large.

As mentioned before, the eating depends only on the length of the predator and the prey, not their age.

When the preys "know" that the consumption has been calculated, they subtract, for each length group, the number eaten from the age-length keys, the number taken from each age group being proportional to its abundance, relative to the total abundance in the length group in question.

In what follows, these variables will be used:

$prey$	a prey.
$pred$	a fixed predator.
l	a length group in $prey$.
L	a length group of the predator in question.
$S_{pred,prey}(l, L)$	the suitability of length group l in $prey$ as food for length group L of the predator.
$N_{prey}(l)$	the abundance number in length group l of $prey$.
$W_{prey}(l)$	the mean weight in length group l of $prey$.
$N_{pred}(L)$	the number in length group L of $pred$.
$W_{pred}(L)$	the mean weight in length group L of $pred$.

The stocks that eat calculate their consumption as follows:

Define

$$\phi_{pred}(l, L, prey) := S_{prey,pred}(l, L)N_{prey}(l)W_{prey}(l), \quad (3.3.1)$$

and

$$\psi_{pred}(L) := \frac{\sum_{l,prey} \phi_{pred}(l, L, prey)}{\sum_{l,prey} \phi_{pred}(l, L, prey) + AE_1}, \quad (3.3.2)$$

where E_1 is a constant and A is the size of the area in question. The amount length group L of $pred$ eats of length group l of $prey$ is then

$$N_{pred}(L)H_{pred}(W, L, T)\psi_{pred}(L)\frac{\phi_{pred}(l, L, prey)}{\sum_{l,prey} \phi_{pred}(l, L, prey)}, \quad (3.3.3)$$

where T is the temperature of the area and H is a function, called *maximum consumption*. The function ψ is called *feeding level*. (Taken from [4] notice though that there N is used for density, instead of absolute numbers as here.)

Note: Other food is included in the preys, although it does not have the full dynamics of a stock.

3.3.3 Growth

As described above, the growth calculations should result in the matrices $G = (g_{ij})_{j=1,\dots,m}^{i=1,\dots,l}$ and $W = (w_{ij})_{j=1,\dots,m}^{i=1,\dots,l}$, where g_{ij} is the proportion of the length group i whose growth is j length groups and w_{ij} is its change in mean weight. Since length cannot exceed the length in the maximum length group, the population whose growth should exceed it, is put in the maximum length group.

The growth is implemented as follows:

Declare the following variables:

N	abundance number
W	mean weight
l	length
ψ	feeding level
C	consumption
p	a vector of parameters for the growth function
T	temperature of the area in question
Δt	size of the time step

If the sub-stock does not eat, the feeding level is set to 0.

Given functions that calculate increase in length and change in mean weight, $l(N, W, p, \psi, C, T, \Delta t)$ and $w(N, W, p, \psi, C, T, \Delta t)$, the length increase and change in mean weight for each length group can be calculated. Let

$$\Delta l_i := l(N_i, W_i, l_i, p, \psi_i, C_i, T, \Delta t)$$

and

$$\Delta w_i := w(N_i, W_i, l_i, p, \psi_i, C_i, T, \Delta t)$$

be the length and mean weight change of length group i , respectively. Note that Δl_i is required to be ≥ 0 .

The growth may be calculated on a coarser scale than the sub-stock sizes are kept at, but must be interpolated to the same scale. Assume that has been done, and i is therefore the number of a length group of the sub-stock.

Let $G = (G_1, \dots, G_m)$ be a vector valued functions of length increase such that its values are of length m and $\sum_{i=1}^m G_i = 1$. Let then $G_j(\Delta l_i)$ be the proportion of length group i whose growth is j length groups, i.e.

$$g_{ij} := G_j(\Delta l_i). \quad (3.3.4)$$

Given the growth distribution of the length group, it has to be decided how the mean weight change is to be distributed. It is quite obvious that the constant distribution will not do.

Let a single length group be given, with mean length l , p_i be the proportion of the length group whose length is to increase of δl_i . Then the weight increase of the population corresponding to the length increase δl_i is

$$\delta w_i := pW \frac{\delta l_i}{l} + a,$$

where

$$a := \Delta w - pW \frac{\Delta l}{l}$$

and p is a constant.

This is justified by:

- Assuming that $W = \alpha l^p$, so that

$$\begin{aligned}\Delta w &\approx \frac{dw}{dt} \Delta t = p\alpha l^{p-1} \frac{dl}{dt} \Delta t \\ &= p\alpha l^p \frac{1}{l} \frac{dl}{dt} \\ &\approx pW \frac{\Delta l}{l}.\end{aligned}\tag{3.3.5}$$

- Calculating the factor a so that

$$\sum_j \delta w_j p_j = \Delta w,$$

because

$$\begin{aligned}\sum_j \delta w_j p_j &= \sum_j pW \frac{\delta l_j}{l} p_j + a \sum_j p_j \\ &= pW \frac{\Delta l_j}{l} + \Delta w - pW \frac{\Delta l_j}{l} \\ &= \Delta w,\end{aligned}\tag{3.3.6}$$

on the assumption that

$$\Delta l = \sum_j \delta l_j p_j,$$

i.e. that the function G above fulfills the condition that the average of the distributed growth equals the calculated mean growth.

After the length increase and mean weight change have been calculated, the update is straightforward.

3.3.4 Catch and Fleet

Catch can be implemented in three different ways. First, there is the possibility of direct subtraction. Then the program is supplied with catch in numbers of sub-stock, by age and length, per area and time step. As is, there is no guarantee that negative sub-stock sizes do not occur. That should be mended.

Then there are the two ways of implementing catch through the use of fleet. The total catch of the fleet and their suitability for the various sub-stocks is set, and then they work like the predating sub-stocks, calculate the amount eaten, inform their preys and adjust their eating. This way the catch comes at the same time as the feeding of the predators, neither before nor after.

If the fleet is set to catch a total amount $A_{t,a}$ on some area and time step, the amount caught at that time of length group l of a prey *prey* is

$$A_{t,a} \frac{\phi_{fleet}(l, prey)}{\sum_{prey,l} \phi_{fleet}(l, prey)}. \quad (3.3.7)$$

If the catch is set to be linear to the abundance numbers of the preys, the amount caught of length group l of the prey $prey$ on the area a and time step t is

$$cB_{t,a} \phi_{fleet}(l, prey), \quad (3.3.8)$$

where $B_{t,a}$ is preset and c is a constant.

Here $\phi_{fleet}(l, prey)$ is used identically to $\phi_{pred}(l, L, prey)$ in the section on eating.

Further details

In order to be able to use the same functions as for the sub-stocks when calculating the suitabilities the fleet have for their preys, each fleet has its “length”, as a predator, used only for writing

$$\phi_{fleet}(l, prey) := \phi(l, L_{fleet}, prey).$$

Note that L_{fleet} may depend on the fleet.

Notice that there is no natural action to take if

$$\sum_{prey,l} \phi(l, prey) = 0.$$

3.4 Specific functions currently implemented

All the functions specified in this section can easily be modified or new functions added.

3.4.1 Suitability functions

The suitability functions currently included are:

$$S_1(l, L) = \frac{1}{1 + e^{-\alpha - \beta l - \gamma L}}, \quad (3.4.1)$$

where α, β and γ are constants, the constant function

$$S_2(l, L) = \alpha,$$

where α is a constant, and

$$S_3(l, L) = \begin{cases} p_0 + p_2 e^{-\frac{(\ln \frac{L}{l} - p_1)^2}{p_3}} & \text{if } \ln \frac{L}{l} \leq p_1, \\ p_0 + p_2 e^{-\frac{(\ln \frac{L}{l} - p_1)^2}{p_4}} & \text{if } \ln \frac{L}{l} > p_1. \end{cases}$$

where p is a vector of parameters. This last function is discussed further in section 7.3 on page 88.

It is also possible to read the suitability of each length group of predator of each length group of prey from file.

3.4.2 Maximum consumption

Currently, only one function is available for calculating the maximum consumption. This is taken from [4] and adjusted as described in chapter 7:

$$H(W, L, T) = m_0 e^{m_1 T - m_2 T^3} L^{m_3}, \quad (3.4.2)$$

where m is a vector of parameters.

3.4.3 Growth functions

In this section, the variables N , W , l , ψ , C , T and Δt are used in the same way as in the section on growth, as are the vectors of parameters p and q .

The first set of growth functions is taken from [4]:

$$l_1(N, W, l, p, \psi, C, T, \Delta t) = \Delta t p_0 l^{p_1} \psi (p_2 T + p_3), \quad (3.4.3)$$

and

$$w_1(N, W, l, q, \psi, C, T, \Delta t) = \Delta t q_0 W^{q_1} (\psi - q_2)(q_3 T + q_4), \quad (3.4.4)$$

where p and q denote the vectors of parameters.

When little or no dynamics in the growth of a sub-stock can be simulated, e.g. because of lack of data on its diet, it may be necessary to read the growth from an external file. The second set of growth functions is of this kind, the length increase and mean weight change of each length group on each area and time step is read from file and the “functions” are thus completely determined by the data files.

The third set of growth functions is:

$$w_3(N, W, l, q, \psi, C, T, \Delta t) = \Delta t q_0 e^{q_1 T} \left(\left(\frac{W}{q_2} \right)^{q_4} - \left(\frac{W}{q_3} \right)^{q_5} \right), \quad (3.4.5)$$

and

$$l_3(N, W, l, p, \psi, C, T, \Delta t) = \begin{cases} \frac{\Delta W}{p_6 p_7 l^{p_7 - 1}} f(r(l)) & \text{if } \Delta W > 0, \\ 0 & \text{if } \Delta W < 0, \end{cases} \quad (3.4.6)$$

where the functions r and f are defined with

$$f(x) := \begin{cases} 0 & \text{if } p_3 + p_4x \leq 0, \\ p_5 & \text{if } p_3 + p_4x \geq p_5, \\ p_3 + p_4x & \text{else,} \end{cases} \quad (3.4.7)$$

and

$$r(l) := \frac{W - W_{ref}(l)g(p_8)}{W}, \quad (3.4.8)$$

where W_{ref} is the reference weight for length l and the function g is defined with:

$$g(x) := p_0 + x(p_1 + p_2x). \quad (3.4.9)$$

This set of equations is described further in chapter 7.

The fourth set is:

$$w_4(N, W, l, q, \psi, C, T, \Delta t) = \Delta t \left[\frac{C}{q_0 w^{q_1}} - q_2 w^{q_3} e^{q_4 T + q_5} \right] \quad (3.4.10)$$

and the length update is carried out in the same way as in the third set of growth functions, i.e. by equations (3.4.6)-(3.4.9), but with the feeding level ψ instead of the parameter p_8 .

The fifth set is:

$$w_5(N, W, l, q, \psi, C, T, \Delta t) = \Delta t M q_0 e^{q_1 T} \left(\left(\frac{W}{q_2} \right)^{q_4} - \left(\frac{W}{q_3} \right)^{q_5} \right), \quad (3.4.11)$$

where $M = y_{year} s_{step} a_{area}$, is a multiplication constant, possibly different for each year, step and area. The length update is carried out in exactly the same way as in the third set of growth functions, i.e. by equations (3.4.6)-(3.4.9).

3.4.4 Maturity functions.

Currently there are two functions to calculate the proportion of an age-length group of an immature sub-stock that moves to an mature sub-stock.

$$P_1(a, l) = \frac{1}{1 - M} \frac{dM}{dt}, \quad (3.4.12)$$

where M is the maturity ogive and is taken to be:

$$M(l(t), a(t)) = \frac{1}{1 + e^{-\alpha - \beta l(t) - \gamma a(t)}},$$

so

$$\frac{1}{1-M} \frac{dM}{dt} = \left(\beta \frac{dl}{dt} + \gamma \frac{da}{dt} \right) M,$$

where $l(t)$ is the length at time t and $a(t)$ the age at time t , the age being regarded as a continuous variable.

This is a gradual process, done on every time step.

The second function is more likely to be used for annual (or stepwise) maturity. Given a list of time steps, s_1, \dots, s_n , and a list of lengths, l_1, \dots, l_n ,

$$P_2(a, l) = \begin{cases} 1 & \text{if there is an } i \text{ such that } s_i \text{ is the current step and } l > l_i, \\ 0 & \text{else.} \end{cases} \quad (3.4.13)$$

3.5 The method of maximum likelihood

3.5.1 The likelihood function

In order to estimate the values of various variables used in the simulation, the method of maximum likelihood is used.

Let x_1, \dots, x_n be the variables whose values are to be found by estimation and $S(x_1, \dots, x_n)$ denote the result of the simulation. If there exists some kind of an assessment of the ‘‘correctness’’ of the outcome of the simulation, $L(S)$, the objective becomes to find those values of x_1, \dots, x_n that maximize $L(S(x_1, \dots, x_n))$.

A detailed description of the likelihood functions currently implemented in Bor-micon will be given in chapter 4.

3.5.2 The connection between variables

In the program, each of the variables in the optimization (the x_i -s above), corresponds to one or more variable in the simulation. This allows for enforcing equality constraints between unrelated variables. A practical usage of this might be e.g. to let the sub-stocks corresponding to a mature and immature part of a stock have the same feeding level half value.

3.6 Measures taken to reduce calculations

3.6.1 Length group divisions and storage of age-length keys

The length group divisions of the sub-stocks are read at the beginning of the simulation. They should be divided into length groups of equal lengths, though not necessarily the same length for all the sub-stocks.

Some boundaries may be known on the possible minimum and maximum length of each age group, allowing the age-length keys to be kept as a bandmatrix, instead of a full matrix. This reduces unnecessary calculations with zeroes. If 3-8 years old

Icelandic cod is taken as an example, with the minimum length 20 cm, maximum length 110 cm and 1cm range, there is a total of $6 * (110 - 20) = 540$ cells in a full matrix of the age-length keys. However, with reasonable boundaries this may be reduced down to $(70-20)+(80-30)+(100-35)+(105-40)+(110-50)+(110-60) = 340$ cells.

3.6.2 Defined in areas

The sub-stocks need not exist in all the areas used in the simulation. Some may exist on, say, area 1 and 2, some on 2 and 3, and other on areas 1, 2 and 3. This becomes important as the number of areas and species increases.

3.6.3 Predation and growth

Since it was believed that division into fine length groups was needed for keeping stock abundance numbers, some method had to be employed to reduce the calculations for the predation as each length group of predator eats each length group of prey. Therefore the time needed increases greatly as the number of length groups in predator and prey is increased. Hence, every sub-stock has a special coarse length group division that is used when eating and growing and another coarse division that is used when acting as a prey. It was only for simplification that the same length group division was required for eating and growing, as the feeding level may be used when calculating the growth.

Since the growth is originally calculated on a coarse scale, it is interpolated to the fine length group division of the sub-stock before proceeding further.

When a sub-stock is a prey, it has a coarse length group division as such. It may well be unnecessary to let the length group division used as a prey be different from the one used in eating and growing.

3.6.4 Precalculations

In order to reduce recalculations, many values are precalculated and stored at the start of the run of the program. They are:

Conversion between length group divisions

The mappings from one length group division to another is always precalculated. This is used when moving from an immature sub-stock to a mature sub-stock, when converting between the equal-spacing length group division of the sub-stocks and the length group division used when eating, etc.

Suitability

The suitability is precalculated and kept in appropriate data structures.

Natural Mortality

The values $e^{-\Delta t M_a}$ are precalculated.

Maturation

In the gradual maturity, the maturity ogive, $M(l, a)$, is precalculated.

Interpolation

Before interpolating from a coarse length group division to a finer one, coefficients are precalculated. This is done at the same time as the conversion mapping between the divisions is precalculated.

The interpolation is linear, and constant outside the region of definition. The interpolation points are (c_i, y_i) , where c_i is the center point of length group i in the coarser division and y_i is the value of the function to be interpolated. The precalculation consists of finding, for each of the finer length groups, a coefficient r such that the value of the interpolated function at the center of the length group is $ry_i + (1 - r)y_{i+1}$, where i and $i + 1$ are the numbers of the coarse length groups whose centers are nearest to the center of the finer one in question.

Migration matrices

Since the same migration matrix may be used on many time steps, they are adjusted at the beginning of the run by scaling the columns to sum to unity.

Chapter 4

Likelihood Functions

4.1 Introduction

One of the main aims of the BORMICON model is to estimate values of selected unknown parameters. The likelihood function serves as a general measure of how well a model with a given set of parameters fits data and parameter estimation is therefore undertaken by maximizing the likelihood function over values of the unknown parameters.

The form of the likelihood function for a particular model and data set will vary depending on the nature of the data. Since fisheries data come from various sources, a large number of different likelihood functions have been implemented in Bormicon. When such different data sources are combined in one analysis, the likelihood function becomes a product of the likelihood function for each subset. The individual pieces will be referred to as likelihood components.

As is common practice, maximum likelihood estimation of parameters is implemented in Bormicon through minimising the negative log likelihood. The negative log likelihood will be referred to as the objective function. Thus, the objective function serves as a measure of the discrepancy between the output of the model and measurements.

This chapter gives a description of the likelihood functions currently implemented in Bormicon.

Typically, several components enter the objective function in any single estimation. Thus the objective function becomes a weighted sum of several components:

$$l = \sum_i w_i \ell_i$$

The weights are necessary for several reasons. Notably, they can be used to prevent some components from dominating the likelihood function, to reduce the effect of low quality data and as a priori estimates of the variance in each subset of data.

4.1.1 Aggregation

In the model each species is typically split into mature and immature part (or even more substocks). Each substock is then disaggregated by age, length and region. Measurements that available to this level of disaggregation are quite rare. Commonly available measurements include:

- Length distribution alone is measured.
- Length and age are measured but maturity stage classification not available.
- Only catch biomass per unit effort is available.

In order to compare model values to such measurements the modelled values need to be aggregated to the same level.

4.1.2 Likelihood components

The following likelihood components are included in the model:

Survey Indices Compare the development of certain stock components to survey indices. Section 4.2.

Predator indices Compare the development of the consumption of some predators (fleets) on some preys to measurements. Section 4.3.

Catch Statistics Compare the mean length, mean weight or other statistics of the catch of substocks to measurements. Section 4.4.

Catch Distribution Compare age and/or length distribution of the catch of substocks to measurements. Section 4.5.

Stock Distribution Compare proportions of different substocks to measurements (% mature). Section 4.6.

Understocking Compare the catch to the biomass in a region. If the catch is greater than the biomass the difference is used in the likelihood function. . . Section 4.7

Stomach Content Compare the calculated consumption proportions in stomach or length distribution in stomachs to stomach content data. Section 4.8.

Mark-Recapture Compare the number of recaptures from a tagging experiment to the output from the model. Section 4.9.

4.1.3 Naming conventions

In this chapter the following naming conventions will be used. The classification variables will be used as indices when relevant.

- r A region or aggregation of regions.
- s A substock or aggregation of substocks. Each species is often divided into a number of substocks, such as immature, mature etc.
- f Fleet.
- t Time or time step.
- a An age or age groups.
- l A length group or aggregation of length groups.
- \bar{l} Mean length in biological samples.
- W Mean weight (usually in kg)
- C Catch or consumption.
- n Number of groups; thus, n_a denotes the number of age groups.
- N Number of fish in a substock or a sample.
- I A survey index.
- ℓ Log-likelihood.
- p Proportions in biological samples.
- π Proportions in model population.
- w Weights for components of the likelihood function.
- σ Standard deviation in population (model).
- S Standard deviation in samples.

When dealing both with measured quantities and quantities from the model, a hat over a symbol identifies a quantity as estimated with the model. For example, C_{al} denotes the measured catch in numbers of fish of age a in length group l but \hat{C}_{al} the corresponding quantity from the model.

4.2 Survey Indices

The likelihood component for survey indices are used to compare the development of a substock to indices from standardized survey. Examples of surveys where it can be used are standardized bottom trawl surveys and acoustic measurements. The surveys can take place in the same month every year as is common practice with ground fish surveys or alternatively on a less regular basis.

There are 2 types of survey index likelihood components in the model.

- Survey indices using the abundance in numbers by age groups.
- Survey indices using abundance in numbers by length groups.

In each case the model can provide a timeseries using the specified aggregation. The calculated objective function for a series of survey indices can optionally be calculated by either of two equations.

$$\ell := \sum_t \{\log I_t - (\alpha + \beta \log N_t)\}^2 \quad (4.2.1)$$

$$\ell := \sum_t \frac{\{I_t - (\alpha + \beta N_t^\gamma)\}^2}{\sigma_t^2} \quad (4.2.2)$$

The coefficients α and β in 4.2.1 can be estimated in a number of different ways. The approach taken depends on the nature of the measurements:

- The coefficients are found by linear regression of $\log I_t$ vs. $\log N_t$.
- β is specified and α found by constrained linear regression of $\log I_t$ vs. $\log N_t$ (i.e. as the average difference). The most common value of β is 1 corresponding to linear relationship between I_t and N_t .
- Both α and β are specified and thus fixed. Typically this applies when a measurement is considered to represent the absolute number of individuals in a stock (as is often assumed with acoustic measurements) α should be set to 0 and β to 1.

It should be noted that the resulting estimates of the coefficients are simply the analytical solutions to the maximum likelihood estimation procedure. Thus, there is no need to include the slope and the intercept in the regressions as unknown parameters, since the optimum values of those is known, conditionally on all other values in the model and conditionally on the form chosen for the regression.

In the case of equation 4.2.2 there are more combinations available:

- All 3 coefficients estimated.
- $\alpha = 0$. In this case the form of the equation is the same as in 4.2.1, but the resulting estimates may be quite different as the fit is done on the original scale and the variance function is different
- $\gamma = 1$. A straight line of the form $I_t = \alpha + \beta N_t$ is fitted to the data.
- $\gamma = 1$ and $\alpha = 0$. A straight line with zero intercept fitted to data.
- $\gamma = 1$, $\alpha = 0$ and $\beta = 1$. The index is an absolute measurement of the stock(s).

When equation 4.2.2 is used there are also some possible variations on the definition of the variance:

- σ_t^2 is read from file. In many cases calculation of survey indices are accompanied by an estimate of their variance. In those cases the estimated variance of the survey index is used for σ_t^2 .

- $\sigma_t^2 = a + N_t^b$

Typically b will be taken as 2. When $b = 2$ is used along with $a = 0$ it is possible that individual low survey abundance values (zero or near-zero) may become influential, as may happen in ordinary log-log regressions. Naturally, in reality a value of $N_t = 0$ necessitates $I_t = 0$ but not conversely and hence the influence of near-zero values may not be desirable.

4.3 Abundance indices from commercial fleets and fish predators

Since Bormicon does not need to distinguish functionally between fish predators and a fishing fleet, the handling of catch per unit of effort (CPUE) indices from a fleet is exactly as if these data came from a predator's stomach.

An appropriate objective function for comparing CPUE data from a fleet to results from the model is through the use of a linear regression with variations as described above for survey indices. The same method can be used to compare in general the modelled and observed consumption in numbers or biomass by any predator on any prey.

In addition to comparing CPUE data from fleets to output from model it is possible to use this approach to:

- Compare stomach content or consumption calculated from stomach content data to consumption according to model. The consumption is then used as index in the model assuming linear relationship between consumption calculated from stomach content data and consumption according to the model.
- Compare the biomass of a (sub-)stock to corresponding acoustic measurements. Here the "selection pattern" of the "fleet" is a model of the TS values as function of length.

4.4 Biological samples from the catches: Summaries by age group

Biological sampling of catches typically yield data on the age, length and maturity in the catches. Within the model a number of statistics relevant to such catch information can be computed. The following describes statistics pertinent to measures which are classified by age group. Typically these are also disaggregated by region and year.

Statistics commonly calculate from biological data include mean length at age, the standard deviation of length within age group and mean weight at age. The corresponding objective functions can be calculated in the following manner:

$$\begin{aligned}\ell_1 &= \sum_{t,r,a} \frac{(\bar{l}_{tra} - \hat{l}_{tra})^2}{\sigma_{tra}^2} N_{tra}, \\ \ell_2 &= \sum_{t,r,a} \frac{(\bar{l}_{tra} - \hat{l}_{tra})^2}{S_{tra}^2} N_{tra}, \\ \ell_3 &= \sum_{t,r,a} \frac{(W_{tra} - \hat{W}_{tra})^2}{S_{tra}^2} N_{tra}, \\ \ell_4 &= \sum_{t,r,a} (W_{tra} - \hat{W}_{tra})^2 N_{tra}.\end{aligned}$$

Although not included in this list, a useful addition would be to compare S_{tra} to σ_{tra} through the use of a chi-square distribution.

4.5 Biological samples from the catches: Summaries by length group

Even for fish stocks where ageing is difficult or impossible, it is possible to obtain length distributions of catches. When ageing is also possible, one can obtain the frequency of fish in each age-length category as well as proportions at age and the distribution of ages in a fixed length group.

Within the model, the catch of each substock(s) by fleet(s) in a region or combination of regions can be aggregated into a number (n_l) of length groups, and a number (n_a) of agegroups.

Suppose first that there is only one age group, so that all the data is collapsed into a single length distribution.

The proportions for each length-cell are then calculated:

$$\pi_l = \frac{\hat{N}_l}{\sum_{i=1}^{n_l} \hat{N}_i}.$$

The corresponding objective function is based on the likelihood function from the multinomial distribution so that:

$$\ell = \sum_{t,r} \left(\log N_{tr}! - \sum_{l=1}^{n_l} \log N_{trl}! + \sum_{l=1}^{n_l} N_{trl} \log \pi_{trl} \right),$$

On the other hand if there are several age groups, then the age-length information can be used to obtain an age-length key (ALK), i.e. provide information on the distribution of ages at a given length:

$$\pi_{al} = \frac{\hat{N}_{al}}{\sum_{j=1}^{n_a} \hat{N}_{jl}},$$

i.e. provide the conditional probabilities of ages at length (sometimes denoted $\pi(a|l)$).

The corresponding objective function is based on the likelihood function from the multinomial distribution so that:

$$\ell = \sum_{t,r,a} \left(\log N_{tra}! - \sum_{l=1}^{n_l} \log N_{tral}! + \sum_{l=1}^{n_l} N_{tral} \log \pi_{tral} \right).$$

In some cases there may be measurements in a cell where there is no fish according to the model. The probability of this outcome is 0 so this should never happen if the model is correct. When applying the model this can occur under a number of circumstances. Notably, when parameters are being estimated individual values being tested can be outside the range of feasible parameters, ageing errors occur etc.

To take care of such practical problems, the above equations can be modified with a specified minimum probability p_{min} where probabilities less than this minimum probability are set to p_{min} .

4.6 Stock distribution

Stock distribution is used to find the proportion of different stock components in the catch of fleet(s). Typical use is to compare percent mature disaggregated by region and age (or length) group to measurements. With capelin the ratio of sexes in the spawning stock could also be compared to measurements. Age, length group, and region aggregation is specified as when using catch distribution.

The calculations at each step proceed as follows:

1. Each substock is aggregated as specified.
2. The proportion of each stockcomponent (or aggregation of stockcomponents) is calculated by.

$$\pi_{sal} = N_{sal} / \sum_{s=1}^{n_s} N_{sal}$$

The log-likelihood for the stock distribution class is calculated by:

$$\ell = \sum_{t,r,l} \left(\log N_{tral}! - \sum_s \log N_{trals}! + \sum_s N_{trals} \log \pi_{trals} \right).$$

In addition, as with the age-length distribution of catch, this formula can be augmented with a minimum probability so that if the calculated $p_{sal} < p_{min}$ and $N_{sal} > 0$ then $p_{sal} = p_{min}$.

4.7 Understocking

This compares the catch by fleet(s) of stock(s) in a region to the biomass of the stock(s) in that region. In typical use of the Bormicon model the total catch of

stock(s) in a region is read from a data file. It happens regularly in simulations that there is not enough of a stock in a region to cover the catch. This can be due to an incorrect migration pattern, too little growth or other wrong assumptions in the model. When this happens, simulations proceed and the “fleet” simply catches all that is available in the region. In parameter estimation a “penalty” needs to be given when this happens. The penalty is calculated by:

$$\ell = \sum_{tr} (C_{trf} - \hat{C}_{trf})^b,$$

where only terms with $C_{trf} > \hat{C}_{trf}$ are included in the sum.

In most simulations to date the value of b has been 2 which is the default value in the model.

One question that pops up if a substock should be allowed to be completely depleted or some specified fraction left. Minimum fraction left can be specified in the model. Most often that fraction has been 0% but other values have been tested.

4.8 Stomach content

A predator’s consumption is calculated by equations (3.3.1)-(3.3.3). Many of the parameters in these equations have to be estimated. Some of the dynamics that can help in this estimation are:

- Growth of the predator – applies if the prey is a major part of the diet of the predator.
- Biomass or number of the prey (if it has been measured) – applies if the consumption by the predator accounts for a large part of the mortality of the prey.

In most cases the abundance or biomass of the prey stocks is not well known. In the case of exploited stocks like capelin and shrimp indices are available. Estimates of absolute stocksize are available for the catchable part of these stocks. These estimates can change by use of a predation model involving major predator like cod. Recruitment indices are available for capelin and shrimp but little information is available on absolute abundance (not even order of magnitude).

The best way to estimate consumption parameters is through analysis of stomach samples. Stomach samples can give information on predation in cases where other data fail:

- Where little is known about the stock size of the prey.
- The prey is not a major part of the diet of the predator.

If consumption by a predator accounts for a large part of the mortality of the prey the stomach samples give ideas about the abundance of the prey. There are though some major problems in the use of stomach samples:

- Interaction between catchability of gear and stomach content. Sampling is typically done with demersal trawl. Part of the stock might be pelagic at the time of sampling and not be feeding on the same preys as the part near the bottom.
- Stomach evacuation rates based on experiments give nonlinear relationship between evacuation rate (consumption) and stomach content [23],

$$D = a_0 1.09^{T-6} L_{\text{pred}}^{1.15} \sqrt{Q}, \quad (4.8.1)$$

where D is the amount evacuated per unit-time, T temperature and Q the stomach content. The evacuation rate model must be applied to each individual stomach.

- Evacuation rate of preys is species dependent [12]. The fat content also affects the evacuation rate of a prey; higher fat percentage means slower evacuation. Some species (capelin) show large seasonal oscillations in fat content.
- Evacuation rate of a prey is size dependent, smaller prey disappearing faster. If the digestion is thought to occur from the surface then the following equations apply,

$$D = \alpha_0 l^2, \quad (4.8.2)$$

$$W_{\text{prey}} = \alpha_1 l^3. \quad (4.8.3)$$

These equations combined give

$$T_d = \frac{3\alpha_1 L}{\alpha_0} \quad (4.8.4)$$

Here T_d is the time it takes for the prey to be digested (disappear).

Equations (4.8.3) and (4.8.4) indicate that smaller prey is underestimated in stomach samples.

4.8.1 The likelihood functions

Currently there are 3 likelihood functions in Bormicon to handle stomach content data. In addition predator indices can be suitable to handle stomach content data.

Using mass proportions of a prey in the diet of the predator

Proportion of a prey of length l in the stomach samples from predators of length L is calculated and compared to the same proportion in the model π_{preyLl} .

As indicated by the nonlinear relationship between consumption and stomach content (equation (4.8.1)) the proportion of a prey in the total stomach content in a region can be different from the proportion of the prey in the diet.

The problem of different digestion rate of preys and prey lengthgroups is treated in the model by digestion coefficients,

$$\pi_{prey,L,l} = \frac{d_{prey,l}C_{prey,L,l}}{\sum_{prey,l} d_{prey,l}C_{prey,L,l}} \quad (4.8.5)$$

$$d_{prey,l} = \alpha + \beta l^\gamma \quad (4.8.6)$$

where Q is the stomach content and d the evacuation rate coefficient.

α , β and γ are coefficients given by the user of the model. In principle they can be estimated. According to 4.8.4 $\alpha = 0$, $\beta = 1$ and $\gamma = 1$ should be used.

The log-likelihood is ,

$$\ell_1 = \sum_L N_L \sum_{prey,l} \frac{(p_{prey,L,l} - \pi_{prey,L,l})^2}{S_{prey,L,l}^2}. \quad (4.8.7)$$

Comparing calculated consumption to consumption calculated from stomach content data

Weighted sum of squares between the calculated consumption from the model and the calculated consumption from stomach samples.

The log-likelihood is

$$\ell_2 = \sum_L N_L \sum_{prey} \sum_l \frac{(C_{prey,L,l} - d_{prey,L,l} \hat{C}_{prey,L,l})^2}{S_{prey,L,l}^2}.$$

A number of attempts have been made to calculate consumption from stomach samples [14, 3]. The calculated consumption can also be used to calculate proportions for equation (4.8.7). In many cases using predator indices may be a better choice than using this likelihood function.

Using proportions in number of a prey or preys in stomach data

Proportions in numbers of a lengthgroup of a prey are compared to stomach content data.

The log-likelihood function is

$$\ell = \sum_{t,r} \left(\log N_{t,r}! - \sum \log N_{t,r,prey,l}! + \sum_{prey,l} (N_{t,r,prey,l} \log \pi_{t,r,prey,l}) \right) \quad (4.8.8)$$

The ratios $\pi_{t,r,prey,l}$ are calculated from equation 4.8.5

Typical use of 4.8.8 is to compare length distributions in stomach samples to measurement.

4.8.2 The aggregation

The aggregation used is as follows:

- Regions to aggregate over; most often only one region.
- Predators to aggregate over. Sometimes the maturity of the predator is not recorded when taking stomach samples. Then two stocks have to be specified here, mature and immature.
- Predator's length group division.
- List of preys. This is a table where preys in the same line are combined as is necessary when mature and immature part are separate substocks in the model but maturity is not recorded in the stomach samples.
- Length group division of the preys, one for each prey. When preys are combined, the same length group division is used for them all.
- Digestion coefficients of the preys, one for each lengthgroup of every prey and one common. When preys are combined only one set of coefficients is given for each combination.

4.8.3 Further work

The current treatment of stomach samples in the Bormicon model is considered preliminary. The goal is to include a model that transforms consumption into stomach content that can be compared directly to stomach content data. This kind of model will possibly become complicated involving some parameters that are not well known, for example:

- Distribution of time between meals.
- Distribution of meal size.

Work on this problem has been done by [17] assuming the meal size to follow negative binomial distribution and time between meals to follow the Poisson distribution. [12] has looked at evacuation of meals when the stomach does not empty between meals.

Many of the consumption characteristics are also region dependent. Near Iceland the cod-capelin interaction is often in a narrow area near the edge of continental shelves while fish closer to the coast does not eat capelin at all [14].

4.9 Mark-recapture data

In Bormicon, markings are introduced as separate substocks that migrate and grow as any other substocks. The initial values are zero but the number marked is introduced as recruitment.

At time t there are \hat{N}_{tr} fishes from a marking experiment in region r . The fraction caught is p_{tr} . The number recaptured is N_{tr} . The log-likelihood function is just a binomial model,

$$\begin{aligned} \ell = \sum_{tr} & \left(\log \hat{N}_{tr}! - \log N_{tr}! - \log(\hat{N}_{tr} - N_{tr})! \right. \\ & \left. + N_{tr} \log p_{tr} + (\hat{N}_{tr} - N_{tr}) \log(1 - p_{tr}) \right). \end{aligned}$$

It can happen that the number of recaptures in a region is larger than the number of fish that should be there according to the model. Two possible reasons for those events are:

- Migration model is not correct.
- Fish that are marked together tend to stay together. Sometimes more than one fish from a marking experiment comes in the same haul which should be very improbable if not for this group behaviour.

To account for this ℓ_{max} is specified. If the calculated value of ℓ is larger than ℓ_{max} , ℓ is set equal to ℓ_{max} .

If the number of marking experiments is large the program soon becomes very heavy. One way to reduce computation time is to let marking substocks only have one age and length group. The only dynamics then are migration and mortality. Fishing effort must then be introduced as fishing mortality, not by giving the catch in a region as usually done in the model. Specified fishing mortality is introduced in the model as *linear fleet* where the effort is specified for every region and timestep. (The catch of linear fleet is proportional to abundance of the prey stocks). Combining all marking experiments in the same month and region can also be a way to reduce computation.

One of the problems with using marking experiments is that the total effort is generally not known disaggregated by regions and time. One way to account for this problem is to let the fleet follow the fish and use an equation of the form,

$$E \propto B^k, \tag{4.9.1}$$

where B is the biomass of the substock in the region and E the effort in the region at time t . Letting k equal to one in (4.9.1) gives

$$C \propto B^2.$$

Many other things than the amount of fish can affect the effort in an area, like

- distance to harbours,
- type of bottom,
- patchiness of the distribution in the area.

Part III

Cod

Chapter 5

Selection patterns in the cod fishery

Gardar Jóhannesson, Gunnar Stefánsson, Kjartan Magnússon and Höskuldur Björnsson

5.1 Summary

Several different methods for computing selection patterns in the cod fishery are compared and a method is chosen for use within Bormicon.

5.2 Relationship between suitability and selection

The usual cohort and VPA equations ([30]) include a fishing mortality which is often written as a product of an overall fishing mortality and a selection pattern. A fleet is usually assumed to harvest a fish stock according to these catch equations. In a multispecies/multifleet model such as Bormicon, however, it is of some interest to replace the fleet behaviour equations by corresponding predator equations since this will allow the fleet to enter as a regular predator in the system. For this reason it is of some interest to consider the relationship between the catch equation and the equations describing the consumption by a predator.

Let C_t^w be the total catch of the fleet and C_i^w be the catch of the particular “prey” group in terms of weight. If the fleet is treated as a predator with suitabilities S_j for the various “prey” groups, then the equation giving the catch of group i is

$$C_i^w = \frac{W_i N_i S_i}{\sum_j W_j N_j S_j} C_t^w$$

and hence

$$\frac{C_i^w}{C_t^w} = \frac{W_i N_i S_i}{\sum_j W_j N_j S_j}. \quad (5.2.1)$$

On the other hand the same catch is given in terms of the selection pattern (s_i) and the effort (f) by

$$C_i^w = s_i f N_i W_i.$$

Then

$$C_t^w = \sum_j C_j^w = \sum_j s_j f N_j W_j,$$

which gives

$$\frac{C_i^w}{C_t^w} = \frac{f s_i W_i N_i}{\sum_j f s_j W_j N_j}. \quad (5.2.2)$$

Note that the total catch is assumed to be fixed analogous to a fixed ration size. Equating the two expressions for C_i^w/C_t^w , (5.2.1) and (5.2.2), gives

$$\frac{s_i}{\sum_j s_j N_j W_j} = \frac{S_i}{\sum_j S_j N_j W_j}$$

from which it follows that

$$s_i = a S_i \quad \text{for all } i.$$

where the proportionality constant a is independent of i . The selection pattern and suitabilities for a fixed predator or fleet are therefore proportional.

It turns out that this relationship is a simple proportional one. A particular consequence of this is that if fishing fleets are treated as predators in the model, then initial values for their suitability can be obtained simply by scaling their selection patterns as obtained e.g. from single-species multi-fleet VPA analyses.

5.3 Survey data

Groundfish surveys can provide catches in numbers at length. If the groundfish survey is assumed to catch a constant proportion of each length group, then the indices at length can be assumed to be proportional to the abundance at length. If the fleet operates in such a fashion that the selectivity is constant after a certain age, then the catch equation would indicate that the ratio of catch to survey numbers at length should be fixed after a certain length. Further assuming that the fish are fully selected to the survey at a length shorter than to the commercial fleet, then the commercial selection pattern will be reflected in the ration of catch to survey numbers at length.

5.4 Single species assessment data - single fleet

Regular single species assessments such as those given in [34], give fishing mortalities at age.

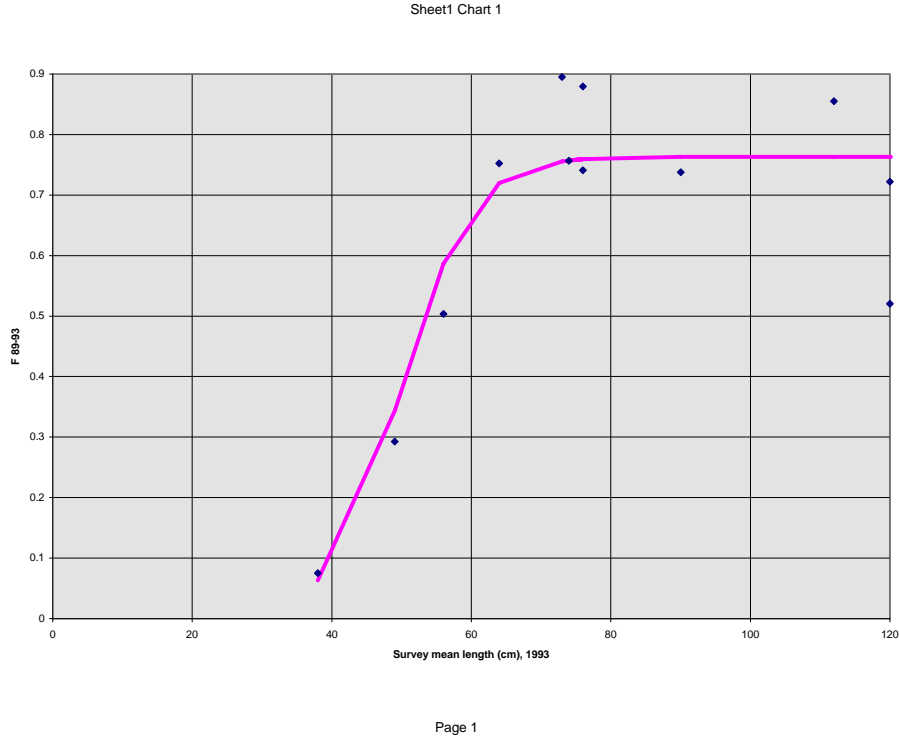


Figure 5.4.1: Selection pattern at length.

Combining mean length at age from groundfish surveys, with total fishing mortality at age produces figure 5.4.1. Here the total fishing mortality has been averaged over the years 1988-1993 and the mean length at age is taken as the average for the northern area.

It is seen that the fishing mortality seems to be a reasonably smooth and mostly increasing function of length, and a possible corresponding smooth curve is included in the figure.

As the fishing mortality is for the total fleet which operates in different areas, it is not obvious what should be taken as the corresponding mean length since the catchability of the survey will vary from one region to another.

Thus it will be almost impossible to estimate a single population mean length at age. To alleviate this problem, the selection should be investigated for different regions separately.

5.5 Single species assessment data - separate fleets

Fishing mortalities of cod by age group, fleet and year are given in [34].

These individual fleet results can be used along with mean length at age from the groundfish surveys in order to estimate the selection pattern at age, as is done in [39].

5.6 Initial values of parameters

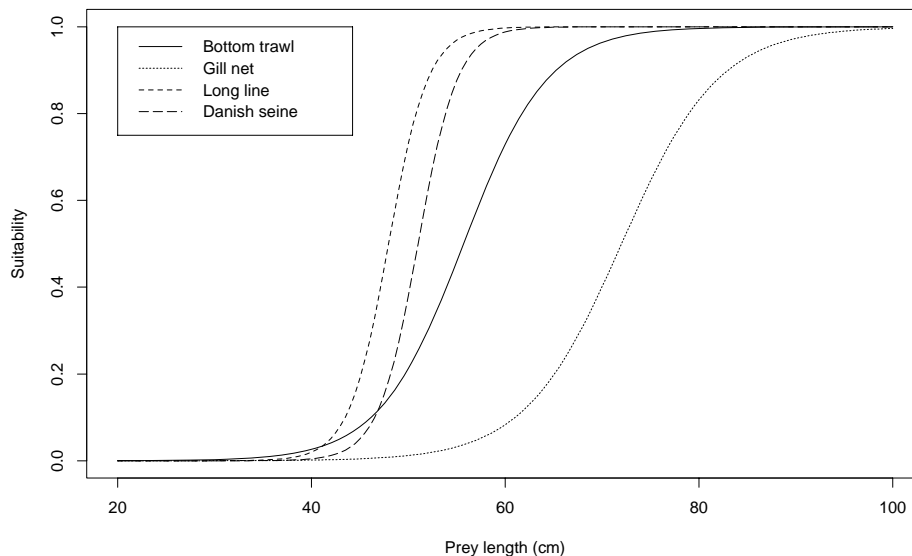


Figure 5.6.1: Suitabilities for the fleets.

It is clear from the above that there are a number of different possible approaches to the estimation of the selection pattern or suitability of the different fleets with regard to the species of interest.

	Bottom trawl	Gill net	Long line	Danish seine
β	-12.8	-14.4	-23.5	-24.99
γ	0.23	0.20	0.49	0.49

Table 5.6.1: Initial values of the selection parameters for the fleets

The approach taken in this monograph is to assume a suitability function of the type

$$S(l, L) = \frac{1}{1 + e^{-(\beta l + \gamma L)}},$$

which is the function given in equation 3.4.1 with $\alpha = 0$. To obtain initial values for the parameters β and γ a single species model of cod was set up in Bormicon, and the parameters estimated using catch length distributions for each fleet. The resulting suitability curves are shown in figure 5.6.1 and the corresponding values of the parameters are given in table 5.6.1.

5.7 Future work

Since there are a number of different approaches to the estimation of the selection/suitability of the various fleets, it is of interest to compare these different approaches in terms of the effect on the overall model results.

Chapter 6

Survey Indices, Initial Values and Renewal

Höskuldur Björnsson and Ólafur Karvel Pálsson

6.1 Introduction

As described in chapter 4 one option in the likelihood function is to use indices from a survey as time series. The indices can have different levels of aggregation, with respect to area, age, length and maturity.

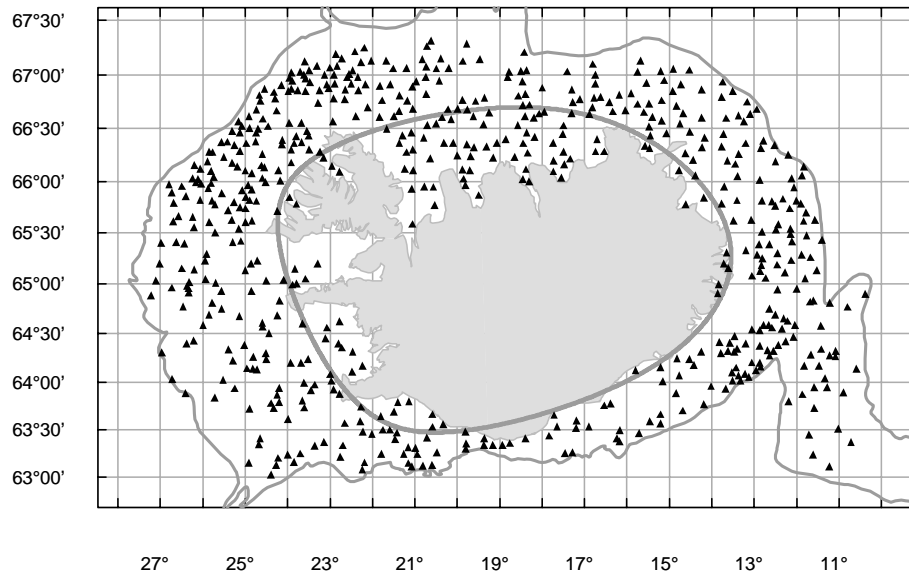


Figure 6.1.1: Tows in the Icelandic groundfish survey 1995.

The Icelandic groundfish survey has conducted annually in March every year since 1985. For this task 5 trawlers have worked 550-600 trawling stations in the

continental shelf down to depth of 500 m. Figure 6.1.1 shows the tows in 1995 and the 500 m depth contour. Standard tow length in the groundfish survey is 4 miles. The trawl design has remained unchanged throughout the years although the trawlers have undergone some changes (increase) in length and engine power.

Prior to 1985 surveys with 150 - 200 tows were conducted in March on research vessels. Smaller surveys at other times of the year have also been carried out in most years during the last 20 years [25].

The Icelandic groundfish survey is clearly the best standardized survey and will be used in the likelihood function. Other surveys would have to be included in a different way since they are not strictly standardized. However, data from these surveys may be important since for the groundfish survey only gives information for one month of the year.

The number of cod caught in each groundfish survey has varied from 50,000 to 160,000. Of these more than 40,000 have been length measured and 2500 to 3000 otolith samples have been collected in each survey for age analysis. Aged cod have also been weighted since 1993.

The otolith sampling scheme was changed in 1989 from area and length stratified sampling to random sampling. In the stratified sampling scheme the survey area was divided into 10 sub-areas and 10-30 otoliths were collected in each 5 cm length interval of the fish in each sub-area. In the random sampling scheme otolith samples were collected from 2-4% of the cod in the northern part and 20-25% in the southern area. This difference is due to more cod being caught in the northern area and apparent difference in catchability of mature fish in the southern area and immature fish in the northern area.

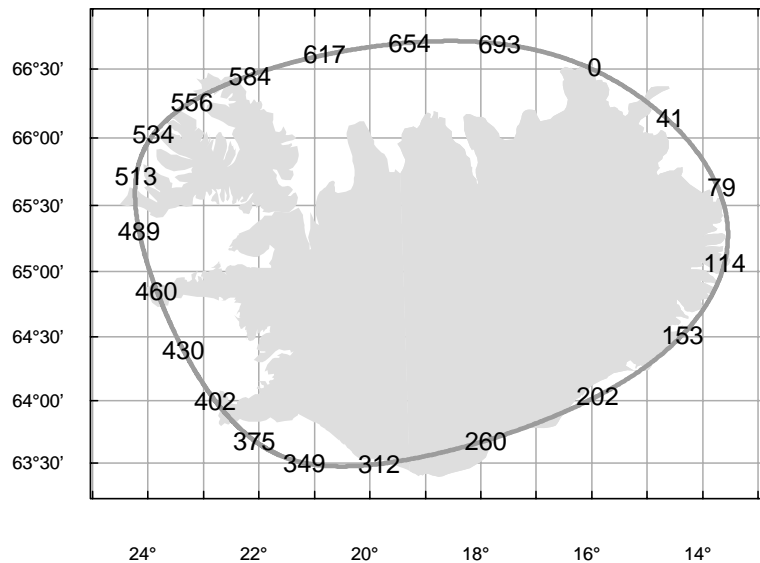


Figure 6.1.2: Curve used to calculate the coordinates.

Calculation of survey indices is done in 2 steps.

1. Calculating the number at age per station. Divided between mature and immature if needed.
2. Calculating index for each yearclass.

Each step will be described separately here after. In all of these steps extensive use is made of natural and smoothing splines. The smoothers used are `ns` (natural spline), `s` (smoothing spline) and `ps` (periodic spline) in S-plus. The coordinate system used is distance along and from the curve shown in figure 6.1.2. Distances along the curve at selected points are shown in the figure.

For renewal and initial conditions of the Bormicon model the spatial distribution and length distribution of certain age groups and maturity classes is needed. Data from the groundfish surveys is the source of this information which is calibrated by number from VPA runs (chapter 8).

6.2 Calculating the number at age per station

The problem here is similar to the problem of calculating catch at age and the same methodology can as a matter of fact be used.

A multinomial model is used where the conditional probabilities are modelled directly,

$$P_{a|L} = f(L) + g(\theta)h(L).$$

$P_{a|L}$ is the probability that fish of length L is of age a . θ refers to the coordinate along the curve (figure 6.1.2). Distance from the curve is not in the model but can easily be added. $h(L) = c_1 + c_2L$ is used. $f(L)$ is the natural spline and $g(\theta)$ the periodic spline.

McCullagh and Neel [18] show how a Poisson glm model can be used to estimate multinomial data. The problem using the Poisson model directly is that there are too many factors to estimate. As the problem is set up here each combination of tow and length would be a separate factor in a Poisson model. The value of this factor is just the total number of that length at that station. B.D.Ripley has written a program **multinom** that rewrites the Poisson likelihood function taking into account that the value of many of the factors is known.

Due to different otolith sampling procedure 1985 to 1988 than later the formulas used are different.

6.2.1 Random otolith sampling 1989 to 1995

For data sampled during this period each of the ages 4 to 7 are splitted into mature and immature fish and each group treated as a separate yearclass. This gives the number in each age and maturity class. Tests were done to split each age group 4 to 7 in 4 parts, immature male, mature male, immature female and mature female.

It was found that the difference in length between sexes and maturity classes for cod of given age is not large. Thus, treating the yearclass as one group and multiplying by the maturity % for the area gives similar results.

6.2.2 Stratified otholith sampling 1985 to 1988

In the stratified sampling scheme samples of the most common age groups tended to be taken on the first stations in each area, resulting in a patchy distribution of the otoliths sampled (figure 6.2.1).

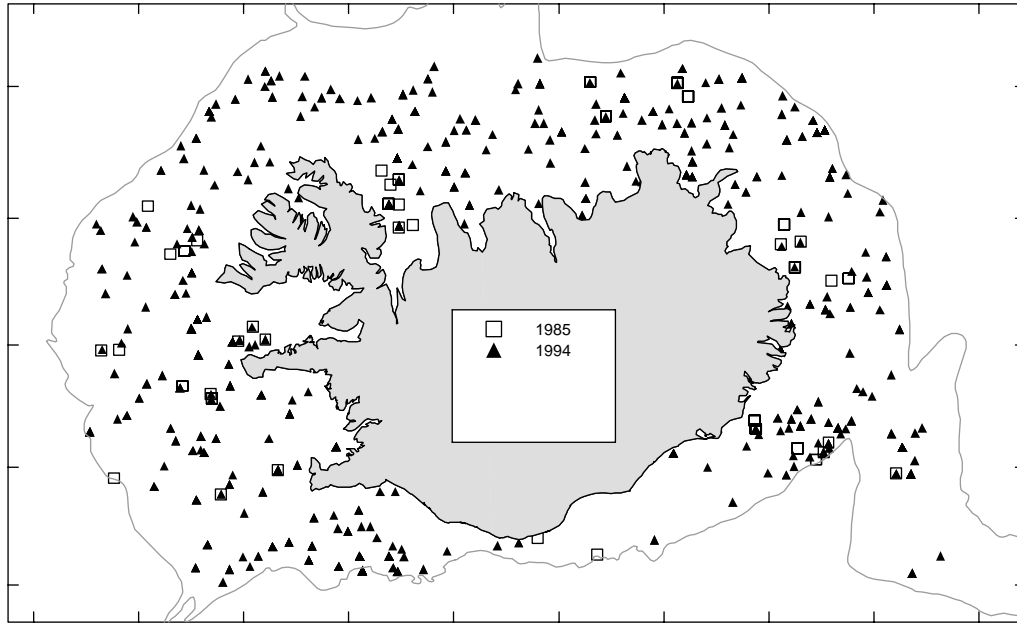


Figure 6.2.1: Otholith sampling from 5 year old cod in 1985 and 1994.

Figure 6.2.1 shows the stations where otholith samples of 5 year old cod were taken in 1985 and 1994. As may be seen large areas are unsampled in 1985. The length at age increases in a clockwise direction from the south-west to the north-east and the east area. In the north-east fish near the coast is usually smaller than fish in deeper waters (figure 6.2.2). This difference causes difficulties since the otholith samples of common length groups in 1985 to 1988 seem to be more frequent in the shallower waters. Calculation of maturity ratios from the survey can for the same reasons also be difficult in those years.

The model run used here was the same as for the surveys with random sampling except agegroups were not split in maturity classes.

One of the tests of the model is to plot the predicted length distribution of each yearclass in each area. This was done for the 1985 survey to get initial conditions for Bormicon. Spread between agegroups, especially between age 2 and age 3 in 1985, was found to occur frequently. When making the initial condition (6.4 chapter 8) the

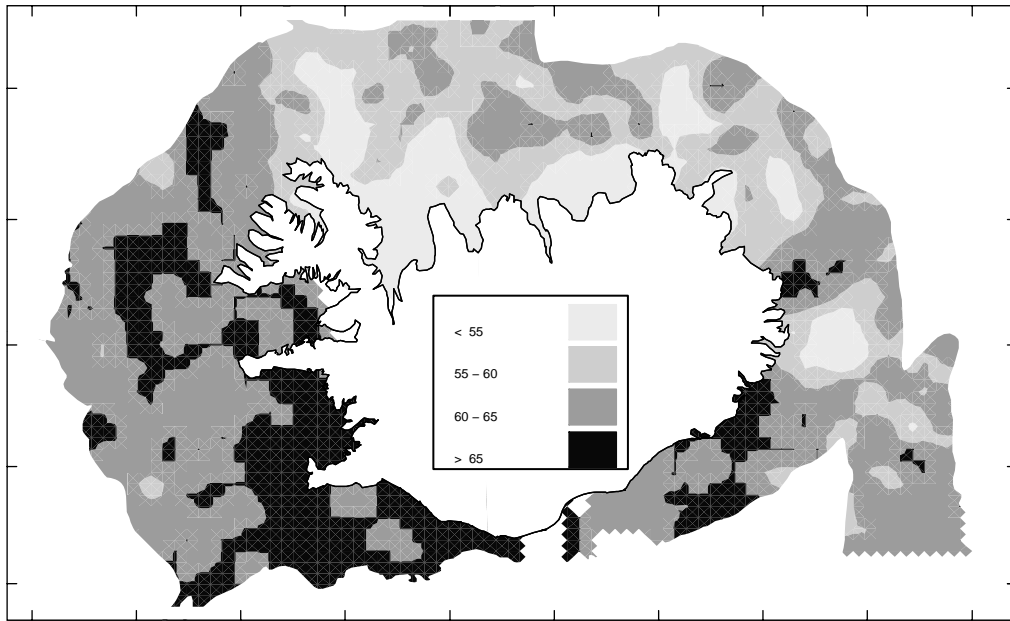


Figure 6.2.2: Length of 5 year old cod in the survey 1994.

otolith samples were prefiltered before running the multinomial model, removing the tails of the length distributions.

6.3 Calculating indices for each agegroup

When the number at age for each station is available the next step is to calculate an index for each area. A simple method is to calculate the mean number of fish per nautical mile towed in the area and multiply by the size of the area.

The method used here is to define a grid as a unit for the calculations. This grid was initially designed to make contour plots. The single most important item to consider when selecting the grid is not to let the grid cover larger area than the datapoints since extrapolation is not desirable. Figure 6.3.1 shows the grid used in the calculations.

The method used here consists of two separate models, a delta model for the probability of fish or no fish on a station and a gamma model for tows which contain fish [37]. The boundaries between stations with fish and no fish have to be defined and are set to 0.5 to 1-8 years old fish, falling to 0.1 for 11 year old cod. The number of fish of given age per station is a rational number since it is calculated from age-length keys.

The delta model used is

$$p(\theta, d) = g_1(\theta) * h_1(d),$$

where θ is the distance along the curve in figure 6.1.2 and d the distance from the

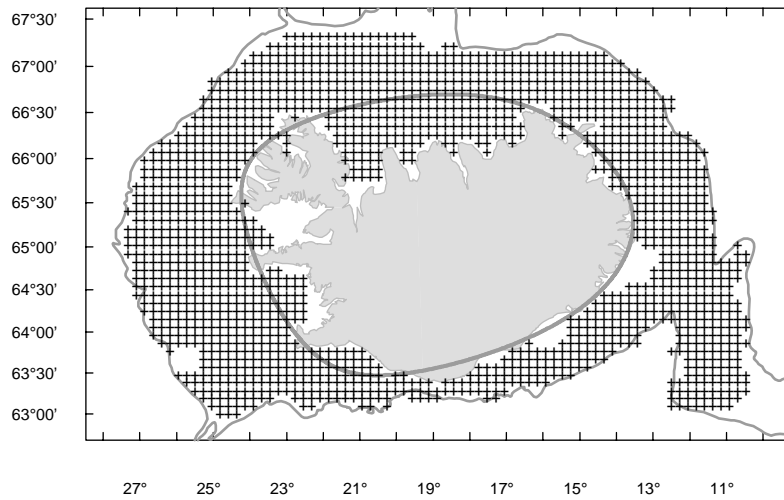


Figure 6.3.1: Grid used in the calculations.

curve. $p(\theta, d)$ is then the probability of a given age at the location (θ, d) . In the present implementation $g_1(\theta)$ is a periodic spline and $h_1(d)$ a natural spline. The model is a glm model using the binomial family.

The gamma model is of similar form:

$$N_g(\theta, d) = g_2(\theta) * h_2(d)$$

g_2 is a periodic spline and $h_2(d)$ a natural spline. The model is a glm model using the gamma family and log link. Usually the number of degrees of freedom in the gamma model are fewer than in the delta model. The difference depends on the number of tows containing fish.

The gamma model can easily give values at grid points that exceed the highest estimated values at data points. This may occur when some kind of extrapolation takes place. If some stations near the boundaries contain no fish they are not included in the gamma model and a prediction at near gridpoints means extrapolation. The binomial model does not go fast enough to zero to cancel these effects.

The method used to overcome this problem is:

The value at a grid point is set to zero if the predicted value of the gamma model is higher than the highest predicted value at a data point. This is often a reasonable approach but not always so it is best to check the points where this happens.

Finally, the predicted value at a grid point is

$$N(\theta, d) = N_g(\theta, d) * p(\theta, d).$$

The index for each area is then the sum of the values at the gridpoints within the area.

The method described here does not give results that are much different from stratified means etc. A characteristic of the method that is often an advantage is

that points near the edges of the survey area are reduced in weight. Gridding of the data means that points in areas of sparse sampling get more weight. The output is also ready for contour plots. Gridding can also be beneficial when surveys are not standardized from one year to another. The main disadvantages over stratified mean is that the method is more difficult to understand and can only be run under specialized software (S-plus) on powerful computers. Another method used for gridding is described in [22].

Both gridding methods can be used to create length disaggregated indices. Subsequently, a length group is handled identically to an agegroup.

Two sets of age and area disaggregated survey indices for the bormicon model.

1. Using the multinomial model for age-length keys and periodic spline for gridding.
2. Using the methods described in [22]. Assuming normal distribution in length at age.

Figures 6.3.2 and 6.3.3 show the total survey indices vs. estimated number at age from VPA runs ((million fishes) [20]. The figures indicate for most ages linear relationship between survey indices and estimated number from VPA runs. There are few outliers in the indices most notably age 3 in 1988, especially in figure 6.3.2.

Indices disaggregated by maturity are also available for the year 1989. For proper application the run has to be extended to 1994 or 1995 to get reasonable timeseries. Calculating maturity disaggregated indices for 1985 to 1988, however, will be difficult.

6.4 Initial Conditions

6.4.1 Distributions

To start the simulation the model needs data on the initial state of the stock i.e. length distribution of mature and immature fish in each area. This data is extracted from groundfish surveys in March and VPA year-class sizes. Length distributions (6.4.1, 6.4.2 and 6.4.3) and spatial distributions of the stock (6.4.4 and 6.4.5) are obtained from the surveys. Stock numbers are then scaled up so that the total number is equal to the VPA year-class size. Thus, calculation of initial conditions relies heavily on survey indices as described in section 6.2.

Two sets of initial values were calculated, for 1982 and 1985. In 1985 the otolith sampling was stratified and there were problems producing satisfactory length length distributions for each area. In particular this was the case for 3 year old cod of the poor 1982 year-class which is immediately adjacent to the very large 1983 year-class. To solve this problem the otolith samples were filtered. In each area only the center of the length distribution of each age group was used but the tails were omitted. (10% on each side). Thus, most of the “smearing” between age groups was avoided.

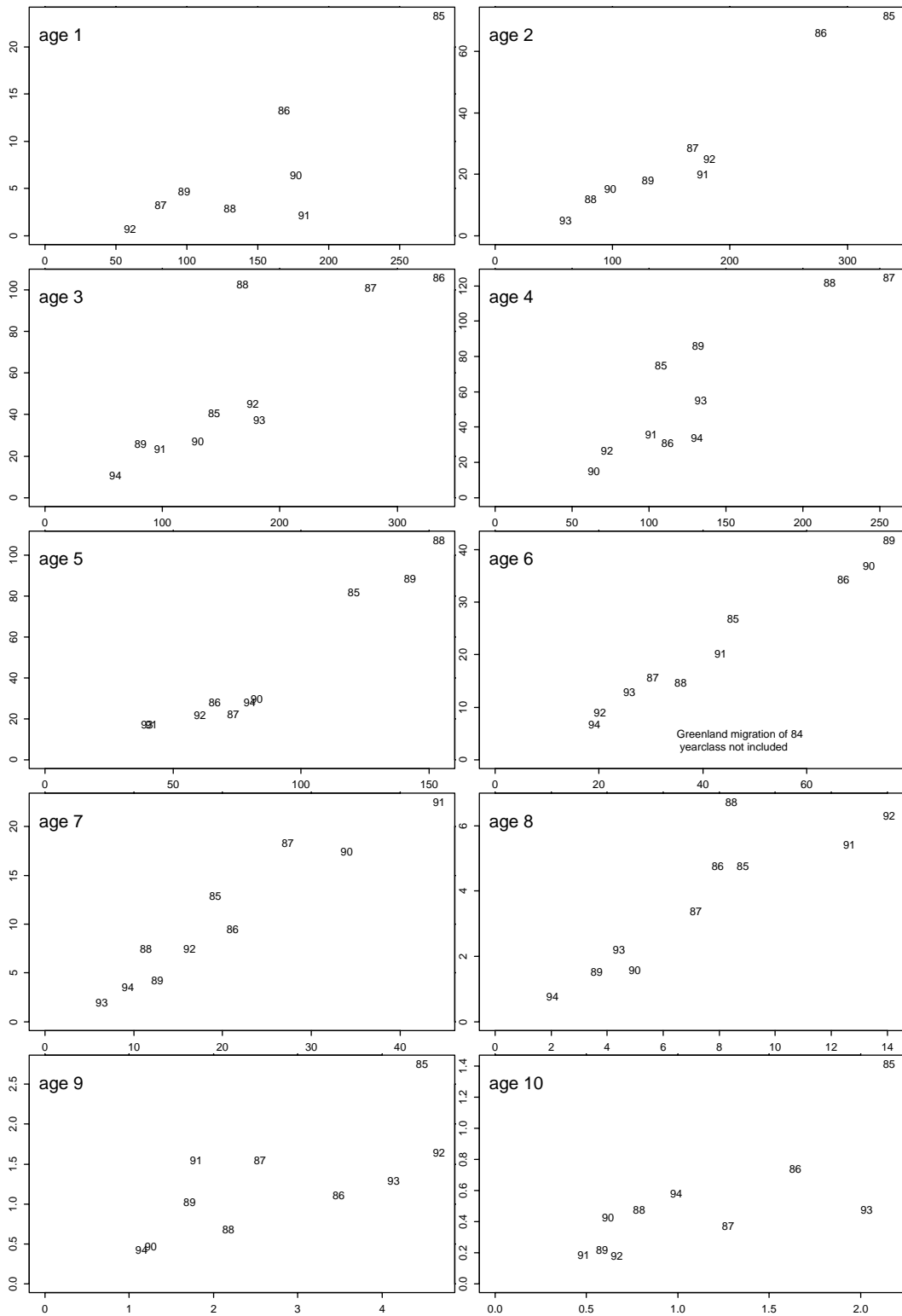


Figure 6.3.2: Survey indices calculated from multinomial model.

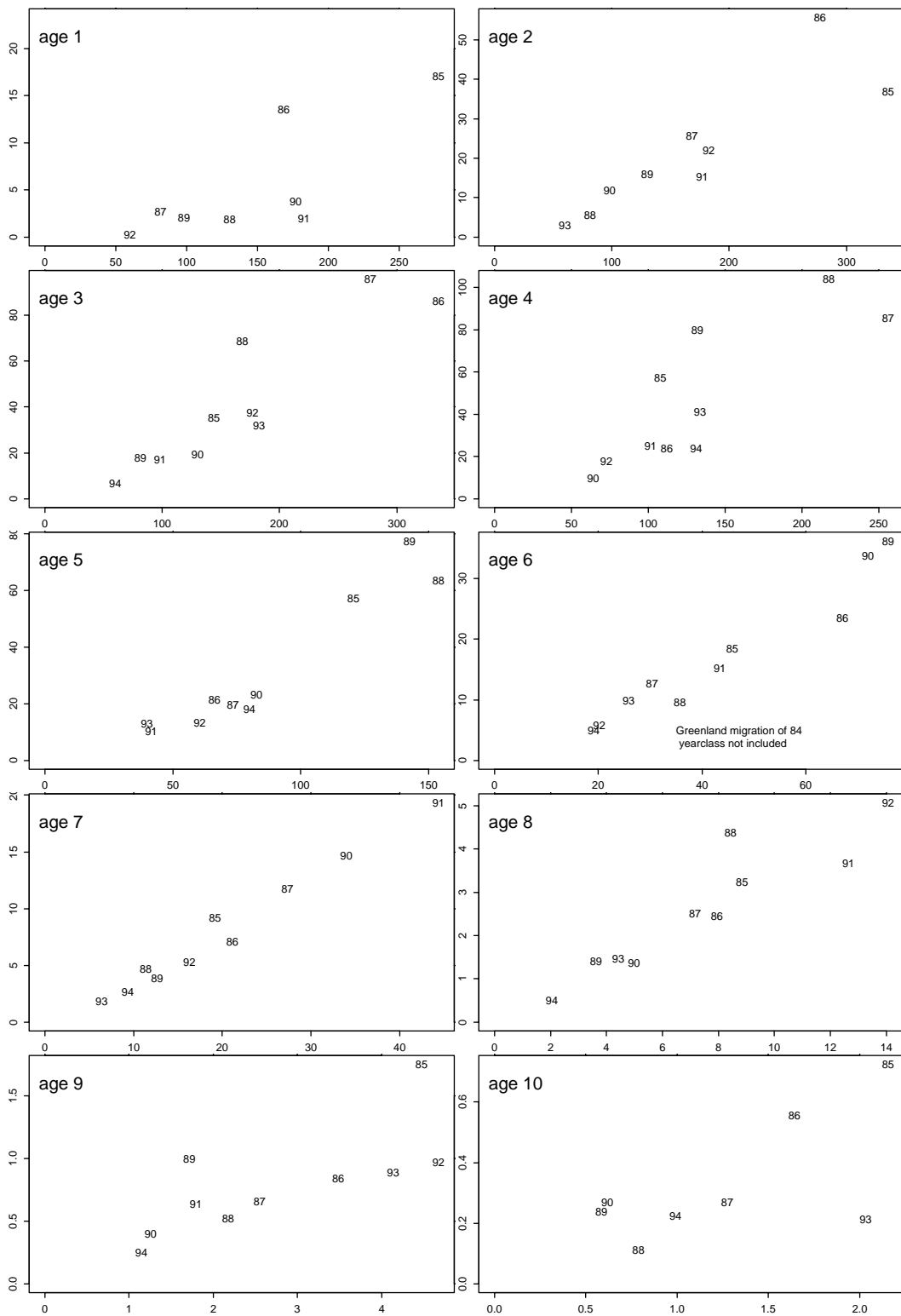


Figure 6.3.3: Survey indices calculated by normal distribution in length at age.

When length at age had been calculated, tails with values of less than 0.5% of the maximum value, were cut off. Some “cleaning” was also needed in areas where an age group was virtually non-existent.

6.4.2 Maturity

Estimating maturity at age has also created some problems. The otolith samples of the first survey years do not cover the area adequately. Further, there is a difference in catchability between mature and immature fish in some areas [27].

Observed maturity ratio in the survey 1985 was found using the following equation (glm model in S-plus). Figure 6.4.2 should be consulted regarding the meaning of the coordinate θ .

$$\begin{aligned} & \text{mat ns}(age, \text{knots} = c(5, 6, 7, 8, 9, 10)) * \\ & \text{ps}(\theta, \text{knots} = c(100, 260, 416, 673), \text{period} = c(0, 731.95)) \end{aligned} \quad (6.4.1)$$

This model was used to split the survey indices in mature and immature parts, and subsequently scaling the indices to the VPA numbers. Table 6.4.1 shows the number of immature, mature and the total number in each age group used.

	3	4	5	6	7	8	9	10	11
Immature	144.0	104.4	99.5	25.6	8.3	2.4	0.0	0.0	0.0
Mature	0.0	3.4	21.2	20.2	10.9	6.4	4.5	2.2	0.5
Total	144.0	107.8	120.7	45.8	19.2	8.8	4.5	2.2	0.5

Table 6.4.1: Total number of immature and mature cod by age groups.

6.5 Renewal

Renewal is calculated in a similar way except here only the number of age 3 is needed and no division in mature and immature part has to be done.

6.6 Further work

Improvements that can be made in calculations of the initial conditions are for example to multiply survey indices of mature fish in certain areas by a catchability factor. That would increase the number of mature fish in each yearclass and probably improve the distribution for March. Currently the model is started January 1. so getting the March distribution is not so relevant. These issues need further refinement in the future.

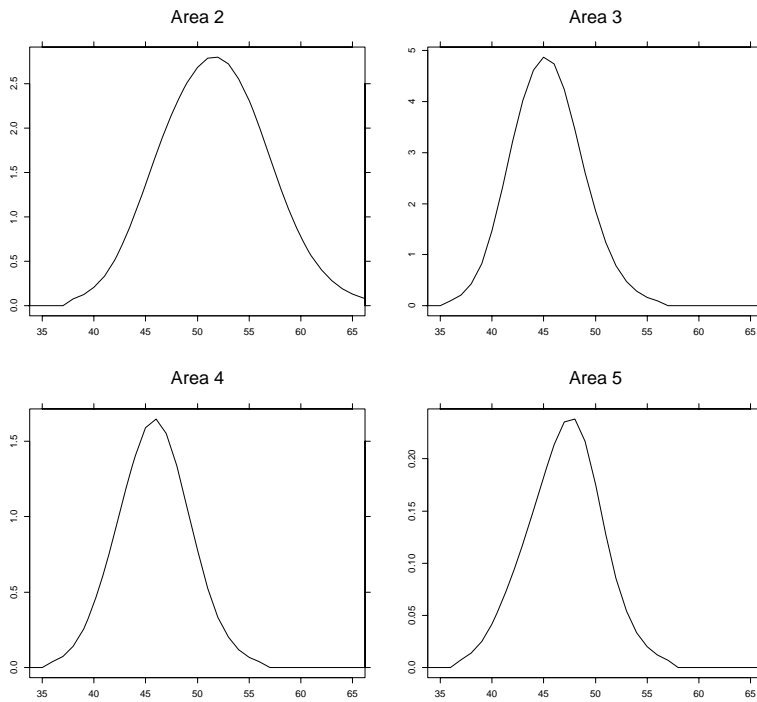


Figure 6.4.1: Length distribution of 4 year cod in initial conditions.

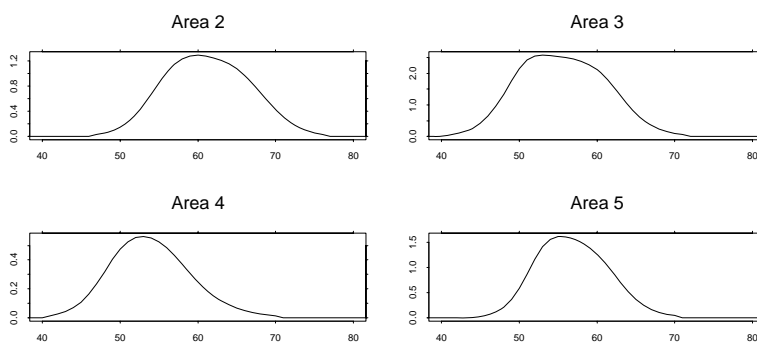


Figure 6.4.2: Length distributions of 5 year cod by area in initial conditions.

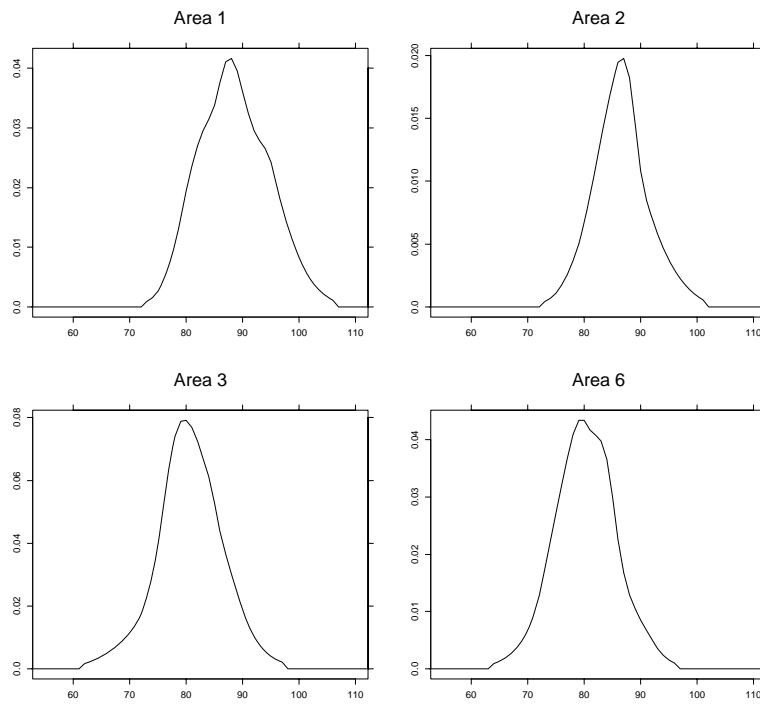


Figure 6.4.3: Length distributions of 6 year cod by area in initial conditions.

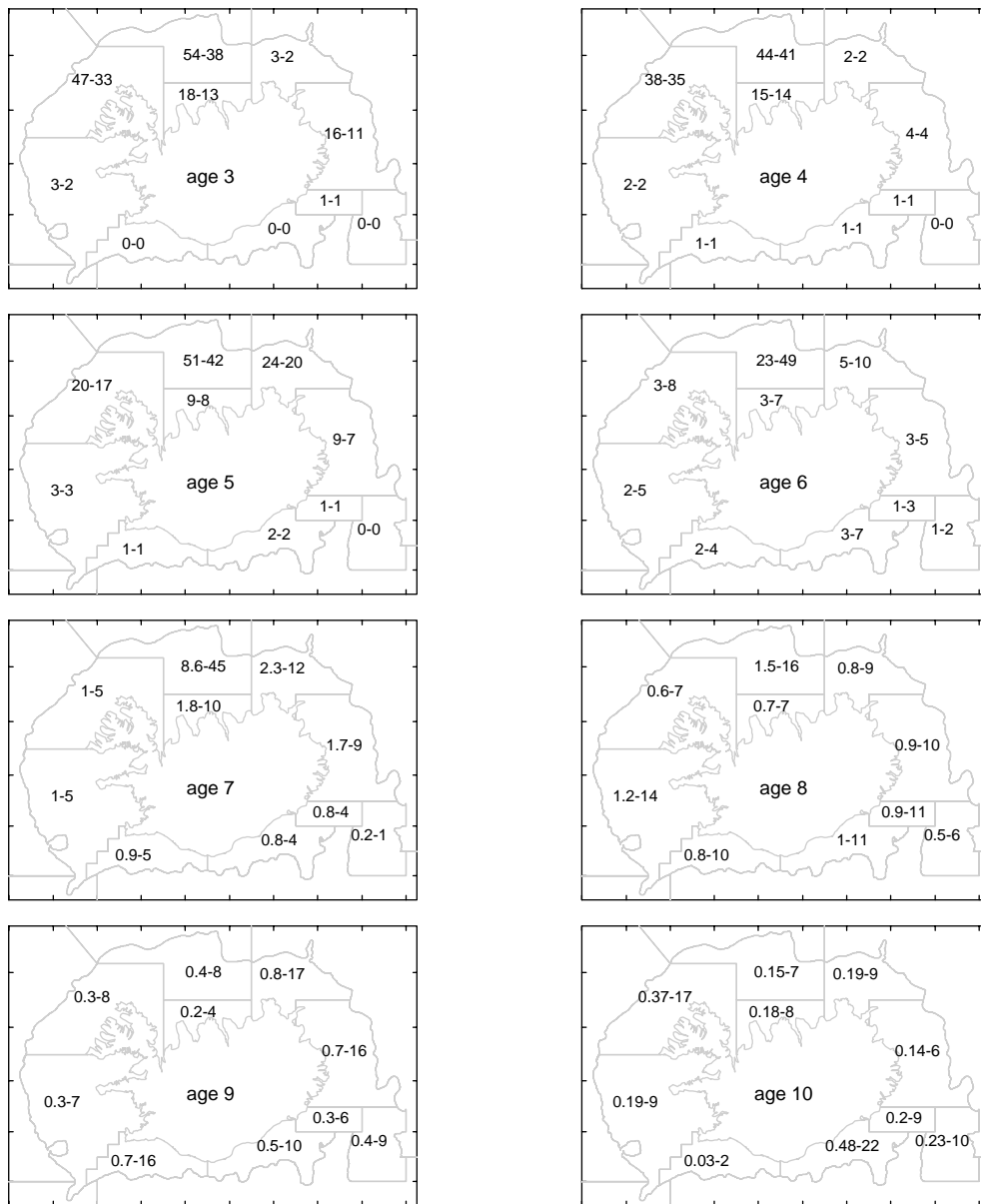


Figure 6.4.4: Spatial distributions by age group used in initial conditions (number in millions and percentage of year-class size).

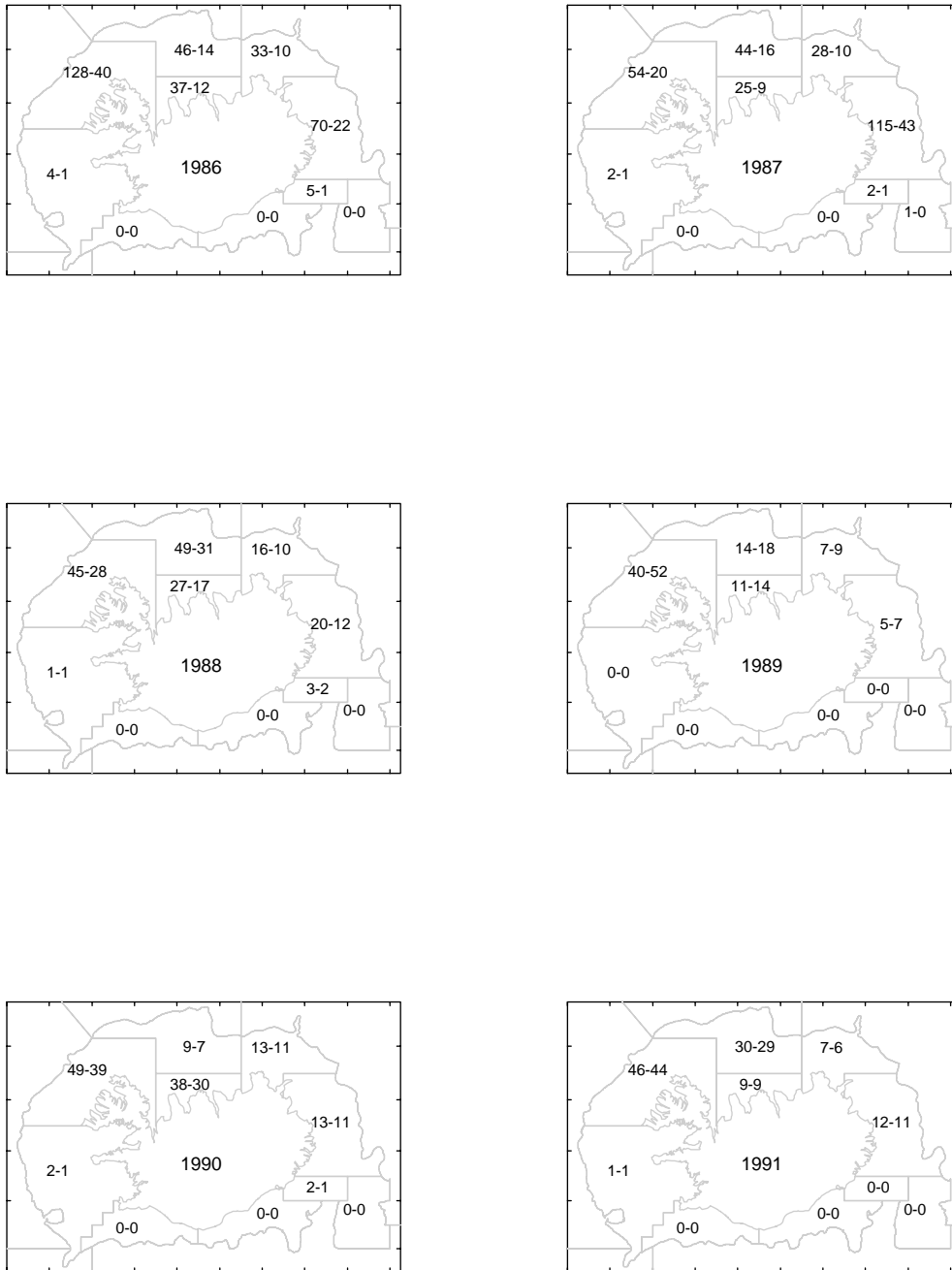


Figure 6.4.5: Spatial distributions of 3 year old recruits 1986-91 (number in millions and percentage of year-class size).

Chapter 7

General Ecology of Cod

Höskuldur Björnsson, Halldór Narfi Stefánsson, Ólafur Karvel Pálsson, Hjálmar Vilhjálmsson and Gunnar Stefánsson

The general ecology of cod in Icelandic waters has been extensively investigated. Several of these investigations have dealt directly or indirectly with the individual growth of cod. Thus, [14] and [15] discuss the trophic status of the cod stock with an emphasis on the importance of the capelin stock in this context.

Similarly, [44] find that the size of the capelin stock affects the individual growth of cod, but other factors tend to be less important. However, there are some indications [33] that the size of the cod stock itself may be of some importance and this has been used in some instances [43].

It is clear that all of the previous analyses suffer from the lack of incorporation of spatial information and this was in fact pointed out in [10].

7.1 Consumption

Consumption by cod is calculated as described in chapter 3. In the basic model, cod only has two preys available, capelin and other food. The suitability of capelin as prey for cod will be described in detail in section 7.3.

In [4] the following equation is used for maximum consumption of cod:

$$H_{cod}(W) = 0.7e^{0.104T-0.000112T^3}W^{0.8}, \quad (7.1.1)$$

where W is in kilograms and H in g/day. In Bormicon this equation is converted to length (in cm) by the relationship $W = 0.01L^3$ which leads to:

$$H_{cod}(L) = 4.2510^{-5}e^{0.104T-0.000112T^3}L^{2.4}. \quad (7.1.2)$$

This is the same as formula 3.4.2.

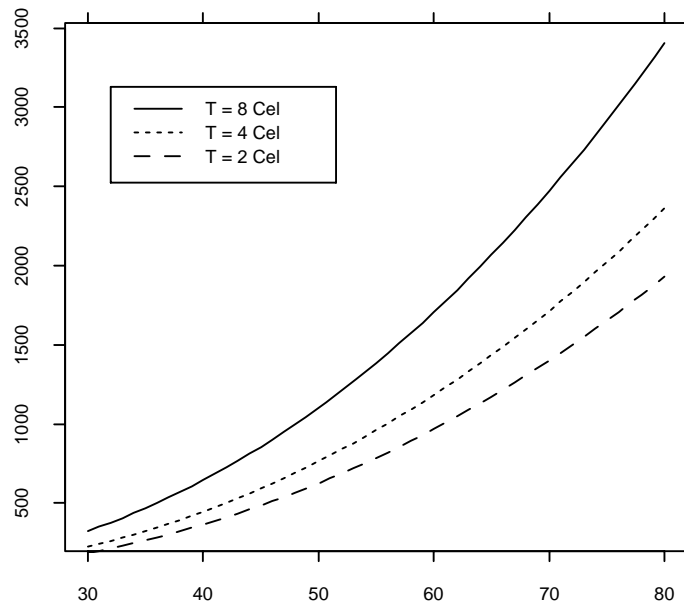


Figure 7.1.1: Maximum consumption vs. length at different temperatures.

Predation in the model is based on the length of the predator so equation 7.1.2 suits the model better. In equation 7.1.2 condition of the fish does not affect maximum consumption while in equation 7.1.1 fish in good condition can eat more.

Figure 7.1.1 shows maximum consumption versus length according to 7.1.2 at different temperatures. Maximum consumption changes much with temperature and is 75% more at 8°C than at 2°C.

7.2 Growth

The model uses both length and weight growth. [4] describes a growth model where length and weight growth is calculated independently. It is difficult to keep length-weight relationship in such a model.

The proposed model here consists of two steps.

1. Calculating the growth in weight.
2. Calculating the growth in length from the growth in weight.

In the single species model the cod is not a predator, and then the growth in weight is calculated from only the current mean weight. In the basic model the cod is a predator and has two preys available, capelin and other food, and in this case the growth in weight is calculated from feeding.

7.2.1 Calculating the growth in weight

Single species model

In the single species model for cod, von Bertalanffy's growth function, given by equation 3.4.5 on page 40, is used:

$$\frac{dW}{dt} = a \left(\left(\frac{W}{W_\infty} \right)^{2/3} - \frac{W}{W_\infty} \right) \delta_{year} \delta_{step} \delta_{area},$$

where W is the mean weight and W_∞ the maximum weight.

The values of the parameters W_∞ and a are different for each substock, 0-group, 1-and-2-group, immature cod, and mature cod, but the deltas are the same for all substocks. Estimates for the growth parameters were obtained by running a optimization in Bormicon. The likelihood function used was catch statistics, described in section 4.4, with data from otolith samples from the catch of all the four fleets in the model. First the parameters W_∞ and a were estimated. Then the area effect was estimated, keeping all other parameters fixed, then the step effect and at last the year effect.

Basic model

The growth in weight is calculated from feeding based on the estimated maintenance energy and efficiency in conversion to body weight. The formula used here is derived from [13](WRONG!):

$$F = 0.00747W^{0.8}e^{0.081T+0.76V} + 1.27GW^{0.15}. \quad (7.2.1)$$

F : Feeding in kcals/day.

T : Temperature in °C.

V : Average swimming speed in bodylengths/sec.

G : Growth in g/day.

Rearranging gives:

$$G = \frac{F}{1.27W^{0.15}} - 0.0063W^{0.65}e^{0.081T+0.76V}, \quad (7.2.2)$$

which is equation 3.4.10.

[13](WRONG!!) uses $V = 0.28$ bl/sec. Figure 7.2.1 shows the conversion efficiency vs. bodylength according to this equation. Complications arise when the

energy content of the prey is much different from the energy content of the predator. Preys with high fat content have high energy content. As an example the energy content of cod flesh is approximately 0.9 kcal/g and the average energy content of the cod 1.0 kcal/g. The energy content of capelin with 15% fat is 2 kcal/g while lean capelin has only 1.2 kcal/g.

The question is then if 2 g of lean capelin are equivalent to 1.2 g of fat capelin. There is no single answer to this question. In a situation when much of the food is used for growth the protein content of the food is more important while for maintainance the fat can be used. To some extent the fat can be used to build up the liver which can help the fish later during starving periods.

In the first implementation in the program growth of cod in g will be calculated from the **mass** consumed as if the energy content of the prey is the same as of the predator. Thus we arrive at the function presented in chapter 3, equation 3.4.10.

7.2.2 Calculating the growth in length from the growth in weight

In this step a length-weight relationship of the form $W = aL^b$ is assumed. Differentiation gives

$$\Delta W = abL^{b-1}\Delta L, \quad (7.2.3)$$

hence

$$\Delta L = \frac{\Delta W}{abL^{b-1}}. \quad (7.2.4)$$

Deviances from this formula need to be implemented. Reduction in weight should not result in reduction in length. Also a fish in bad condition should increase in weight before its length starts increasing.

Define the function g with

$$g(x) := l_0 + x(l_1 + l_2x), \quad (7.2.5)$$

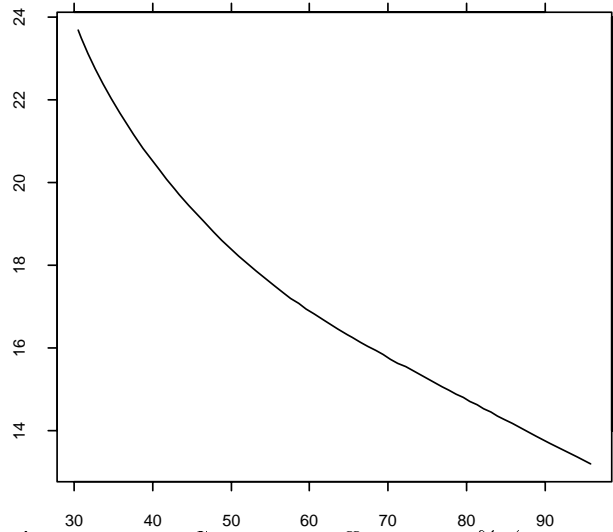


Figure 7.2.1: Conversion efficiency in % (i.e. 100 times growth/consumption) as a function of length with $\psi = 0.5$, $T = 4^\circ\text{C}$. Weight is converted to bodylength by the formula $W = 0.01L^3$ and the consumption is set $0.5H_{cod}(L)$ (eq. 7.1.2), so $\psi = 0.5$.

the piecewise linear function f with

$$f(x) := \begin{cases} 0 & \text{if } l_3 + l_4x \leq 0, \\ l_5 & \text{if } l_3 + l_4x \geq l_5, \\ l_3 + l_4x & \text{else,} \end{cases} \quad (7.2.6)$$

and let

$$r(L) := \frac{W - W_{ref}(L)g(\psi(L))}{W}, \quad (7.2.7)$$

where l_0, \dots, l_5 are constants and $\psi(L)$ is the feeding level. In the case of von Bertalanffy's growth function, when there is no consumption, the feeding level is an additional parameter, and is generally put equal to 0.5.

The formula used for the length increase can then be written as

$$\Delta L := \begin{cases} \frac{\Delta W}{abL^{b-1}} f(r(L)) & \text{if } \Delta W > 0, \\ 0 & \text{if } \Delta W < 0. \end{cases} \quad (7.2.8)$$

The problem can be looked at as an control problem where the setpoint is the curve $W_{ref}(L)g(\psi(L))$, that is, $W_{ref}(L)g(\psi(L))$ is a reference length-weight relationship that the fish follows at the feeding level $\psi(L)$. The function $g(\psi(L))$ increases the reference weight at a given length when the fish eats more. With a suitable chosen values of the constants l_0, \dots, l_5 , such as those to obtain fig. 7.2.2 and 7.2.3, increased consumption moves the reference curve up and the fish needs time to reach the curve again.

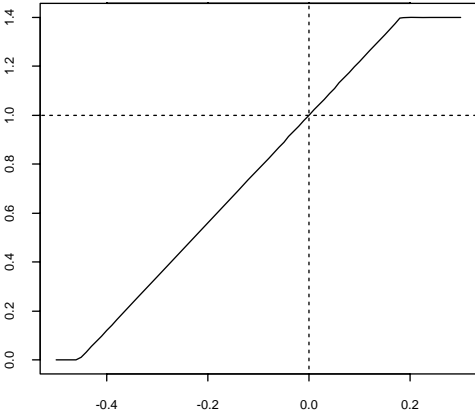


Figure 7.2.2: The function f with $l_3 = 1, l_4 = 2$ and $l_5 = 1.4$

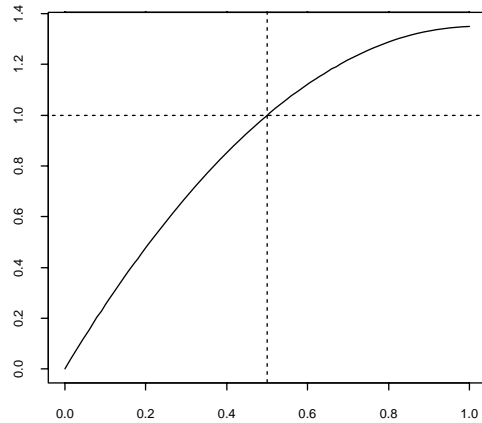


Figure 7.2.3: The function g with $l_0 = 0, l_1 = 2.6$ and $l_2 = -1.2$

I.e. with increased consumption the feeding level, $\psi(L)$, increases and therefore $g(\psi(L))$ increases so $r(L)$ becomes < 0 and the multiplicative factor $f(r(L))$ in eq. 7.2.8 is < 1 .

The function f should fulfill the conditions

$$f(x) \begin{cases} < 1 & \text{if } x < 0, \\ = 1 & \text{if } x = 0, \\ > 1 & \text{if } x > 0, \end{cases} \quad (7.2.9)$$

i.e. $l_3 = 1, l_4 > 0$ and $l_5 > 1$. If not the system is unstable, i.e. deviance from the reference curve increases. Here the function $g(\psi)$ is scaled so that $g(0.5) = 1$ (compare with figures 7.2.2 and 7.2.3).

Figures 7.2.4 to 7.2.9 show the results simulations of the growth model. The simulations are done in S-plus. The x -axis in the figures is either length in cm or time from the start of the simulation in months.

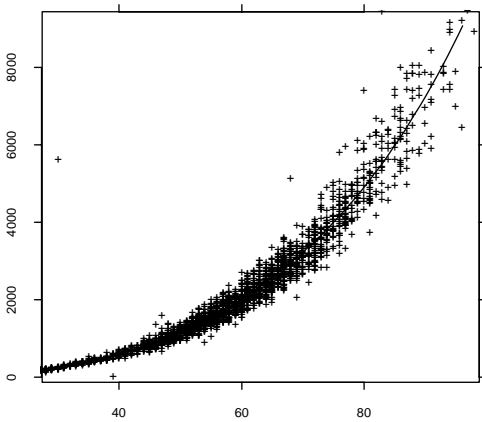


Figure 7.2.4: Reference length-weight with data from ground fish survey 1994

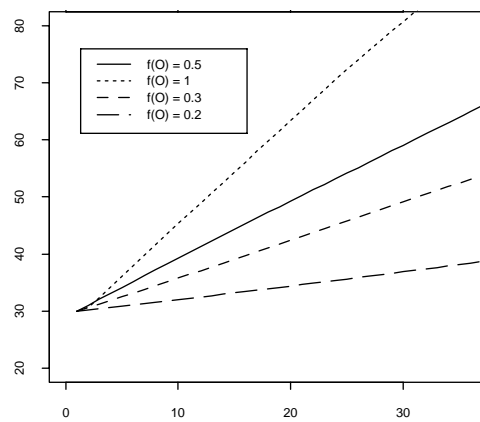


Figure 7.2.5: Growth in length at various feeding levels and 4°C

Figure 7.2.2 shows the plot of the function f and figure 7.2.3 the function g . Figure 7.2.4 shows the reference length-weight relationship with data from the groundfish survey 1994 (ungutted weight).

Figure 7.2.5 shows length growth at different feeding levels and 4°C temperature. The time on the x -axis is in month. At $\psi = 0.5$ the growth is approximately 1cm/month which is about the average growth of 3 - 5 year cod near Iceland. At $\psi = 0.2$ there is very little growth. All the curves start at 30 cm.

Figure 7.2.6 shows the simulated length-weight relationship at different feeding levels. The curve at $\psi = 0.5$ corresponds to the reference curve given.

Figure 7.2.7 shows weight vs. time in months at different temperatures. All the fish start at 230 g. After 20 months fish living at 4°C weighs 1000 g but fish at 8°C 2000 g. When food is scarce the fish loses weight faster at higher temperature.

Figure 7.2.8 and 7.2.9 show how 6 months starving period affects the fish according to the model. Figure 7.2.8 shows weight as function of time in but figure 7.2.9 shows the length-weight relationship. Temperature is 4°C and $\psi = 0.5$ outside the

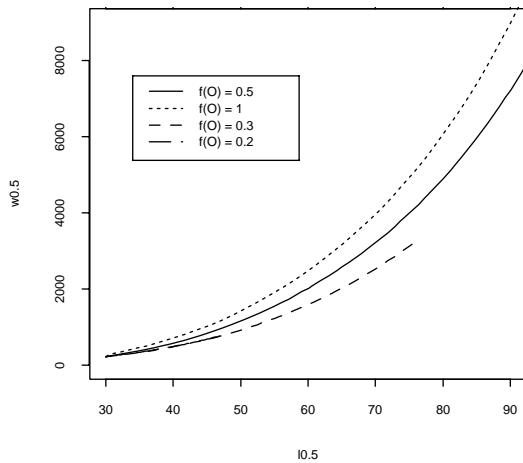


Figure 7.2.6: Length-weight relationship at various feeding levels and $T = 4^{\circ}\text{C}$

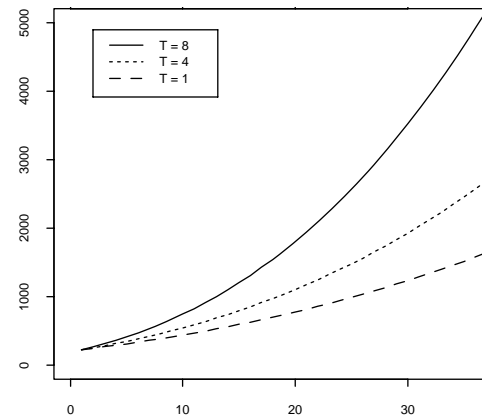


Figure 7.2.7: Growth in weight at different temperatures with $\psi = 0.5$

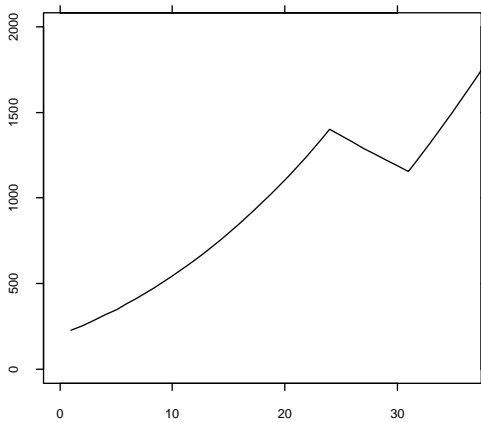


Figure 7.2.8: Weight of fish vs. time with $\psi = 0.5$, $T = 4^{\circ}\text{C}$ and 6 months starving period

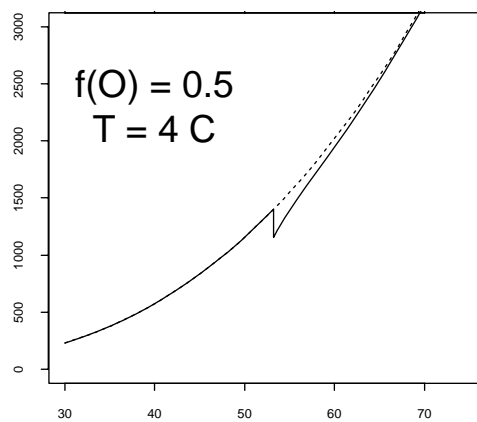


Figure 7.2.9: Length-weight relationship with $\psi = 0.5$, $T = 4^{\circ}\text{C}$ and 6 months starving period

starving period. Figure 7.2.9 shows how the weight of the fish drops below the reference curve when starving but reaches it gradually when the consumption starts again.

As may be seen in Figure 7.2.9 the growth in length according to the model is not reduced much with increasing length. Increased reduction in length growth can be implemented by various means, such as:

- Less amount of suitable food for larger fish.
- Different parameters in the growth function for mature fish.

- Loss in weight due to spawning.

7.2.3 Growth Distribution

In chapter 3 the algorithm used for upgrading the length distribution in each area according to growth is described. What has to be given for each species is the distribution matrix (i.e. discrete values of the function G in equation 3.3.4).

For cod the resolution used in the length distribution is 1 cm. For cod in the groundfish survey the variance in length at age (in cm) is not far from the mean in agegroups 1 - 6. This indicates that the Poisson distribution might be suitable. Simulations in S-plus confirmed that this was the case.

Maximum allowed growth in one month was 3 cm and maximum mean growth in one month 3 cm. The part of the Poisson distribution above 3 cm was included in the 3 cm class and the distribution arranged to give correct mean length. It needs good will to call this Poisson distribution when the mean growth is above 1.5 cm/month.

The weight update was done by assuming $W \propto L^3$.

7.3 Suitabilities

7.3.1 The model

A predator's consumption of a prey is described in chapter 3:

$$C_{pred}(L) := H_{pred}(L, T) \frac{\sum_{l, prey} \phi_{pred}(l, L, prey)}{\sum_{l, prey} \phi_{pred}(l, L, prey) + AE_1}, \quad (7.3.1)$$

where

$$\phi_{pred}(l, L, prey) := S_{prey, pred}(l, L) N_{prey}(l) W_{prey}(l). \quad (7.3.2)$$

Here $S_{prey, pred}(l, L)$ is called the suitability of prey of length l as food for predator of length L . Now fix the predator and prey and write $S(l, L)$ instead of $S_{prey, pred}(l, L)$.

Suitability can be any positive number but it is convenient in practice to keep it between 0 and 1. It is convenient to divide it into 3 functions.

$$S(l, L) := \rho \xi g_{lL} \quad (7.3.3)$$

The function ρ involves characteristics of the prey like mobility, colour, pelagic vs. demersal etc. The function ξ describes the overlap of the predator and the prey which is partly taken care of by the area division in the model. The function g_{lL} describes the size preference of the predator and an example is given in [5] as:

$$g_{lL} = e^{-\frac{(\ln \frac{w_{pred}}{w_{prey}} - \eta)^2}{2\sigma^2}} \quad (7.3.4)$$

For use in Bormicon weights of predator and prey have to be converted to lengths. The function implemented in Bormicon is:

$$g_{lL} = \begin{cases} p_0 + p_2 e^{-\frac{(\ln \frac{L}{l} - p_1)^2}{p_3}} & \text{if } \ln \frac{L}{l} \leq p_1, \\ p_0 + p_2 e^{-\frac{(\ln \frac{L}{l} - p_1)^2}{p_4}} & \text{if } \ln \frac{L}{l} > p_1. \end{cases} \quad (7.3.5)$$

Equation 7.3.5 can be made identical to equation 7.3.5 if simple power relationship between length and weight is assumed, $p_0 = 0$ and $p_3 = p_4$.

The function in equation 7.3.5 has a peak at $l_{opt} = \frac{L}{e^{p_1}}$. By using $\max(0, g_{lL})$ instead of g_{lL} (as is done in Bormicon) p_0 can be used to get rid of tails in the suitability function if it is negative.

One difference between the implementation in Bormicon and equation 7.3.4 is that the value of the parameter σ in 7.3.4 is not the same on different sides of the peak. In 7.2.3 p_3 is the value when $l > l_{opt}$ and p_4 when $l \leq l_{opt}$.

7.3.2 Fitting to Icelandic stomach content data

A number of cod stomachs from Icelandic waters has been analysed since 1979 and the sampling effort has been particularly extensive since 1992. Usually when cod stomachs are analysed the length of prey is measured when possible. In January 1993 and 1994 simultaneous measurements of the capelin stock and cod stomach sampling were attempted.

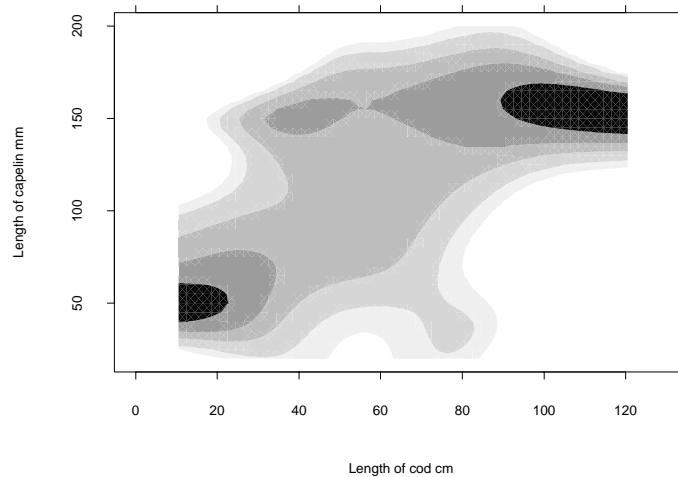


Figure 7.3.1: Length of capelin as prey from cod stomachs

Figure 7.3.1 shows a contour plot from the cod stomach content data base. All data found in the data base is used. Majority of stomachs in the data base is from March when mature capelin is relatively accessible for cod compared to other times

of year [25]. From the figure it looks like $L = 0.25 - 0.3l$ is the near the optimum length of the prey. The maximum size of prey that a predator can eat seems to be $L = 0.45l$. It seems on the other hand large cod can occasionally eat very small capelin so the suitability never goes all the way to zero in that end.

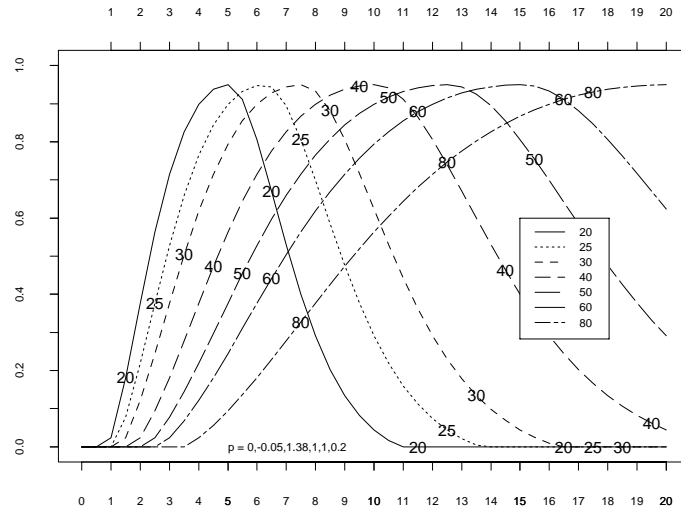


Figure 7.3.2: Simulated suitability function

Figure 7.3.2 shows the suitability vs. length of prey for different values of the prey length. The parameter values used in equation 7.3.5 are $p_0 = -0.05$, $p_1 = 1.38$, $p_2 = 1$, $p_3 = 1$, $p_4 = 0.2$. The value of p_1 corresponds to the optimum length of prey being 25% of the length of the predator.

7.4 Maturation

Many of the principles in the maturation process are well understood [57]. In particular it is known that for many species early maturation is initiated under periods of increased food, but decreasing the food supply tends to first suppress growth and delay maturation, and in fact the net result of starvation may be to lead to maturation at a smaller size but older age [1].

Indication of this process have been observed for salmon ([45] and [31]), haddock ([7]), convict cichlid ([46]), three-spined stickleback ([56], [59] and [58]) and cod in captivity.

A most natural model should therefore be to assume the proportion which is to become mature as a function which depends on the growth in a specified period. Unfortunately the data required to estimate this function is not available for the Icelandic cod, and hence a more ad hoc approach is taken.

The aftereffect of maturation may then be to decrease growth somewhat, as is observed in salmon ([45]), but this effect has not been observed in the Icelandic cod.

7.4.1 Maturation model

The model used to describe the proportion mature at age is described in section 4.3.5, where a simple updating routine is used to increment the number of mature fish in such a fashion as to obtain an orderly development of the maturity ogive.

The data for the model was prepared by fitting a model to data from the ground fish survey 1994.

$$M = \frac{1}{1 + e^{-(\alpha + \beta l + \gamma a)}} \quad (7.4.1)$$

where M is the maturity ogive. Proportion mature at age was unusually high in 1994 [20]. In the input data to the Bormicon runs mature cod is only 4 year and older and larger than 40 cm. Before fitting the model all cod that did not satisfy these conditions was set immature and given more weight (5 times) than other data points.

The parameters that came out of this fit were $\alpha = -8.08$, $\beta = 0.056$ and $\gamma = 0.74$. The resulting ogives are shown in figure 7.4.1. The triangles in the figure show the mean length of each agegroup.

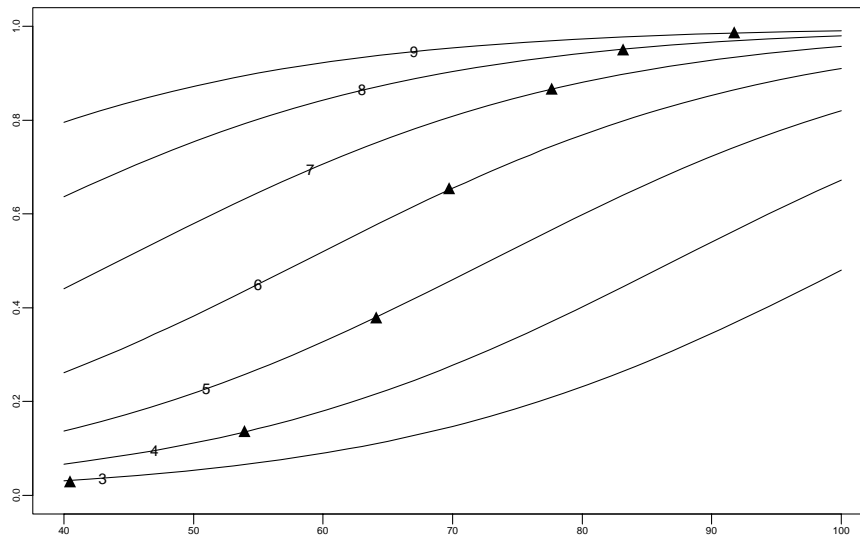


Figure 7.4.1: Maturity ogives used.

7.4.2 Future work

It is clear that the overall model could be made considerably more realistic by including a more ecologically realistic model for the maturation process. This probably requires specialized data collection in the form of either tagged individual fish

(possibly groups of fish) observed in captivity ([28]) or back calculation from individual otoliths ([29]).

7.5 Spawning Weight Loss

To account for the weight loss of mature cod due to spawning, an average value (in percent of body weight) is used for each age. To obtain sensible values for the weight loss, data from the 1995 and 1996 Icelandic groundfish surveys was used. The ratio of the weight of the roes or milt to the total body weight was found, and the mean for each agegroup calculated. Figure 7.5.1 shows this ratio for each individual fish, the line of best fit, and mean values for each agegroup. The mean values are also shown in table 7.5.1.

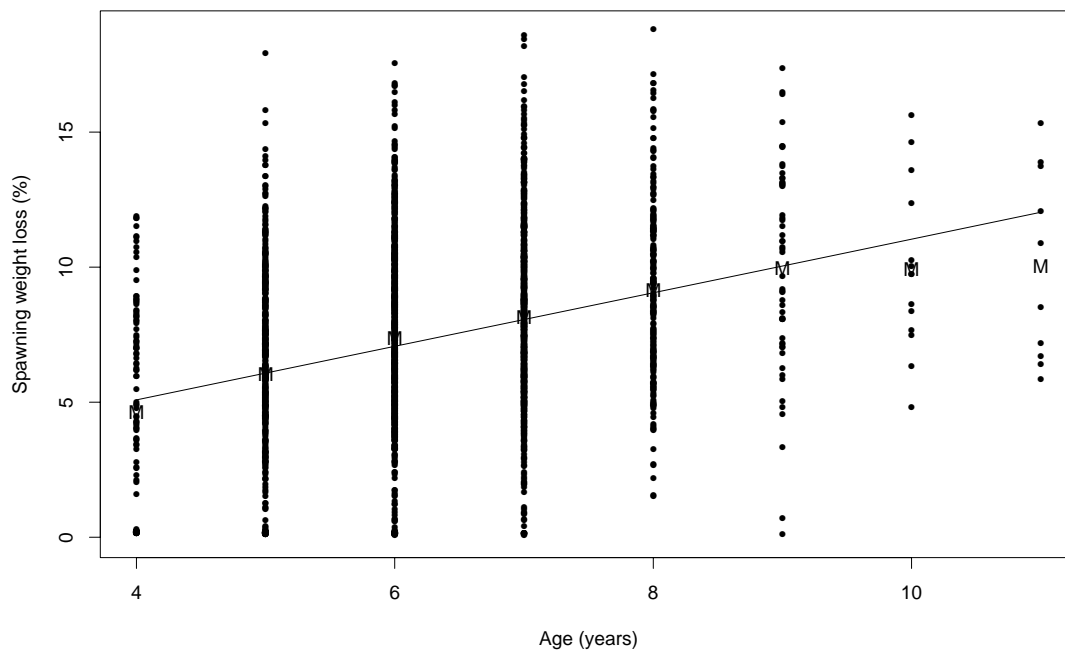


Figure 7.5.1: Spawning weight loss of cod for each individual sample (*), the mean for each agegroup (M) and the line of best fit.

age	4	5	6	7	8	9	10	11
% loss	4.54	5.95	7.29	8.07	9.06	9.88	9.86	9.97

Table 7.5.1: Spawning weight loss of cod (in %). Mean for each agegroup.

Chapter 8

Cod Migrations

Hersir Sigurgeirsson, Höskuldur Björnsson, Gunnar Stefánsson, Halldór Narfi Stefánsson

8.1 Background

General, qualitative knowledge of the migration pattern of cod in waters surrounding Iceland is quite extensive. Thus, cod is known to migrate between the various Bormicon areas as part of the feeding and spawning strategies.

In addition to these migration patterns, larval drift to Greenland has been observed in some years (e.g. [53]). Such drift has been seen to correspond to later migration from Greenland to the spawning areas off the south and west coasts of Iceland.

In this monograph only migration between Bormicon areas 1-10 will be considered. The immigration from Greenland in 1990 ([38] and [6]) is introduced as immigration to stock and the number of fishes immigrating is estimated in some simulations. The immigration is 6 years old cod with mean length 60 cm entering area 2 in January 1990.

The above qualitative information needs to be drawn first into a simple conceptual model and then cast into a mathematical model containing parameters to be estimated for later use in the overall model describing major components in the ecosystem surrounding the cod.

As described in chapter 2, the migration pattern needs to be considered separately for mature or immature fish. The migratory pattern for immature fish is described mainly in form of dispersion, whereas the mature component undertakes a major spawning migration.

8.2 Migration patterns

The main principle in the simulation of the migrations is to keep the model simple and the number of parameters low. Of course this implies that the model might be poor, and well known migration patterns impossible to simulate. However, when these limitations become more restricting, it is easy to modify the model slightly and introduce additional parameters.

In the present implementation, the same migration matrices have been used for all years in the simulations. The effects of this need to be further examined. Furthermore, migration in the northern areas is likely to be temperature dependent and difference in temperature between years can be large.

8.2.1 The immature part of the stock

For immature cod the same migration matrix is used for all months. The migrations are parametrized with 2 parameters one describing general dispersion and the other migrations to the west in the northern area. 8.2.1 and 8.2.2.

The reasoning for using westwards migrations is that most of the catch of immature cod is off the North-West coast while a large part of the recruitment seems to be off the North and the North-East coast.

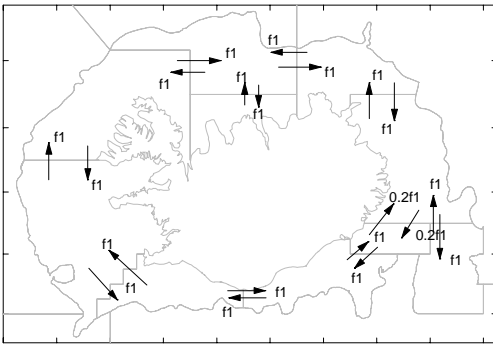


Figure 8.2.1: Dispersion of cod (immature and mature)

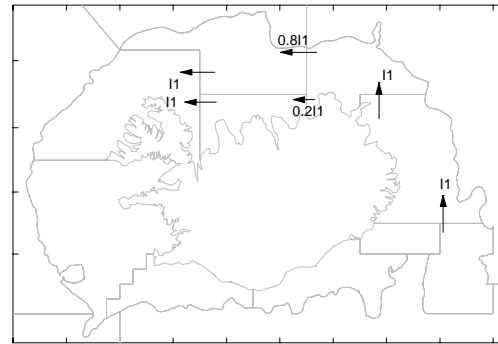


Figure 8.2.2: Migration of immature cod

The value used for the dispersion parameter $f1$ was 0.025 for all immature cod. The value of the parameter $l1$ describing westwards migration was 0 for age one and younger but was estimated for immature cod older than one year. The estimated value was between 0.01 and 0.015 in the simulations in chapter 15 but 0.00 in chapter 16.

The migrations of mature cod can be roughly split up in two periods, January-April and June-December. In January-April the cod undertakes southward spawning migrations, both clockwise and counter clockwise around Iceland to the spawning areas off southern Iceland. As a first approximation one parameter is used to simulate these migrations, as shown in Figure 8.2.3. All fish in areas 3 and 4 take the

western route, while all fish in area 5 take the eastern route. A possible modification is to allow a part of the fish in areas 3 and 4 to take the eastern spawning route by adding a parameter for migration between the areas 3 and 5, and 4 and 5. In May the cod is not allowed to migrate at all, except for the dispersion. In June-December the mature cod migrates back north, again part clockwise and part counter clockwise. Four parameters are used for this pattern, as shown in Figure 8.2.4.

Dispersion used for mature cod is identical to that used for immature cod (8.2.1) and the value used for the parameter f_1 is 0.05.

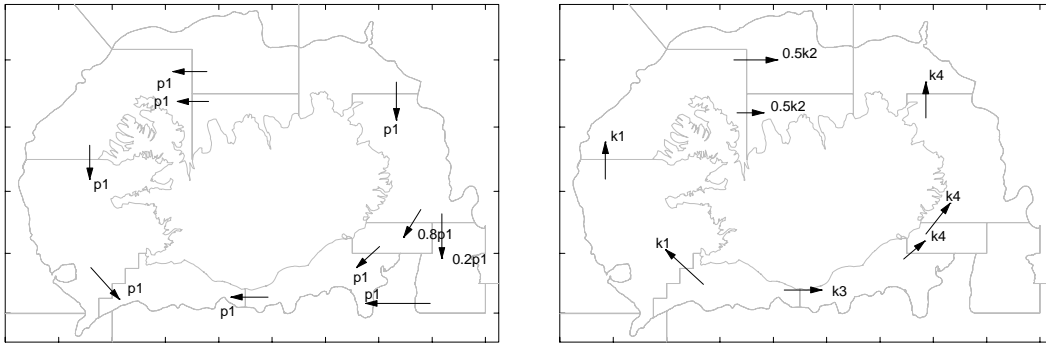


Figure 8.2.3: Migration of mature cod in January-April. Figure 8.2.4: Migration of mature cod in June-December.

Values of the migration parameters of mature cod were not estimated in the simulations described in chapter 14 to 16. The values used there were obtained in smaller simulations using the Bormicon model .

- Using area and disaggregated survey indices and understocking to estimate the parameters
- Using tagdata to estimate the parameters

8.3 Values of migration parameters obtained by using survey indices

To obtain the first set of migration parameters a single species was set up where the only parameters to be estimated were the five migration parameters in figures 8.2.3 and 8.2.4 and growth parameters for cod.

The period of the simulation was from 1985 to 1996. Age of cod was 3 to 11 with number of age 3 cod obtained from [2]. Only area and age disaggregated survey indices and understocking were used in the objective function. To reduce the number of parameters estimated the value of the parameters k_3 and k_4 (8.2.4) was the same.

The values of the parameters obtained are shown in table 8.3.1 and the distribution of mature cod using the estimated parameters is shown in 8.3.1.

	p1	k1	k2	k3	k4
Estimated from survey indices:	0.30	0.25	0.0150	0.014	0.014
Estimated from tagging data :	0.29	0.24	0.04	-0.02	0.26

Table 8.3.1: The estimated values of the migration parameters for 8.2.3 and 8.2.4.

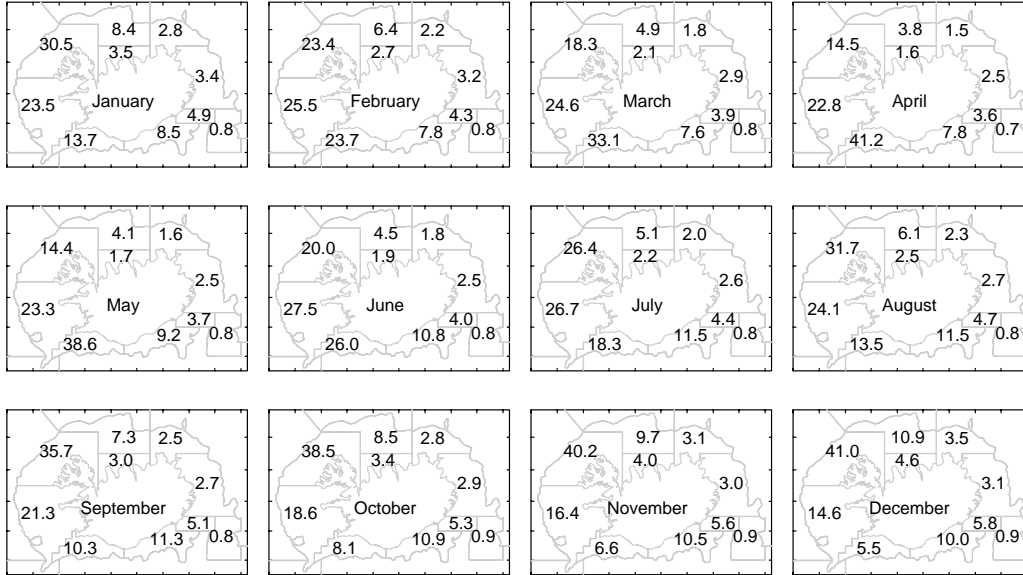


Figure 8.3.1: Distribution of mature cod according to migration pattern estimated from survey indices and understocking.

The figure is obtained by running a simulation for 10 years where the only dynamics are migration of the stock (no mortality or growth). After The stock was initially uniformly distributed on Bormicon 1 - 10. The distribution in figure 8.3.1 is the distribution of the stock in the tenth year, but in the last 5-6 years of the simulation the distribution pattern was almost exactly the same.

8.4 Values of migration parameter

Tagging data is in many ways the most natural data to estimate migrations. Extensive to obtain initial values of the migration parameters for mature cod the likelihood function described in section 4.9 was used along with data from tagging experiments carried out in Icelandic waters in the years 1948-1986 ([11])

The simulation was started in January in the year 0 and ended in December in the year 4. All tagging experiments carried out in the same area and the same month of the year were combined, and introduced as a separate stock with one length group and one age group and no dynamics other than migrations. Since it is generally not possible to record the maturity stage of a tagged fish to be released, only recaptures

of fish that were longer than 70 cm at tagging were included, and the number of tagged fish scaled accordingly. Furthermore, only recaptures in Bormicon areas 1-10 were included, and the number of tagged fish scaled again. Only those months and areas where the number of tagged fish was greater than 10 and any recaptures were recorded were included. The natural mortality and tagging mortality were set to 0.3, and the fishing mortality to 0.5 (0.49), the same in all areas. The loss of tags from living fish and non-reporting of captured tags were implemented by multiplying the number of tagged fish by 0.9.

The constant k_3 in $??$ was set to 50. It means that if the number of recaptures recorded was greater than the number of marked fish on the area, a constant of 50 times the difference between recaptured fishes and available fishes was added to the objective function.

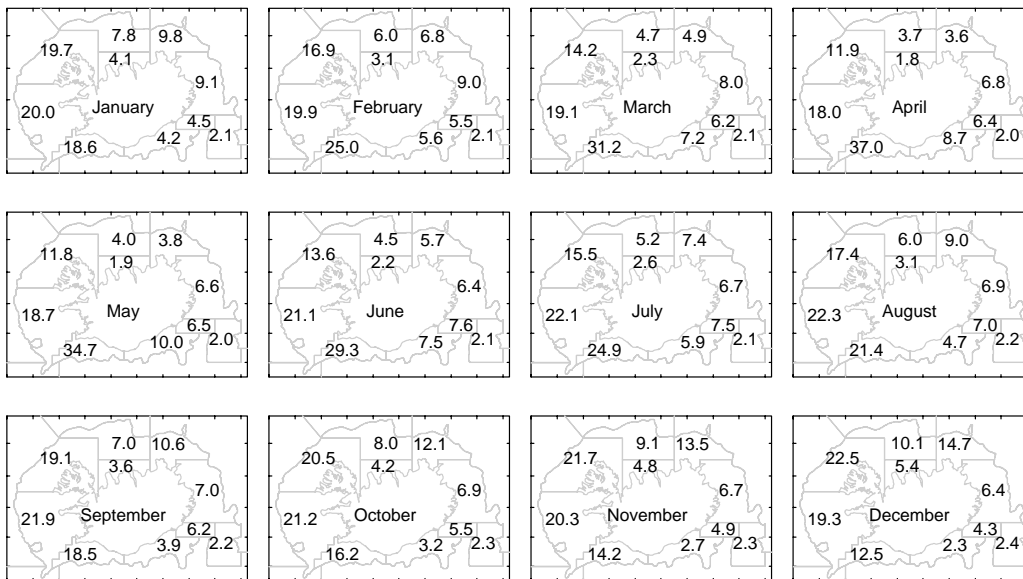


Figure 8.4.1: Distribution of mature cod according to migration pattern estimated from survey indices and understocking.

Table 8.3.1 gives the estimated values of the migration parameters as and figure 8.2.1 shows the distribution of mature fish. Negative value of the coefficient k_3 does not look too good but it must be born in mind that the migration is added to dispersion (8.2.1 so the no element of a migration matrix becomes negative. Compared to 8.4.1 there is more fish east and north-east of Iceland but less off the south-east and north-west coast. This is not surprising as understocking of cod is used to estimate the parameters used to make 8.2.1. The North-West and South-East areas are important fishing grounds and to avoid understocking there fish must migrate to those areas. The difference could also reflect changes in distribution of the cod stock but a lot of the tag-data is from the warm period prior to 1965. The North-East and East areas are usually rather cold and were possibly more suitable for cod during the warm period.

As no other dynamics complicate the model the use of tagdata as described here allows to estimate more parameters in the migration pattern than has been done here. An attempt was made to estimated the parameters in the migration pattern shown in 8.4.2 and 8.4.3. The number of parameters estimated is 12 . The values of the parameters and the value of the objective function are shown in ?? . The objective function is the same as before and its value is 52286 compared to 52630 when 5 parameters were estimated.

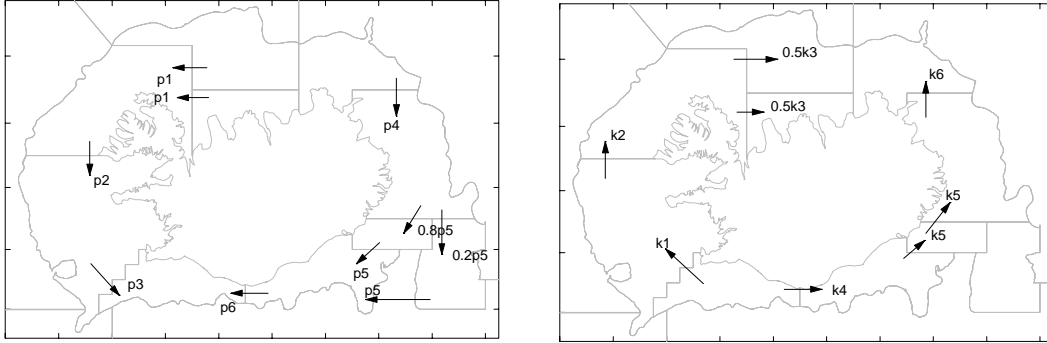


Figure 8.4.2: Migration of mature cod in January-April. Figure 8.4.3: Migration of mature cod in June-December.

Distribution of mature cod according to the estimated migration pattern is shown in 8.4.2. The distribution is similar to the distribution in 8.4.3. using the values of the parameters estimated from survey indices and understocking.

parameter	p1	p2	p3	p4	p5	p6	k1	k2	k3	k4	k5	k6
estimated value	0.30	0.31	0.25	0.09	0.30	0.54	0.07	0.19	0.04	0.01	0.27	0.06

Table 8.4.1: The estimated values of the migration parameters for 8.4.2 and 8.4.3.

The migration pattern estimated from survey indices and understocking was used in most simulation in chapter 15 but in one alternative the migration pattern shown in 8.4.2 and 8.4.3 was used. That the migration pattern obtained from survey indices and understocking was used has historical explanations, those were the first likelihood function available in the model.

Estimating the migration parameters of mature cod in the cod-capelin simulations was not attempted. Identification of mature cod is uncertain in the latter part of the year and the spawning mortality (mostly fishing) has often been very high.

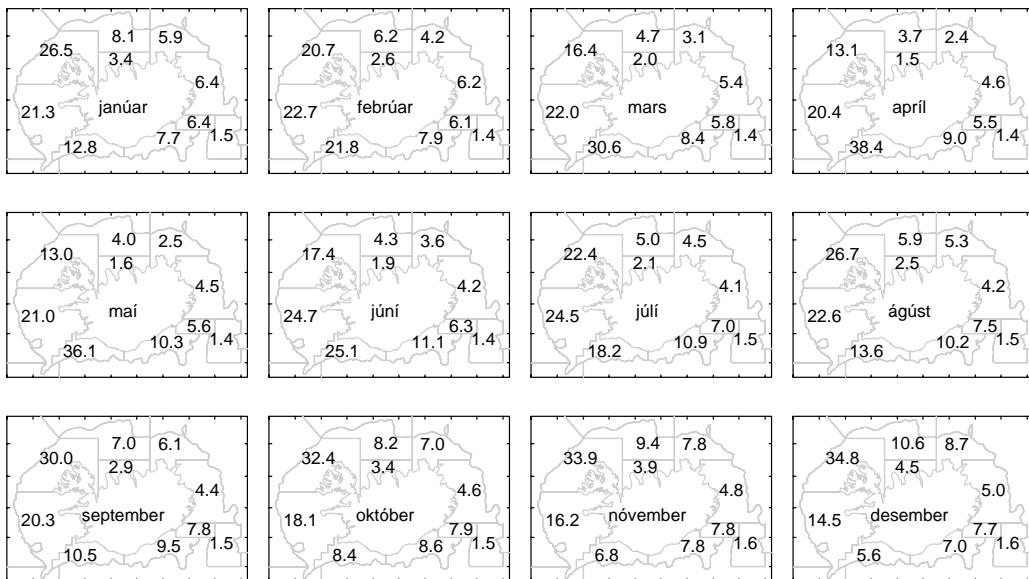


Figure 8.4.4: Distribution of mature cod based on the estimated migration matrices.

Part IV

Capelin

Chapter 9

Capelin fisheries

Hjálmar Vilhjálmsson and Anita Björk Lund

9.1 Background

Directed fishing on the Icelandic capelin does not have a long history. An Icelandic winter fishery of pre-spawning and spawning capelin started in a modest way in 1964 when a few herring seiners landed 8.6 thous. tonnes for reduction. In view of the limited participation, this small beginning was, however, considered a success and aroused considerable interest. In 1965 the number of participating vessels was, therefore, much larger, and the catch increased to almost 50,000 tonnes.

In the beginning, the winter capelin fishery did not start until late February, and consequently took place off the western part of the south coast and southwest of Iceland only. However, the winter capelin fishery soon gained momentum and importance. It became customary for the fleet to go out as soon as the first spawning migration was located off the eastern south coast, and by 1969 almost all the Icelandic herring fleet had become involved in the winter capelin fishery. This, together with the earlier start of the season, resulted in the total catch reaching 170 thousand tonnes in 1969.

In the 1970 and 1971 seasons the catch amounted to 190,000 and 198,000 tonnes, respectively. The duration of the coastal phase of the winter capelin season is largely determined by the time difference between the arrival of the first and last spawning migrations, since each migration usually spends only 3 - 4 weeks in the warm coastal waters before the capelin spawn and die. The very early appearance of the first spawning migration in 1972, together with an obviously large spawning stock that arrived on the south coast grounds over an unusually long period of time, resulted in a record catch of 276,500 tonnes in the 1972 season. By then it had become clear that in the short winter season, the shore-based processing facilities were a limiting factor. Therefore, if no arrangements were made to induce the transport of capelin to factories outside the immediate vicinity of the fishing area, the total capelin catch would probably range between 200,000 and 300,000 tonnes at most.

Before the 1973 winter season a coordinating body, the Capelin Board, was established in order to synchronize fishing and production. This was mainly accomplished by dividing the fishing grounds into several price zones and allocating higher prices for longer trips. The total catch in the 1973 season amounted to 440,000 tonnes, an increase of more than 100 percent, as compared to the average for the previous three years. Although the season started this year in deep waters off Southeast Iceland already in the fourth week of January and lasted into April, there is no doubt that the operations of the Capelin Board were responsible for a major part of this large increase.

By the late 1970s the increased size of the capelin boats and radical changes in the fishery had lessened the need for a central authority for directing landings of the catch. In 1979 the prize zone system was discontinued, and from then on the Capelin Board functioned as an information centre for available landing spaces and waiting time in the various ports where the factories were located. With the ever increasing size of the vessels fishing for capelin and the continuing reduction in their numbers (from 136 vessels with a carrying capacity between 250 and 350 tonnes in 1974, to some 45 vessels, each capable of carrying from 600 to 1600 tonnes in 1994), the need for such an information service diminished greatly. The Capelin Board was, therefore, disbanded in 1990, and its role of keeping catch statistics taken over by the Ministry of Fisheries. During its time of operation, the Capelin Board kept detailed catch statistics and issued annual reports. Thus, from 1973 the Icelandic capelin catch is available by months and seasons, divided on statistical squares of 1 degree of longitude by 0.5 degree of latitude. Similar catch records have also been kept in 1991-1995.

The winter fishery of capelin takes place exclusively within the Icelandic economic zone and is conducted by vessels using purse seines. For a while in the early 1970s several skippers also experimented fishing for capelin with pelagic trawls. The main purpose was to investigate whether capelin could be fished by this gear when schooling below the range of capelin seines or when the fish were distributed in concentrations too scattered for seining. Although it proved possible to obtain good catches by pelagic trawling, it soon became obvious that the prerequisite for high density was much the same with regard to trawling as for seining. This is not surprising, since in both cases the catch was sold for the same low-price product and, therefore, had to be obtained quickly and in large quantities. Furthermore, periods when capelin were not available to the seiners became progressively shorter with increasing size and depth of that type of fishing gear, and it became ever more obvious that the two types of gear were difficult or even impossible to operate in the same area. The trawl lost out in this competition, being much more cumbersome to handle, and in addition the trawler skippers had to give the right of way to the stationary purse seiners.

Apart from the initial 1970 experiment, the winter fishery of capelin in offshore areas east and northeast of Iceland has generally been successful when catch restrictions have not been in force. Using the modern type large seines, designed

for the summer and autumn fishery, catches in January alone have ranged between 133,000 and 210,000 tonnes in the 1987 - 1990 period. But even so, the failure of the initial 1970 fishery when capelin were too sparsely distributed and below the range of purse seining, is not, however, an isolated case. Only 65,000 tonnes were caught in January 1992, and for the same reasons, probably have been even more disappointing if fishing had been allowed in January 1991. In the latter case, however, capelin abundance was much lower. Furthermore, the capelin were very dispersed during their southward migration through the deeper offshore area east of Iceland in the winters of 1993-1995. It was mainly for this reason that, in these years, the winter fishery could not begin until the first spawning migration reached the relatively shallow area some 30 - 50 naut. miles off the southeast coast.

A summer capelin fishery was begun in 1976. In that year three chartered capelin boats and a research vessel tried to locate and fish capelin off the western north coast of Iceland ([8]). By then considerable developments had taken place in the Icelandic capelin fleet. Larger vessels were being commissioned, and due to the oceanic winter fishery off North and East Iceland in January and February the purse seines had become both larger and deeper. The research vessel began scouting for capelin off the Vestfirðir peninsula on 23 June 1976 and quickly located fishable concentrations at the ice edge north of the peninsula.

By mid-July the charter vessels had taken several individual loads of 500 - 1300 tonnes each, and the first capelin fishing boats began to arrive. Around that time the capelin began a slow migration to the southwest, and in the latter half of July and in August the fishery mainly took place at or just off the shelf edge to the north and northwest of the Vestfirðir peninsula.

In September most of the boats left the capelin grounds to fish for herring in the North Sea area, and at the end of the month only 5 vessels remained fishing for capelin off the Vestfirðir peninsula. In October and November the capelin assembled in large, dense schools in the central area of the Iceland-Greenland Ridge, mainly between 66°15'N and 67°00'N, where good catches were consistently taken by the remaining boats.

In late October and November the number of fishing boats increased again and catch rates remained reasonably high when weather permitted fishing operations. Altogether, 29 boats took part in this first summer capelin fishing season in the oceanic area between Iceland, Greenland and Jan Mayen, which continued until 20 December. Because of their relatively shallow, coastal type capelin seines, some of the vessels, however, did not do very well. Nevertheless, the fishery was on the whole profitable.

In view of the success of the Icelandic summer fishery in 1976 and the existence of occasional reports of capelin in the area west of Jan Mayen in the 1960s, a vessel, chartered by the Norwegian Directory of Fisheries, as well as a number of Norwegian capelin boats on their way home from a fishery on the banks off Newfoundland and Labrador, searched for capelin in the central and northern Iceland Sea in July 1977, but without success. In 1977 the Icelanders, on the other hand, caught about

260,000 tonnes of capelin in deep waters off the Vestfirðir peninsula and off the western north coast of Iceland, south of 68°30'N, from mid-July until the end of the year.

In the following year, the central and northern Iceland Sea was again searched by chartered Norwegian fishing vessels, this time in August and September. This scouting effort revealed the presence of capelin to the west and northwest of Jan Mayen around mid-August, where a Norwegian fishery soon began. In the weeks that followed, these capelin slowly migrated to the northwest and north of the island. Good catches were made fairly constantly in the area, until in the latter half of September when the capelin scattered before beginning their return migration back south towards Iceland. In September the Norwegians were joined by Icelandic as well as some Faroese vessels in the Jan Mayen area, where these parties took a total catch of 210,000 tonnes in the summer of 1978.

In the following period, 1979 - 1987, Norwegian, Faroese and for a while some Danish vessels conducted a successful capelin fishery in the area between Jan Mayen and Greenland in the months of July - September. Exceptions were the years of 1982 and 1983 when a fishing ban had to be imposed due to low stock abundance. The Icelanders, on the other hand, mainly fished within their own economic zone, and although Icelandic fishing vessels occasionally visited the Jan Mayen area, their landings from that fishery were insignificant in comparison to their total catch of capelin.

The capelin had an exceptionally westerly distribution in 1988, and practically no capelin could be located in the Jan Mayen zone. Since Norwegian vessels were not allowed to fish west of the equi-distance line between Jan Mayen and Greenland, their 1988 summer fishery was a failure yielding only a catch of 11,500 tonnes. The same is in part true for the Icelandic summer and autumn fishery in 1988. Until late October the fishable stock remained almost entirely within the Greenlandic exclusive economic zone and, thus, was also out of bounds with respect to the Icelandic capelin fleet. In consequence, over 90% of the Icelandic catch of 311,400 tonnes in the 1988 summer/autumn season was taken in November and December. About ten Faroese vessels, operating on Greenlandic licence, had, on the other hand, a fairly successful season with a total catch of 48,500 tonnes in the summer and autumn of 1988.

On the basis of the high abundance of 1-group capelin, recorded in the 1988 August survey, the fishable stock of the 1989/90 season was expected to be abundant. Prior to the beginning of the summer fishery, an agreement had been reached between Greenland, Iceland and Norway on fishing rights of these nations anywhere in the capelin distribution area within limits set by catch quotas. Furthermore, for protecting the juvenile part of the stock it was agreed that large parts of the shelf area off North and Northeast Iceland should remain closed to the summer and autumn fishery. In spite of this, the summer/autumn fishery of 1990 was an even more dismal failure than that of the previous year. There was extensive drift ice in the area between Iceland and Greenland as well as in the southern Iceland Sea. Practically no capelin could be located in open waters until December, probably

because they did not, as in 1988, migrate to feed in the central and northern Iceland Sea in the summer of 1989. Apart from 1982 and 1983, when all fishing of capelin was banned, the catch in the summer/autumn 1989 season is the lowest on record for this phase of the fishery, since it was begun in the 1970s. However, when the spawning migration had reached the area off North-east and East Iceland in early January, catch rates improved greatly and continued at a high level until the end of the winter season in March 1990.

The summer and autumn fishery was also a failure in 1990. In late July, scouting by Norwegian fishing vessels located commercial concentrations in a small area some 110 nautical miles north of Melrakkaslétta (NE-Iceland), where Norwegian and Faroese vessels took about 22,000 and 2,700 tonnes respectively in the first half of August. Extensive scouting by a Norwegian research vessel south of 72°N, did not reveal any capelin concentrations north of 68°30'N. And on 11 August Norwegian and Faroese fishing operations ceased since no further capelin concentrations could be located. Due to the Norwegian and Faroese experience, the Icelandic fleet did not begin fishing for capelin until October 1990. However, catch rates were low and the fishable stock was mixed with juveniles. This resulted in the area off the western north coast of Iceland soon being closed to the fishery. The total international catch in the 1990 summer and autumn season amounted to only 111,200 tonnes when all fishing was temporarily suspended in late December on account of low acoustic stock abundance estimates. The fishery was not opened again until after repeated acoustic assessments of stock abundance in January and early February 1991, when the total allowable catch for the whole of the 1990/91 season was set at 300,000 tonnes of which only 180 thousand tonnes remained to be taken.

All information available prior to the 1991 summer season, pointed to a low abundance of the fishable stock. The fishery was, therefore, not opened until late October after acoustic surveys of stock abundance had been carried out. Norwegian research vessels surveyed the central and northern Iceland Sea in August 1991 but found no capelin north of 69°N. Like in 1990, most of the fishable stock was distributed together with juveniles off the western north coast of Iceland in the period October - December. Consequently, that area was closed to capelin fishing until the end of the year, and the autumn fishery yielded only 56,000 tonnes over the two month period November - December 1991.

The 1992 summer fishery for capelin started in the area some 100 - 120 nautical miles north of Melrakkaslétta (68°20' - 68°30' N, 16°25'W). In July and the first half of August, Icelandic, Norwegian and Faroese vessels continued to fish capelin in the Iceland Sea off the eastern north coast of Iceland, gradually moving northward with the north migrating capelin. In the latter half of August this capelin retraced its former route, south to the shelf edge north of Melrakkaslétta, whereupon it turned west to mix with the rest of the maturing stock and immature capelin off the western north coast of Iceland. Like in the previous years, the fishable stock remained in an extremely scattered condition and mixed with immature capelin from September 1992 until the end of the year. For this reason, and because extensive areas were

closed to the fishery due to high proportion of juveniles, catch rates remained low for most of the time in this period. Therefore, the total catch during July - December 1992 amounted only to 307,000 tonnes.

The Icelandic capelin fishery in 1993 began in the area between 68°N and $68^{\circ}30'$, $14-18^{\circ}\text{W}$. The Icelandic boats were soon joined by Norwegian and Faroese vessels and the Greenlandic boat Ammassat. The fishing area gradually moved to the north and in the latter half of July the main part of the catch was taken between $68^{\circ}30'$ and 69°N , $16-18^{\circ}\text{W}$. The northward movement of the fishing area continued in August when most of the catch was taken between $69^{\circ}30'\text{N}$ and $71^{\circ}30'\text{N}$, $15-18^{\circ}\text{W}$. Catch rates remained high, both in July and in August, and landings were at times limited by the production capacity of the shore-based reduction plants. The Norwegian vessels fished most of their allocated TAC in July.

In September the capelin gradually began migrating back south from the northern feeding area and during the latter half of the month the catches were mainly taken between $68^{\circ}30'\text{N}$ and 69°N , $18-19^{\circ}\text{W}$. High catch rates were at times obtained in September when Icelandic, Faroese and Greenlandic vessels caught about 110 thous. tonnes in all.

In the beginning of October good catches were taken at the shelf edge NNW of the Vestfirðir peninsula. However, the fishable stock soon scattered and mixed with immatures south of 68°N off the western north coast of Iceland. The scattered condition of the fishable stock prevailed throughout the rest of the year. Due to this behaviour and area closures to protect immature capelin, only 21.5 thous. tonnes were taken in November and December 1993.

In the first half of July 1994 the fleet was mainly fishing with relatively high catch rates off the eastern north coast of Iceland at about latitude 68°N . The fishery gradually moved to the west and was in the latter half of July conducted off the western north coast of Iceland, but with reduced catch rates. By August, the fishery had shifted to the area between the Vestfirðir peninsula and Greenland, south of Scoresby Sound, where the fleet finally lost contact with the fishable stock.

In spite of intensive search, hardly any fishable concentrations were located during the remainder of the 1994 summer/autumn season. Thus, 218,000 t were taken in July, 89,000 t in August and only 17,000 t during the period September-December. Thus, the total capelin catch in the 1994 summer/autumn season amounted to just under 324,000 tonnes.

In the 20 years of summer and autumn fishery for the Icelandic capelin, we have, therefore, seen very large fluctuations, where periods of large catches have alternated with periods of poor fishing. While the low in the summer/autumn fishery in the early 1980s is obviously associated with reduced capelin abundance, the failure of the summer, and also in part the autumn fishery in 1987 - 1990, can only in part be explained by shortage of capelin. As mentioned above, the extreme western distribution of capelin in 1987, and their failure to migrate to the central and northern Iceland Sea in 1988, placed them out of reach of both the Icelandic and Norwegian fishing fleets until late autumn. In the summer and autumn of

1989 ice prevented fishing operations between Northwest Iceland and Greenland as well as in the southern Iceland Sea much of the time. At the same time, however, stock abundance was declining and continued to do so in 1990. This, together with scattered distribution of the capelin, resulted in totally unsuitable summer and autumn fishing conditions in these two years. Since the same behaviour pattern was also observed in the period October - December 1991 it seems most likely that if a summer fishery had been attempted, it would also have failed in 1991.

A part of the adult stock began a northward migration in the summer of 1992, only to return from that area already during the latter half of August. While remaining in the northern area, these capelin yielded good catches, but from then on the situation became similar to that of the 2 - 3 previous years. Good catches were again obtained in the central and northern part of the Iceland Sea in the summer of 1993 while the 1994 summer fishery was a partial failure. Due to a southwesterly distribution of the north migrating part of the stock.

In summary, it seems that a prerequisite for a successful summer, autumn and, in part an early winter fishery also, is that a large part of the maturing, fishable stock migrates to feed in the Iceland Sea in summer. Experience shows that good catches can usually be taken in this area during the height of the feeding season. Later, when these capelin arrive in the shelf area off North and Northwest Iceland, their fat content is high and there is little need for continued feeding activity. Such capelin will therefore form dense concentrations which are easily fished. Conversely, when all or most of the maturing, fishable stock has to feed in or near the north Icelandic shelf area, there probably is a shortage of food which the capelin compensates for by continued active feeding in autumn and winter. The main food category, available at that time of year, is euphausiids. This type of prey is much more active than the copepods, which are the main food item during the summertime. When feeding on euphausiids, the capelin, therefore, tend to be distributed in more scattered concentrations than would be expected when they are feeding on copepods or when they are in a condition of rest.

On the other hand, the winter fishery proper is based on schools of pre-spawning capelin after they have arrived in the shallow waters off the south and west coasts of Iceland. The behaviour of the capelin in these waters is very predictable in comparison to that in the more oceanic areas and they are generally easily fished. The success of the winter fishery depends, therefore, mainly on the number of migrations (stock abundance) and weather conditions.

9.2 The catch data

The catch data for the years 1985-1989/90 was obtained from the annual reports of the Capelin Committee ¹, where the capelin catch (thous. tonnes) is given for each square and week of the fishing season. This data was unfortunately not included in

¹These reports are published in the journal *Ægir*.

the reports published after 1989/90 so the catch data for the years 1991-1993 had to be found by other means.

The catch data for 1991-1993 was based on the catch given in the *catch records* made by the fishing trawlers each year. This data is unfortunately not complete because of the poor return rate of these records and because not all returned records have been entered into the Oracle database of the MRI. Therefore some steps had to be taken to take the missing data into account in order to obtain the right total capelin catch each year as published by the MRI in its annual report. These steps are not explained here but are documented in a README file situated with the catch data files.

Tables containing the capelin catch in tonnes for each square of the season and month of the year, were created from the above mentioned data. Then the following formula was used to get the capelin catch of each Bormicon area in the years 1985-1993.

$$C_{(a_k, m, y)} = \sum_{i=1}^{Nr_{sq} \text{ in } a_k} (c_{(sq_i, m, y)} * p_{sq_i \text{ in } a_k}) \quad (9.2.1)$$

$C_{(a_k, m, y)}$:	Capelin catch in area k in month m and year y.
$Nr_{sq} \text{ in } a_k$:	The number of squares that fall within or intersect area k.
$c_{(sq_i, m, y)}$:	Capelin catch in square i month m and year y.
$p_{sq_i \text{ in } a_k}$:	Percentage of square i that falls within area k.

The final data files are shown in the following section.

9.3 Stock assessments

It is well known that in order to carry out successful acoustic evaluation of the abundance of any stock of fish, a comprehensive knowledge of its biology and, in particular, the migrations and general behaviour pattern of its various components must be obtained. There are many reasons for this, the most obvious being:

- The necessity of knowing the possible extent of the distribution area at various points in time.
- The fact that the behaviour and distribution pattern of the fish may be almost constantly shifting.
- That the varying admixture of other fish species or organisms, and even the ratio between year classes among the target species, may affect the results of such surveys.

Due to gear selection it is indeed often difficult to establish the effects of the last two variables. In addition, there are environmental variables such as weather, water depth and, in the present case, the extension of drift ice that have to be considered. The survey should, therefore, be timed in such a way that the effects of as many as possible of the above variables are at their minimum or at least as stable as can be expected.

The adult capelin are often recorded by sonar in small but very dense schools in the near-surface layers during the main feeding season, and furthermore that they are often widely distributed and may be periodically located in ice-covered areas. As early as in the late 1970s, this phenomenon and its possible effect on acoustic abundance estimation had been recognized.

Because of the southward migration from the northern feeding grounds, capelin usually occupy only part of their normal summer distribution area in October. Nevertheless, at that time of year a considerable part of the biomass may in some years be found almost anywhere within a large part of the maximum distribution area. It is also clear that the size of the distribution area of the maturing stock diminishes rapidly from October onwards, making more detailed surveying often possible in November and December. There are two main reasons why most of the autumn surveys have been carried out in October and not later in the year. One is the generally worsening weather and ice conditions near the end of the year. The other is the necessity to assess the fishable stock abundance as soon as possible to provide a basis for management advice on catch quotas.

The maturing, fishable stock usually migrates in the beginning of the year in a clockwise direction to pass the east coast of Iceland and subsequently enter the south coast spawning grounds in late January and in February. The waters off East and Northeast Iceland are almost always ice-free at that time of the year and the spawning stock assembled, often in more or less continuous scattering layers, in a limited and well defined area that can be surveyed in detail in a matter of days. When these migrations have been located, quick and accurate estimates of abundance can be obtained in calm periods.

The winter surveys are also valuable for comparison with the abundance estimates based on autumn surveys of the year before, i.e. for estimation of natural mortality rates. The winter surveys are in fact considered the most accurate means for measuring adult capelin abundance, and catch quotas have, therefore, always been adjusted on the basis of the winter estimates when these have been available and have differed from the autumn values. In most cases the winter estimates have been obtained off East and Northeast Iceland in January and/or early February. However, various reasons have dictated that this could not always be done, in which cases the stock can be assessed in the shallow waters off the eastern south coast.

The abundance of the adult or fishable part of the Icelandic capelin stock was first assessed by acoustic methods in late October 1978. Because of an intense scouting activity and due to previous information supplied by the fishing fleet, it was clear that at the time of the survey practically all of the adult stock was assembled

in a limited area in the region of the Iceland-Greenland Channel. The assessment was repeated two more times resulting in similar estimates of abundance on two occasions. A storm prevented the completion of the third estimate.

In 1979 the Norwegian Institute of Marine Research, Bergen joined the Icelandic Marine Research Institute in assessing adult capelin abundance in the Iceland-Greenland-Jan Mayen area. The first joint survey was carried out in July-August of that year and failed to register but part of the stock, in all probability because of near-surface distribution. This is also true for a joint survey in September-October of that year. After this experience the autumn surveys have usually been carried out in October and repeated in November when conditions were found to be inadequate due to fish distribution and behaviour and/or drift ice. Lately, the main autumn survey has been further delayed and carried out in late October and November in order to reduce the risk of having to repeat autumn stock assessments. Norwegian participation in the autumn surveys continued uninterrupted until 1984. After that Norwegian research activity in the above area has been centred around capelin migrations and hydrographic measurements in the Iceland Sea in summer (July-August).

As mentioned above, an estimate of adult capelin abundance can usually be obtained in January/February, when that part of the stock has segregated from the juveniles and is distributed in areas of relatively small geographical extension. From the beginning of these surveys in the winter of 1979 until the mid-1980s it was considered necessary to re-assess this part of the stock for comparison with the autumn estimate(s) and the large catches, often taken in the period mid-October until the end of January. Since 1979 such mid-winter assessments have indeed been carried out annually, with the exception of 1986 and 1988, when it was not considered necessary due to the late but apparently reliable estimates of stock abundance obtained in the fall of 1985 and 1987. Furthermore, the January survey of 1993 failed to register but part of the spawning migration because of adverse weather conditions.

Two slightly different strategies, one for the autumn surveys and another for the winter surveys, have been followed in measuring adult capelin stock abundance.

Experience has shown that spatial variations in the the maximum distribution of the maturing stock in autumn are so large that the possible distribution area can not be covered effectively because of the usual constraints imposed, mainly by variable weather conditions and drift ice. In order to cover the current distribution area within the time limits set by available vessel-time, a non-random survey track of parallel transects, arranged as described above and spaced about 15 - 20 naut. miles apart, has been adopted. Furthermore, in the light of information from past surveys and fishing activities, it is sometimes possible to determine the approximate area of stock distribution in advance. When this is not possible the usual procedure is somewhat different. After having located some part of the distribution area, usually between Northwest Iceland and Greenland, the necessary length of each transect can be determined in view of the existing hydrographic situation. This often allows

the exclusion of parts of the area with a fair degree of confidence, and thus the running of the survey vessels for extended periods through waters of zero capelin registrations can be avoided. The time thus saved may then be used for running additional transects in areas of very high densities. Otherwise, the pre-determined survey procedure is maintained.

A different strategy is applied for the winter situation proper and is frequently used for the deep water area east and northeast of Iceland in the January/February period. Then the distribution of the maturing stock is often very restricted, densities high and the capelin migrating towards the spawning grounds at considerable speed. Furthermore, periods of good surveying conditions are often few, short and sometimes far between. Under these circumstances a rough pilot survey is usually run in order to establish the location(s) of the spawning stock. After that an abundance estimate can be obtained in a very short time and in more detail than would have been possible without this previous knowledge. In the earlier winter surveys a zig-zag pattern of transects was sometimes used. Like in the autumn surveys, this approach was soon abandoned in favour of parallel transects at approximately right angles to the biomass distribution. Once having found roughly the location of the spawning stock in winter, the predetermined space between transects is one half of that most frequently used in the autumn surveys, i.e. about 10 naut. miles but frequently reduced to 5 naut. miles in areas of high and uneven densities. The spacing of transects during winter assessments of the much more evenly distributed immature stock component is, however, usually 15 - 20 naut. miles apart.

In addition, acoustic abundance estimates have occasionally been obtained in the shallow coastal waters off the eastern south coast. In this area the distribution has become very restricted and the density may be almost one order of magnitude greater than that of the more oceanic areas. On these occasions, parallel transects are run at right angles to the coast as before, but the distance between them often shortened to no more than 2 naut. miles and the echo-integrating intervals to 0.5 naut. miles or less.

9.4 Data creation

The survey results of the autumn and winter acoustic surveys, discussed in section 9.3, were used to construct the capelin recruitment and stock abundance data. The survey results include tables containing estimates of the number, mean weight and biomass of mature and immature capelin in various age and length groups. There is one table for each square and/or region in each survey. Tables 9.4.1 and 9.4.2 are an example of these survey tables as used in the data creation for the Bormicon model.

Lg:	The length division of the survey.
Nr age i:	Number of capelin in each length group and age group i.
Nr mat:	Number of mature capelin in each length group.

Lg	Nr age 1	Nr age 2	...	Nr age n	Nr mat	Total	Wt	Av.vol
				:				
Tot .nr								
Av.len								
Biomass								
Av.vol								

Table 9.4.1: A survey result table containing the estimated number, mean weight and biomass of capelin. There is one table for each square and region in the survey.

Total:	Total number of capelin in each length group.
Wt:	Weight of capelin in each length group.
Av.vol:	Mean weight of capelin in each length group.
Tot. nr:	Total number of capelin in each age group.
Av.len:	Mean length of capelin in each age group.
Biomass:	Total biomass in each age group.
Av.vol:	Average volume in each age group.

Lg	Mw age 1	Mw age 2	...	Mw age n	Mat	Mw Lg	Nr Lg
				:			
Mw age							
Nr age							

Table 9.4.2: A survey result table containing the mean weight (distribution of volume) of each age and length group of capelin. There is one table for each region in the survey.

Lg:	The length division of the survey.
Mw age i:	Mean weight of capelin in each length group and age group i.
Mat:	Mean weight of mature capelin in each length group.
Wt Lg:	Mean weight of capelin in each length group.
Nr Lg:	Number of capelin in each length group.
Wt age:	Mean weight of capelin in each age group.
Nr age:	Number of capelin in each age group.

The estimates of 1-group capelin abundance, measured during the August 1985-1992 surveys, were used to construct the recruitment data, both recruitment in number and mean weight (section 9.4.1 and 9.4.2). The estimates of the capelin stock abundance, measured during the Jan/Feb 1985-1992 surveys, were used to construct the stock abundance data, both in number and mean weight (section 9.4.3 and 9.4.4). ²

²Note that the data obtained from the Jan/Feb surveys are not complete because of unsuccess-

9.4.1 Recruitment in number

The number of 1-group capelin for each Bormicon area in 1985-1992 was found by subtracting the estimated number of 1-group capelin in each length group and survey region from each year's survey results, as well as the squares of each region (table ??).

Lg	Nr reg 1	Nr reg 2	...	Nr reg N
Square	Region			

Table 9.4.3: The data columns subtracted from the results of the acoustic surveys in August (9.4.1).

Lg:	The length division of the survey.
Nr reg i:	Number of 1-group capelin in region i.
Square:	The number of the square.
Region:	The number of the region to which the relevant square belongs to. ³

Then the following formula was used to divide the number of 1-group capelin in each length group on each Bormicon area, the given year.

$$N(l)_{(a_k,y)} = \sum_{j=1}^{Nr_r \text{ in } a_k} \left(\frac{\sum_{i=1}^{Nr_{sq} \text{ in } r_j} p_{sq_i}}{Nr_{sq} \text{ in } r_j} * N(l)_{(r_j,y)} * s_y \right) \quad (9.4.1)$$

$N(l)_{(a_k,y)}$:	Number of 1-group capelin in each length group l in area k the year y.
$Nr_r \text{ in } a_k$:	The number of survey regions that falls within or intersect area k.
$Nr_{sq} \text{ in } r_j$:	The number of squares in region j that falls within or intersect area k.
p_{sq_i} :	Percentage of square i in region j that falls within area k.
$N(l)_{(r_j,y)}$:	Number of 1-group capelin in each length group l in the survey region j the year y.
s_y :	Because of inaccurate survey estimates (underestimated) the results were multiplied with the August estimates of 1-group capelin and divided by the back-calculated number of 1-group capelin on August 1 (see below).

ful surveys due to weather and/or capelin behaviour in the years 1986 and 1990-1991. The Nov/Dec survey in 1987 was used to create the stock abundance data for 1988 (see page 239 in citeVilh:The:94).

³The survey regions for the year 1990 were missing from the results, so the survey squares were obtained from Figure LVI in [55].

$$s_y = \frac{N_{(calc,y)}}{N_{(total,y)}} \quad (9.4.2)$$

- s_y : Scale for the year y .
 $N_{(total,y)}$: Estimated total number of 1-group capelin in the August survey the year y .⁴
 $N_{(calc,y)}$: Back-calculated total number of 1-group capelin before the beginning of the fishery on August 1 the year y .⁵

The final data files, one file for each year, can be found in section 9.5.1.

9.4.2 Recruitment: Mean weight

The mean weight of 1-group capelin for each Bormicon area in 1985-1992 was found by subtracting the estimates of mean weight in each length group and survey region from each year's survey results (table 9.4.4).

Lg	Wt reg 1	Wt reg 2	...	Wt reg N
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Table 9.4.4: The data columns subtracted from the acoustic surveys in August (9.4.1).

- Lg: The length division of the survey.
Wt reg i : Mean weight (av.vol) of 1-group capelin in region i .

Then the following formula was used to get the mean weight of 1-group capelin in each length group for each Bormicon area and year. No scaling was necessary.

$$W(l)_{(a_k,y)} = \frac{\sum_{j=1}^{Nr_{r \text{ in } a_k}} W(l)_{(r_j,y)}}{Nr(l)_{r \text{ in } a_k}} \quad (9.4.3)$$

- $W(l)_{(a_k,y)}$: Mean weight of 1-group capelin in each length group l in area k the year y .
 $Nr(l)_{r \text{ in } a_k}$: The number of survey regions in each length group l that fall within or intersect area k .
 $W(l)_{(r_j,y)}$: Mean weight of 1-group capelin in each length group l in survey region j the year y .

The final data files, one file for each year, can be found in section 9.5.1.

⁴See table XVI on page 278 in [55].

⁵See table 15.6 page 161 in [55].

9.4.3 Stock abundance in number

The capelin stock abundance for each Bormicon area in 1985-1992 was found by subtracting from each year's survey results the estimated number of capelin in each age and length group, the total number in each length group and the total biomass for each survey region (table 9.4.5).

Lg	Nr age 1	Nr age 2	...	Nr age N	Nr mat	Total
			:			
Biomass						X

Square	Region
--------	--------

Square	Total biomass
--------	---------------

Table 9.4.5: The data columns subtracted from the results of the acoustic surveys (9.4.1).

Lg:	The length division of the survey.
Nr age i:	Number of capelin in age group i.
Nr mat:	Number of mature capelin in each length group.
Total:	Total number of capelin in each length group.
Biomass:	Total biomass of each survey region.
Square:	The number of the square.
Region:	The number of the region to which the relevant square belongs to. ⁶
Total biomass:	The total biomass measured in the relevant square.

Then the following formula was used to divide the stock abundance in each age and length group on each Bormicon area, the given year.

$$N(l, a)_{(a_k, y)} = \sum_{j=1}^{Nr_r \text{ in } a_k} \sum_{i=1}^{Nr_{sq} \text{ in } r_j} \left(\frac{B_{sq_i}}{B_{r_j}} * N(l, a)_{(r_j, y)} * p_{sq_i \text{ in } a_k} \right) \quad (9.4.4)$$

$N(l, a)_{(a_k, y)}$:	Number of capelin in each length l and age group a for area k in the year y.
$Nr_r \text{ in } a_k$:	The number of survey regions that fall within or intersect area k.
$Nr_{sq} \text{ in } r_j$:	The number of squares in region j that falls within or intersect area k.
B_{sq_i} :	Total capelin biomass of square i.
B_{r_j} :	Total capelin biomass of the survey region j.
$N(l, a)_{r_j}$:	Number of capelin in each length l and age group a in the survey region j.
$p_{sq_i \text{ in } a_k}$:	Percentage of square i that falls within area k.

At last the stock abundance was divided into mature and immature parts based on the abundance estimates of mature capelin in each survey (column *Nr mat*).

Because of inaccurate survey results in 1985, the acoustic estimates of 2-group capelin in January 1985 were multiplied with the calculated number of 2-group capelin on 1 January, 211.6 billions, divided with the acoustic estimates of 58.7 billions ([55], pages 162 and 278).

The final data files consist of one file for each Bormicon area, maturity stage and year (see section 9.5.2).

9.4.4 Stock abundance: Mean weight

The mean weight of the capelin stock abundance for each Bormicon area in 1985-1992 was obtained by subtracting the estimated mean weight for each age, length group and region, from each years survey results (table 9.4.6). ⁷

Lg	Mw age 1	Mw age2	...	Mw age N
----	----------	---------	-----	----------

Table 9.4.6: The data columns subtracted from the results of the acoustic surveys (9.4.2).

Lg: The length groups of the survey.
 Mw age i: The mean weight of each length group in age group i for each region in the survey.

Then the following formula was used to get the mean weight of capelin in each age and length group for each Bormicon area the given year.

$$W(l, a)_{(a_k, y)} = \frac{\sum_{i=1}^{Nr_{sq \text{ in } a_k}} W(l, a)_{sq_i}}{Nr(l, a)_{sq \text{ in } a_k}} \quad (9.4.5)$$

$W(l, a)_{a_k}$: Mean weight of capelin in each age a and length group l in area k.
 $Nr_{sq \text{ in } a_k}$: The number of squares that fall within or intersect area k.
 $W(l, a)_{reg_{sq_i}}$: Mean weight of capelin in each age a and length group l in square i.
 $Nr(l, a)_{sq \text{ in } a_k}$: The number of squares in each age a and length group l that intersect area k.

The final data files consist of one file for each Bormicon area and year (see section 9.5.2).

⁷The survey results tables used to estimate the mean weight (Distribution of volume, table 9.4.2) where only obtainable for the year 1985, 1986 and 1988. These tables can probably be found on tapes for 1987, 1989-1992.

9.4.5 Tables

Areas	jan	feb	mar	apr	mai	jun	jul	aug	sep	oct	nov	dec
1	0.0	0.0	15.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	23.6	28.0	0.0
3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.7	78.2	97.1	3.2
5	65.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	68.4
6	3.1	19.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8	0.0	53.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9	0.0	92.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	0.0	0.0	47.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	33.0	79.0	52.4	4.8
12	48.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	60.1
13	0.0	0.0	3.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.1	0.0
16	0.0	0.0	0.0	0.0	0.0	0.0	0.0	30.1	47.9	32.3	0.0	0.0

Table 9.4.7: The capelin catch (thous. tonnes) in 1985.

Areas	jan	feb	mar	apr	mai	jun	jul	aug	sep	oct	nov	dec
1	0.0	31.1	6.6	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0	25.4	16.2	0.0
3	8.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.5	40.7	91.3	21.9
5	1.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	36.4
6	77.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7	5.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8	30.3	0.0	1.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9	28.8	59.3	2.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	0.0	33.6	16.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11	5.3	0.0	0.0	0.0	0.0	0.0	0.0	5.1	68.6	43.4	31.9	19.6
12	25.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	27.9
13	0.0	5.5	2.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	13.2	0.0	13.7	4.6	0.0
16	0.0	0.0	0.0	0.0	0.0	0.0	0.0	31.8	52.9	0.0	0.0	0.0

Table 9.4.8: The capelin catch (thous. tonnes) in 1986.

Areas	jan	feb	mar	apr	mai	jun	jul	aug	sep	oct	nov	dec
1	0.0	0.0	78.9	5.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.9	33.6	0.0
3	3.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.6	45.6	39.4
5	2.8	9.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	28.3
6	111.7	34.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8	0.0	72.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9	0.0	61.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	0.0	26.6	62.4	2.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11	5.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.9	8.9	30.5	65.7
12	7.2	5.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	19.9
13	0.0	7.5	1.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.3	14.6	0.0
16	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.1	0.0	0.0	0.0

Table 9.4.9: The capelin catch (thous. tonnes) in 1987.

Areas	jan	feb	mar	apr	mai	jun	jul	aug	sep	oct	nov	dec
1	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	2.8	0.2	0.0
3	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	5.6	29.3	0.0
5	23.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	37.4	19.6
6	51.7	1.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.9	12.4
7	1.6	1.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8	0.0	71.5	4.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9	0.0	132.6	98.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	0.0	0.0	51.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.4	18.6	47.6	0.0
12	132.6	10.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	53.0	65.1
13	0.0	0.4	15.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.5	0.0	0.0	0.0	0.0
16	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.5	1.1	0.0

Table 9.4.10: The capelin catch (thous. tonnes) in 1988.

Areas	jan	feb	mar	apr	mai	jun	jul	aug	sep	oct	nov	dec
1	0.0	0.0	36.7	29.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	27.6	5.3
5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0
6	89.7	6.5	1.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7	1.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8	0.0	0.1	100.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9	0.0	97.6	61.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	0.0	47.6	28.4	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.3	8.5
12	73.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	2.8
13	0.0	27.1	6.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0

Table 9.4.11: The capelin catch (thous. tonnes) in 1989.

Areas	jan	feb	mar	apr	mai	jun	jul	aug	sep	oct	nov	dec
1	0	51.2	34.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.2	19.8	1.5
4	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	4.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.1	19.7	1.4
6	113.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7	2.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8	68.4	9.3	34.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9	5.4	167.7	12.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	0	40.9	3.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.4	7.5	0.6
12	47.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.5	7.5	0.5
13	0	14.7	1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 9.4.12: The capelin catch (thous. tonnes) in 1990.

Areas	jan	feb	mar	apr	mai	jun	jul	aug	sep	oct	nov	dec
1	0	20.7	42.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	0	0.0	19.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.4
4	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	21.6
6	6.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.2
7	2.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9	2.6	32.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	0	57.5	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.2
12	1.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	20.5
13	0.6	12.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15	0	0.0	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 9.4.13: The capelin catch (thous. tonnes) in 1991.

Areas	jan	feb	mar	apr	mai	jun	jul	aug	sep	oct	nov	dec
1	0	67.4	103.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	0	1.8	0.0	0.0	0.0	0.0	0.0	0.0	5.0	0.0	0.0	0.0
3	0	3.3	0.0	0.0	0.0	0.0	0.0	0.0	26.4	31.5	1.8	2.4
4	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	2.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.7	4.5	0.0
6	24.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	15.5	0.9
7	2.5	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8	25.3	2.8	12.8	0.0	0.0	0.0	0.0	0.0	1.1	0.0	0.0	0.0
9	10.2	169.0	27.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	0	60.5	40.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11	0	2.7	0.0	0.0	0.0	0.0	0.0	14.4	3.9	5.2	0.5	0.0
12	11.3	0.0	0.0	0.0	0.0	0.0	11.5	8.6	0.8	2.8	23.3	0.3
13	0	3.8	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16	0	0.0	0.0	0.0	0.0	0.0	24.5	21.5	0.0	0.0	0.0	0.0

Table 9.4.14: The capelin catch (thous. tonnes) in 1992.

Areas	jan	feb	mar	apr	mai	jun	jul	aug	sep	oct	nov	dec
1	0	42.5	68.3	2.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	0	0.0	20.9	0.0	0.0	0.0	0.0	0.0	0.0	10.7	0.1	0.0
3	0.4	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	15.4	2.9	3.0
4	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.0	3.9
6	21.2	1.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.0
7	0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8	9.5	31.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9	0	118.3	6.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	0	75.7	20.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11	0.5	0.0	0.0	0.0	0.0	0.0	4.8	0.0	0.9	11.2	0.7	4.4
12	0.1	0.0	0.0	0.0	0.0	0.0	16.0	0.0	0.0	0.5	0.2	3.1
13	0	8.7	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15	0	0.1	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.0	0.0
16	0	0.0	0.0	0.0	0.0	0.0	112.1	133.3	94.6	1.2	0.0	0.0

Table 9.4.15: The capelin catch (thous. tonnes) in 1993.

9.5 Tables

9.5.1 Recruitment tables

Length	2	3	5	6	11	12	15	16
7	0.0	26.8	245.6	24.1	107.0	151.4	0.0	0.0
7.5	0.0	44.3	645.7	211.7	177.4	457.0	0.0	9.6
8	27.9	296.7	2300.0	593.2	917.1	1563.7	164.0	109.0
8.5	0.0	283.7	3349.6	792.5	1134.8	2248.8	0.0	44.9
9	145.3	1185.4	5713.8	1027.4	3053.5	3707.1	164.0	32.1
9.5	150.2	1234.0	5960.8	953.3	3261.9	3820.2	340.9	0.0
10	408.1	2114.9	3091.7	555.7	3669.9	2005.8	340.9	9.6
10.5	417.4	2114.5	2886.5	459.2	3734.1	1853.9	679.3	29.4
11	468.8	2001.7	1292.4	222.5	3388.4	834.6	2532.3	0.0
11.5	440.7	1755.4	1504.4	173.3	3372.9	937.4	4057.4	0.0
12	103.3	265.2	0.0	0.0	687.0	4.4	2030.0	17.8
12.5	46.9	127.7	0.0	0.0	295.0	0.0	848.4	0.0
13	9.3	8.5	0.0	0.0	60.2	0.0	335.7	0.0
14.5	0.0	0.0	17.4	12.5	0.0	15.0	0.0	0.0
15.5	0.0	0.0	18.6	13.4	0.0	16.1	0.0	0.0

Table 9.5.1: The number of 1-group capelin (millions) in each length group and Bormicon area in 1985.

Length	2	3	5	6	11	12	15	16
6.5	2.7	58.6	15.3	25.1	47.0	67.8	0.0	0.0
7	32.4	701.5	183.7	300.5	563.1	812.8	0.0	0.0
7.5	68.1	1473.4	386.0	631.2	1182.8	1707.3	0.0	0.0
8	195.8	4236.3	1109.7	1814.6	3417.7	4919.9	0.0	69.0
8.5	389.5	8425.4	2207.0	3609.0	6830.0	9806.7	0.0	117.1
9	466.9	9193.7	2392.0	3911.5	7650.6	10635.9	252.4	176.3
9.5	476.0	6315.3	1582.8	2588.3	5946.9	7036.4	1109.4	85.2
10	468.4	4519.2	1083.1	1771.1	4823.6	4813.0	1563.7	72.9
10.5	300.6	2157.0	487.1	796.5	2691.2	2194.3	1210.4	95.0
11	143.1	1103.3	253.2	414.1	1358.1	1160.0	555.2	79.5
11.5	131.2	844.5	185.5	303.3	1116.5	837.6	555.2	34.4
12	106.3	632.2	135.7	221.9	869.9	611.5	464.5	22.6
12.5	42.9	59.5	0.0	0.0	227.8	0.0	242.1	0.0

Table 9.5.2: The number of 1-group capelin (millions) in each length group and Bormicon area in 1986.

Length	2	3	5	6	11	12	15	16
6	4.4	24.0	80.3	17.5	207.6	149.8	46.3	49.8
6.5	36.6	24.0	721.4	157.0	207.6	1247.0	282.4	49.8
7	10.6	176.8	155.9	33.9	1529.0	358.3	181.1	366.5
7.5	84.1	426.1	1543.8	335.9	3684.8	2862.6	866.5	883.1
8	103.0	856.7	1785.4	388.4	7408.3	3499.2	1256.6	1775.5
8.5	92.9	1598.1	1355.4	294.9	13819.8	3147.5	1616.9	3312.1
9	64.4	1964.5	674.1	146.7	16988.3	2171.5	1622.3	4071.5
9.5	79.6	1560.1	1103.2	240.0	13491.4	2696.3	1497.5	3233.4
10	58.6	898.8	889.1	193.4	7772.6	1987.2	956.1	1862.8
10.5	14.2	369.5	168.1	36.6	3194.9	479.1	320.3	765.7
11	11.3	380.2	107.7	23.4	3287.4	381.3	305.6	787.9
11.5	3.0	186.3	3.0	0.6	1611.1	101.6	131.4	386.1
12	0.7	42.8	0.0	0.0	370.0	22.2	29.9	88.7
12.5	0.0	2.0	0.0	0.0	17.0	1.0	1.4	4.1

Table 9.5.3: The number of 1-group capelin (millions) in each length group and Bormicon area in 1987.

Length	2	3	5	6	11	12	15
6.5	2.7	37.0	22.7	14.0	24.1	26.0	0.0
7	46.2	625.6	2697.3	1655.6	406.8	3088.0	0.0
7.5	108.6	976.0	3849.6	2362.8	678.9	4407.1	74.7
8	335.6	2045.8	4893.2	3003.4	1553.9	5601.8	378.1
8.5	584.7	1907.6	2353.6	1444.6	1778.5	2694.4	909.9
9	912.6	2800.7	436.1	267.7	2676.9	499.2	1447.2
9.5	970.6	2402.7	116.2	71.3	2524.2	133.1	1626.4
10	967.2	1556.3	67.8	41.6	2045.5	77.6	1747.6
10.5	615.7	1095.0	22.7	14.0	1360.6	26.0	1096.8
11	276.7	532.4	0.0	0.0	634.1	0.0	486.8
11.5	61.1	187.2	0.0	0.0	179.0	0.0	96.9
12	7.2	25.9	0.0	0.0	23.2	0.0	10.8
12.5	0.9	12.4	0.0	0.0	8.1	0.0	0.0
13	3.8	0.7	0.0	0.0	5.0	0.0	7.6
13.5	3.5	5.7	0.0	0.0	7.5	0.0	6.4
15	0.9	12.4	0.0	0.0	8.1	0.0	0.0

Table 9.5.4: The number of 1-group capelin (millions) in each length group and Bormicon area in 1988.

Length	2	3	4	5	6	11	12	15
7.5	13.6	62.8	10.5	56.9	40.4	71.6	54.2	0.0
8	9.8	59.2	7.5	212.5	151.1	72.6	202.4	0.0
8.5	235.3	1059.2	181.0	690.0	490.6	1199.7	657.4	0.0
9	698.1	3025.0	537.0	609.6	433.5	3383.0	580.9	0.0
9.5	1412.5	5916.1	1061.9	331.6	235.8	6590.3	316.0	24.3
10	1588.0	6193.5	1110.8	235.7	167.6	6899.3	224.6	82.0
10.5	1080.9	3875.0	696.6	43.7	31.1	4313.1	41.6	51.2
11	403.4	1330.8	238.8	20.4	14.5	1482.0	19.5	26.8
11.5	333.9	1176.4	211.0	48.0	34.1	1310.4	45.7	15.2
12	0.0	1.5	0.0	17.8	12.7	2.2	17.0	0.0
13.5	7.5	32.2	5.8	0.0	0.0	35.8	0.0	0.0

Table 9.5.5: The number of 1-group capelin (millions) in each length group and Bormicon area in 1989.

Length	2	3	5	6	11	12	15
6.5	5.6	12.3	2.6	2.8	13.0	2.9	6.3
7.5	29.0	63.3	13.5	14.2	67.1	14.9	32.2
8	201.7	439.8	93.7	98.6	465.9	103.5	223.8
8.5	815.1	1777.7	378.7	398.6	1883.3	418.5	904.8
9	1588.3	3463.9	737.8	776.7	3669.7	815.5	1763.0
9.5	2563.9	5591.6	1191.0	1253.7	5923.9	1316.4	2846.0
10	3439.9	7502.2	1598.0	1682.1	7947.9	1766.2	3818.4
10.5	2413.8	5264.4	1121.3	1180.4	5577.2	1239.4	2679.4
11	1742.7	3800.8	809.6	852.2	4026.6	894.8	1934.5
11.5	1168.8	2549.1	543.0	571.5	2700.6	600.1	1297.4
12	472.3	1030.0	219.4	230.9	1091.2	242.5	524.2
12.5	166.6	363.3	77.4	81.5	384.9	85.5	184.9

Table 9.5.6: The number of 1-group capelin (millions) in each length group and Bormicon area in 1990.

Length	2	3	5	6	11	12	15
7.5	0.0	0.0	8.1	9.0	0.0	0.9	2010.9
8	0.0	0.0	33.6	37.3	0.0	3.7	3014.8
8.5	0.0	0.0	583.5	648.4	0.0	64.8	5028.6
9	0.0	0.0	2950.0	3277.7	0.0	327.8	7541.5
9.5	0.0	185.2	5847.5	6497.2	0.0	649.7	10057.3
10	0.0	791.8	5657.9	6286.5	0.0	628.7	6032.6
10.5	28.7	1270.7	6814.2	7571.3	132.9	757.1	5048.5
11	25.1	1269.5	3983.9	4426.6	116.3	442.7	9569.7
11.5	38.1	1037.9	1332.5	1480.5	176.5	148.1	10083.6
12	11.7	329.7	835.0	927.7	54.0	92.8	9058.4
12.5	6.3	94.8	0.0	0.0	29.1	0.0	7545.8
13	0.0	92.6	0.0	0.0	0.0	0.0	2512.8
13.5	0.0	0.0	0.0	0.0	0.0	0.0	2010.9
14	5.4	1.8	0.0	0.0	24.9	0.0	505.7
14.5	17.9	6.1	0.0	0.0	83.1	0.0	12.4

Table 9.5.7: The number of 1-group capelin (millions) in each length group and Bormicon area in 1991.

Length	2	3	5	6	11	12	15	16
7	0.0	1.7	1.4	1.0	1.7	1.4	0.0	0.0
7.5	0.0	2.0	1.8	1.7	2.0	1.8	0.0	2.0
8	1.0	1.3	2.0	2.0	1.3	2.0	1.0	2.0
8.5	0.0	2.0	2.0	2.0	2.0	2.0	0.0	2.5
9	1.9	2.3	2.8	2.7	2.3	2.8	2.0	3.3
9.5	2.4	2.6	3.2	3.1	2.6	3.2	2.0	0.0
10	3.2	3.5	4.0	4.0	3.5	4.0	3.0	5.0
10.5	3.6	4.1	4.8	4.6	4.1	4.5	3.3	4.5
11	4.9	5.1	5.2	4.8	5.1	5.2	5.0	0.0
11.5	5.4	5.6	6.0	5.9	6.0	6.3	5.5	7.0
12	6.7	6.7	0.0	0.0	7.1	8.0	7.0	8.0
12.5	8.0	8.0	0.0	0.0	8.0	0.0	8.2	0.0
13	9.1	9.1	0.0	0.0	9.1	0.0	9.1	0.0
14.5	0.0	0.0	14.6	14.6	0.0	14.6	0.0	0.0
15.5	0.0	0.0	16.9	16.9	0.0	16.9	0.0	0.0

Table 9.5.8: The mean weight (gr) of 1-group capelin in each Bormicon area in 1985.

Length	2	3	5	6	11	12	15	16
6.5	1.0	1.0	1.0	1.0	1.0	1.0	0.0	0.0
7	1.0	1.0	1.0	1.0	1.0	1.0	0.0	0.0
7.5	2.0	2.0	2.0	2.0	2.0	2.0	0.0	0.0
8	2.3	2.3	2.3	2.3	2.2	2.2	0.0	2.0
8.5	2.5	2.5	2.5	2.5	2.2	2.2	0.0	2.5
9	2.9	2.9	2.9	2.9	3.0	2.9	3.0	3.5
9.5	3.1	3.1	3.1	3.1	3.0	3.1	3.0	3.5
10	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.5
10.5	4.9	4.9	4.7	4.7	4.8	4.8	5.0	4.9
11	5.8	5.8	5.7	5.7	5.9	5.9	5.9	6.0
11.5	6.2	6.2	5.6	5.6	6.1	5.8	6.8	6.0
12	7.4	7.4	6.9	6.9	7.2	7.0	7.8	7.0
12.5	7.0	7.0	0.0	0.0	7.0	0.0	7.0	0.0

Table 9.5.9: The mean weight (gr) of 1-group capelin in each Bormicon area in 1986.

Length	2	3	5	6	11	12	15	16
6	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
6.5	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
7	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
7.5	2.0	1.9	2.0	2.0	1.9	2.0	2.0	1.9
8	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
8.5	2.9	2.8	3.0	3.0	2.8	2.9	2.9	2.8
9	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
9.5	3.4	3.2	3.5	3.5	3.2	3.4	3.4	3.2
10	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
10.5	4.9	4.8	5.0	5.0	4.8	4.9	4.9	4.8
11	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0
11.5	6.0	6.1	6.0	6.0	6.1	6.0	6.0	6.1
12	6.9	6.9	0.0	0.0	6.9	6.9	6.9	6.9
12.5	8.2	8.2	0.0	0.0	8.2	8.2	8.2	8.2

Table 9.5.10: The mean weight (gr) of 1-group capelin in each Bormicon area in 1987.

Length	2	3	5	6	11	12	15
6.5	1.0	1.0	1.0	1.0	1.0	1.0	0.0
7	1.0	1.0	1.0	1.0	1.0	1.0	0.0
7.5	1.3	1.3	1.4	1.4	1.3	1.4	1.0
8	2.1	2.1	2.0	2.0	2.1	2.0	2.0
8.5	2.4	2.4	2.0	2.0	2.4	2.0	2.4
9	3.0	3.0	2.5	2.5	3.0	2.5	3.0
9.5	3.8	3.8	3.0	3.0	3.8	3.0	3.8
10	4.2	4.2	4.0	4.0	4.2	4.0	4.1
10.5	5.0	5.0	4.0	4.0	5.0	4.0	4.9
11	6.0	6.0	0.0	0.0	6.0	0.0	6.1
11.5	7.0	7.0	0.0	0.0	7.0	0.0	7.1
12	8.4	8.4	0.0	0.0	8.4	0.0	8.4
12.5	9.5	9.5	0.0	0.0	9.5	0.0	0.0
13	11.2	11.2	0.0	0.0	11.2	0.0	11.2
13.5	12.6	12.6	0.0	0.0	12.6	0.0	12.9
15	15.6	15.6	0.0	0.0	15.6	0.0	0.0

Table 9.5.11: The mean weight (gr) of 1-group capelin in each Bormicon area in 1988.

Length	2	3	4	5	6	11	12	15
7.5	1.0	1.2	1.0	1.3	1.3	1.2	1.3	0.0
8	2.0	2.0	2.0	2.0	2.0	2.0	2.0	0.0
8.5	2.1	2.1	2.1	2.0	2.0	2.1	2.0	0.0
9	2.9	2.4	2.9	2.0	2.0	2.4	2.0	0.0
9.5	3.0	2.9	3.0	2.8	2.8	2.9	2.8	3.0
10	3.2	3.2	3.3	3.0	3.0	3.2	3.0	3.2
10.5	4.0	4.0	4.0	3.9	3.9	4.0	3.9	4.0
11	5.0	4.9	5.0	4.7	4.7	4.9	4.7	5.0
11.5	6.0	5.8	6.0	5.3	5.3	5.8	5.3	6.0
12	0.0	7.0	0.0	7.0	7.0	7.0	7.0	0.0
13.5	10.1	10.1	10.1	0.0	0.0	10.1	0.0	0.0

Table 9.5.12: The mean weight (gr) of 1-group capelin in each Bormicon area in 1989.

Length	2	3	5	6	11	12	15
6.5	1.0	1.0	1.0	1.0	1.0	1.0	1.0
7.5	1.4	1.4	1.4	1.4	1.4	1.4	1.4
8	2.0	2.0	2.0	2.0	2.0	2.0	2.0
8.5	2.3	2.3	2.3	2.3	2.3	2.3	2.3
9	2.9	2.9	2.9	2.9	2.9	2.9	2.9
9.5	3.1	3.1	3.1	3.1	3.1	3.1	3.1
10	3.9	3.9	3.9	3.9	3.9	3.9	3.9
10.5	4.4	4.4	4.4	4.4	4.4	4.4	4.4
11	5.1	5.1	5.1	5.1	5.1	5.1	5.1
11.5	5.8	5.8	5.8	5.8	5.8	5.8	5.8
12	6.6	6.6	6.6	6.6	6.6	6.6	6.6
12.5	7.0	7.0	7.0	7.0	7.0	7.0	7.0

Table 9.5.13: The mean weight (gr) of 1-group capelin in each Bormicon area in 1990.

Length	2	3	5	6	11	12	15
7.5	0.0	0.0	1.0	1.0	0.0	1.0	2.0
8	0.0	0.0	1.6	1.6	0.0	1.6	1.8
8.5	0.0	0.0	2.0	2.0	0.0	2.0	2.8
9	0.0	0.0	2.7	2.7	0.0	2.7	3.1
9.5	0.0	4.0	3.0	3.0	0.0	3.0	3.8
10	0.0	4.0	3.5	3.5	0.0	3.5	4.3
10.5	4.8	4.4	4.0	4.0	4.8	4.0	5.2
11	4.8	4.9	5.0	5.0	4.8	5.0	5.6
11.5	6.0	6.4	5.4	5.4	6.0	5.4	6.5
12	6.9	7.4	7.2	7.2	6.9	7.2	7.8
12.5	7.2	8.1	0.0	0.0	7.2	0.0	8.5
13	0.0	10.1	0.0	0.0	0.0	0.0	11.1
13.5	0.0	0.0	0.0	0.0	0.0	0.0	13.1
14	13.0	13.0	0.0	0.0	13.0	0.0	13.5
14.5	14.7	14.7	0.0	0.0	14.7	0.0	14.7

Table 9.5.14: The mean weight (gr) of 1-group capelin in each Bormicon area in 1991.

9.5.2 Abundance tables

Stock abundance 1985

Length	Two	Three
8.5	59.4	0.0
9	487.4	0.0
9.5	873.6	0.0
10	1767.4	0.0
10.5	1234.8	0.0
11	969.2	0.0
11.5	979.9	0.0
12	918.9	0.0
12.5	391.9	22.2
13	63.1	37.8
13.5	60.9	48.6

Table 9.5.15: The number of immature capelin (millions) in each age and length group for Bormicon area 2 in 1985.

Length	Two	Three
8.5	19.0	0.0
9	451.2	0.0
9.5	832.1	0.0
10	2027.7	14.6
10.5	2050.7	0.0
11	6528.4	0.0
11.5	7076.2	0.0
12	6108.5	0.0
12.5	7532.2	581.9
13	1401.5	1992.2
13.5	1236.9	3598.2

Table 9.5.16: The number of immature capelin (millions) in each age and length group for Bormicon area 3 in 1985.

Length	Two	Three
8.5	0.0	0.0
9	0.0	0.0
9.5	0.0	0.0
10	0.0	0.0
10.5	0.0	0.0
11	0.0	0.0
11.5	0.0	0.0
12	0.0	0.0
12.5	0.0	0.0
13	4.8	0.0
13.5	0.0	6.3

Table 9.5.17: The number of immature capelin (millions) in each age and length group for Bormicon area 5 in 1985.

Length	Two	Three
8.5	0.0	0.0
9	0.0	0.0
9.5	0.0	0.0
10	0.0	0.0
10.5	0.0	0.0
11	0.0	0.0
11.5	0.0	0.0
12	0.0	0.0
12.5	0.0	24.8
13	2.9	66.4
13.5	0.0	216.9

Table 9.5.18: The number of immature capelin (millions) in each age and length group for Bormicon area 6 in 1985.

Length	Two	Three
8.5	0.0	0.0
9	0.0	0.0
9.5	0.0	0.0
10	0.0	0.0
10.5	0.0	0.0
11	0.0	0.0
11.5	0.0	0.0
12	0.0	0.0
12.5	0.0	2.0
13	0.0	5.4
13.5	0.0	17.2

Table 9.5.19: The number of immature capelin (millions) in each age and length group for Bormicon area 7 in 1985.

Length	Two	Three
8.5	313.1	0.0
9	2634.7	0.0
9.5	4726.7	0.0
10	9637.8	3.3
10.5	6870.5	0.0
11	6457.0	0.0
11.5	6631.1	0.0
12	6104.6	0.0
12.5	3669.6	241.5
13	631.7	627.7
13.5	584.6	1031.5

Table 9.5.20: The number of immature capelin (millions) in each age and length group for Bormicon area 11 in 1985.

Length	Two	Three
8.5	0.0	0.0
9	0.0	0.0
9.5	0.0	0.0
10	0.0	0.0
10.5	0.0	0.0
11	0.0	0.0
11.5	0.0	0.0
12	0.0	0.0
12.5	0.0	7.2
13	24.7	19.3
13.5	0.0	94.6

Table 9.5.21: The number of immature capelin (millions) in each age and length group for Bormicon area 12 in 1985.

Length	Two	Three
8.5	906.0	0.0
9	7429.4	0.0
9.5	13313.5	0.0
10	26924.0	0.0
10.5	18787.4	0.0
11	14569.4	0.0
11.5	14712.8	0.0
12	13816.9	0.0
12.5	5715.5	318.4
13	913.6	505.5
13.5	885.9	613.0

Table 9.5.22: The number of immature capelin (millions) in each age and length group for Bormicon area 15 in 1985.

Length	Two	Three	Four	Five
14	0.5	53.4	0.0	0.0
14.5	43.0	27.4	0.0	0.0
15	12.2	6.6	0.1	0.0
15.5	0.0	4.3	0.0	0.0
16	0.0	0.1	0.0	0.0
16.5	0.0	0.0	0.0	0.0
17	0.0	0.0	0.0	0.0
17.5	0.0	0.0	0.0	0.0
18	0.0	0.0	0.0	0.0
18.5	0.0	0.0	0.0	0.0
19	0.0	0.0	0.0	0.0
19.5	0.0	0.0	0.0	0.0
20	0.0	0.0	0.0	0.0

Table 9.5.23: The number of mature capelin (millions) in each age and length group for Bormicon area 2 in 1985.

Length	Two	Three	Four	Five
14	196.2	2248.0	0.0	0.0
14.5	634.2	1786.7	0.0	0.0
15	205.8	1398.5	55.2	0.0
15.5	0.0	443.8	0.0	0.0
16	0.0	60.1	0.0	0.0
16.5	0.0	0.0	0.0	0.0
17	0.0	0.0	0.0	0.0
17.5	0.0	0.0	0.0	0.0
18	0.0	0.0	0.0	0.0
18.5	0.0	0.0	0.0	0.0
19	0.0	0.0	0.0	0.0
19.5	0.0	0.0	0.0	0.0
20	0.0	0.0	0.0	0.0

Table 9.5.24: The number of mature capelin (millions) in each age and length group for Bormicon area 3 in 1985.

Length	Two	Three	Four	Five
14	50.4	74.5	0.0	0.0
14.5	34.0	175.8	9.4	0.0
15	36.6	183.9	25.6	0.0
15.5	0.0	201.4	45.5	0.0
16	0.0	278.1	66.4	0.0
16.5	0.0	282.5	79.7	7.2
17	0.0	187.3	203.5	0.0
17.5	0.0	128.4	229.4	0.0
18	0.0	32.1	170.8	0.0
18.5	0.0	14.6	88.3	0.0
19	0.0	0.0	71.0	0.0
19.5	0.0	0.0	18.6	0.0
20	0.0	0.0	18.6	0.0

Table 9.5.25: The number of mature capelin (millions) in each age and length group for Bormicon area 5 in 1985.

Length	Two	Three	Four	Five
14	31.1	565.4	0.0	0.0
14.5	21.0	1120.3	5.8	0.0
15	22.6	1180.0	122.3	0.0
15.5	0.0	1053.6	101.8	0.0
16	0.0	1319.1	281.7	0.0
16.5	0.0	1020.6	550.3	4.5
17	0.0	869.1	601.2	0.0
17.5	0.0	622.7	740.5	0.0
18	0.0	366.3	691.9	27.0
18.5	0.0	130.8	536.7	29.9
19	0.0	0.0	173.6	0.0
19.5	0.0	35.7	120.9	0.0
20	0.0	0.0	36.3	0.0

Table 9.5.26: The number of mature capelin (millions) in each age and length group for Bormicon area 6 in 1985.

Length	Two	Three	Four	Five
14	0.0	41.9	0.0	0.0
14.5	0.0	81.7	0.0	0.0
15	0.0	86.1	8.6	0.0
15.5	0.0	75.0	5.9	0.0
16	0.0	92.6	19.4	0.0
16.5	0.0	68.3	40.4	0.0
17	0.0	60.8	38.4	0.0
17.5	0.0	43.9	48.3	0.0
18	0.0	28.0	47.3	2.2
18.5	0.0	9.8	38.9	2.4
19	0.0	0.0	10.5	0.0
19.5	0.0	2.9	8.8	0.0
20	0.0	0.0	2.0	0.0

Table 9.5.27: The number of mature capelin (millions) in each age and length group for Bormicon area 7 in 1985.

Length	Two	Three	Four	Five
14	44.9	764.2	0.0	0.0
14.5	361.1	529.3	0.0	0.0
15	107.9	337.1	12.6	0.0
15.5	0.0	118.6	0.0	0.0
16	0.0	13.7	0.0	0.0
16.5	0.0	0.0	0.0	0.0
17	0.0	0.0	0.0	0.0
17.5	0.0	0.0	0.0	0.0
18	0.0	0.0	0.0	0.0
18.5	0.0	0.0	0.0	0.0
19	0.0	0.0	0.0	0.0
19.5	0.0	0.0	0.0	0.0
20	0.0	0.0	0.0	0.0

Table 9.5.28: The number of mature capelin (millions) in each age and length group for Bormicon area 11 in 1985.

Length	Two	Three	Four	Five
14	260.9	536.3	0.0	0.0
14.5	175.8	1203.4	48.8	0.0
15	189.5	1261.2	163.5	0.0
15.5	0.0	1312.0	256.8	0.0
16	0.0	1772.3	413.5	0.0
16.5	0.0	1707.7	557.6	37.3
17	0.0	1187.9	1191.0	0.0
17.5	0.0	822.1	1360.9	0.0
18	0.0	266.7	1054.1	7.8
18.5	0.0	110.8	597.1	8.7
19	0.0	0.0	404.9	0.0
19.5	0.0	10.4	127.8	0.0
20	0.0	0.0	103.2	0.0

Table 9.5.29: The number of mature capelin (millions) in each age and length group for Bormicon area 12 in 1985.

Length	Two	Three	Four	Five
14	0.0	734.5	0.0	0.0
14.5	634.2	354.7	0.0	0.0
15	178.7	51.0	0.0	0.0
15.5	0.0	50.3	0.0	0.0
16	0.0	0.0	0.0	0.0
16.5	0.0	0.0	0.0	0.0
17	0.0	0.0	0.0	0.0
17.5	0.0	0.0	0.0	0.0
18	0.0	0.0	0.0	0.0
18.5	0.0	0.0	0.0	0.0
19	0.0	0.0	0.0	0.0
19.5	0.0	0.0	0.0	0.0
20	0.0	0.0	0.0	0.0

Table 9.5.30: The number of mature capelin (millions) in each age and length group for Bormicon area 15 in 1985.

Length	Two	Three	Four	Five
8.5	2.0	0.0	0.0	0.0
9	2.2	0.0	0.0	0.0
9.5	3.0	0.0	0.0	0.0
10	3.0	7.0	0.0	0.0
10.5	4.0	0.0	0.0	0.0
11	4.6	0.0	0.0	0.0
11.5	5.0	0.0	0.0	0.0
12	6.1	0.0	0.0	0.0
12.5	7.2	7.0	0.0	0.0
13	8.4	8.2	0.0	0.0
13.5	9.7	9.5	0.0	0.0
14	10.0	11.0	0.0	0.0
14.5	12.0	12.3	0.0	0.0
15	15.0	13.8	14.0	0.0
15.5	0.0	16.4	0.0	0.0
16	0.0	18.0	0.0	0.0

Table 9.5.31: The mean weight of capelin (gr) in each age and length group for Bormicon area 2 in 1985.

Length	Two	Three	Four	Five
13.5	0.0	9.5	0.0	0.0
14	12.0	11.6	0.0	0.0
14.5	13.0	13.4	13.5	0.0
15	15.0	15.0	17.2	0.0
15.5	0.0	16.9	17.8	0.0
16	0.0	18.5	18.4	0.0
16.5	0.0	22.2	22.9	23.0
17	0.0	24.5	24.6	0.0
17.5	0.0	27.1	27.1	0.0
18	0.0	31.7	29.8	0.0
18.5	0.0	33.0	32.2	0.0
19	0.0	0.0	36.3	0.0
19.5	0.0	0.0	40.0	0.0
20	0.0	0.0	41.0	0.0

Table 9.5.33: The mean weight of capelin (gr) in each age and length group for Bormicon area 5 in 1985.

Length	Two	Three	Four	Five
8.5	2.0	0.0	0.0	0.0
9	2.2	0.0	0.0	0.0
9.5	3.0	0.0	0.0	0.0
10	3.0	7.0	0.0	0.0
10.5	4.0	0.0	0.0	0.0
11	4.6	0.0	0.0	0.0
11.5	5.0	0.0	0.0	0.0
12	6.1	0.0	0.0	0.0
12.5	7.2	7.0	0.0	0.0
13	8.4	8.2	0.0	0.0
13.5	9.7	9.5	0.0	0.0
14	10.0	11.0	0.0	0.0
14.5	12.0	12.3	0.0	0.0
15	15.0	13.8	14.0	0.0
15.5	0.0	16.4	0.0	0.0
16	0.0	18.0	0.0	0.0

Table 9.5.32: The mean weight of capelin (gr) in each age and length group for Bormicon area 3 in 1985.

Length	Two	Three	Four	Five
12.5	0.0	12.0	0.0	0.0
13	10.0	9.0	0.0	0.0
13.5	0.0	10.5	0.0	0.0
14	12.0	11.6	0.0	0.0
14.5	13.0	13.5	13.5	0.0
15	15.0	15.2	16.2	0.0
15.5	0.0	16.6	17.0	0.0
16	0.0	18.9	18.7	0.0
16.5	0.0	22.0	22.4	23.0
17	0.0	24.2	23.8	0.0
17.5	0.0	26.8	27.0	0.0
18	0.0	31.2	30.4	27.0
18.5	0.0	33.5	33.6	33.0
19	0.0	0.0	37.6	0.0
19.5	0.0	14.0	39.8	0.0
20	0.0	0.0	43.0	0.0

Table 9.5.34: The mean weight of capelin (gr) in each age and length group for Bormicon area 6 in 1985.

Length	Two	Three	Four	Five
12.5	0.0	12.0	0.0	0.0
13	0.0	9.0	0.0	0.0
13.5	0.0	11.5	0.0	0.0
14	0.0	11.7	0.0	0.0
14.5	0.0	13.6	0.0	0.0
15	0.0	15.3	15.3	0.0
15.5	0.0	16.4	16.3	0.0
16	0.0	19.3	19.0	0.0
16.5	0.0	21.8	21.9	0.0
17	0.0	24.0	23.0	0.0
17.5	0.0	26.6	27.0	0.0
18	0.0	30.6	30.9	27.0
18.5	0.0	34.0	35.1	33.0
19	0.0	0.0	39.0	0.0
19.5	0.0	14.0	39.7	0.0
20	0.0	0.0	45.0	0.0

Table 9.5.35: The mean weight of capelin (gr) in each age and length group for Bormicon area 7 in 1985.

Length	Two	Three	Four	Five
12.5	0.0	12.0	0.0	0.0
13	10.0	9.0	0.0	0.0
13.5	0.0	10.5	0.0	0.0
14	12.0	11.6	0.0	0.0
14.5	13.0	13.5	13.5	0.0
15	15.0	15.2	16.2	0.0
15.5	0.0	16.6	17.0	0.0
16	0.0	18.9	18.7	0.0
16.5	0.0	22.0	22.4	23.0
17	0.0	24.2	23.8	0.0
17.5	0.0	26.8	27.0	0.0
18	0.0	31.2	30.4	27.0
18.5	0.0	33.5	33.6	33.0
19	0.0	0.0	37.6	0.0
19.5	0.0	14.0	39.8	0.0
20	0.0	0.0	43.0	0.0

Table 9.5.37: The mean weight of capelin (gr) in each age and length group for Bormicon area 12 in 1985.

Length	Two	Three	Four	Five
8.5	2.0	0.0	0.0	0.0
9	2.2	0.0	0.0	0.0
9.5	3.0	0.0	0.0	0.0
10	3.0	7.0	0.0	0.0
10.5	4.0	0.0	0.0	0.0
11	4.6	0.0	0.0	0.0
11.5	5.0	0.0	0.0	0.0
12	6.1	0.0	0.0	0.0
12.5	7.2	7.0	0.0	0.0
13	8.4	8.2	0.0	0.0
13.5	9.7	9.5	0.0	0.0
14	10.0	11.0	0.0	0.0
14.5	12.0	12.3	0.0	0.0
15	15.0	13.8	14.0	0.0
15.5	0.0	16.4	0.0	0.0
16	0.0	18.0	0.0	0.0

Table 9.5.36: The mean weight of capelin (gr) in each age and length group for Bormicon area 11 in 1985.

Length	Two	Three	Four	Five
8.5	2.0	0.0	0.0	0.0
9	2.4	0.0	0.0	0.0
9.5	3.0	0.0	0.0	0.0
10	3.1	0.0	0.0	0.0
10.5	4.0	0.0	0.0	0.0
11	4.6	0.0	0.0	0.0
11.5	5.2	0.0	0.0	0.0
12	6.0	0.0	0.0	0.0
12.5	7.3	7.0	0.0	0.0
13	8.8	7.9	0.0	0.0
13.5	10.0	9.5	0.0	0.0
14	0.0	10.9	0.0	0.0
14.5	12.7	12.0	0.0	0.0
15	16.0	14.0	0.0	0.0
15.5	0.0	17.0	0.0	0.0

Table 9.5.38: The mean weight of capelin (gr) in each age and length group for Bormicon area 15 in 1985.

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Length	Two	Three
8.5	3.5	0.0
9	3.5	0.0
9.5	56.1	0.0
10	66.4	0.0
10.5	356.7	0.0
11	272.4	0.0
11.5	408.6	0.0
12	352.4	35.1
12.5	59.9	279.5
13	0.0	494.8
13.5	39.6	701.7
14	38.8	682.2
14.5	15.0	553.8
15	38.2	411.3

Table 9.5.39: The number of immature capelin (millions) in each length group for Bormicon area 2 in 1986.

Length	Two	Three
8.5	10.2	0.0
9	48.7	0.0
9.5	170.1	0.0
10	445.3	0.0
10.5	1069.5	0.0
11	796.8	0.0
11.5	711.8	0.0
12	353.6	135.2
12.5	140.7	403.7
13	62.4	499.9
13.5	39.7	556.5
14	28.6	350.6
14.5	6.2	286.6
15	0.0	144.7

Table 9.5.41: The number of immature capelin (millions) in each length group for Bormicon area 5 in 1986.

Length	Two	Three
8.5	9.4	0.0
9	12.7	0.0
9.5	2197.1	0.0
10	5146.7	0.0
10.5	6662.3	0.0
11	5475.6	0.0
11.5	3951.9	0.0
12	2164.5	395.7
12.5	678.3	1613.4
13	126.0	2340.7
13.5	147.0	2794.4
14	142.5	2287.5
14.5	67.1	1686.8
15	93.8	1126.6

Table 9.5.40: The number of immature capelin (millions) in each length group for Bormicon area 3 in 1986.

Length	Two	Three
8.5	27.9	0.0
9	132.7	0.0
9.5	464.0	0.0
10	1214.6	0.0
10.5	2917.2	0.0
11	2173.4	0.0
11.5	1941.6	0.0
12	964.5	368.8
12.5	383.7	1101.1
13	170.2	1363.6
13.5	108.2	1518.0
14	77.9	956.4
14.5	16.8	781.8
15	0.0	394.8

Table 9.5.42: The number of immature capelin (millions) in each length group for Bormicon area 6 in 1986.

Length	Two	Three
8.5	23.0	0.0
9	28.0	0.0
9.5	1294.0	0.0
10	2700.6	0.0
10.5	4932.6	0.0
11	3939.7	0.0
11.5	3945.5	0.0
12	2819.0	371.1
12.5	626.3	2200.4
13	62.5	3643.4
13.5	273.6	4916.4
14	266.1	4569.2
14.5	108.1	3632.8
15	238.6	2634.7

Table 9.5.43: The number of immature capelin (millions) in each length group for Bormicon area 11 in 1986.

Length	Two	Three
8.5	17.7	0.0
9	84.1	0.0
9.5	294.1	0.0
10	769.8	0.0
10.5	1849.0	0.0
11	1377.5	0.0
11.5	1230.6	0.0
12	611.4	233.8
12.5	243.2	697.9
13	107.9	864.3
13.5	68.6	962.1
14	49.4	606.2
14.5	10.7	495.5
15	0.0	250.2

Table 9.5.44: The number of immature capelin (millions) in each length group for Bormicon area 12 in 1986.

Length	Two	Three
8.5	2.3	0.0
9	2.3	0.0
9.5	37.4	0.0
10	44.2	0.0
10.5	237.7	0.0
11	181.5	0.0
11.5	272.3	0.0
12	234.9	23.4
12.5	39.9	186.3
13	0.0	329.7
13.5	26.4	467.6
14	25.8	454.6
14.5	10.0	369.1
15	25.5	274.1

Table 9.5.45: The number of immature capelin (millions) in each length group for Bormicon area 15 in 1986.

Length	Two	Three	Four	Five
15.5	7.3	243.7	7.3	0.0
16	0.0	134.1	6.5	0.0
16.5	7.3	117.8	58.9	7.2
17	7.1	88.0	29.2	0.0
17.5	0.0	25.9	34.7	0.0
18	0.0	13.1	53.5	0.0
18.5	0.0	0.0	7.6	0.0

Table 9.5.46: The number of mature capelin (millions) in each length group for Bormicon area 2 in 1986.

Length	Two	Three	Four	Five
15.5	18.0	780.8	18.0	0.0
16	0.0	415.1	16.1	0.0
16.5	18.0	290.8	313.3	17.8
17	17.5	216.5	71.8	0.0
17.5	0.0	63.7	86.4	0.0
18	0.0	32.5	131.8	0.0
18.5	0.0	0.1	18.7	0.0

Table 9.5.47: The number of mature capelin (millions) in each length group for Bormicon area 3 in 1986.

Length	Two	Three	Four	Five
15.5	0.0	74.2	0.0	0.0
16	0.0	28.4	2.8	0.0
16.5	0.0	18.2	4.4	0.0
17	0.0	6.0	0.0	0.0
17.5	0.0	0.0	13.6	0.0
18	0.0	3.7	3.9	0.0
18.5	0.0	1.6	0.0	0.0

Table 9.5.48: The number of mature capelin (millions) in each length group for Bormicon area 5 in 1986.

Length	Two	Three	Four	Five
15.5	0.0	202.4	0.0	0.0
16	0.0	77.4	7.7	0.0
16.5	0.0	49.5	12.0	0.0
17	0.0	16.3	0.0	0.0
17.5	0.0	0.0	37.0	0.0
18	0.0	10.1	10.6	0.0
18.5	0.0	4.3	0.0	0.0

Table 9.5.49: The number of mature capelin (millions) in each length group for Bormicon area 6 in 1986.

Length	Two	Three	Four	Five
15.5	45.8	1611.3	45.8	0.0
16	0.0	878.7	40.7	0.0
16.5	45.8	738.0	444.5	45.2
17	44.6	550.3	182.6	0.0
17.5	0.0	162.1	218.7	0.0
18	0.0	82.4	334.9	0.0
18.5	0.0	0.2	47.6	0.0

Table 9.5.50: The number of mature capelin (millions) in each length group for Bormicon area 11 in 1986.

Length	Two	Three	Four	Five
15.5	0.0	128.3	0.0	0.0
16	0.0	49.1	4.9	0.0
16.5	0.0	31.4	7.6	0.0
17	0.0	10.4	0.0	0.0
17.5	0.0	0.0	23.5	0.0
18	0.0	6.4	6.7	0.0
18.5	0.0	2.7	0.0	0.0

Table 9.5.51: The number of mature capelin (millions) in each length group for Bormicon area 12 in 1986.

Length	Two	Three	Four	Five
15.5	4.9	162.4	4.9	0.0
16	0.0	89.3	4.3	0.0
16.5	4.9	78.5	39.3	4.8
17	4.8	58.6	19.5	0.0
17.5	0.0	17.3	23.1	0.0
18	0.0	8.7	35.7	0.0
18.5	0.0	0.0	5.1	0.0

Table 9.5.52: The number of mature capelin (millions) in each length group for Bormicon area 15 in 1986.

Length	Two	Three	Four	Five
8.5	2.0	0.0	0.0	0.0
9	3.0	0.0	0.0	0.0
9.5	3.0	0.0	0.0	0.0
10	2.9	0.0	0.0	0.0
10.5	3.7	0.0	0.0	0.0
11	4.0	0.0	0.0	0.0
11.5	4.9	0.0	0.0	0.0
12	5.9	6.3	0.0	0.0
12.5	7.2	7.2	0.0	0.0
13	0.0	7.7	0.0	0.0
13.5	9.5	9.2	0.0	0.0
14	11.4	10.9	0.0	0.0
14.5	15.0	12.7	0.0	0.0
15	16.0	15.1	14.7	0.0
15.5	19.0	16.9	19.0	0.0
16	0.0	20.0	22.0	0.0
16.5	25.0	22.9	24.3	18.0
17	28.0	26.3	26.5	0.0
17.5	0.0	29.7	28.5	0.0
18	0.0	37.0	32.4	0.0
18.5	0.0	0.0	36.0	0.0

Table 9.5.53: The mean weight of capelin (gr) in each age and length group for Bormicon area 2 in 1986.

Length	Two	Three	Four	Five
8.5	2.0	0.0	0.0	0.0
9	2.5	0.0	0.0	0.0
9.5	2.9	0.0	0.0	0.0
10	3.0	0.0	0.0	0.0
10.5	3.9	0.0	0.0	0.0
11	4.2	0.0	0.0	0.0
11.5	5.1	0.0	0.0	0.0
12	5.7	6.0	0.0	0.0
12.5	7.0	6.8	0.0	0.0
13	7.6	7.9	0.0	0.0
13.5	9.8	9.3	0.0	0.0
14	10.7	10.9	0.0	0.0
14.5	14.3	12.4	12.0	0.0
15	16.0	14.3	15.6	0.0
15.5	19.0	16.0	19.0	0.0
16	0.0	18.9	19.5	0.0
16.5	25.0	22.4	21.4	18.0
17	28.0	24.2	26.5	0.0
17.5	0.0	29.7	28.4	0.0
18	0.0	31.5	33.2	0.0
18.5	0.0	36.0	36.0	0.0

Table 9.5.54: The mean weight of capelin (gr) in each age and length group for Bormicon area 3 in 1986.

Length	Two	Three	Four	Five
8.5	2.0	0.0	0.0	0.0
9	2.0	0.0	0.0	0.0
9.5	2.6	0.0	0.0	0.0
10	3.0	0.0	0.0	0.0
10.5	3.9	0.0	0.0	0.0
11	4.0	0.0	0.0	0.0
11.5	5.0	0.0	0.0	0.0
12	5.8	5.9	0.0	0.0
12.5	6.8	6.7	0.0	0.0
13	7.7	8.2	0.0	0.0
13.5	9.8	9.4	0.0	0.0
14	10.8	10.7	0.0	0.0
14.5	14.0	12.4	12.0	0.0
15	0.0	14.1	16.0	0.0
15.5	0.0	16.1	0.0	0.0
16	0.0	17.7	17.0	0.0
16.5	0.0	22.0	20.0	0.0
17	0.0	22.0	0.0	0.0
17.5	0.0	0.0	28.3	0.0
18	0.0	26.0	34.0	0.0
18.5	0.0	36.0	0.0	0.0

Table 9.5.55: The mean weight of capelin (gr) in each age and length group for Bormicon area 5 in 1986.

Length	Two	Three	Four	Five
8.5	2.0	0.0	0.0	0.0
9	2.0	0.0	0.0	0.0
9.5	2.6	0.0	0.0	0.0
10	3.0	0.0	0.0	0.0
10.5	3.9	0.0	0.0	0.0
11	4.0	0.0	0.0	0.0
11.5	5.0	0.0	0.0	0.0
12	5.8	5.9	0.0	0.0
12.5	6.8	6.7	0.0	0.0
13	7.7	8.2	0.0	0.0
13.5	9.8	9.4	0.0	0.0
14	10.8	10.7	0.0	0.0
14.5	14.0	12.4	12.0	0.0
15	0.0	14.1	16.0	0.0
15.5	0.0	16.1	0.0	0.0
16	0.0	17.7	17.0	0.0
16.5	0.0	22.0	20.0	0.0
17	0.0	22.0	0.0	0.0
17.5	0.0	0.0	28.3	0.0
18	0.0	26.0	34.0	0.0
18.5	0.0	36.0	0.0	0.0

Table 9.5.56: The mean weight of capelin (gr) in each age and length group for Bormicon area 6 in 1986.

Length	Two	Three	Four	Five
8.5	2.0	0.0	0.0	0.0
9	2.5	0.0	0.0	0.0
9.5	2.9	0.0	0.0	0.0
10	3.0	0.0	0.0	0.0
10.5	3.9	0.0	0.0	0.0
11	4.2	0.0	0.0	0.0
11.5	5.1	0.0	0.0	0.0
12	5.7	6.0	0.0	0.0
12.5	7.0	6.8	0.0	0.0
13	7.6	7.9	0.0	0.0
13.5	9.8	9.3	0.0	0.0
14	10.7	10.9	0.0	0.0
14.5	14.3	12.4	12.0	0.0
15	16.0	14.3	15.6	0.0
15.5	19.0	16.0	19.0	0.0
16	0.0	18.9	19.5	0.0
16.5	25.0	22.4	21.4	18.0
17	28.0	24.2	26.5	0.0
17.5	0.0	29.7	28.4	0.0
18	0.0	31.5	33.2	0.0
18.5	0.0	36.0	36.0	0.0

Table 9.5.57: The mean weight of capelin (gr) in each age and length group for Bormicon area 11 in 1986.

Length	Two	Three	Four	Five
8.5	2.0	0.0	0.0	0.0
9	2.0	0.0	0.0	0.0
9.5	2.6	0.0	0.0	0.0
10	3.0	0.0	0.0	0.0
10.5	3.9	0.0	0.0	0.0
11	4.0	0.0	0.0	0.0
11.5	5.0	0.0	0.0	0.0
12	5.8	5.9	0.0	0.0
12.5	6.8	6.7	0.0	0.0
13	7.7	8.2	0.0	0.0
13.5	9.8	9.4	0.0	0.0
14	10.8	10.7	0.0	0.0
14.5	14.0	12.4	12.0	0.0
15	0.0	14.1	16.0	0.0
15.5	0.0	16.1	0.0	0.0
16	0.0	17.7	17.0	0.0
16.5	0.0	22.0	20.0	0.0
17	0.0	22.0	0.0	0.0
17.5	0.0	0.0	28.3	0.0
18	0.0	26.0	34.0	0.0
18.5	0.0	36.0	0.0	0.0

Table 9.5.58: The mean weight of capelin (gr) in each age and length group for Bormicon area 12 in 1986.

Length	Two	Three	Four	Five
8.5	2.0	0.0	0.0	0.0
9	3.0	0.0	0.0	0.0
9.5	3.0	0.0	0.0	0.0
10	2.9	0.0	0.0	0.0
10.5	3.7	0.0	0.0	0.0
11	4.0	0.0	0.0	0.0
11.5	4.9	0.0	0.0	0.0
12	5.9	6.3	0.0	0.0
12.5	7.2	7.2	0.0	0.0
13	0.0	7.7	0.0	0.0
13.5	9.5	9.2	0.0	0.0
14	11.4	10.9	0.0	0.0
14.5	15.0	12.7	0.0	0.0
15	16.0	15.1	14.7	0.0
15.5	19.0	16.9	19.0	0.0
16	0.0	20.0	22.0	0.0
16.5	25.0	22.9	24.3	18.0
17	28.0	26.3	26.5	0.0
17.5	0.0	29.7	28.5	0.0
18	0.0	37.0	32.4	0.0
18.5	0.0	0.0	36.0	0.0

Table 9.5.59: The mean weight of capelin (gr) in each age and length group for Bormicon area 15 in 1986.

Stock abundance in 1987

Length	Two	Three
8.5	23.1	0.0
9	355.3	0.0
9.5	578.5	0.0
10	609.9	7.6
10.5	778.3	0.0
11	1147.4	0.0
11.5	1140.4	0.0
12	1345.5	0.0
12.5	753.6	99.4
13	231.7	220.0
13.5	424.3	508.6
14	69.3	414.0
14.5	44.5	326.0
15	17.3	274.6

Table 9.5.60: The number of immature capelin (millions) in each age and length group for Bormicon area 2 in 1987.

Length	Two	Three
8.5	0.0	0.0
9	0.0	0.0
9.5	0.0	0.0
10	0.1	0.0
10.5	0.1	0.0
11	0.2	0.0
11.5	0.3	0.0
12	0.1	0.0
12.5	0.1	0.0
13	0.1	0.1
13.5	0.1	0.3
14	0.1	0.6

Table 9.5.62: The number of immature capelin (millions) in each age and length group for Bormicon area 5 in 1987.

Length	Two	Three
8.5	79.0	0.0
9	1189.1	1.9
9.5	1932.7	1.8
10	2044.0	25.3
10.5	2608.6	0.0
11	3848.4	0.0
11.5	3834.6	0.0
12	4507.8	1.6
12.5	2528.5	335.7
13	784.6	747.5
13.5	1422.3	1724.8
14	236.7	1431.4
14.5	0.0	0.0
15	0.0	0.0

Table 9.5.61: The number of immature capelin (millions) in each age and length group for Bormicon area 3 in 1987.

Length	Two	Three
8.5	27.4	0.0
9	27.4	28.1
9.5	0.0	27.4
10	92.5	0.0
10.5	125.1	0.0
11	222.0	0.0
11.5	364.9	0.0
12	186.5	24.4
12.5	158.4	53.3
13	159.9	186.5
13.5	71.0	385.6
14	77.0	724.5

Table 9.5.63: The number of immature capelin (millions) in each age and length group for Bormicon area 6 in 1987.

Length	Two	Three
8.5	18.4	0.0
9	244.3	2.8
9.5	393.3	2.7
10	423.9	5.1
10.5	541.7	0.0
11	802.3	0.0
11.5	811.8	0.0
12	933.4	2.4
12.5	528.2	72.9
13	173.5	168.2
13.5	295.6	384.3
14	54.8	353.8

Table 9.5.64: The number of immature capelin (millions) in each age and length group for Bormicon area 11 in 1987.

Length	Two	Three
8.5	5.0	0.0
9	5.0	5.2
9.5	0.0	5.0
10	17.0	0.0
10.5	23.0	0.0
11	40.9	0.0
11.5	67.2	0.0
12	34.3	4.5
12.5	29.2	9.8
13	29.4	34.3
13.5	13.1	71.0
14	14.2	133.4

Table 9.5.65: The number of immature capelin (millions) in each age and length group for Bormicon area 12 in 1987.

Length	Two	Three
8.5	3.0	0.0
9	45.9	0.0
9.5	74.7	0.0
10	78.7	1.0
10.5	100.5	0.0
11	148.1	0.0
11.5	147.2	0.0
12	173.7	0.0
12.5	97.3	12.8
13	29.9	28.4
13.5	54.8	65.6
14	8.9	53.4
14.5	5.7	42.1
15	2.2	35.4

Table 9.5.66: The number of immature capelin (millions) in each age and length group for Bormicon area 15 in 1987.

Length	Two	Three	Four	Five
15.5	8.0	111.7	24.1	0.0
16	0.0	68.7	76.3	0.0
16.5	0.0	39.0	19.4	0.0
17	0.0	4.9	0.0	0.0
17.5	0.0	0.0	0.0	0.0
18	0.0	0.0	2.3	0.0
18.5	0.0	0.0	0.0	0.0
19	0.0	0.0	0.0	0.0
19.5	0.0	0.0	0.0	0.0
20	0.0	0.0	0.0	0.0

Table 9.5.67: The number of mature capelin (millions) in each age and length group for Bormicon area 2 in 1987.

Length	Two	Three	Four	Five
14.5	153.1	1171.8	156.6	0.0
15	57.7	1081.7	212.5	0.0
15.5	26.6	500.4	210.0	0.0
16	0.0	331.6	439.7	0.0
16.5	0.0	215.1	292.8	2.2
17	0.0	114.3	219.4	2.6
17.5	0.0	36.0	181.9	6.8
18	0.0	34.9	140.0	0.0
18.5	0.0	11.2	85.3	0.0
19	0.0	2.4	42.7	0.0
19.5	0.0	1.9	13.2	0.0
20	0.0	0.0	2.2	0.0

Table 9.5.68: The number of mature capelin (millions) in each age and length group for Bormicon area 3 in 1987.

Length	Two	Three	Four	Five
14.5	0.1	1.0	0.1	0.0
15	0.0	1.9	0.8	0.0
15.5	0.0	1.5	1.5	0.0
16	0.0	1.2	2.1	0.0
16.5	0.0	1.0	2.6	0.0
17	0.0	1.1	2.5	0.0
17.5	0.0	0.4	2.1	0.1
18	0.0	0.4	1.5	0.0
18.5	0.0	0.1	1.0	0.0
19	0.0	0.0	0.5	0.0
19.5	0.0	0.0	0.2	0.0
20	0.0	0.0	0.0	0.0

Table 9.5.69: The number of mature capelin (millions) in each age and length group for Bormicon area 5 in 1987.

Length	Two	Three	Four	Five
14.5	67.3	1239.6	100.7	0.0
15	0.0	2471.1	1039.1	0.0
15.5	0.0	1914.6	1947.9	0.0
16	0.0	1532.7	2777.5	0.0
16.5	0.0	1272.9	3427.3	32.6
17	0.0	1475.0	3299.3	38.5
17.5	0.0	541.0	2734.6	102.1
18	0.0	524.7	1987.1	0.0
18.5	0.0	168.7	1281.8	0.0
19	0.0	35.5	641.6	0.0
19.5	0.0	28.9	199.1	0.0
20	0.0	0.0	33.3	0.0

Table 9.5.70: The number of mature capelin (millions) in each age and length group for Bormicon area 6 in 1987.

Length	Two	Three	Four	Five
14.5	37.0	345.4	40.5	0.0
15	11.8	433.2	132.8	0.0
15.5	5.4	266.9	210.7	0.0
16	0.0	199.7	329.0	0.0
16.5	0.0	153.5	355.1	3.2
17	0.0	150.5	329.2	3.8
17.5	0.0	54.0	272.8	10.2
18	0.0	52.3	199.8	0.0
18.5	0.0	16.8	127.9	0.0
19	0.0	3.5	64.0	0.0
19.5	0.0	2.9	19.9	0.0
20	0.0	0.0	3.3	0.0

Table 9.5.71: The number of mature capelin (millions) in each age and length group for Bormicon area 11 in 1987.

Length	Two	Three	Four	Five
14.5	12.4	228.3	18.5	0.0
15	0.0	455.1	191.4	0.0
15.5	0.0	352.6	358.7	0.0
16	0.0	282.3	511.5	0.0
16.5	0.0	234.4	631.2	6.0
17	0.0	271.6	607.6	7.1
17.5	0.0	99.6	503.6	18.8
18	0.0	96.6	365.9	0.0
18.5	0.0	31.1	236.1	0.0
19	0.0	6.5	118.2	0.0
19.5	0.0	5.3	36.7	0.0
20	0.0	0.0	6.1	0.0

Table 9.5.72: The number of mature capelin (millions) in each age and length group for Bormicon area 12 in 1987.

Length	Two	Three	Four	Five
14.5	0.0	0.0	0.0	0.0
15	0.0	0.0	0.0	0.0
15.5	1.0	14.4	3.1	0.0
16	0.0	8.9	9.8	0.0
16.5	0.0	5.0	2.5	0.0
17	0.0	0.6	0.0	0.0
17.5	0.0	0.0	0.0	0.0
18	0.0	0.0	0.3	0.0
18.5	0.0	0.0	0.0	0.0
19	0.0	0.0	0.0	0.0
19.5	0.0	0.0	0.0	0.0
20	0.0	0.0	0.0	0.0

Table 9.5.73: The number of mature capelin (millions) in each age and length group for Bormicon area 15 in 1987.

Stock abundance in 1988

Length	Age groups	
	One	Two
8.5	17.3	0
9	55.1	0
9.5	102.5	0
10	87.5	0
10.5	83.3	0
11	56.7	0
11.5	10.2	6.3
12	54.9	38.0
12.5	54.7	87.8
13	5.8	303.8

Table 9.5.74: The number of immature capelin (millions) for each length group in Bormicon area 2 in 1988.

Length	Age groups	
	One	Two
8.5	0	0
9	175.6	0
9.5	265.3	0
10	50.2	0
10.5	153.4	0
11	42.9	0
11.5	12.7	12.7
12	12.7	101.4
12.5	0	419.3
13	0	653.83

Table 9.5.75: The number of immature capelin (millions) for each length group in Bormicon area 3 in 1988.

Length	Age groups	
	One	Two
8.5	0	0
9	249.2	0
9.5	339.0	0
10	44.0	0
10.5	177.3	0
11	37.6	0
11.5	11.1	11.1
12	11.1	141.4
12.5	0	631.3
13	0	889.4

Table 9.5.76: The number of immature capelin (millions) for each length group in Bormicon area 11 in 1988.

Length	Age groups	
	One	Two
8.5	56.7	0
9	87.5	0
9.5	124.8	0
10	209.3	0
10.5	116.0	0
11	119.8	0
11.5	14.0	1.0
12	160.4	65.8
12.5	179.3	132.7
13	19.2	576.7

Table 9.5.77: The number of immature capelin (millions) for each length group in Bormicon area 15 in 1988.

Length	Age groups	
	Two	Three
13.5	585.8	0
14	951.1	8.5
14.5	1239.8	8.7
15	1370.9	63.4
15.5	1584.3	38.8
16	1398.7	239.4
16.5	948.3	543.9
17	573.2	529.9
17.5	196.1	428.0
18	32.1	154.5
18.5	0	191.3
19	0	50.0
19.5	0	0
20	0	0
20.5	0	0

Table 9.5.78: The number of mature capelin (millions) for each length group in Bormicon area 2 in 1988.

Length	Age groups	
	Two	Three
13.5	858.5	0
14	2635.2	17.1
14.5	3624.6	17.6
15	3861.3	175.7
15.5	4403.3	313.8
16	4686.5	704.8
16.5	3579.0	1397.1
17	2471.7	1661.0
17.5	1584.7	1478.0
18	682.7	622.0
18.5	0	795.6
19	0	247.3
19.5	0	230.4
20	0	51.8
20.5	0	128.6

Table 9.5.79: The number of mature capelin (millions) for each length group in Bormicon area 3 in 1988.

Length	Age groups	
	Two	Three
13.5	1089.6	0
14	3554.3	15.0
14.5	4939.5	15.4
15	5080.8	252.1
15.5	5859.8	469.8
16	6548.2	1038.9
16.5	4996.1	1782.8
17	3450.9	2143.9
17.5	2457.7	1946.1
18	1138.2	860.1
18.5	0	1142.1
19	0	396.2
19.5	0	392.5
20	0	88.2
20.5	0	219.0

Table 9.5.80: The number of mature capelin (millions) for each length group in Bormicon area 11 in 1988.

Length	Age groups	
	Two	Three
13.5	1223.6	0
14	1371.5	1.3
14.5	1756.9	1.4
15	1697.3	119.4
15.5	2127.0	6.1
16	1903.7	482.7
16.5	1052.3	667.0
17	460.0	456.1
17.5	191.3	335.1
18	59.0	133.7
18.5	0	228.5
19	0	117.3
19.5	0	0
20	0	0
20.5	0	0

Table 9.5.81: The number of mature capelin (millions) for each length group in Bormicon area 15 in 1988.

Length	Two	Three	Four	Five
8.5	0.0	0.0	0.0	0.0
9	0.0	0.0	0.0	0.0
9.5	0.0	0.0	0.0	0.0
10	0.0	0.0	0.0	0.0
10.5	0.0	0.0	0.0	0.0
11	0.0	0.0	0.0	0.0
11.5	6.0	0.0	0.0	0.0
12	6.8	0.0	0.0	0.0
12.5	8.2	0.0	0.0	0.0
13	9.4	0.0	0.0	0.0
13.5	10.6	0.0	0.0	0.0
14	12.3	10.0	0.0	0.0
14.5	13.8	13.0	0.0	0.0
15	15.4	16.9	0.0	0.0
15.5	17.8	16.5	0.0	0.0
16	19.8	20.5	0.0	0.0
16.5	22.8	22.0	0.0	0.0
17	24.5	25.2	0.0	0.0
17.5	26.9	27.0	0.0	0.0
18	30.5	29.8	0.0	0.0
18.5	0.0	34.7	0.0	0.0
19	0.0	38.5	0.0	0.0
19.5	0.0	0.0	0.0	0.0
20	0.0	0.0	0.0	0.0
20.5	0.0	0.0	0.0	0.0

Table 9.5.82: The mean weight of capelin (gr) in each age and length group for Bormicon area 2 in 1988.

Length	Two	Three	Four	Five
8.5	0.0	0.0	0.0	0.0
9	0.0	0.0	0.0	0.0
9.5	0.0	0.0	0.0	0.0
10	0.0	0.0	0.0	0.0
10.5	0.0	0.0	0.0	0.0
11	0.0	0.0	0.0	0.0
11.5	6.0	0.0	0.0	0.0
12	7.5	0.0	0.0	0.0
12.5	8.2	0.0	0.0	0.0
13	9.7	0.0	0.0	0.0
13.5	10.8	0.0	0.0	0.0
14	12.4	10.0	0.0	0.0
14.5	14.0	13.0	0.0	0.0
15	15.8	16.2	0.0	0.0
15.5	18.0	17.6	0.0	0.0
16	19.8	20.4	0.0	0.0
16.5	23.0	22.0	0.0	0.0
17	25.0	24.9	0.0	0.0
17.5	27.5	27.4	0.0	0.0
18	30.7	31.2	0.0	0.0
18.5	0.0	34.4	0.0	0.0
19	0.0	39.4	0.0	0.0
19.5	0.0	42.5	0.0	0.0
20	0.0	43.0	0.0	0.0
20.5	0.0	54.5	0.0	0.0

Table 9.5.83: The mean weight of capelin (gr) in each age and length group for Bormicon area 3 in 1988.

Length	Two	Three	Four	Five
8.5	0.0	0.0	0.0	0.0
9	0.0	0.0	0.0	0.0
9.5	0.0	0.0	0.0	0.0
10	0.0	0.0	0.0	0.0
10.5	0.0	0.0	0.0	0.0
11	0.0	0.0	0.0	0.0
11.5	6.0	0.0	0.0	0.0
12	7.5	0.0	0.0	0.0
12.5	8.2	0.0	0.0	0.0
13	9.7	0.0	0.0	0.0
13.5	10.8	0.0	0.0	0.0
14	12.4	10.0	0.0	0.0
14.5	14.0	13.0	0.0	0.0
15	15.8	16.2	0.0	0.0
15.5	18.0	17.6	0.0	0.0
16	19.8	20.4	0.0	0.0
16.5	23.0	22.0	0.0	0.0
17	25.0	24.9	0.0	0.0
17.5	27.5	27.4	0.0	0.0
18	30.7	31.2	0.0	0.0
18.5	0.0	34.4	0.0	0.0
19	0.0	39.4	0.0	0.0
19.5	0.0	42.5	0.0	0.0
20	0.0	43.0	0.0	0.0
20.5	0.0	54.5	0.0	0.0

Table 9.5.84: The mean weight of capelin (gr) in each age and length group for Bormicon area 11 in 1988.

Length	Two	Three	Four	Five
8.5	0.0	0.0	0.0	0.0
9	0.0	0.0	0.0	0.0
9.5	0.0	0.0	0.0	0.0
10	0.0	0.0	0.0	0.0
10.5	0.0	0.0	0.0	0.0
11	0.0	0.0	0.0	0.0
11.5	6.0	0.0	0.0	0.0
12	6.8	0.0	0.0	0.0
12.5	8.2	0.0	0.0	0.0
13	9.4	0.0	0.0	0.0
13.5	10.6	0.0	0.0	0.0
14	12.3	10.0	0.0	0.0
14.5	13.8	13.0	0.0	0.0
15	15.4	16.9	0.0	0.0
15.5	17.8	16.5	0.0	0.0
16	19.8	20.5	0.0	0.0
16.5	22.8	22.0	0.0	0.0
17	24.5	25.2	0.0	0.0
17.5	26.9	27.0	0.0	0.0
18	30.5	29.8	0.0	0.0
18.5	0.0	34.7	0.0	0.0
19	0.0	38.5	0.0	0.0
19.5	0.0	0.0	0.0	0.0
20	0.0	0.0	0.0	0.0
20.5	0.0	0.0	0.0	0.0

Table 9.5.85: The mean weight of capelin (gr) in each age and length group for Bormicon area 15 in 1988.

Stock abundance in 1989

Length	One	Two	Three
8	0.0	68.4	0.0
8.5	0.0	394.6	0.0
9	0.0	1770.1	0.0
9.5	0.0	2074.1	0.0
10	0.0	1820.7	0.0
10.5	0.0	962.2	0.0
11	0.0	408.2	0.0
11.5	0.0	161.6	0.0
12	0.0	81.1	13.5
12.5	0.0	12.5	12.5
13	0.0	0.0	14.8

Table 9.5.86: The number of immature capelin (millions) in each age and length group for Bormicon area 2 in 1989.

Length	One	Two	Three
8	0.0	45.6	0.0
8.5	0.0	263.2	0.0
9	0.0	1180.6	0.0
9.5	0.0	1383.4	0.0
10	0.0	1214.4	0.0
10.5	0.0	641.8	0.0
11	0.0	272.3	0.0
11.5	0.0	107.8	0.0
12	0.0	54.1	9.0
12.5	0.0	8.3	8.3
13	0.0	0.0	9.8

Table 9.5.87: The number of immature capelin (millions) in each age and length group for Bormicon area 3 in 1989.

Length	One	Two	Three
8	0.0	0.1	0.0
8.5	0.0	2.3	0.0
9	0.0	9.9	0.0
9.5	0.0	9.9	0.0
10	0.0	6.0	0.0
10.5	0.0	3.8	0.5
11	0.0	0.4	0.0
11.5	0.0	0.3	0.6
12	0.0	0.0	0.8
12.5	0.0	0.0	3.2
13	0.0	0.0	7.6

Table 9.5.88: The number of immature capelin (millions) in each age and length group for Bormicon area 5 in 1989.

Length	One	Two	Three
8	0.0	5.3	0.0
8.5	0.0	117.4	0.0
9	0.0	503.9	0.0
9.5	0.0	504.4	0.0
10	0.0	303.6	0.0
10.5	0.0	192.8	23.9
11	0.0	22.2	0.0
11.5	0.0	14.6	29.3
12	0.0	0.0	40.3
12.5	0.0	0.0	164.0
13	0.0	0.0	385.6

Table 9.5.89: The number of immature capelin (millions) in each age and length group for Bormicon area 6 in 1989.

Length	One	Two	Three
8	0.0	163.7	0.0
8.5	0.0	944.0	0.0
9	0.0	4234.3	0.0
9.5	0.0	4961.5	0.0
10	0.0	4355.3	0.0
10.5	0.0	2301.8	0.0
11	0.0	976.6	0.0
11.5	0.0	386.7	0.0
12	0.0	193.9	32.2
12.5	0.0	29.9	29.9
13	0.0	0.0	35.3

Table 9.5.90: The number of immature capelin (millions) in each age and length group for Bormicon area 11 in 1989.

Length	One	Two	Three
8	0.0	6.6	0.0
8.5	0.0	145.3	0.0
9	0.0	623.3	0.0
9.5	0.0	623.8	0.0
10	0.0	375.5	0.0
10.5	0.0	238.5	29.6
11	0.0	27.4	0.0
11.5	0.0	18.1	36.2
12	0.0	0.0	49.9
12.5	0.0	0.0	202.8
13	0.0	0.0	476.9

Table 9.5.91: The number of immature capelin (millions) in each age and length group for Bormicon area 12 in 1989.

Length	One	Two	Three
8	0.0	144.8	0.0
8.5	0.0	835.3	0.0
9	0.0	3746.7	0.0
9.5	0.0	4390.1	0.0
10	0.0	3853.7	0.0
10.5	0.0	2036.7	0.0
11	0.0	864.1	0.0
11.5	0.0	342.1	0.0
12	0.0	171.6	28.5
12.5	0.0	26.4	26.4
13	0.0	0.0	31.2

Table 9.5.92: The number of immature capelin (millions) in each age and length group for Bormicon area 15 in 1989.

Length	Two	Three	Four	Five
13.5	0.0	14.8	0.0	0.0
14	0.0	5.2	0.0	0.0
14.5	0.0	25.0	0.0	0.0
15	0.0	2.6	0.0	0.0
15.5	0.0	5.2	0.0	0.0
16	0.0	2.6	0.0	0.0
16.5	0.0	0.0	0.0	0.0
17	0.0	0.0	0.0	0.0
17.5	0.0	0.0	0.0	0.0
18	0.0	0.0	0.0	0.0
18.5	0.0	0.0	0.0	0.0
19	0.0	0.0	0.0	0.0
19.5	0.0	0.0	0.0	0.0

Table 9.5.93: The number of mature capelin (millions) in each age and length group for Bormicon area 2 in 1989.

Length	Two	Three	Four	Five
13.5	0.0	9.8	0.0	0.0
14	0.0	3.5	0.0	0.0
14.5	0.0	16.7	0.0	0.0
15	0.0	1.7	0.0	0.0
15.5	0.0	3.5	0.0	0.0
16	0.0	1.7	0.0	0.0
16.5	0.0	0.0	0.0	0.0
17	0.0	0.0	0.0	0.0
17.5	0.0	0.0	0.0	0.0
18	0.0	0.0	0.0	0.0
18.5	0.0	0.0	0.0	0.0
19	0.0	0.0	0.0	0.0
19.5	0.0	0.0	0.0	0.0

Table 9.5.94: The number of mature capelin (millions) in each age and length group for Bormicon area 3 in 1989.

Length	Two	Three	Four	Five
13.5	0.0	16.4	0.0	0.0
14	0.0	32.0	0.6	0.0
14.5	0.0	55.0	0.3	0.0
15	0.0	51.4	4.8	0.0
15.5	0.0	53.7	9.2	0.0
16	0.0	44.3	17.1	0.0
16.5	0.0	39.1	20.8	0.0
17	0.0	19.1	21.6	0.0
17.5	0.0	8.2	16.4	0.0
18	0.0	1.4	6.5	0.0
18.5	0.0	0.4	1.4	0.0
19	0.0	0.0	0.9	0.0
19.5	0.0	0.0	0.3	0.0

Table 9.5.95: The number of mature capelin (millions) in each age and length group for Bormicon area 5 in 1989.

Length	Two	Three	Four	Five
13.5	0.0	831.4	0.0	0.0
14	0.0	1623.0	31.9	0.0
14.5	0.0	2789.9	16.4	0.0
15	0.0	2606.5	242.9	0.0
15.5	0.0	2726.6	466.2	0.0
16	0.0	2246.6	869.6	0.0
16.5	0.0	1983.8	1055.3	0.0
17	0.0	970.2	1096.0	0.0
17.5	0.0	417.1	834.5	0.0
18	0.0	72.7	327.5	0.0
18.5	0.0	18.2	73.6	0.0
19	0.0	0.0	46.1	0.0
19.5	0.0	0.0	16.0	0.0

Table 9.5.96: The number of mature capelin (millions) in each age and length group for Bormicon area 6 in 1989.

Length	Two	Three	Four	Five
13.5	0.0	35.3	0.0	0.0
14	0.0	12.4	0.0	0.0
14.5	0.0	59.7	0.0	0.0
15	0.0	6.2	0.0	0.0
15.5	0.0	12.4	0.0	0.0
16	0.0	6.2	0.0	0.0
16.5	0.0	0.0	0.0	0.0
17	0.0	0.0	0.0	0.0
17.5	0.0	0.0	0.0	0.0
18	0.0	0.0	0.0	0.0
18.5	0.0	0.0	0.0	0.0
19	0.0	0.0	0.0	0.0
19.5	0.0	0.0	0.0	0.0

Table 9.5.97: The number of mature capelin (millions) in each age and length group for Bormicon area 11 in 1989.

Length	Two	Three	Four	Five
13.5	0.0	1028.4	0.0	0.0
14	0.0	2007.4	39.5	0.0
14.5	0.0	3450.8	20.3	0.0
15	0.0	3223.8	300.4	0.0
15.5	0.0	3372.4	576.7	0.0
16	0.0	2778.7	1075.5	0.0
16.5	0.0	2453.6	1305.2	0.0
17	0.0	1200.0	1355.6	0.0
17.5	0.0	515.8	1032.2	0.0
18	0.0	89.9	405.1	0.0
18.5	0.0	22.5	91.0	0.0
19	0.0	0.0	57.0	0.0
19.5	0.0	0.0	19.7	0.0

Table 9.5.98: The number of mature capelin (millions) in each age and length group for Bormicon area 12 in 1989.

Length	Two	Three	Four	Five
13.5	0.0	31.2	0.0	0.0
14	0.0	11.0	0.0	0.0
14.5	0.0	52.8	0.0	0.0
15	0.0	5.5	0.0	0.0
15.5	0.0	11.0	0.0	0.0
16	0.0	5.5	0.0	0.0
16.5	0.0	0.0	0.0	0.0
17	0.0	0.0	0.0	0.0
17.5	0.0	0.0	0.0	0.0
18	0.0	0.0	0.0	0.0
18.5	0.0	0.0	0.0	0.0
19	0.0	0.0	0.0	0.0
19.5	0.0	0.0	0.0	0.0

Table 9.5.99: The number of mature capelin (millions) in each age and length group for Bormicon area 15 in 1989.

Stock abundance in 1990

Length	One	Two	Three
9	0.0	0.8	0.0
9.5	0.0	3.6	0.0
10	0.0	3.9	0.0
10.5	0.0	2.9	0.0
11	0.0	2.7	0.0
11.5	0.0	1.5	0.0
12	0.0	2.2	2.2
12.5	0.0	0.3	3.4

Table 9.5.100: The number of immature capelin (millions) in each age and length group for Bormicon area 5 in 1990.

Length	One	Two	Three
9	0.0	32.5	0.0
9.5	0.0	141.3	0.0
10	0.0	152.4	0.0
10.5	0.0	111.7	0.0
11	0.0	102.9	0.0
11.5	0.0	59.2	0.0
12	0.0	85.4	85.4
12.5	0.0	11.7	130.1

Table 9.5.101: The number of immature capelin (millions) in each age and length group for Bormicon area 6 in 1990.

Length	One	Two	Three
9	0.0	33.6	0.0
9.5	0.0	146.1	0.0
10	0.0	157.6	0.0
10.5	0.0	115.5	0.0
11	0.0	106.4	0.0
11.5	0.0	61.3	0.0
12	0.0	88.4	88.4
12.5	0.0	12.0	134.6

Table 9.5.102: The number of immature capelin (millions) in each age and length group for Bormicon area 12 in 1990.

Length	Two	Three	Four	Five
13	2.0	10.4	0.0	0.0
13.5	1.5	14.6	0.0	0.0
14	2.4	27.4	1.1	0.0
14.5	2.2	47.5	0.8	0.0
15	1.8	45.8	2.9	0.0
15.5	2.0	56.1	11.4	0.0
16	0.6	40.2	12.9	0.0
16.5	0.0	36.5	22.2	0.0
17	0.0	26.9	21.8	0.3
17.5	0.0	10.2	19.7	1.0
18	0.0	4.8	16.4	1.0
18.5	0.0	0.0	11.2	1.0
19	0.0	1.0	4.0	0.0
19.5	0.0	0.1	2.1	0.0

Table 9.5.103: The number of mature capelin (millions) in each age and length group for Bormicon area 5 in 1990.

Length	Two	Three	Four	Five
13	78.6	405.4	0.0	0.0
13.5	56.3	567.0	0.0	0.0
14	94.7	1065.1	42.7	0.0
14.5	86.4	1846.2	30.6	0.0
15	70.4	1776.8	113.1	0.0
15.5	77.2	2178.3	443.7	0.0
16	21.8	1560.3	501.0	0.0
16.5	0.0	1418.0	862.7	0.0
17	0.0	1044.7	846.2	11.7
17.5	0.0	395.2	764.6	37.9
18	0.0	187.4	637.4	37.4
18.5	0.0	0.0	435.5	39.3
19	0.0	37.9	155.8	0.0
19.5	0.0	2.4	80.6	0.0

Table 9.5.104: The number of mature capelin (millions) in each age and length group for Bormicon area 6 in 1990.

Length	Two	Three	Four	Five
13	81.3	419.2	0.0	0.0
13.5	58.2	586.4	0.0	0.0
14	97.9	1101.5	44.2	0.0
14.5	89.4	1909.3	31.6	0.0
15	72.8	1837.5	117.0	0.0
15.5	79.8	2252.7	458.9	0.0
16	22.6	1613.6	518.1	0.0
16.5	0.0	1466.5	892.2	0.0
17	0.0	1080.4	875.1	12.0
17.5	0.0	408.7	790.7	39.2
18	0.0	193.8	659.2	38.7
18.5	0.0	0.0	450.3	40.7
19	0.0	39.2	161.2	0.0
19.5	0.0	2.5	83.3	0.0

Table 9.5.105: The number of mature capelin (millions) in each age and length group for Bormicon area 12 in 1990.

Stock abundance in 1991

Length	One	Two	Three
8.5	0.0	10.8	0.0
9	0.0	51.2	0.0
9.5	0.0	120.4	0.0
10	0.0	129.4	0.0
10.5	0.0	64.4	0.0
11	0.0	33.1	0.0
11.5	0.0	13.2	0.0
12	0.0	0.0	0.0
12.5	0.0	6.6	4.2

Table 9.5.106: The number of immature capelin (millions) in each age and length group for Bormicon area 5 in 1991.

Length	One	Two	Three
8.5	0.0	0.6	0.0
9	0.0	14.4	0.0
9.5	0.0	75.5	0.0
10	0.0	80.8	0.0
10.5	0.0	62.7	0.0
11	0.0	29.3	0.0
11.5	0.0	17.2	7.9
12	0.0	10.4	0.0
12.5	0.0	0.4	3.9

Table 9.5.107: The number of immature capelin (millions) in each age and length group for Bormicon area 6 in 1991.

Length	One	Two	Three
8.5	0.0	6.6	0.0
9	0.0	38.4	0.0
9.5	0.0	117.0	0.0
10	0.0	125.6	0.0
10.5	0.0	76.8	0.0
11	0.0	37.6	0.0
11.5	0.0	18.5	5.1
12	0.0	6.6	0.0
12.5	0.0	4.0	4.9

Table 9.5.108: The number of immature capelin (millions) in each age and length group for Bormicon area 12 in 1991.

Length	Two	Three	Four	Five
13	0.0	11.4	0.0	0.0
13.5	11.4	35.5	0.0	0.0
14	15.0	68.6	0.0	0.0
14.5	30.1	252.2	19.9	0.0
15	19.3	341.8	0.0	0.0
15.5	58.4	361.1	41.5	0.0
16	0.0	505.6	54.8	0.0
16.5	0.0	395.4	72.2	0.0
17	0.0	501.9	84.9	0.0
17.5	0.0	294.3	92.1	0.0
18	0.0	155.9	24.7	0.0
18.5	0.0	16.2	41.5	0.0
19	0.0	0.0	0.0	0.0
19.5	0.0	0.0	17.5	0.0
20	0.0	0.0	11.4	0.0

Table 9.5.109: The number of mature capelin (millions) in each age and length group for Bormicon area 5 in 1991.

Length	Two	Three	Four	Five
13	25.0	63.5	0.0	0.0
13.5	15.3	196.7	0.0	0.0
14	28.9	605.7	0.0	0.0
14.5	14.4	788.9	40.8	0.0
15	24.2	799.3	0.0	0.0
15.5	3.1	710.6	104.2	0.0
16	0.0	878.9	173.3	0.0
16.5	0.0	594.6	177.9	0.0
17	0.0	357.3	217.6	0.0
17.5	0.0	167.3	146.0	0.0
18	0.0	49.9	59.3	0.0
18.5	0.0	20.4	15.1	0.0
19	0.0	0.0	0.0	0.0
19.5	0.0	0.0	0.9	0.0
20	0.0	0.0	0.6	0.0

Table 9.5.110: The number of mature capelin (millions) in each age and length group for Bormicon area 6 in 1991.

Length	Two	Three	Four	Five
13	16.0	47.1	0.0	0.0
13.5	16.3	145.8	0.0	0.0
14	27.0	425.6	0.0	0.0
14.5	26.4	647.6	37.4	0.0
15	26.5	705.5	0.0	0.0
15.5	35.4	659.9	90.2	0.0
16	0.0	849.9	141.9	0.0
16.5	0.0	605.5	154.8	0.0
17	0.0	515.1	187.4	0.0
17.5	0.0	275.1	145.8	0.0
18	0.0	121.0	52.0	0.0
18.5	0.0	22.3	33.4	0.0
19	0.0	0.0	0.0	0.0
19.5	0.0	0.0	10.6	0.0
20	0.0	0.0	6.9	0.0

Table 9.5.111: The number of mature capelin (millions) in each age and length group for Bormicon area 12 in 1991.

Stock abundance in 1992

Length	One	Two	Three
9	0.0	11.4	0.0
9.5	0.0	59.4	0.0
10	0.0	211.4	0.0
10.5	0.0	332.3	0.0
11	0.0	388.8	0.0
11.5	0.0	421.5	0.0
12	0.0	156.6	1.7
12.5	0.0	127.7	15.7
13	0.0	72.6	30.0
13.5	0.0	55.0	39.5
14	0.0	44.2	32.9

Table 9.5.112: The number of immature capelin (millions) in each age and length group for Bormicon area 2 in 1992.

Length	One	Two	Three
9	0.0	333.5	0.0
9.5	0.0	1739.8	0.0
10	0.0	6193.9	0.0
10.5	0.0	9734.8	0.0
11	0.0	11388.8	0.0
11.5	0.0	12348.5	0.0
12	0.0	4587.9	51.0
12.5	0.0	3739.8	460.6
13	0.0	2126.5	878.4
13.5	0.0	0.0	0.0
14	0.0	0.0	0.0

Table 9.5.113: The number of immature capelin (millions) in each age and length group for Bormicon area 3 in 1992.

Length	One	Two	Three
9	0.0	0.0	0.0
9.5	0.0	5.2	0.0
10	0.0	34.1	0.0
10.5	0.0	102.3	0.0
11	0.0	53.5	0.0
11.5	0.0	72.4	0.0
12	0.0	123.2	5.2
12.5	0.0	131.1	16.3
13	0.0	136.9	89.7

Table 9.5.114: The number of immature capelin (millions) in each age and length group for Bormicon area 5 in 1992.

Length	One	Two	Three
9	0.0	19.2	0.0
9.5	0.0	27.2	0.0
10	0.0	14.2	0.0
10.5	0.0	47.2	0.0
11	0.0	63.6	0.0
11.5	0.0	94.5	0.0
12	0.0	82.9	28.7
12.5	0.0	128.3	35.2
13	0.0	117.7	220.0

Table 9.5.115: The number of immature capelin (millions) in each age and length group for Bormicon area 6 in 1992.

Length	One	Two	Three
9	0.0	0.0	0.0
9.5	0.0	0.0	0.0
10	0.0	0.0	0.0
10.5	0.0	5.1	0.0
11	0.0	15.8	0.0
11.5	0.0	25.0	0.0
12	0.0	12.5	8.2
12.5	0.0	26.5	15.8
13	0.0	20.6	62.2
13.5	0.0	0.0	0.0
14	0.0	0.0	0.0

Table 9.5.116: The number of immature capelin (millions) in each age and length group for Bormicon area 7 in 1992.

Length	One	Two	Three
9	0.0	106.0	0.0
9.5	0.0	553.1	0.0
10	0.0	1968.9	0.0
10.5	0.0	3094.6	0.0
11	0.0	3620.4	0.0
11.5	0.0	3925.4	0.0
12	0.0	1458.4	16.2
12.5	0.0	1188.8	146.4
13	0.0	676.0	279.2
13.5	0.0	512.4	367.8
14	0.0	411.8	306.0

Table 9.5.117: The number of immature capelin (millions) in each age and length group for Bormicon area 11 in 1992.

Length	One	Two	Three
9	0.0	11.8	0.0
9.5	0.0	21.5	0.0
10	0.0	39.6	0.0
10.5	0.0	118.3	0.0
11	0.0	77.0	0.0
11.5	0.0	107.0	0.0
12	0.0	154.3	16.9
12.5	0.0	180.0	25.8
13	0.0	182.6	175.0
13.5	0.0	0.0	0.0
14	0.0	0.0	0.0

Table 9.5.118: The number of immature capelin (millions) in each age and length group for Bormicon area 12 in 1992.

Length	One	Two	Three
9	0.0	0.1	0.0
9.5	0.0	0.8	0.0
10	0.0	2.8	0.0
10.5	0.0	4.3	0.0
11	0.0	5.1	0.0
11.5	0.0	5.5	0.0
12	0.0	2.0	0.0
12.5	0.0	1.7	0.2
13	0.0	0.9	0.4
13.5	0.0	0.7	0.5
14	0.0	0.6	0.4

Table 9.5.119: The number of immature capelin (millions) in each age and length group for Bormicon area 15 in 1992.

Length	Two	Three	Four	Five
13.5	0.0	0.0	0.0	
14	0.0	0.0	0.0	
14.5	21.1	21.1	0.0	0.0
15	3.4	10.1	0.0	0.0
15.5	0.9	5.3	0.0	0.0
16	0.8	3.5	0.0	0.0
16.5	0.0	1.7	0.0	0.0
17	0.0	1.1	0.6	0.0
17.5	0.0	0.6	0.3	0.0
18	0.0	0.3	0.3	0.0
18.5	0.0	0.0	0.3	0.0
19	0.0	0.0	0.0	0.0

Table 9.5.120: The number of mature capelin (millions) in each age and length group for Bormicon area 2 in 1992.

Length	Two	Three	Four	Five
13.5	1649.9	1157.1	40.7	0.0
14	1362.4	971.7	0.0	0.0
14.5	637.1	675.1	0.0	0.0
15	126.3	479.5	9.0	0.0
15.5	75.4	365.8	9.0	0.0
16	32.7	266.0	28.0	0.0
16.5	0.0	98.3	0.0	0.0
17	0.0	52.3	16.3	0.0
17.5	0.0	25.3	8.1	0.0
18	0.0	0.0	0.0	0.0
18.5	0.0	0.0	0.0	0.0
19	0.0	0.0	0.0	0.0

Table 9.5.121: The number of mature capelin (millions) in each age and length group for Bormicon area 3 in 1992.

Length	Two	Three	Four	Five
13.5	266.9	223.4	0.0	0.0
14	317.3	573.7	6.3	0.0
14.5	196.1	628.8	6.3	0.0
15	191.9	676.0	28.3	0.0
15.5	152.1	687.5	6.8	0.0
16	34.6	439.5	20.5	0.0
16.5	6.3	318.8	12.6	0.0
17	0.0	146.8	21.0	0.0
17.5	0.0	104.4	12.6	0.0
18	0.0	22.6	11.0	0.0
18.5	0.0	11.0	0.0	0.0
19	0.0	0.0	5.2	0.0

Table 9.5.122: The number of mature capelin (millions) in each age and length group for Bormicon area 5 in 1992.

Length	Two	Three	Four	Five
13.5	241.2	883.1	11.1	0.0
14	373.6	2055.0	11.8	0.0
14.5	315.5	2738.9	47.4	0.0
15	163.1	3895.3	177.3	0.0
15.5	75.9	3872.6	279.8	0.0
16	41.5	4303.9	567.5	0.0
16.5	0.0	3049.7	401.8	0.0
17	0.0	1987.8	418.2	0.0
17.5	0.0	1081.4	315.6	0.0
18	0.0	569.2	227.1	0.0
18.5	0.0	154.3	90.3	0.0
19	0.0	0.0	24.3	0.0

Table 9.5.123: The number of mature capelin (millions) in each age and length group for Bormicon area 6 in 1992.

Length	Two	Three	Four	Five
13.5	46.1	230.6	0.0	0.0
14	43.6	398.7	0.0	0.0
14.5	21.9	459.1	4.3	0.0
15	13.5	769.7	31.8	0.0
15.5	4.3	723.4	54.0	0.0
16	0.0	717.5	142.4	0.0
16.5	0.0	522.1	93.3	0.0
17	0.0	303.2	100.9	0.0
17.5	0.0	195.9	79.2	0.0
18	0.0	85.6	42.8	0.0
18.5	0.0	20.4	24.5	0.0
19	0.0	0.0	2.3	0.0

Table 9.5.124: The number of mature capelin (millions) in each age and length group for Bormicon area 7 in 1992.

Length	Two	Three	Four	Five
13.5	0.0	0.0	0.0	0.0
14	0.0	0.0	0.0	0.0
14.5	196.5	196.5	0.0	0.0
15	31.3	94.3	0.0	0.0
15.5	8.7	48.9	0.0	0.0
16	7.5	32.4	0.0	0.0
16.5	0.0	16.0	0.0	0.0
17	0.0	10.6	5.2	0.0
17.5	0.0	5.2	2.6	0.0
18	0.0	2.6	2.6	0.0
18.5	0.0	0.0	2.6	0.0
19	0.0	0.0	0.0	0.0

Table 9.5.125: The number of mature capelin (millions) in each age and length group for Bormicon area 11 in 1992.

Length	Two	Three	Four	Five
13.5	359.4	591.5	6.9	0.0
14	488.1	1517.5	12.9	0.0
14.5	357.2	1947.9	32.0	0.0
15	265.2	2494.5	113.5	0.0
15.5	181.5	2522.0	142.3	0.0
16	56.9	2566.8	272.5	0.0
16.5	5.7	1816.4	196.3	0.0
17	0.0	1153.6	208.8	0.0
17.5	0.0	629.0	152.6	0.0
18	0.0	313.5	121.1	0.0
18.5	0.0	91.3	39.2	0.0
19	0.0	0.0	18.2	0.0

Table 9.5.126: The number of mature capelin (millions) in each age and length group for Bormicon area 12 in 1992.

Length	Two	Three	Four	Five
13.5	0.0	0.0	0.0	0.0
14	0.0	0.0	0.0	0.0
14.5	0.3	0.3	0.0	0.0
15	0.0	0.1	0.0	0.0
15.5	0.0	0.1	0.0	0.0
16	0.0	0.0	0.0	0.0
16.5	0.0	0.0	0.0	0.0
17	0.0	0.0	0.0	0.0
17.5	0.0	0.0	0.0	0.0
18	0.0	0.0	0.0	0.0
18.5	0.0	0.0	0.0	0.0
19	0.0	0.0	0.0	0.0

Table 9.5.127: The number of mature capelin (millions) in each age and length group for Bormicon area 15 in 1992.

Chapter 10

Capelin: Consumption and growth

Hjálmar Vilhjálmsson and Halldór Narfi Stefánsson

10.1 Initial Values and recruitment

In the simulations presented in this book capelin enters the model in August at age 0. In August the 0-group survey takes place. The distribution and length distribution of 0-group capelin is obtained from the survey but the yearclass strength is usually estimated. According to [55] the correlation between yearclass strength of capelin and 0-group capelin is not significant. Using the distribution and mean length might be questionable but other data is not available.

When estimating the distribution an abundance index was calculated on a grid using kriging. The value at the grid points inside each area were then summed to get an abundance index for the area.

Length distribution of capelin in each area in the 0-group survey were used directly as length distribution of the recruitment. To get the weight of each length group the length-weight relationship $W = aL^b$ was used with $a = 0.000596$ and $b = 3.762$.(10.2.1.

Initial data are for January 1982 involve abundance, distribution and mean length of immature and mature capelin. In January 1982 the mature part of the capelin stock was at the lowest level observed. The number of age 3 and age 4 mature capelin were set to 11.7 and 0.8 billion individuals and the number of age 3 immature capelin to 3 billion individuals ([55] appendix II). These numbers were usually used unchanged while the number of age 1 and 2 capelin was estimated with initial values 188 and 41 billion individuals.

10.2 Capelin growth

As explained in the previous section(s) the growth of adult capelin does not correlate well with data on annual zooplankton abundance north of Iceland in spring since

Stock component	a	b
Immature capelin	1.015	3.594
Mature males	0.42	3.913
Mature females	0.745	3.698

Table 10.2.1: Coefficients used to make reference length-weight relationships for capelin

Stock component	a	W_{inf}
Immature capelin	0.1688	0.0575
Mature capelin	323	0.0292

Table 10.2.2: Estimated growth parameters for immature and mature capelin

the data on plankton production is mostly limited to the Icelandic shelf area and waters immediately adjacent to it. However, it has been observed that the winter growth of adult capelin correlates with salinity in the shelf area off the central north coast of Iceland.

In order to model the consumption of capelin in Bormicon, it is now evident that more data is needed than is available, as the areas occupied by adult capelin are different from those for which data exists on zooplankton abundance. And in order to model the growth of capelin, it would be possible to make use of the correlation between salinity and the winter growth of adult capelin.

That approach was though not taken but instead the growth of capelin was modelled using the Von Bertalanfys growth function. As described in chapter 4 the model allows to multiply the growth according to the Von Bertalanffys growth function by year, month and area effect.

As a first approximation the year and areaeffect were excluded but a month effect was included. It is known ([55]) that the growth of immature capelin is negligible during the winter and the growth of mature capelin is much less than during the summer. Figure 10.2.1 shows the month effect used.

As described in chapter 4 the model needs both growth in length and weight. To convert from length to weight a reference length weight relationship is needed. 10.2.2 shows the reference length-weight relationship used. The curve is made using relationship of the form $W = aL^b$ using the following values of the parameters from 10.2.1. The values are obtained from table 14.4 in [55]. For immature capelin the August values were used but the October values for mature capelin. The value for mature capelin was the mean of the values calculated for males and females. When comparing the curves in 10.2.2 it must be born in mind that the range where both mature and immature individuals exist is from 11.5 to 15 cm.

The parameters W_{inf} and a in 3.4.5 were estimated in a single species capelin simulation by fitting mean length and mean weight at age to data from citeVil94 (Appendix II). 10.2.3 and 10.2.4 show the assumed growth of capelin according to [55]. The simulation used for estimation did not involve any mortality or migration

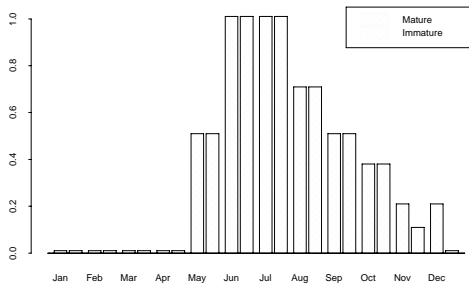


Figure 10.2.1: The month effect that multiplies the calculated growth from the Von Bertalanfy's growth function

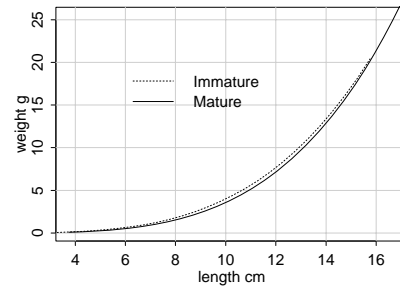


Figure 10.2.2: The reference length - weight relationship used for immature and mature capelin

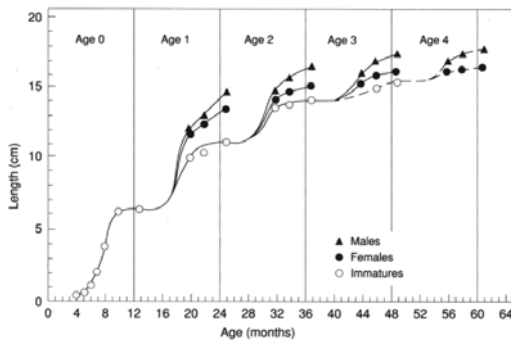


Figure 10.2.3: The average monthly growth in length of immature (lowest curve), female (middle curve) and male (uppermost curve) capelin in the years 1979-1993.

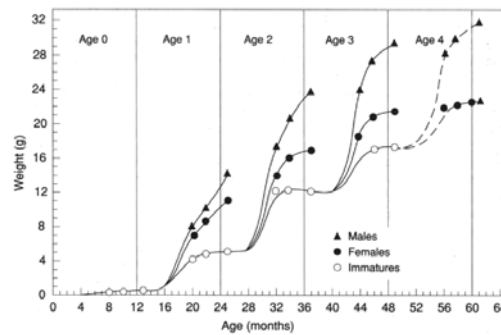


Figure 10.2.4: The average monthly growth in weight of immature (lowest curve), female (middle curve) and male (uppermost curve) capelin in the years 1979-1993.

of the capelin, the only dynamics involved were growth. The maturation model used was the same as is used throughout this book that all capelin that reaches 11.5 cm in May matures.

The simulation was started in August 1985 to January 1990 involving only the 1985 yearclass. Initially the mean length was 4.5cm. Estimated value of the parameters W_{inf} and a are shown in 10.2.2.

That the value of W_{inf} is higher for immature than mature capelin might seem surprising. As immature capelin is always much smaller than W_{inf} for both immature and mature capelin this means simply that the estimated growth is linear.

10.2.5 to 10.2.8 show the estimated growth of capelin and the data used in the fit. Usually the data fits quite well except the length of immature capelin. As the weight of immature capelin fits better this indicates the the reference length-

weight relationship is not compatible with the data used in the estimation. Looking at 10.2.2 immature capelin seems to be heavier than mature capelin of the same length in the range where both stock components exist. If the October values for the coefficients were used immature capelin would on the other hand become lighter than mature capelin of the same length.

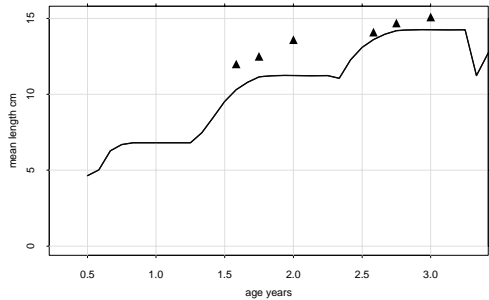


Figure 10.2.5: Estimated length of immature capelin. Points indicate data used to fit the growth model.

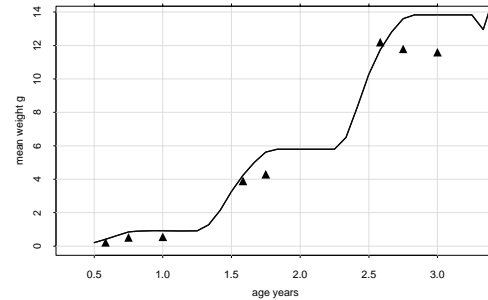


Figure 10.2.6: Estimated weight of immature capelin. Points indicate data used to fit the growth model.

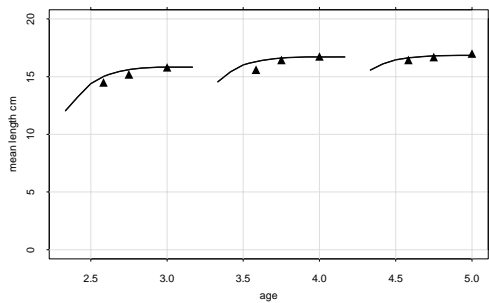


Figure 10.2.7: Estimated length of mature capelin. Points indicate data used to fit the growth model.

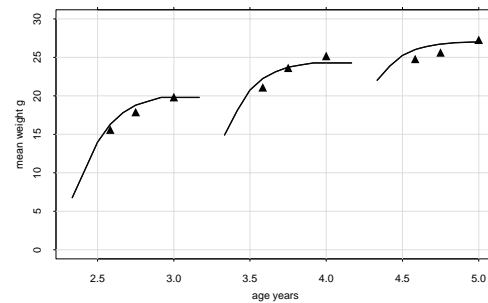


Figure 10.2.8: Estimated weight of mature capelin. Points indicate data used to fit the growth model.

To test the maturation model the model was changed so the maturation length in May was 11cm and 12cm. Both gave higher value of the objective function than using 11.5cm making the authors extremely happy with the maturation model used.

Chapter 11

Capelin Migrations

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11.1 Feeding and early winter migrations

11.1.1 0-group capelin

The 0-group capelin are in August mainly distributed over the submarine terrace off Northwest and North Iceland and to a lesser and more irregular extent off East Iceland as well as over the outer parts of the East-Greenland shelf in the northern and northwestern Irminger Sea.

Specific studies of distribution, drift patterns or possible active migrations of 0-group capelin in autumn and early winter have never been undertaken. On the basis of observations made during surveys of older stock components, it seems, however, that the 0-group capelin overwinter mainly in the shelf areas off North and East Iceland, from the coast to the outer edge of the shelf. In addition, 0-group capelin belonging to this stock are often numerous over the western part of the Iceland-Greenland Ridge, particularly north of the Dohrn Bank and in neighbouring areas in late autumn and early winter.

Because of its small size and apparently poor swimming ability, it seems likely that the location of the main winter distribution area of 0-group capelin is mostly the result of its drift-pattern and only in part due to active migration, if at all.

11.1.2 Juvenile 1-group capelin

For clarification it is pointed out that the age prefix of a year class is changed on 1 January and not at its actual time of birth, which in this case would be nearer to 1 April. From this follows that as of 1 January age group 1 suddenly becomes age group 2 and so on.

Since 1982 the annual 0-group surveys carried out in August have included acoustic measurements of the abundance of 1-group capelin in the southern Iceland Sea and adjacent waters. These surveys have provided a fairly detailed picture of the distribution of 1-group capelin at that time of the year and, together with surveys in late autumn and winter, have revealed the general migration pattern of this stock component in the summer, autumn and winter periods.

In August the distribution pattern of most of the 1-group capelin has been remarkably similar in the 11 year period 1982 - 1992 of which an example is given in figure 11.1.1. Thus, this stock component has generally been found over the Icelandic continental shelf, from 20 - 50 naut. miles offshore to the shelf edge in the area from east of Iceland, north- and westward to about 30°W . However, the main distribution area has usually been off the central and western north coast of Iceland, where the distribution of 1-group capelin may at times be still farther offshore. Although the extreme northern limit of the 1-group distribution in August has most frequently been about 68°N - $68^{\circ}30'\text{N}$, 1-group capelin have occasionally also been recorded in the central Iceland Sea.

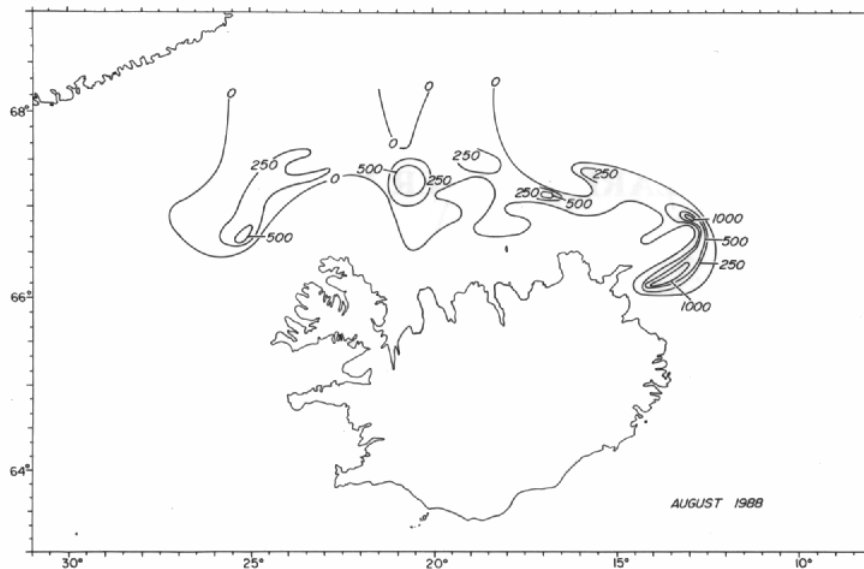


Figure 11.1.1: An example of a typical distribution pattern of 1-group capelin in August.

In autumn and early winter the bulk of the 1-group capelin are located in the area north and northeast of Iceland. It seems that in the January - April period most of these capelin will, as 2-group, migrate slowly westward to the area off the western north coast and to the northwest and west of the Vestfirðir peninsula. From there these capelin subsequently start their feeding migrations in spring. The remainder overwinters off East and Northeast Iceland and migrates north and northwest from

there to feed.

11.1.3 Immature 2-group capelin

As a rule, a considerable part of each year class will not mature and spawn as three year olds. The proportion of a year class not maturing to spawn until at age 4 seems to depend on year class size and be higher the larger the year class. Since the year class size is highly variable, the total numbers of these capelin may vary greatly and sometimes amount to more than one half of very large year classes. Thus, by number only 40% of the capelin belonging to the very large 1983 year class spawned at age 3, leaving 60% remaining immature for one more year to spawn at age 4. On the other hand, the corresponding maturing ratio for the small 1987 year class was 80% spawning at age 3, while over 90% of the very small 1980 year class spawned at that age.

Immature 2-group capelin will remain in that state of maturity until in their third year, when the maturing process sets in for spawning at age 4. Surveys have shown that the feeding migrations of immature 2-group fish are similar to those of the 1-group juveniles, with the exception that they generally have a more northerly as well as westerly distribution. In summer, therefore, these capelin have a wider distribution than the 1-group and are found over and outside the slopes of the submarine terrace off the western north coast of Iceland and in the deep waters of the Iceland-Greenland Channel. At times, immature 2-group capelin may also be found still farther west and north as well as off Northeast Iceland.

The 1-group juveniles and, in particular, the 2-group immatures that in summer were distributed at higher latitudes in the area between Greenland and Jan Mayen and over the East Greenland shelf in the region off Scoresby Sound, retreat towards south along the Polar Front as the flow of cold, arctic water from the north increases and cools down the surface layers in autumn. It seems that this part of the capelin stock generally arrives in October and November in the area near the outer slope of the shelf over the Iceland-Greenland Ridge and/or on either side of the Iceland-Greenland Channel to the west of the Vestfirðir peninsula.

In the 1980s and the early 1990s, the centre of the mid-winter (January - February) distribution of the juvenile 2-group capelin and the immature part of the 3-group has generally been off the western north coast and the Vestfirðir peninsula (figure 13.2). However, this is not always so. The 2-group immatures often show a tendency to follow the spawning migration eastward off the north coast to the area off Northeast and East Iceland in variable quantities and stay there, until beginning their feeding migration to the north as 3-group in the spring of the following year.

It is of interest that in the 1981 - 1992 period there was only one instance when considerable quantities of 3-group immatures were distributed off East and Northeast Iceland in late winter. This happened in 1986 and was due to the very large year class of 1983 of which only about 40 percent matured to spawn as 3 year olds. In the winter of 1986 there were, therefore, large numbers of immature 3 year

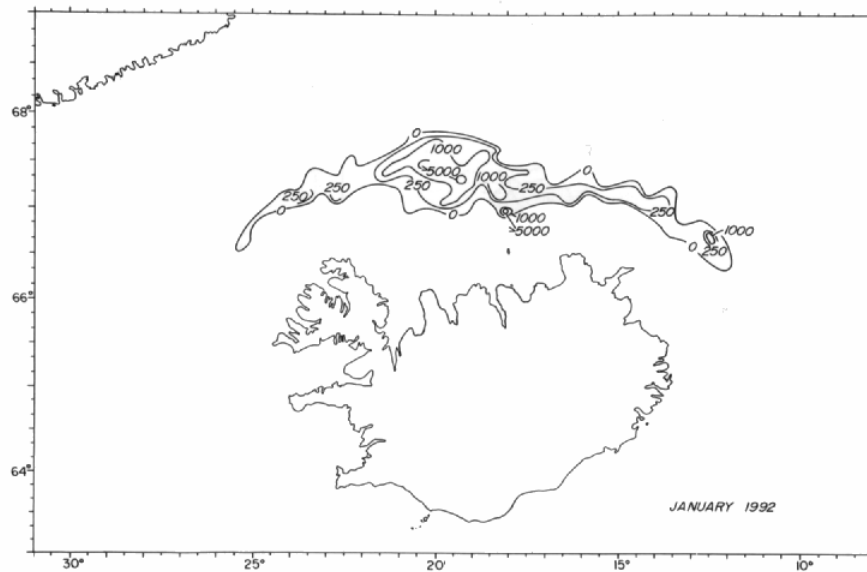


Figure 11.1.2: A typical mid-winter distribution pattern of juvenile 2-group capelin in the 1980s and early 1990s.

olds of which a very considerable proportion followed the 1986 spawning stock and overwintered off East and Northeast Iceland. The same is probably true for those years in the 1969 - 1976 period when much immature 3-group capelin were observed in the east Icelandic area.

11.1.4 The adult stock

In 1978 the combined information from scouting operations and the fishery clearly demonstrated a feeding migration of adult capelin from the north Icelandic area along the Polar Front to the area west and northwest of Jan Mayen in July and August and a return migration south along the front in September and October. These migrations were also documented by the results of tagging experiments carried out in July and early August of the same year. The movements of the fishable stock as described by these tagging experiments are illustrated in figure 11.1.3.

Through research as well as information from the fishery, a more detailed picture was established in the following years of the summer/autumn feeding migrations of the adult Icelandic capelin stock in the Iceland Sea. In this period the adult or maturing stock was often divided between two areas during the feeding season, which have often been referred to as northern and southern components.

The southern component feeds in the waters over the Iceland-Greenland Ridge and off North Iceland where it is often mixed with juveniles. This part of the stock generally does not migrate much beyond 68° - 69° N, i.e. the area where the East-

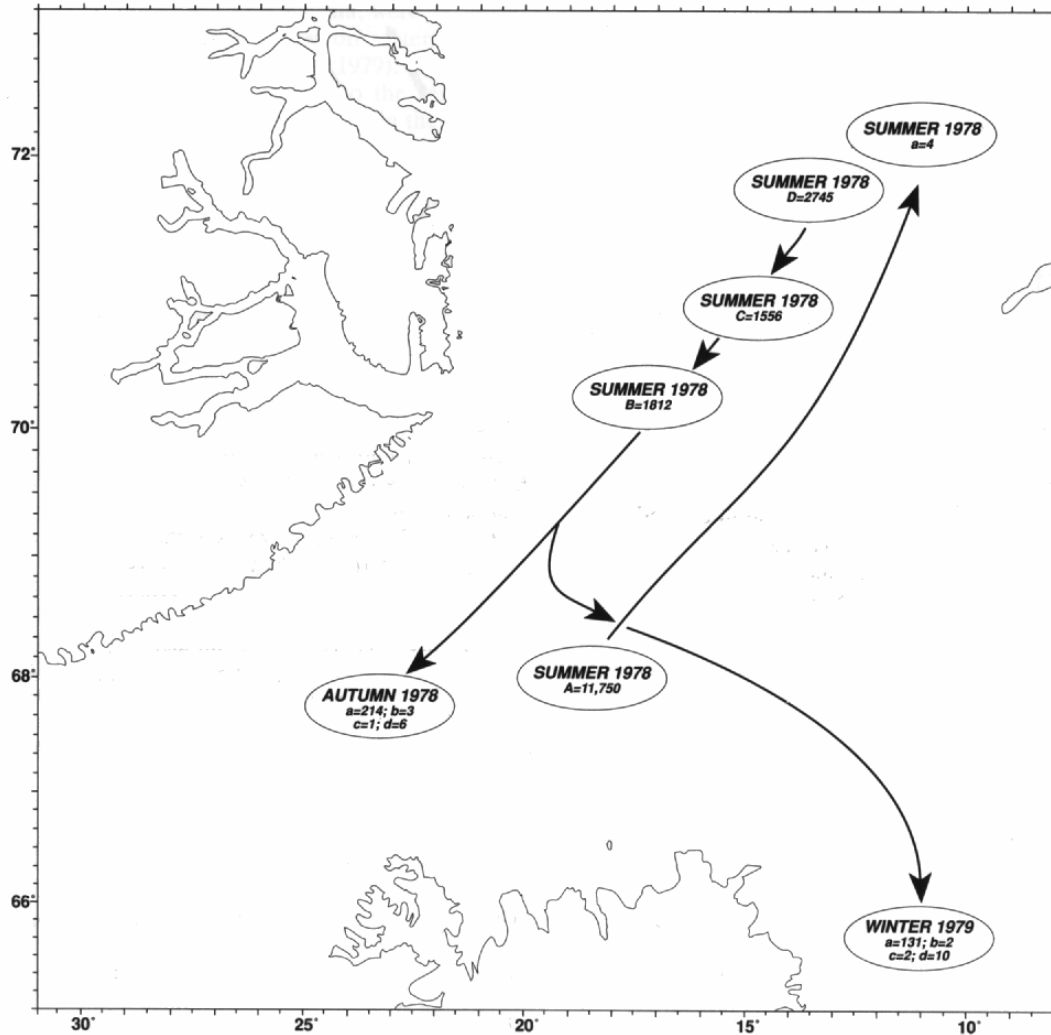


Figure 11.1.3: The movements of the fishable stock in 1978-1979 as illustrated by the tagging of capelin and returns of capelin tags from Norwegian and Icelandic meal and oil factories. Capital letters denote taggings and low case letters denote recaptures.

Icelandic Current branches off from the East- Greenland Current. The northern component, consisting of the oldest and largest fish, on the other hand, undertakes a long northward migration to the area between Greenland and Jan Mayen and to the north of Jan Mayen to 72° - 74°N. As a rule, these capelin are not mixed with juveniles in summer and autumn and in late September they start migrating back south again. In October - November both components begin to assemble and mix in the wintering area near the edge and outer part of the submarine terrace

off North or Northwest Iceland. From there the spawning migration usually starts in December and as a rule follows the shelf edge off North and East Iceland in a clockwise direction as described in section 11.2.1.

The general movements of the maturing stock in summer and autumn are illustrated in figure 11.1.4. It is assumed that they describe the most common migration pattern of the adult stock during the feeding season. However, in spite of the relatively short period of observation (15 years), it has become equally clear that these migrations are subject to changes, which sometimes may indeed be quite dramatic.

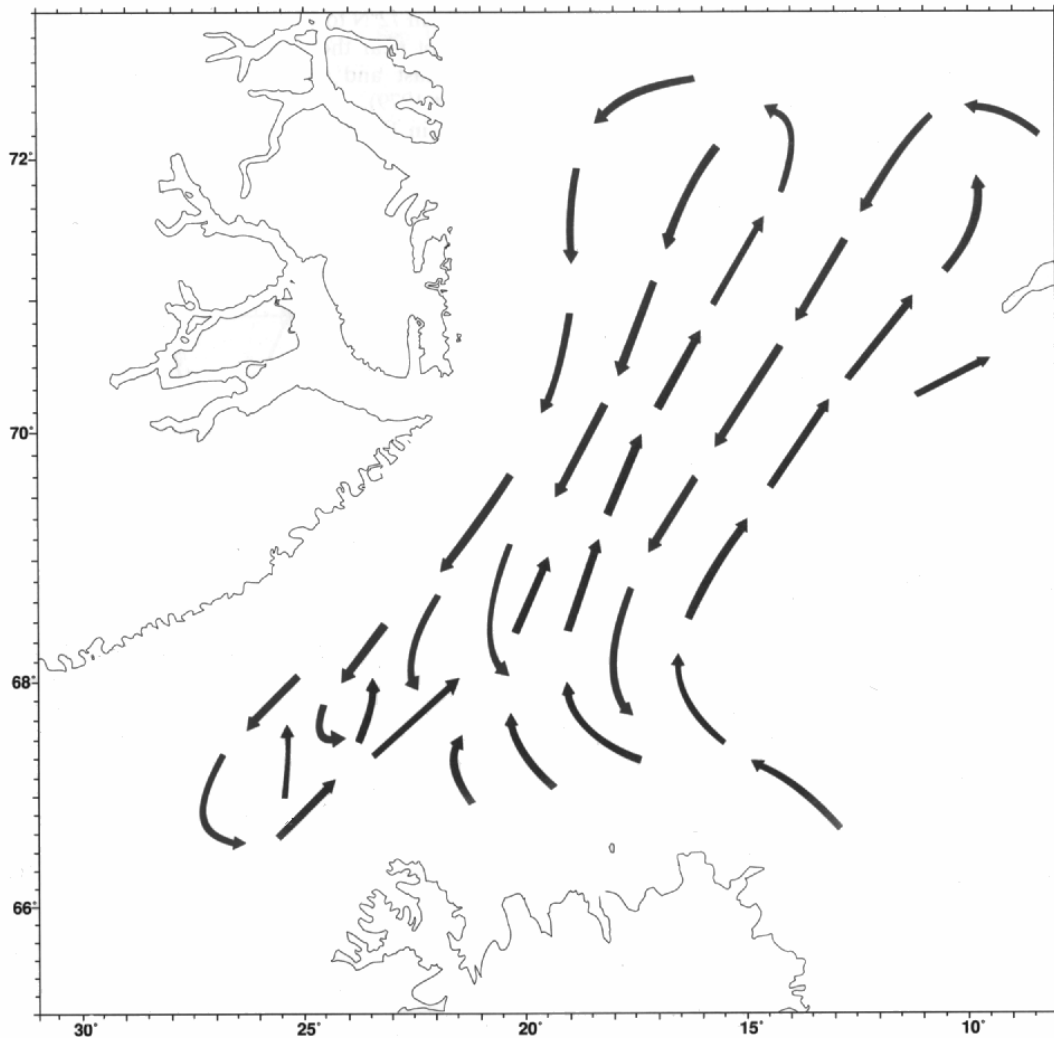


Figure 11.1.4: A common migration pattern of the maturing part of the capelin stock in the feeding season. Upward arrows: spring and summer. Downward arrows: autumn.

In most years of the since 1978 the maturing stock of capelin undertook lengthy

feeding migrations to the central and northern part of the Iceland Sea in summer and returned to the areas off North and Northwest Iceland in autumn. These migrations have been documented by frequent observations of capelin distribution in the July/August period and again in October/November. During their feeding migrations the capelin have followed the eastern boundary of the East-Greenland Current quite closely and longitudinal changes in the migration route from one year to another have been linked to changes in the distribution of polar water from the East-Greenland Current and the temperature regime of the Iceland Sea.

When comparing capelin distribution to environmental variables, it should, however, be borne in mind that actual acoustic abundance assessment has proven impossible at the height of the feeding season. This applies in particular to the central and northern Iceland Sea and is mostly due to capelin feeding in the immediate surface layers at a depth of 5 - 10 m where they are out of range of vertically registering echo sounders. Although this probably does not cause actual gaps in the observed capelin distribution, it may account for distribution centres not being registered where they should have been in July - August and thus to some extent give a distorted picture of the actual distribution pattern.

No capelin migrated to feed in the central and northern Iceland Sea in 1988. In that year a broad tongue of subzero temperatures reached almost to 12°W in deep waters north of Iceland, with a tongue of water of < -1°C extending east to about 13°40'W, indicating extremely cold conditions in the central and northern Iceland Sea. In migrating for feeding in the central and eastern Iceland Sea the capelin would in 1988 have had to either traverse a wide area of inhospitable waters or circumnavigate it. With the initial westerly distribution of the adult stock in spring and early summer of 1988 neither of these choices were accepted. A hypothesis that capelin will not migrate for any length of time through waters colder than -1°C is thus strongly supported by the 1988 data and explains why the normal migration pattern was disrupted that year.

In spite of drift ice, which because of prevailing winds covered quite extensive parts of the Iceland Sea for periods of time in summer and autumn of 1989, these waters were, on the whole, relatively warm below the surface layer both in August and October. Although hydrographic data are not available for the central and northern Iceland Sea in July - August 1990, Icelandic summer and autumn data from the area south of 68°30'N indicate average or mild conditions in that part of the area. And in August 1991 the central Iceland Sea was relatively very warm. Nevertheless, the apparently normal migration pattern for feeding in the central and northern Iceland Sea was not established again.

The northward migration in early summer of 1992 was halted at about 70°N from where the capelin retraced their path to the north Icelandic area in the latter half of August. In 1993 capelin again migrated to feed in the northern Iceland sea in summer, but in 1994 very few capelin were registered north of 70°N.

11.2 Spawning migrations

11.2.1 The eastern spawning route

Usually the spawning migrations from the wintering area north and northwest of Iceland begin in December. The migrations initially follow the outer shelf edge off North and East Iceland in a clockwise fashion. This sea area is characterized by the presence of the boundary zone between the north Icelandic winter water with temperatures of 1.5 - 2.5°C covering the shelf area and the arctic surface waters of the East Icelandic Current with temperatures of 0 - 2°C, usually encountered at a short distance outside the edge of the Icelandic shelf.

When arriving in the area about 50 - 80 naut. miles off the southern east coast of Iceland, the spawning migrations encounter sharp current boundaries and temperature gradients where the warm Atlantic water (about 7°C) of the North Atlantic Drift meets the East Icelandic Current. The capelin will normally stay on the colder side of the boundary until they have reached that stage of maturity when the weight of the female ovaries is about 8 - 10% of their total body weight. At this point the migrations will head for the south and west coast spawning grounds, usually following the boundary zone between the cold and warm water masses, to approach the coast in the region of Hornafjörður at Southeast Iceland. Sometimes, however, the capelin may make a detour to the south or southeast and do not approach the coastal area until at or even west of cape Ingólfshöfði some 60 - 80 naut. miles farther west.

When the capelin with a roe content of 8 - 10% enter the warmer Atlantic water a rapid increase in the rate of maturation is observed. From then on maturation proceeds at a rate described by the weight of the female ovaries, increasing by approximately 1% of their body weight per day, until spawning commences about 3 weeks later. In the first and usually largest runs, spawning will normally take place in the western part of the south coast spawning grounds and/or off the west coast. Later migrations may, however, consist of individuals that are more mature when entering the warm coastal waters. In consequence, these fish will spend much less time in the coastal area before becoming ready to spawn, and under normal circumstances they are responsible for much of the spawning products deposited in the easternmost part of the south coast spawning grounds.

The general position of these migration routes in relation to environmental variables (judged by temperature) in the area is shown in figure 11.2.1. Over the years, deviations from the average geographical position of the eastern migration route(s) have usually been remarkably small except in the area off Southeast Iceland.

The behaviour of the capelin at the boundary zone off East and Southeast Iceland may nevertheless be quite variable. On reaching this area, the spawners often slow down or even stop, apparently to adjust their maturity to a stage suitable for entering the warmer Atlantic waters. The rule seems to be to follow the warm/cold water boundary up to the coast and after that the coastline, as shown in figure 11.2.1. If this course is taken, the prominent migratory schooling behaviour, usually exhibited

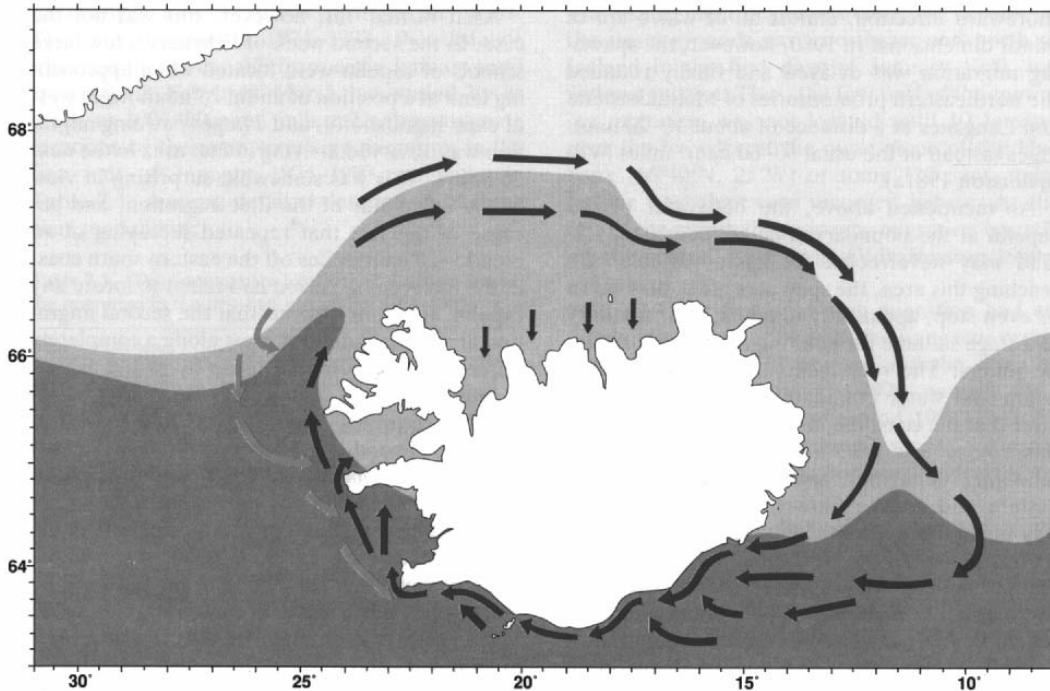


Figure 11.2.1: The location of the spawning routes of the Icelandic capelin.

in the eastern and northern areas, may persist all the way up to the the southeast coast.

Alternatively, the first migration(s) may approach the coastal area along two different routes. In this case the first migration follows the warm/cold water boundary as described above and arrives in the Hornafjörður region from where it continues westward in shallow waters as usually. Later migrations may arrive at the south coast along a completely different route. Thus, after entering the warm Atlantic water off Southeast Iceland, the second migration may navigate west along or outside the shelf edge to approximately the longitude of cape Ingólfshöfði or even farther west before approaching the coast from a southeasterly direction (figure 11.2.1). In later years, it has become obvious that either one of these routes may be used. Many skippers even maintain that in some years capelin will keep to the deep waters off the shelf edge, all the way to Vestmannaeyjar before approaching land. This, however, has never been observed from research vessels. In general, it seems that the less advanced in maturity the capelin are when arriving at the warm water front, the more likely they are to take the longer and more southerly route.

The first, main spawning migrations usually spend about 3 weeks in the warm Atlantic waters before spawning, much of that time in rapid migration towards the west coast spawning grounds. Late spawners tend to be more mature when arriving in the coastal area, migrate much more slowly and spend far less time in

the warm south coast waters before spawning. As a result, it is the size of the first 1 - 3 spawning migrations, their speed of progress along the south coast and the time difference between them that determines the duration of the capelin spawning season at South and Southwest Iceland. Usually, these variables also determine the amount of spawn deposition in the main southwestern and western parts of the spawning area. However, deviations arising from the difference in time spent in the warm Atlantic waters in more offshore areas off Southeast Iceland, often complicate the picture and apparently they are sometimes responsible for shortening the time on the coastal spawning grounds, as compared to the “normal” situation.

In spite of the relatively small deviations, observed of the actual spawning migration route along the edge of the continental shelf east and north of Iceland in January, other and more drastic changes have occurred through the years. Thus, in the period 1974 - 1993, the distance travelled by the capelin from early January until spawning in February - March has varied by as much as 300 - 400 naut. miles. The approximate locations of the main spawning migration in the first half of January 1974 - 1993 are given in table 11.2.1.

Year	Latitude	Longitude	Location
1974	65°00'N	11°00'W	Central east coast
1975	66°00'N	11°00'W	East of Langanes
1976	67°15'N	16°00'W	North of Melrakkaslétta
1977	67°40'N	14°00'W	Northeast of Langanes
1978	67°20'N	16°00'W	North of Melrakkaslétta
1979	67°35'N	20°30'W	Western north coast
1980	67°30'N	24°30'W	Northwest of Vestfirðir
1981	67°30'N	13°00'W	Northeast of Langanes
1982-	64°20'N	10°00'W	East of
1993	66°00'N	12°00'W	Iceland

Table 11.2.1: The approximate locations of the main spawning migrations in the first half of January 1974-1993.

In retrospect, the delay of the eastward migration of the spawning stock in the late 1970s as well as in 1980 concurs with the fact that in those years the spawning stock was distributed in or southwest of the Iceland-Greenland Channel in autumn and early winter but not off the north coast of Iceland as has been the case since then for most of the spawning stock at that time of the year.

The speed of the spawning migration in the more oceanic areas off North and East Iceland has always been extremely variable. The capelin may thus migrate in an irregular fashion at speeds of up to 20 - 30 naut. miles per day for periods of several days, while slowing down to 10 - 20 naut. miles per day or even stopping completely for periods of time in between.

The centre of the first migration has most frequently been located in the area off Northeast Iceland in early January. The arrival of these migrations in the cold/warm

water boundary zone off the southern east coast, no more than 100 - 150 naut. miles further south, has nevertheless varied quite remarkably over the years. Thus, in the period 1969 - 1975 the arrival of the spawning migrations in these waters has varied within a time span of approximately one month as shown in table 11.2.2.

Year	Day	Month
1969	01	February
1970	05	February
1971	05	February
1972	10	January
1973	25	January
1974	15	January
1975	05	January

Table 11.2.2: Date of arrival of the first spawning migration at the cold/warm water boundary off Southeast Iceland in 1969-1975.

over the entire area from east of Hornafjörður in the east, to Breiðafjörður on the west coast [47].

The reasons for the variations in travel times from the boundary zone to the spawning grounds are far from clear. Varying feeding conditions and temperature in the northern part of the Iceland Sea, as well as elsewhere in the distribution area of the maturing stock during the previous summer, probably constitute part of the explanation by determining the stage of maturity and thus the physiological state of readiness to cross the cold/warm water boundary when the fish arrive there.

11.2.2 The western spawning migration

In 1977 considerable research effort was, for the first time, devoted to searching for and monitoring migrations of maturing capelin off the northwest peninsula of Iceland (Vestfirðir). However, only small quantities of spawners mixed with immatures were registered at and outside the edge of the shelf between 66°N and 67°30'N. In late February the maturing part of this mixed stock approached the coast by some 10 - 15 naut. miles but otherwise stayed in the same general area (figure 11.2.2). As it turned out, this capelin spawned in the last days of March and in April on the shelf some 20 - 40 naut. miles offshore to the west of the southern Vestfirðir peninsula [48], [54].

Surveying of the area west and northwest of the Vestfirðir peninsula in the winter of 1978 revealed the presence of large amounts of juvenile capelin but no spawners

[50]. However, in the following year (1979) a survey of this area in early February showed the presence of large amounts of capelin, most of which were maturing spawners. Their path of migration in the following 4 weeks south across the outer Látragrúnn bank and east along its southern edge to spawn on both sides of the Snæfellsnes peninsula in the latter half of March 1979, is indicated in figure 11.2.1 [51].

Around 20 February 1980 a small spawning migration was located at Snæfellsnes and two larger ones a few days earlier on the outer Látragrúnn bank as well as west of the Vestfirðir peninsula [52]. These capelin gradually migrated to the Faxaflói area and most of them continued south from there to round the Reykjanes promontory. In part, these capelin migrated some 60 naut. miles east along the south coast before they spawned.

In the 1980s it gradually became clear that mature capelin approaching the west coast spawning grounds from the northwest are by no means an annual occurrence. On the contrary, these approaches became less frequent and smaller than they had been in the latter part of the previous decade. Although the case is by no means clear-cut, it seems that the presence of appreciable concentrations of mature capelin off the Vestfirðir peninsula in winter, and the subsequent migration directly south and southeast towards the west and/or southwest coast spawning grounds is associated with a western distribution of the spawning stock in late autumn and early winter in the year before. This has not been the case in the 1980s or the early 1990s. In this period the number of spawners, arriving along the western route, have always been of minor importance compared to those from the east. It is also possible that capelin, migrating from the west to spawn, had overwintered in the Dohrn Bank area, i.e. in the region of the East-Greenland plateau. However, such cases have never been recorded, neither by research nor fishing vessels.

11.2.3 North coast spawning migrations

In the 1970s several short surveys were carried out in order to study the abundance and migrations of pre-spawning capelin off the north coast in late March and April. With the exception of 1977, when a small migration of spawners consisting of several schools was found in the process of arriving along the western side of the Eyjafjörður

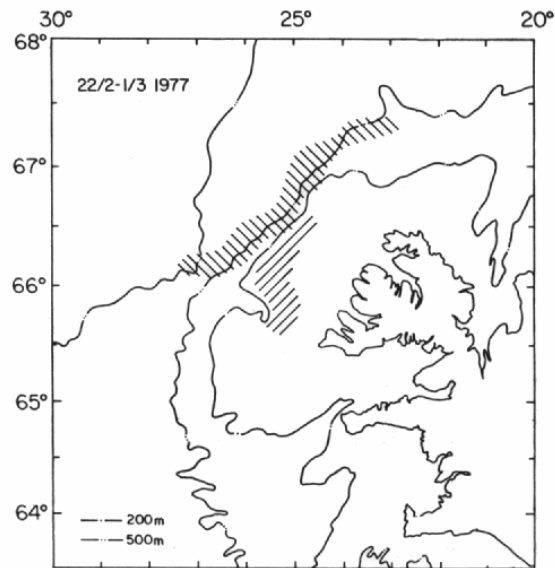


Figure 11.2.2: The observation of capelin entering the banks off the Vestfirðir peninsula from the west to spawn there in March 1977. Distribution area in February (right slope), spawning area in March-April (left slope).

deep from the north, the findings consisted of single schools in shallow waters [49].

In the north Icelandic area capelin spawners generally approach the coast from the north (figure 11.2.1) along the troughs in the submarine plateau that often continue from the fjords cutting into the coastline. Moving south along these submarine valleys, the capelin tend to follow the western slopes of the valleys and in doing so migrate in the direction of the average bottom current. This behaviour persists after the fish have entered the fjords in which they spawn, from where they will continue outwards on the eastern side if they have not already finished their task.

From the evidence that has become available in the last 3 - 4 decades, it is obvious that, in this period, capelin spawning in other areas than those off South and West Iceland have contributed little to the spawning biomass. As mentioned in an earlier section, mass spawning of capelin at North and East Iceland may, however, have been much more common in the 1920s and 1930s [35], [36] than has been the case in recent decades.

11.3 Migration matrices

In this section an attempt to implement some of the things discussed earlier in the chapter will be discussed.

As described in chapter 11 the capelin enters the model in August at age 0 with its distribution set according to the zero group survey.

The migration of capelin are simulated with relatively few migration parameters. The same migration matrices are used for all years (with one exception) which is not according to what has been observed as described in section 11.1.4.

Based on sections 11.1.1, 11.1.2 and 11.1.3 the migrations of immature capelin were divided into three different time periods, i.e. November-January, February-April and May-October. In the time period November-January there seems to be a westward migration from the north and northeast coast of Iceland to the west. In February-April the movement is mainly to the north and in May-October the immature capelin migrates to the east. This migration pattern is simulated with three matrices, one for each time period, parametrized with one parameter each. Figures 11.3.1 to 11.3.3 show the direction of movement in each time period as well as the parameters of the migration matrices.

Based on sections 11.1.4, 11.2.1, 11.2.2 and 11.2.3 the migrations of mature capelin were divided into five different time periods, i.e. December-March, April-May, June-July, August, and September-November. Each of these time periods has its unique direction of movement apart from the months April-May and August when there seems to be no apparent migration of mature capelin. The migration pattern of mature capelin is simulated with three different matrices, one for each time period (discluding the time periods April-May and August for obvious reasons), parametrized with four parameters. Figures 11.3.4-11.3.6 show the direction of movement as well as the parameters of the migration matrices. Dispersion according to 11.3.4 is added to the migration matrices in all months. In the simulations

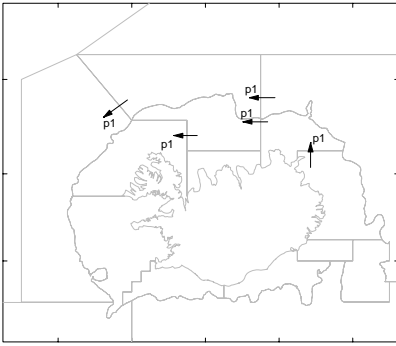


Figure 11.3.1: Migration of immature capelin in February to April

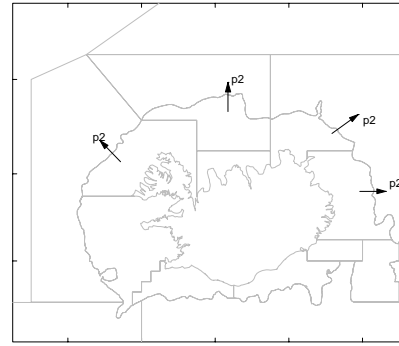


Figure 11.3.2: Migration of immature capelin in May to October

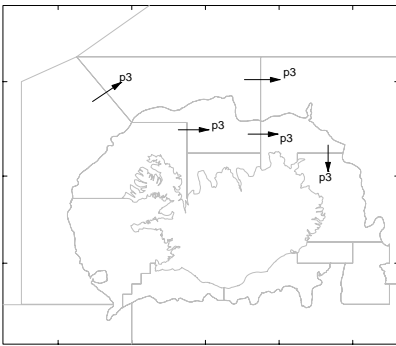


Figure 11.3.3: Migration of immature capelin in September to December

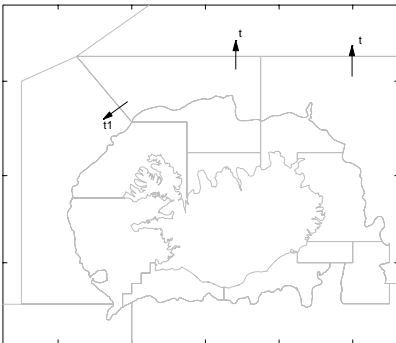


Figure 11.3.4: The migration of mature capelin in June-July.

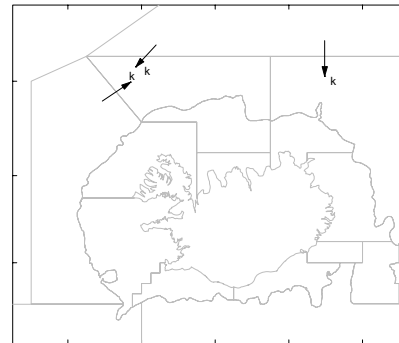


Figure 11.3.5: The migration of mature capelin in September-December.

presented in this book the migration of immature capelin in April and May does not matter for all mature capelin dies after spawning and maturation of capelin does not occur until the end of May.

In addition to the migration described migration patterns, two parameters were added at all time periods to allow some drift between adjacent areas. They are

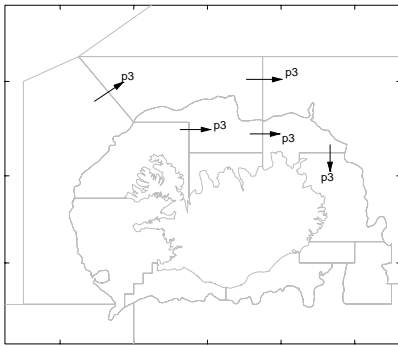


Figure 11.3.6: Migration of mature capelin in January to March

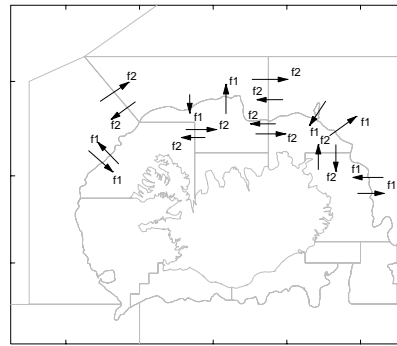


Figure 11.3.7: Dispersion of immature and mature capelin at all periods

common to the immature and mature part of the stock, and are shown in figure 11.3.7. The values used for the dispersion parameters are

The starting values of the migration parameters were obtained by rudimentary changing the initial values until the distribution of immature and mature capelin was sufficiently close to the distribution estimates of the acoustic surveys in 1985-1992. The values of these parameters should therefore capture the main migration of both immature and mature capelin.

	Imm	Mat	Both
p1:	0.17	t: 0.82	f1: 0.05
p2:	0.00	t1: 0.50	f2: 0.01
p3:	0.06	k: 0.06	
		s: 0.88	

Table 11.3.1: The values of the migration parameters for capelin.

The migration parameters shown in 11.3.1 were reestimated in the cod-capelin simulations. Predation by cod is a large part of the mortality of capelin in those simulation. As predation by cod only occurs in areas 1-10 the proportion of capelin in these areas will gradually decrease when capelin does not migrate. This would look like migration outwards 11.3.5 in a single species model. Reestimating the migration parameters is therefore nessecary in multispecies simulations.

11.3.2 shows the estimated values of the migration parameters from a cod-capelin simulation with cod from age 3 to 11 and a simulation where 0 to 2 years old cod is also included.

In those simulations the parameter describing t describing the northward migration of mature in June and July was estimated seperately in 1993 but the catch of capelin in area 16 was 340 thousand tons in that year which is much more than in any other year. The value of the parameter $t1$ is negative but the dispersion parameter $f2$ is added to it making no migration from area 11 to are 15. The value

Name of coefficient	p1	p2	p3	k	t	t_{93}	s	t1
Cod 3 to 11 years	0.36	0.073	0.25	0.39	0.40	0.89	0.89	-0.01
Cod 0 to 11 years	0.25	-0.002	0.19	0.28	0.36	0.89	0.89	-0.01

Table 11.3.2: Estimated values of the migration parameters for capelin from cod-capelin simulations.

of the parameter s describing the spawning migrations was 0.88 which is on the limits of being illegal. (A migration parameter is illegal if an element of a migration matrix becomes negative or larger than one). That the estimated value of s is on the border of becoming illegal indicates that the spawning migration according to 11.3.6 are not fast enough and larger jumps should be allowed. That the migration is not fast enough means that not enough capelin make it to the area west of Iceland (area 1) before spawning.

Simulating the spawning migration of properly by using the same migration matrices in all years and a period of one month is though always going to be difficult. Shortening the period and allowing for variability from one year to another is though something that will not be considered in this book.

The spawning migration of capelin only take few months. Improved modelling of them will not affect the estimated consumption of capelin by the cod-stock much. It will increase the estimated size of the capelin stock to reduce understocking but the estimated capelin consumption by the cod stock is more controlled through stomach samples and cod growth. Interesting local details like consumption of capelin west of Iceland in March can though get lost.

Figure 11.3.8 shows the distribution of capelin from cod-capelin simulation (cod 3-11 years old) . The figure shows the distribution of the capelin that matures in May 1992 until it dies after spawning in 1993. In the simulation all mortality of mature capelin was removed after March 1992. Including the mortality will give completely different picture. Figure 11.3.9 shows the distribution of the 1983 yearclass from september 1983 to August 1985 from the same simulation. All mortality are included in the figure. It gives some ideas about the distribution of capelin in cod-capelin simulation.

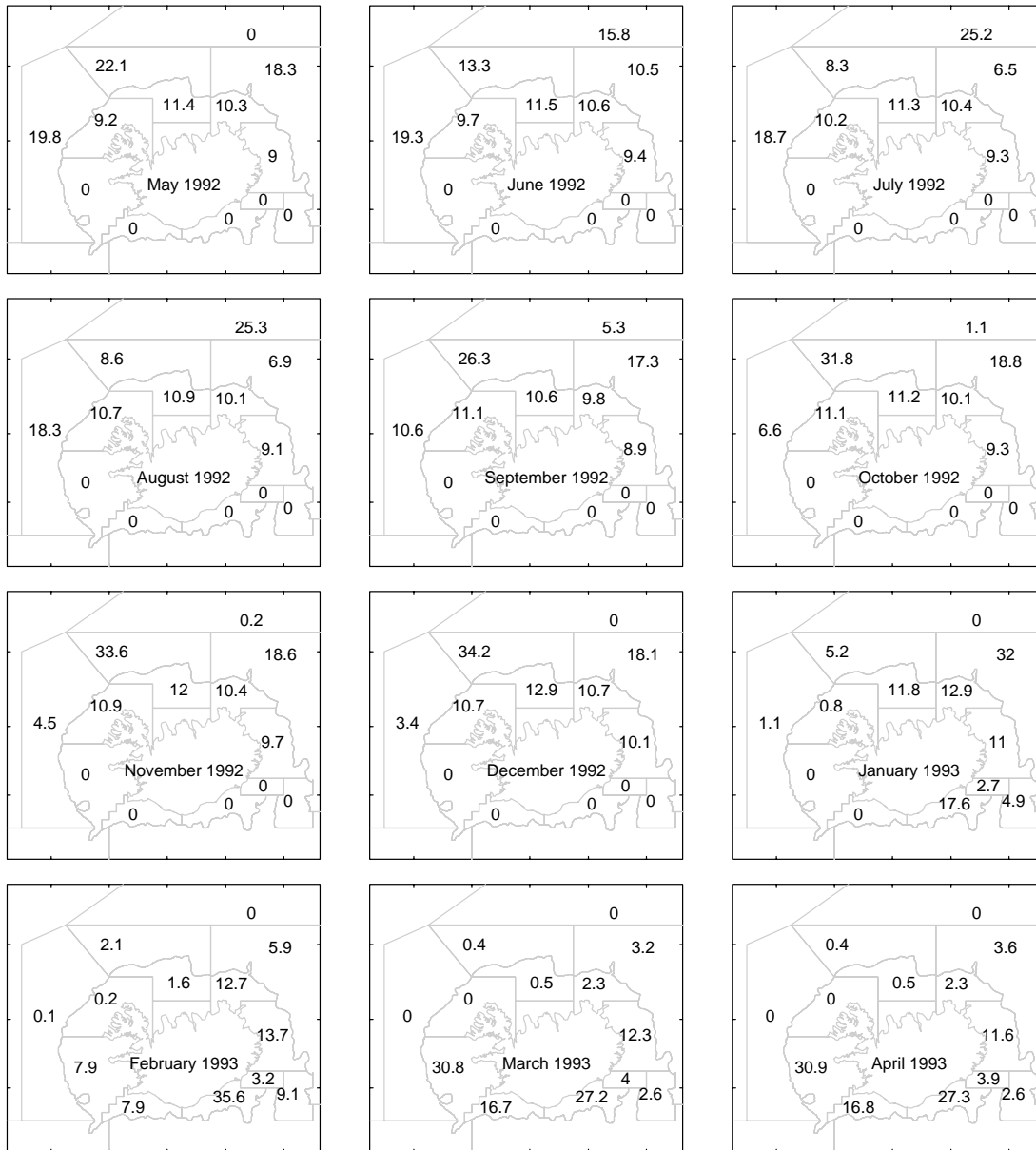


Figure 11.3.8: Distribution of the capelin that matured in May 1992 until it spawns in March 1993

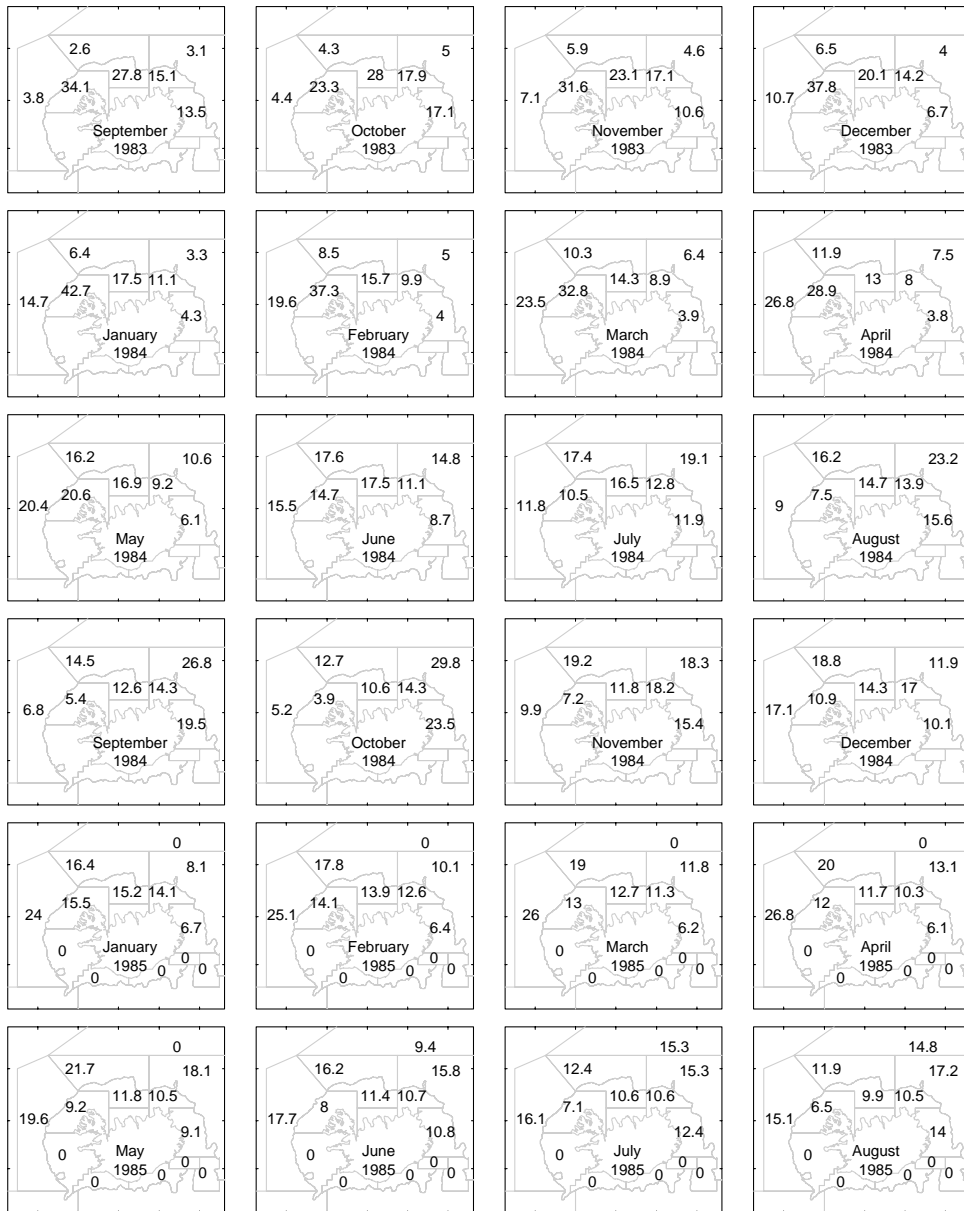


Figure 11.3.9: Distribution of the 1983 yearclass of capelin in cod-capelin simulation

Part V
Simulations

Chapter 12

Cod: Results of single species simulation

Höskuldur Björnsson

12.1 Introduction

This chapter describes the input and output from the use of Bormicon in a single-species simulation of the cod stock. Since there are no species interactions, it should be possible to compare biomass estimates to those obtained from single-species assessments ([20], [38] and [6]).

12.2 Model definitions

Since this is a single-species simulation, the cod is only allowed to eat “other food”. The amount of “other food” is adjusted so that there is plenty of it but the consumption is adjusted by changing the suitability.

The amount of food is the same in all areas and hence ψ , as defined in chapter 4, is constant across areas.

The growth will vary due to temperature differences, implying slow growth in the colder areas.

The fishing fleets are implemented as predators with a specified length based suitability, as detailed in chapter 6. There are 3 different fleets corresponding to the main gear groups (long lines+handlines, bottom and pelagic trawl+Danish seine, gillnets).

Migration of cod is described in chapter 11 where initial values for migration matrices were developed separately for the mature and immature part of the stock. Furthermore, a separate set of migration matrices were estimated for the mature part of the stock based on tag-return data.

In what follows, both sets of matrices for the mature part of the cod stock are tested. Further, the effects of changing the migration parameters for the immature cod are tested.

A total of nine different model simulations were undertaken. Each of these corresponds to a specific set of input parameters, as described in the following table.

Simulation number	ψ	Mig. par p	Mig. par q	Mig. par r	Mature migration matrices
1	0.448	0.05	0.015	0	initial
2	0.448	0.05	0.03	0	initial
3	0.448	0.05	0.05	0.05	initial
4	0.407	0.05	0.05	0.05	initial
5	0.467	0.05	0.05	0.05	initial
7	0.448	0.05	0.05	0.05	initial
11	0.484	0.05	0.05	0.05	initial
12	0.500	0.05	0.05	0.05	initial
13	0.484	0.05	0.05	0.05	estimated

Table 12.2.1: Input to single species simulation.

Note that in the last simulation the estimated migration pattern from tag-return data (chapter 11) is used for mature cod. In simulation 7 different selection pattern for bottom trawl was used. (Chapter 6)

The migration parameters for immature cod are described in detail in chapter 11, but only two are made variable here.

The general immature dispersion parameter, p , is set constant equal to 0.05. However, the parameter q , which controls the clockwise movement, varies from 0.015 through 0.05, and the parameter r which describes the behaviour in the south-east area, is tested at 0 and 0.05.

12.3 Results

An important measure of the adequacy of the model and parameters is how well the model reflect the catches. In particular, the modelled stock abundance should be maintained at a high enough level to be able to account for the actual catches taken.

In some cases the real catches cannot be obtained within the model. This will be referred to as “understocking” throughout this chapter.

The following text table shows how understocking, in thousand tons, occurs in the various areas in each simulation, displayed as the average across all years.

Similarly, the understocking can be tabulated by year, as an average over all the areas.

simulation	1	2	3	4	5	6	7	8	9	10	tot
1	205	2	0	0	0	14	18	66	28	156	489
2	130	0	0	0	0	34	22	72	27	135	420
3	79	0	0	0	0	68	20	47	16	94	324
4	210	1	0	4	0	101	23	74	44	170	627
5	26	0	0	0	0	51	18	23	2	38	158
7	64	0	0	0	0	66	20	44	13	88	295
11	0	0	0	0	0	33	16	2	0	0	51
12	0	0	0	0	0	20	14	0	0	0	34
13	0	0	0	0	0	67	6	42	7	45	167

Table 12.3.1: Understocking by area.

simulation	85	86	87	88	89	90	91	92	93
1	0	0	0	4	76	114	105	97	93
2	0	0	0	6	60	98	89	87	79
3	0	0	3	8	48	54	64	78	69
4	0	0	7	20	117	136	124	117	108
5	0	0	2	4	34	37	12	26	43
7	0	0	3	8	46	52	53	69	63
11	0	0	2	2	19	25	3	0	0
12	0	0	2	1	11	18	2	0	0
13	0	0	8	19	66	48	20	6	0

Table 12.3.2: Understocking by year.

The understocking occurs in areas 6,7 and 8 in 1990 and this is caused by the unusual distribution of the 1984 yearclass. This particular yearclass had an easterly distribution already as 1-group and continued in this fashion for some of its earlier years. In the runs with less growth understocking also occurs in the spawning areas. ([26]).

Figures 12.3.1-12.3.5 show some results from the various simulations.

Figure 12.3.1 shows total stock size for the 6 simulations. Effects of the growth on the stock size can be seen by comparing 5,11 and 12 which are identical except the feeding level is 0.467, 0.484 and 0.5, respectively. The difference is even larger considering understocking of 158,000 in simulation 5 but up to 5 times less in the other simulations.

Simulations with less migration to the west (simulation 1 and 2 compared to 3) result in less growth since this migration is to warmer areas (from areas 3,4,5 and 6 towards area 2).

The estimated migration pattern from recaptures (simulation 13) gives results similar to simulation 11 except that understocking is 167,000 tons compared to

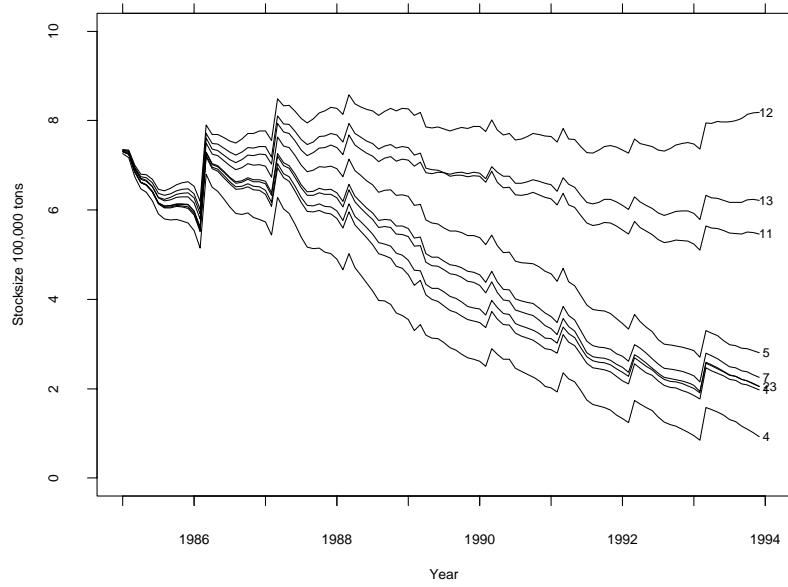


Figure 12.3.1: Total stock size for the 9 simulations.

51,000 tons in simulation 11.

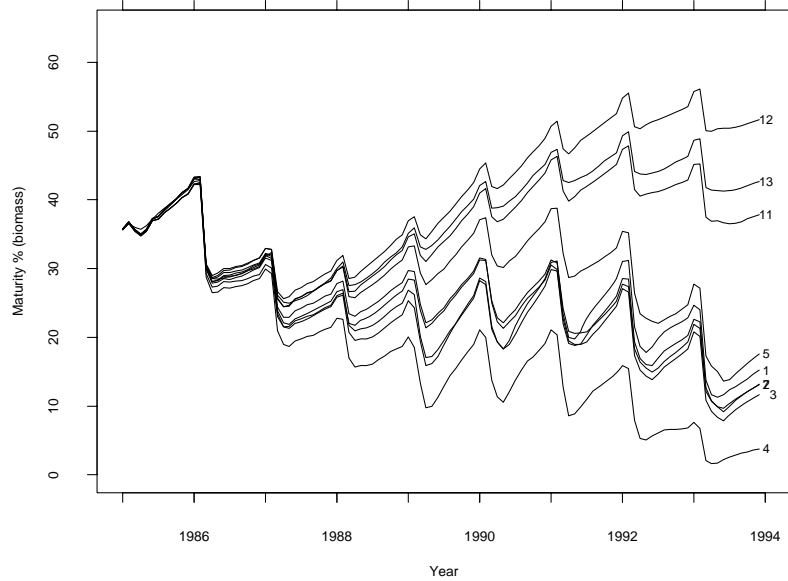


Figure 12.3.2: Biomass of mature stock as percentage of total biomass.

Figure 12.3.3 shows the maturity percentage as function of age for simulation 11. The maturity is lower than has been observed in recent years where maturity at age has been unusually high.

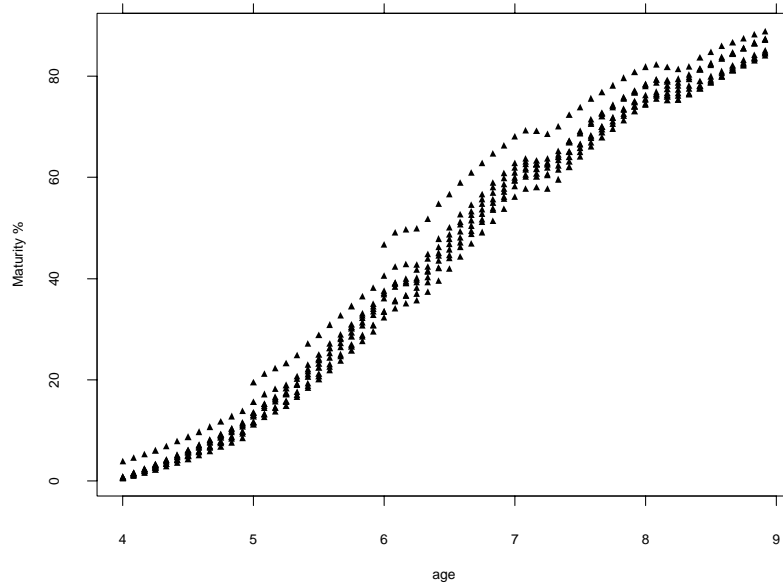


Figure 12.3.3: Maturity percentage as function of age.

Figures 12.3.4 and 12.3.5 show fishing mortality as function of age for simulations 3 and 11. Older fish has higher mortality according to the figure. In figure 12.3.5 comparison is made between the fishing mortality of immature and mature fish (simulation 3).

Figure 12.3.6 shows the mean length from the model (simulation 1) compared to the mean length in the ground fish survey 1995. The model predicts similar growth for smaller fish but more growth than observed for older fish > 5-6 year old. This indicates the need for some slowing-down mechanism in the growth of mature fish during the maturation period. During the spawning period the fish is in warmer areas so its growth increases in this model. Two curves from the simulation appear in the figure for the 1983 and 1984 yearclasses. Figure 12.3.7 shows the mean weight vs. length from the simulation and from the groundfish survey 1995.

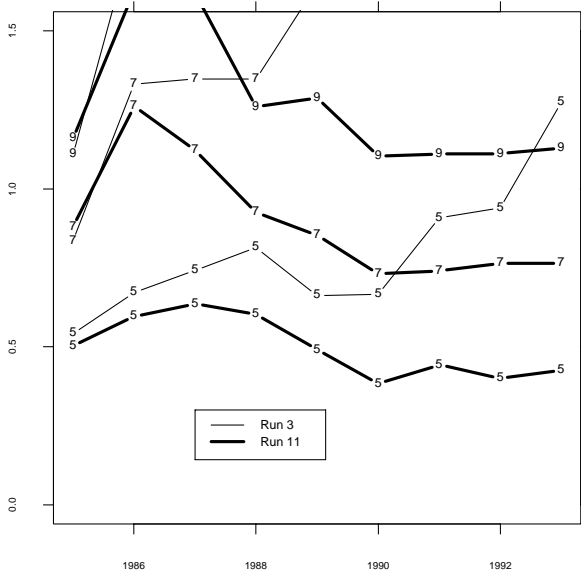


Figure 12.3.4: Fishing mortality for selected age groups.

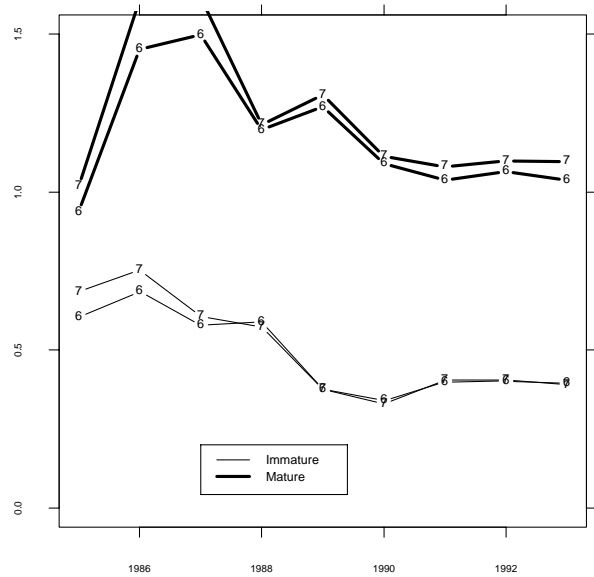


Figure 12.3.5: Fishing mortality for mature and immature fish.

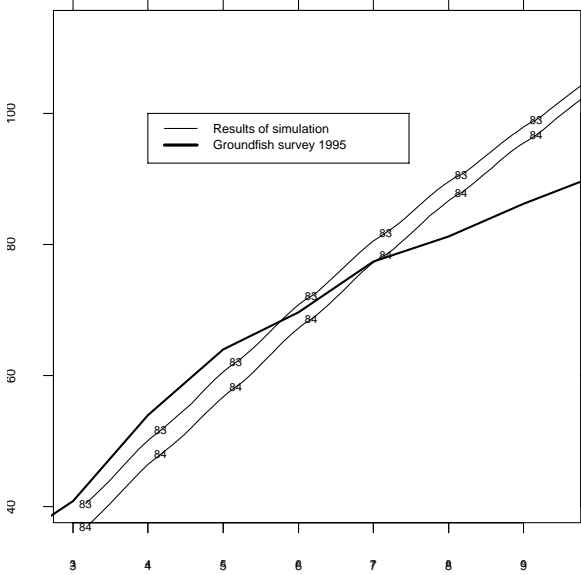


Figure 12.3.6: Mean length vs. age.

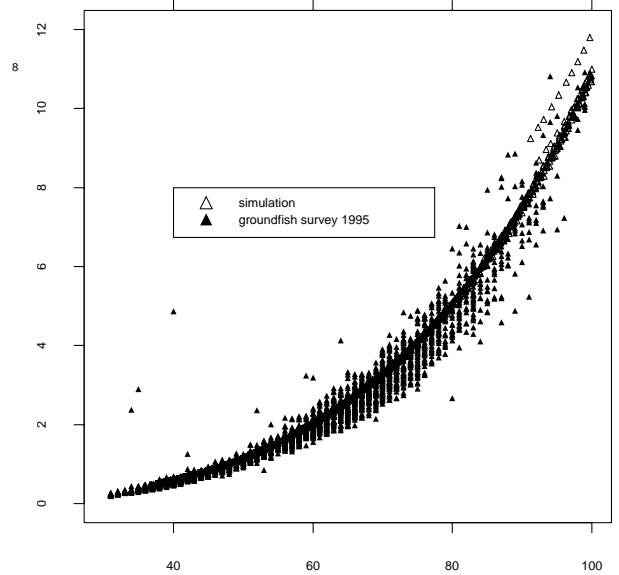


Figure 12.3.7: Mean weight vs. mean length.

Chapter 13

Extended Bormicon examples

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Some examples of the use of Bormicon for simulation and estimation of parameters are presented in this chapter. Two species are considered, cod in the role of a predator and capelin as prey.

As implemented in this example, Bormicon is a model which describes multispecies interactions, technical (fleet) interactions, growth, migration and maturation along with spatial variability in most factors considered. The model accommodates multiple data sources to the temporal and spatial detail needed to describe the processes involved.

Although Bormicon can be used as a simple forward simulation tool, the examples given here include the estimation of unknown parameters through the use of an objective function which can be a negative log-likelihood.

13.1 Base run

The base run for cod and capelin involves the estimation of several unknown parameters with others set at values as described in earlier chapters of this report.

Each species is split into 2 substocks corresponding to immature and mature fish. The capelin enter the model in August at age 0 while cod starts in March at age 3. The simulation period is taken from January 1982 to March 1997. The base natural mortality of cod was set to 0.2 for all agegroups and 0.42 was used for capelin.

In the following text the “northern area” refers to Bormicon areas 2-6 but southern area refers to Bormicon areas 1,7,8,9 and 10 (c.f. 2.1.1). The term “summer” refers to the period from May through October.

Since capelin is the only formally modelled prey, the only other food is "other food". The amount of other food is taken to be large and its suitability low so predation does not affect the amount. The "stock" of other food is split into 3 parts, north-winter, north-summer and south.

As discussed at length in chapter 5, the objective function consists of several components. In this example the following components are used.

1	Area and age disaggregated survey indices for cod
2	Length distribution in survey
3	age distribution in survey
4	conditional probabilities $p(a L)$ in survey
5	length distribution of cod catch
6	conditional probabilities $p(a L)$ in catch
7	age distribution of cod catch
8	accoustic indices from capelin surveys age 1 - 4
9	percentage of capelin in cod stomachs 1982 - 1997
10	understocking of capelin
11	understocking of cod

Each component has an associated weight, which needs to be chosen a priori. The results from model fits may depend quite heavily on the choice of these scaling factors, since the different data sets may contain conflicting information.

A linear relationship between survey abundance indices for cod and stock abundance was assumed in all cases considered. There are indications, however, that the relationship between survey indices and number in stock is nonlinear for several age groups [38] and this might affect some of the results. The reason for the nonlinearity is not clear, however, nor is it clear whether such an inclusion is an improvement rather than an addition of noise due to overparametrisation.

Accoustic abundance estimates of capelin are treated as either proportional or absolute indices. The accoustic measurements for age 3 in the autumn and age 4 in the winter are treated as absolute indices while measurements on younger capelin are treated as proportional indices. An alternative where all accoustic measurements were treated as as proportional indices was also tested.

Including of a term describing understocking of capelin turned out to be an important part of the objective function. As described in chapter 5 understocking is defined to occur when calculated consumption of a prey exceeds the available biomass of the prey. 95% of the biomass was used as criteria for available biomass in this simulation.

It is difficult to adjust the migration pattern so there is always enough capelin in all areas at all times to cover the catch. In the run here the same migration matrices were used in all years. As described in [55] the migration of mature capelin varies from one year to another. This applies both to the northward migration in the summer and the spawning migration. Therefore understocking is unavoidable. If understocking of capelin weights too much in the objective function the model responds by increasing the size of the capelin stock when the migration pattern should change. In the simulation the value of the coefficient b in equation 4.7 was 1.5. Most often the value of b had been 2 but large understocking in area 8 in February 1997 made it nessecary to reduce the value of b . The capelin catch in February 1997 was 460 thousand tonnes which is the highest on record.

In these example runs the final solutions obtained never included any understocking of cod.

The possible treatment of stomach content data is discussed in detail in chapter 5. In the simulations described in what follows, the proportion of prey by weight was used in the objective function.

The proportion of prey in stomachs can in principles be computed directly from measurements of stomach contents. This would have the virtue of simplicity as well as that of statistical uniformity, since this would correspond to direct measurements and not involve any dubious assumptions such as the choice of an evacuation rate model. There are some problems with this approach, however, and in particular it may be reasonable to downweight data corresponding to stomachs with high stomach content. One approach to this is to work through an evacuation rate model.

In the example simulations considered, the stomach content data was transformed by computing the consumption for each stomach sample by an evacuation rate model. The model used was that given by [23].

$$C_{tot} = 2.6 \left(\frac{L}{40} \right)^{1.15} 1.09^{T-6} \sqrt{Q_{tot}} \quad (13.1.1)$$

$$C_{prey} = C_{tot} \frac{Q_{prey}}{Q_{tot}} \quad (13.1.2)$$

This equation is applied to each individual stomach or stomach samples when the stomachs are bulked.

$$p_{pred,prey,A,L} = \frac{\sum C_{pred,tot,A,L}}{\sum C_{pred,prey,A,L}}$$

The summation is over all stomach samples in the same length group in the same area at same time. Therefore all terms except the square root term cancel out and the equation simplifies to:

$$p_{pred,prey,A,L} = \frac{\sum \sqrt{Q_{tot}} \frac{Q_{prey}}{Q_{tot}}}{\sum Q_{tot}}$$

Other evacuation rate models have been proposed [32], [15]. Many of these models can be written in the form $C \propto Q^b$, where the coefficient b is typically between 0.5 (13.1.2) and 1. In particular, $b = 1$ was tested as an alternative (given as alternative 4 below).

If proportions are calculated directly from stomach content the result tends to indicate a higher proportion of capelin. This results from the fact that cod feeding on capelin tends to have more food in the stomach than those not feeding on capelin. The square root term in the above equation reduces the effect of stomach with high stomach content.

This treatment of the data involves the use of a square-root transformation, where other transformations could also have been used and there is no clear reason to

choose one transformation rather than another. This is of course highly undesirable from a statistical or modelling viewpoint, since it corresponds to transforming a y -variable before fitting a regression curve, rather than using an explicit model through a link function and associated distributional assumption, as is standard usage in generalized linear models. Thus, this is somewhat contrary to the principles in Bormicon of including data obtained as measurements into likelihood components, but is used as an example of the possibilities available.

The number of explicitly estimated parameters in the run were 58. In addition to these, a number of regression parameters is estimated implicitly inside the model.

Suitability of capelin as prey of cod	2 parameters
Suitability of otherfood as prey of cod	3 parameters
Maximum consumption of mature and immature cod	2 parameters
Maturation parameters for cod	2 parameters
Recruitment of age 3 cod 1982 - 1997	16 parameters
Migration parameter for immature cod	1 parameter
Multiplier on initial number of capelin	2 parameters
Multiplier on initial number of cod	7 parameters
Recruitment of immature capelin at age 0 1982:1995	14 parameters
Migration parameters for capelin	3 for immature, 3 for mature
Selection pattern of the fleets catching cod	6 parameter, 2 for each fleet
Immigration 6 years old cod from Greenland 1990	1 parameter

Table 13.1.1: Parameters estimated in different parts of the model

The parameters in the suitability of capelin as prey for cod are the same as described in earlier chapter, albeit with separate multipliers estimated for immature and mature capelin.

Figures 13.1.1 to 13.1.7 and tables 13.2.1 to 13.2.5 show some of the output from the base run.

Table 13.1.2 shows some key results from the baserun. A similar table will also be set up to describe outputs for the alternative runs discussed later in the chapter.

Figure 13.1.1 shows the biomass of cod stock according to the model and from the 1997 stock assessment ([21]). The fishable stock of cod 4 years and older from the model and the "catchable" stock from the assessment clearly show similar trends but a somewhat different magnitude where the assessment results are considerably higher than the model output.

It should be noted that the "catchable" stock in [21] is defined as the biomass of 4 year old cod and older, but this biomass is based on numbers in the beginning of the year and the mean weight at age in the catch during the year. The mean weight in the catch during the year will be larger than the mean weight in the beginning of the year. Further, the mean weight of age 4 in catches is much higher than in the

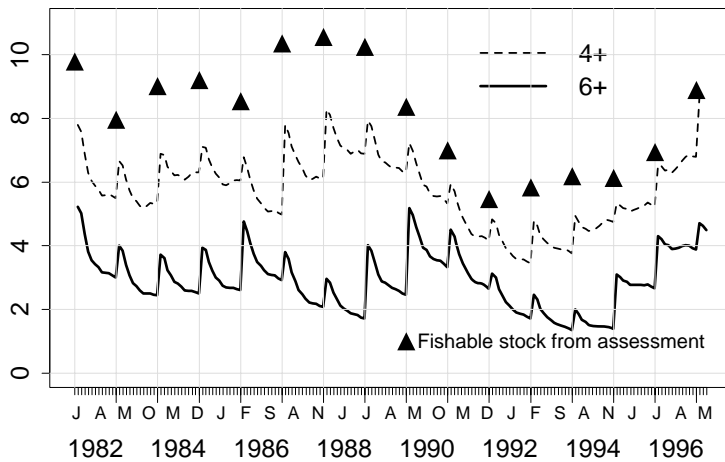


Figure 13.1.1: Biomass of cod stock

sea due to the selectivity of the fishing gear. The output from model in 13.1.1 is an attempt to model the “true” biomass of age 4 and older which is expected to be smaller than the catchable biomass from assessment and the difference is expected to be maximal when the number of age 4 fish is large.

The lower curve in Fig. 13.1.1 shows the biomass of age 6 and older cod. The biomass of this part of the cod stock has more than doubled since 1994. This should be viewed in the light that effort has reduced considerably after 1993.

Figure 13.1.2 shows the number of cod estimated by the model compared to assessment. In most cases the model and assessment compare well for age 3 cod. The migration of age 6 cod from Greenland was estimated 21 million fishes compared to 30 million in the 1997 assessment [19]. The sum of the Icelandic and Greenland part of the 1984 yearclass is on the other hand identical. On the other hand, the estimated number of age 8 cod is always higher in the model.

Figure 13.1.3 shows the biomass of capelin with capelin biomass from the 1997 assessment [21] included for reference. The model predicts higher capelin biomass than the assessment. This is to be expected as the base natural mortality used in the model is the same as in the assessment and the predation by the cod stock is added top of that. The difference between the model estimate and the assessment is, however, not very large except in the last year.

Figure 13.1.4 shows the number of age 1 and age 2 capelin August 1st according to the model. Backcalculated numbers of age 2 capelin from [21] are shown for comparison. The numbers are back calculated using $M = 0.035$ per month.

In the simulation presented here understocking of capelin contributes 5.04% to the total objective (Table 13.1.3). Tables 13.1.4 and 13.1.5 show how understocking of capelin is distributed. The year 82 is not included but no capelin was caught that year.

Figures 13.1.5 and 13.1.5 and Table 13.1.5 show the main characteristics in the estimated consumption by the cod stock. It is seen that the total consumption

	Cod					Capelin			Consumption		
	number January 1st millions			biomass January 1st 1000 tons		biomass October 1st 1000 tons		under stock	1000 tons		per cent
	age 3	age 6	age 8	4+	6+	total	mature	ing	capelin	total	capelin
1982	168	85.4	85.4	779	522	16.0	3.1	0	387	2265	17.1
1983	243	46.3	11.2	666	400	30.0	10.6	0	540	2147	25.1
1984	115	50.0	15.8	689	372	39.3	19.8	43	754	2412	31.2
1985	131	51.6	10.7	710	394	36.4	18.8	42	728	2407	30.3
1986	329	78.1	11.1	678	477	29.3	14.5	0	712	2545	28.0
1987	306	30.8	9.9	779	380	28.7	10.5	75	738	2754	26.8
1988	157	40.3	13.9	828	297	28.7	16.8	188	752	2652	28.4
1989	76	73.7	5.3	794	402	19.1	10.2	139	537	2226	24.1
1990	108	107.8	9.4	722	518	19.5	7.6	122	374	1912	19.6
1991	99	50.7	14.6	594	451	27.2	12.4	39	413	1658	24.9
1992	183	20.7	21.9	483	312	30.9	17.3	2	518	1617	32.1
1993	150	33.2	10.7	479	247	25.0	8.3	96	520	1632	31.9
1994	64	23.8	3.8	494	201	31.8	12.9	158	562	1653	34.0
1995	149	60.2	8.8	534	310	41.3	12.4	57	694	1978	35.1
1996	207	51.4	7.6	653	430	47.3	17.2	61	988	2574	38.4
1997	61	21.7	22.9	868	470			104			

Table 13.1.2: Summary of results from base run

through the year more or less follows the temperature, being lowest in late winter and highest in the autumn. The consumption of capelin by cod is lowest in the spring after the spawning of capelin but is fairly even in the months August to March.

The average percentage of capelin in the diet of cod as seen in Figure 13.1.6 is 28%, although it is seen to vary from 15% in 1982 to 45% in 1996. This is a lower proportion than has been found in earlier work [23]. Possible reasons for this difference include:

- The ratio of prey in stomach can be calculated from consumption estimates based on applying a stomach evacuation rate model to individual stomachs or aggregate stomach samples
- The present model uses acoustic abundance estimates of older capelin as absolute estimates of abundance (with measurement error)
- The total stomach content tends to be higher when the ratio of capelin in stomach is high. This is not taken into account when using only the ratios from stomach samples.

Name of component	Value	Percent
Capelin acoustic surveys	8701	19.57
Agedistribution of catch	3416	7.67
ALK in catch	4009	9.01
Mean length in catch	2105	4.72
Survey indices ages 3-4	141	0.31
Survey indices ages 5-8	971	2.19
Survey indices ages 9-11	673	1.52
Lengthdistribution of catch	4880	10.98
Agedistribution in survey	1071	2.40
ALK in survey	3135	7.05
Mean length in survey	2209	4.96
Length distribution in survey	2596	5.83
Stomach content data	8325	18.71
Understocking of capelin	2242	5.04
Understocking of cod	13	0.03
Total	44488	99.99

Table 13.1.3: Distribution of the objective function on different components

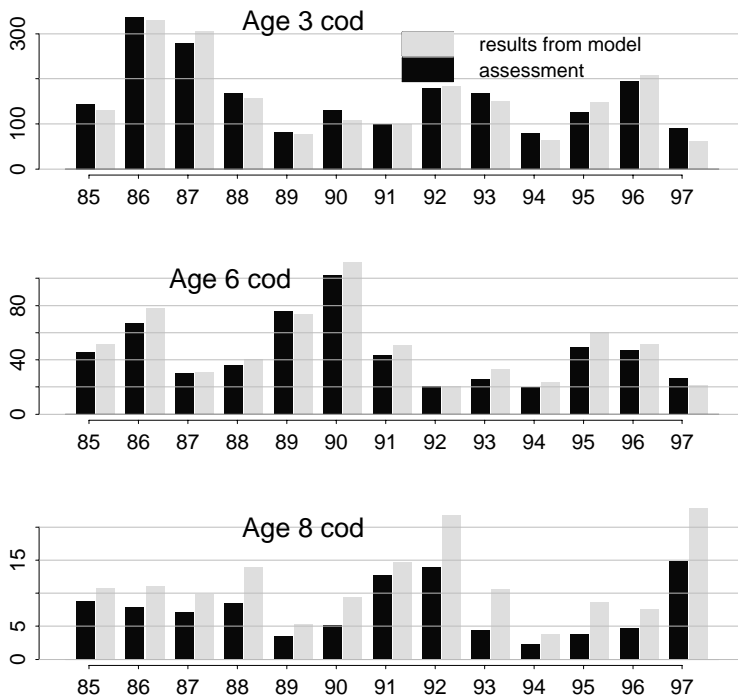


Figure 13.1.2: Number of cod 1st of January

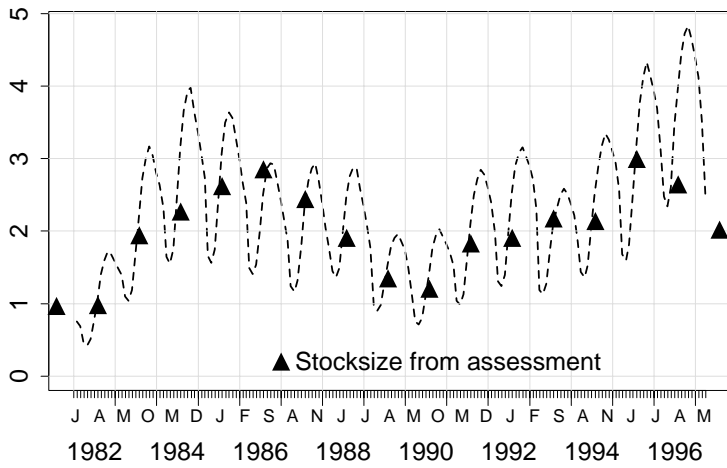


Figure 13.1.3: Biomass of capelin stock

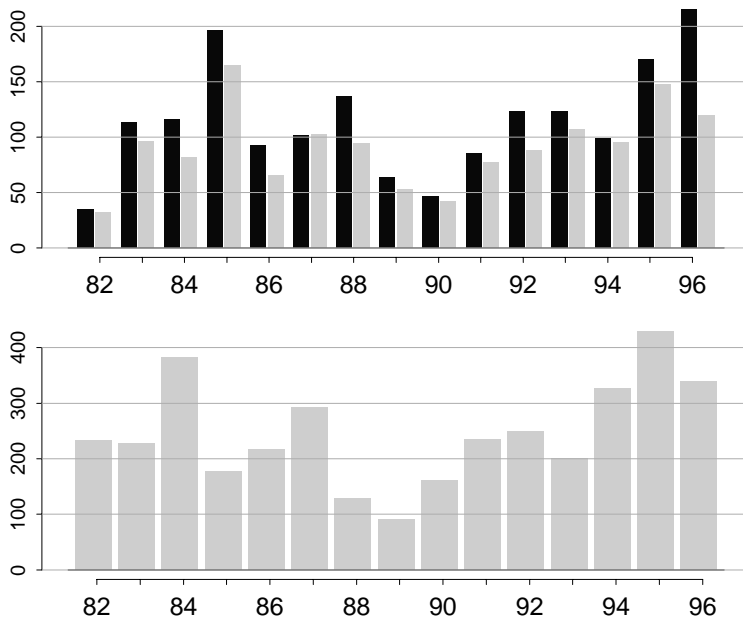


Figure 13.1.4: Number of capelin on August 1. each year

	82	83	84	85	86	87	88	89	90	91	92	93	94	95
True	0	133	831	993	894	812	911	664	696	256	787	851	751	718
Model	0	133	788	952	894	737	723	525	574	218	786	755	594	662
difference	0	0	43	42	0	75	188	139	122	39	2	96	158	57
% difference		0	5	4	0	9	21	21	18	15	0	11	21	8

Table 13.1.4: Understocking of capelin distributed on years

tmp1	1	2	3	5	6	7	8	9	10	11	12	15	16
1982	0	0	0	0	0	0	0	0	0	0	0	0	0
1983	0	0	0	0	0	0	0	0	0	0	0	0	0
1984	18	0	0	0	0	0	0	0	25	0	0	0	0
1985	0	0	0	0	0	0	14	0	0	0	0	0	28
1986	0	0	0	0	0	0	0	0	0	0	0	0	0
1987	5	0	0	0	2	0	65	0	2	0	0	0	0
1988	0	0	0	0	0	0	71	68	49	0	0	0	1
1989	30	0	0	0	35	0	74	0	0	0	0	0	0
1990	0	0	0	0	50	0	72	0	0	0	0	0	0
1991	0	19	0	0	0	0	0	0	18	0	0	1	0
1992	0	1	0	0	0	0	1	0	0	0	0	0	0
1993	2	21	0	0	0	0	0	0	0	0	7	0	66
1994	111	1	0	0	0	0	44	1	1	0	0	0	0
1995	18	7	0	0	0	0	30	0	2	0	0	0	0
1996	23	0	0	0	0	0	29	1	8	0	0	0	0
1997	0	0	0	0	0	0	70	0	35	0	0	0	0

Table 13.1.5: Understocking of capelin (thousand tonnes) distributed on years and areas

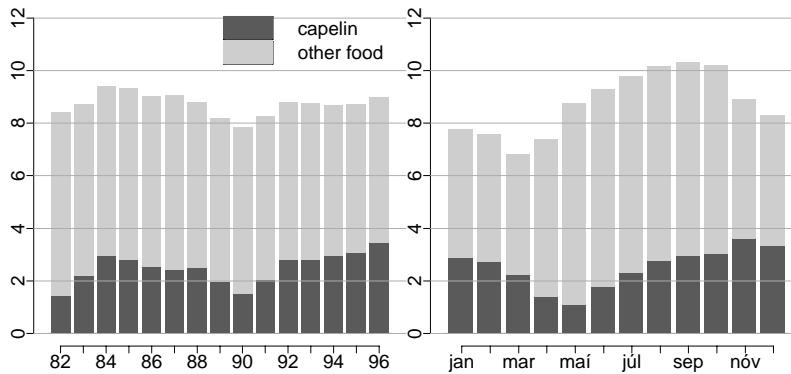


Figure 13.1.5: Consumption by the cod stock g/kg/day

- The growth of cod controls the estimated capelin consumption

The consumption by cod and the growth of cod are directly linked as the growth of cod in the model is calculated from its consumption. The mean length at age in surveys and catches is the single most important indicator of growth and hence data on the mean length at age of cod may directly influence estimates of capelin stock size.

The mean length at age was an important part of the objective function, contributing some 10% in total, as seen in Table 13.1.3. It is therefore of some interest to see how well the model is able to emulate the growth of cod.

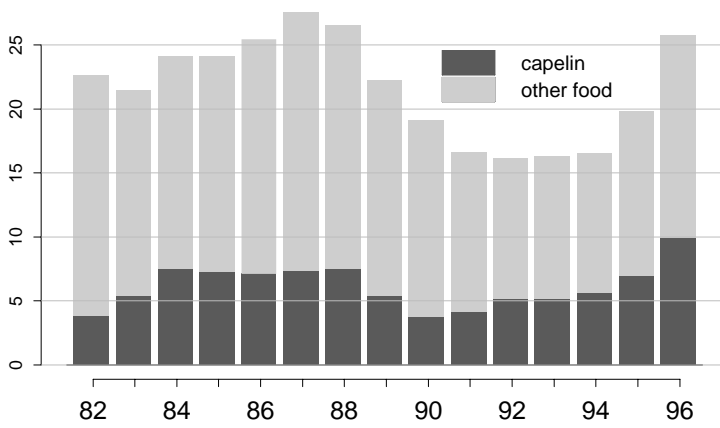


Figure 13.1.6: Consumption by the cod stock 100,000 tons/year

Figure 13.1.7 shows the mean length and mean weight of the 1984 yearclass of cod as estimated by the model. The mean length and weights from the groundfish survey 1994 - 1996 are included in the figures. The mean weight at age of the 1984 yearclass in the catch is also shown in the figure.

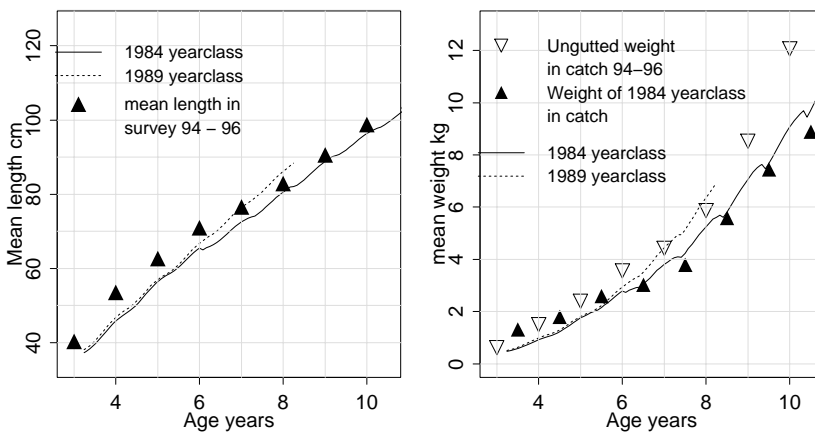


Figure 13.1.7: Mean length and weight at age of 1984 yearclass of cod

13.2 Alternatives

In addition to the base run described above, several variants were considered. These runs are intended to verify the effects of individual assumptions on the final estimates and consist of the following alternatives:

1.	Changing the selection pattern of gillnets catching cod
2.	For mature cod use migration pattern estimated from tags
3.	Adding total consumption.
4.	Adding length distributions in stomach (and total consumption)
5.	Using proportions in stomach content as proportions in consumption
6.	Changing the treatment of capelin so all abundance indices are proportional
7.	Reducing the weight of capelin understocking.
8.	Looking at cod growth.

These runs will be referred to as alternatives 1, alternative 2 etc. The run in the previous section will be referred to as the base run, although alternative 1 could also be considered the basis version since the other alternatives are derived from it. The simulation in alternatives 3 to 6 is the same as in alternative 2, only the calculations of the likelihood function change.

Although the description of each alternative is much shorter than description of the base run as only few items of interest will be investigated, a standard table like 13.1.3 will be presented for all alternatives.

For each alternative the same parameters are estimated as in the base run. Thus the selection patterns of fleets, maturation parameters etc change from one alternative to the next. In some cases it would be more appropriate to fix some of these parameters. If the goal of the analysis is for example to estimate the effect of different treatment of stomach data on capelin consumption (like done here later) using the same recruitment of cod in all cases might be appropriate.

13.2.1 Changing the selection curve of gillnets fisheries for cod

In the baserun presented above a logit function was used to describe the selection pattern of all fleets catching cod. One of the most important commercial gears for catching cod is the gillnet class. The selection patterns of gillnets depend on the meshsizes used and these have varied in time. A tendency to use gillnets with larger meshes has been observed, where in 1993 7 inches was the most common mesh while in 1997 9 inches is observed as the most frequent mesh size.

When all mesh sizes are lumped together in an analysis the resulting gear is really a variable-mesh gear, where the realized average mesh size in a given year depends on the relative yearclass strength available to the different meshes. Overall this will lead to some average selection pattern which may not decline with age as some components of the fleet are likely to track yearclasses as they grow.

The different mesh sizes can be modelled as 4 fleets (one for each meshsize) with a dome shaped selection pattern (the same form as used for capelin consumption by cod). The selection pattern for the gillnets is as described in chapter 6. The catch taken with each mesh size was estimated using log-books from commercial gillnet boats. These logbooks have been collected at the MRI since 1989. The values obtained in chapter 6 were used as initial values for the selection pattern of

the gillnets. The number of parameters was reduced to 2 by using the same value for the parameters p_4 and p_5 (??). The parameter p_0 was set to 0.03. As the catch is given the value of parameter p_2 is not relevant.

The number of parameters estimated is the same as in the base run and the parameters estimated are the same although the two parameters that describe gillnet selectivity now have a different meaning. The definition of the likelihood function is identical to the baserun.

The resulting estimated selection pattern is show in figure 13.2.1. The selection patterns from the base run are also included in the figure. The initial values obtained from the gillnet survey are shown for comparison.

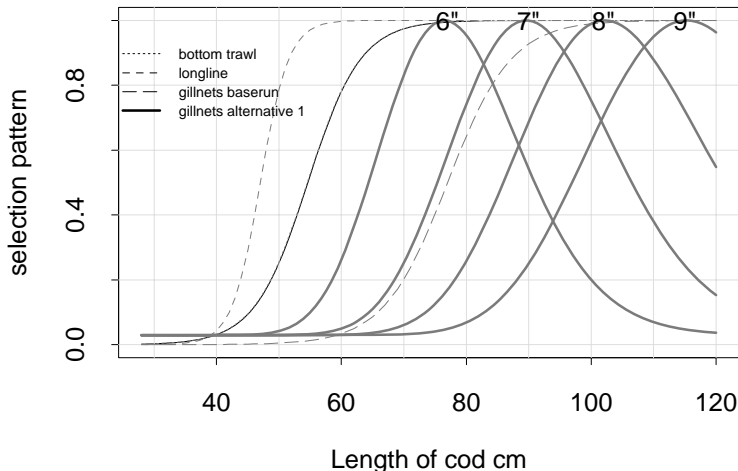


Figure 13.2.1: Estimated selection pattern of fleets catching cod from alternative 1

The solution found is not much different from the solution found in the baserun. Table 13.2.1 compares some statistics to those from the baserun. Table 13.2.1 shows the distribution of the objective function for the two runs. From table 13.2.1 it is seen that the solution found here fits the data better than the solution found in the baserun. One component whose value increases is labelled “Length distribution of catch” which is the component one might a priori expect to decrease. A more detailed examination of this component it is seen that the length distribution in gillnets is responsible for half of this increase.

In short the modelling of gillnets as described here gives lower value of the objective function with the same number of estimated parameters. This setting has therefore been used in other alternatives investigated below.

Naturally increasing the number of parameters can only decrease the total objective function since there is now a larger parameter space over which the minimum is taken. But regardless of whether the decrease in the objective function is due to an increase in the number of parameters or, as in this case, an apparent improvement in the goodness of fit for the same number of parameters, there is a need to verify how concrete the improvement is. In theory a formal statistical test might be applied to verify whether the reduction in the objective function is more than a slight noise

	Cod					Capelin			Consumption		
	number January 1st millions			biomass January 1st 1000 tons		biomass October 1st 1000 tons		under stock	1000 tons		per cent
	age 3	age 6	age 8	4+	6+	total	mature	ing	capelin	total	capelin
1982	168	83.5	12.4	775	518	15.9	3.0	0	416	2260	18.4
1983	243	46.0	11.4	663	399	29.9	10.3	0	564	2134	26.4
1984	119	47.7	15.1	685	368	39.5	19.8	46	783	2403	32.6
1985	134	49.6	10.2	707	387	36.1	18.8	39	747	2385	31.3
1986	343	75.2	10.2	673	466	28.6	14.0	9	735	2539	28.9
1987	306	30.3	9.1	782	370	27.8	10.1	95	765	2752	27.8
1988	154	39.3	12.6	829	291	27.9	16.1	208	756	2624	28.8
1989	79	74.2	5.0	788	401	19.0	9.9	157	547	2192	24.9
1990	106	102.0	8.7	724	522	19.7	7.8	133	396	1906	20.8
1991	97	48.6	14.4	594	449	27.2	12.2	37	431	1651	26.1
1992	180	20.9	21.6	480	311	30.7	17.7	2	535	1604	33.3
1993	151	32.0	9.9	473	243	24.0	7.6	87	528	1609	32.8
1994	64	22.8	3.7	486	195	31.0	12.4	174	568	1622	35.0
1995	142	58.1	8.1	523	298	39.8	12.1	65	698	1926	36.2
1996	193	50.9	7.2	633	415	45.1	16.2	63	958	2460	38.9
1997	60	21.5	21.9	825	451			112			

Table 13.2.1: Some important characteristics of the solution in alternative 1

reduction. This can be done through a likelihood ratio test. The implementation used in this report is not a formal sum of (negative) log-likelihoods, however, but a weighted sum of functions, each of which are approximations to log-likelihoods. Since the weights used are simply examples of what can be used, they cannot be considered reflections of the actual variability in each term in the sum. Thus, the statistical properties of this sum are not at all clear and hence no attempt will be made to indulge in formal statistical tests in this section.

13.2.2 Alternative 2. Cod migration based on tagging data

The migration patterns of mature and immature cod are described in chapter 9. Different estimation techniques are seen to yield somewhat different quantifications of these patterns. Migration parameters for mature cod in the base run were estimated from area and age disaggregated survey indices whereas another set of migration parameters were estimated from tagging data.

Alternative 2 deviates from alternative 1 through the use of the migration pattern described in Chapter 8.2 as detailed in Section 8.2.1. Tables 13.2.2 and 13.2.3 show summaries of the results. The results are quite different from those obtained in alternative 1, and in particular the cod stock is larger. The size of the capelin stock

Name of component	Base run		Alternative 1	
	value	percent	value	percent
Capelin acoustic surveys	8701	19.57	8557	19.64
Agedistribution of catch	3416	7.67	3391	7.79
ALK in catch	4009	9.01	3983	9.14
Mean length in catch	2105	4.72	1946	4.47
Survey indices ages 3-4	141	0.31	141	0.32
Survey indices ages 5-8	971	2.19	974	2.23
Survey indices ages 9-11	673	1.52	581	1.33
Lengthdistribution of catch	4880	10.98	4977	11.41
Agedistribution in survey	1071	2.40	1059	2.43
ALK in survey	3135	7.05	3128	7.18
Mean length in survey	2209	4.96	2136	4.89
Length distribution in survey	2596	5.83	2589	5.94
Stomach content data	8325	18.71	8198	18.81
Understocking of capelin	2242	5.04	1910	4.38
Understocking of cod	13	0.03	10	0.02
Total	44488	100	43579	100

Table 13.2.2: Comparison of the objective function in alternative 1 and baserun

and the proportion of capelin in the diet of cod is similar to alternative 1.

As can be seen in the table, the value of the objective function is lower than in alternative 1. Since the objective function and the parameters estimated are the same this seems to indicate that the migration patten used here models migration of mature cod better than the one used in other simulations.

13.2.3 Alternatives 3 to 6. Different treatment of stomach content data

As described in chapter 5 the model has a number of different possibilities for incorporating stomach content data. These possibilities can be divided in 3 parts.

In alternatives 3 to 5 the different treatment of stomach content data in the objective function is investigated. The forward simulations are formulated in the same fashion as in the base-run and the only model change is in the computation of the objective function, but of course this will lead to a different set of parameter estimates in each case.

In alternative 3 the total consumption for each area and length group of cod is calculated from stomach samples and used as an proportional index in the model. Equation 4.8.1 is used for calculating consumption from stomach. The parameters estimated are the same as in alternative 1.

Alternative 4 is derived from alternative 3 by adding information from the length

	Cod					Capelin			Consumption		
	number January 1st millions			biomass January 1st 1000 tons		biomass October 1st 1000 tons		under stock ing	1000 tons		per cent
	age 3	age 6	age 8	4+	6+	total	mature		capelin	total	capelin
1982	151	87.3	12.5	808	541	16.2	3.1	0	408	2331	17.5
1983	225	52.3	13.6	690	445	30.5	10.9	0	566	2185	25.9
1984	120	46.6	17.5	703	412	39.7	19.8	42	796	2440	32.6
1985	139	44.3	12.8	723	416	36.7	19.3	56	782	2441	32.0
1986	340	69.3	10.6	693	480	28.2	14.0	32	765	2603	29.4
1987	312	30.2	8.4	804	389	27.4	9.9	142	752	2805	26.8
1988	156	38.9	12.0	855	314	27.5	15.9	225	756	2692	28.1
1989	81	74.2	5.2	819	423	18.6	9.6	190	573	2286	25.1
1990	107	106.2	8.6	733	527	19.5	7.4	159	406	1922	21.1
1991	101	47.4	15.0	603	456	27.4	12.6	44	462	1671	27.6
1992	188	20.2	21.3	493	322	30.7	17.0	2	578	1646	35.1
1993	160	30.6	9.6	495	257	25.3	8.3	107	574	1686	34.1
1994	69	22.7	3.8	522	214	31.7	12.9	169	628	1744	36.0
1995	159	60.0	8.1	574	328	40.4	12.0	73	773	2120	36.4
1996	219	54.8	7.7	714	466	45.8	16.0	86	1085	2774	39.1
1997	63	24.2	24.2	952	523			139			

Table 13.2.3: Summary of results from alternative 1

distributions of capelin in cod stomachs to the objective function. The estimated parameters describing the selection pattern of cod eating capelin thus become different. As length distributions of capelin in stomachs are now included an attempt can be made to estimate more parameters in the suitability function of capelin as prey to cod.

As described in chapter 5 (eq. 4.8) the model allows for variation in digestion rates of different preys and different length of preys. The length distribution of consumed preys is scaled before comparing it to stomach data. In this alternative it was assumed that the time a capelin was considered good for length measurements was proportional to its length i.e small capelin is underrepresented in the stomach samples.

Alternative 5 is derived from alternative 4 with the change that mass proportions in stomach are calculated as proportions in stomach content. This is equivalent to assume that the coefficient b in ?? is one.

Tables 13.2.5 to 13.2.7 show summaries of the results from alternative 3 to alternatives 5 and 13.2.3 shows the likelihood components. The weight on different likelihood components is not the same as in alternatives 0 to 2 but the components from the baserun are put in the figure where the components are comparable.

Name of component	Value	Percent	Value1	Percent1	Value2	Percent2
	Alternative 3		Alternative 4		Alternative 5	
Capelin acoustic surveys	8489	17.70	8217	15.72	8162	15.63
Agedistribution of catch	3463	7.22	3434	6.57	3442	6.60
ALK in catch	4046	8.43	4050	7.75	4053	7.77
Mean length in catch	1960	4.10	1978	3.80	1973	3.78
Survey indices ages 3-4	169	0.35	154	0.29	151	0.29
Survey indices ages 5-8	973	2.03	987	1.88	974	1.88
Survey indices ages 9-11	541	1.11	549	1.05	542	1.04
Lengthdistribution of catch	5106	10.64	5026	9.62	5044	9.66
Length distribution in stomachs			5301	10.14	5315	10.18
Agedistribution in survey	1067	2.23	1058	2.03	1057	2.03
ALK in survey	3169	6.60	3167	6.06	3169	6.07
Mean length in survey	2301	4.80	2257	4.32	2260	4.33
Length distribution in survey	2461	5.13	2429	4.65	2446	4.69
Proportions in stomachs	6446	13.44	6446	12.33	6446	12.35
Total consumption	5745	11.96	5676	10.86	5647	10.81
Understocking of capelin	2024	4.22	1515	2.90	1504	2.88
Understocking of cod	14	0.03	13	0.02	15	0.03
Total			52256	99.99	52200	100.02

Table 13.2.4: Distribution of the objective function in alternatives 3 to 5

Looking at the summaries of the results they are all similar. Compared to the base run and alternatives 1 and 2 and the base run the cod stock is smaller and the proportion of capelin in diet of cod is less.

13.2.4 Alternative 6. Changing the treatment of capelin so all abundance indices are proportional

In the base-run abundance indices of the oldest capelin (age 3 in autumn and age 4 in winter) were treated as absolute indices while other indices were proportional. Alternative 6 is based on alternative 4 with the change that all abundance indices proportional.

Table 13.2.8 shows the distribution of the objective function compared to alternative 4. The value of the objective function here is lower than in the baserun. Acoustic indices of capelin and understocking of capelin are the components where the improvement is greatest but an improvement can be seen in every component. The number of parameters estimated is in fact increased by 2, the regression parameters between number in stock and abundance indices for the oldest capelin.

13.2.9 shows standard summaries of the results. What is different from the other alternatives is that the biomass of mature capelin is much higher as might have been

	Cod					Capelin			Consumption		
	number January 1st millions			biomass January 1st 1000 tons		biomass October 1st 1000 tons		under stock ing	1000 tons		per cent capelin
	age 3	age 6	age 8	4+	6+	total	mature		capelin	total	
1982	152	83.5	12.4	799	524	15.7	3.4	0	414	2344	17.6
1983	245	49.9	12.4	689	422	28.3	10.1	0	524	2208	23.8
1984	119	52.4	16.3	715	409	37.1	18.4	26	690	2460	28.1
1985	127	45.7	12.0	734	414	34.8	18.0	19	643	2433	26.4
1986	328	78.1	11.9	695	494	28.3	13.9	20	644	2561	25.2
1987	289	31.4	8.7	791	397	27.4	10.3	76	712	2767	25.7
1988	167	37.6	13.6	830	308	26.8	15.8	202	695	2643	26.3
1989	96	71.2	5.3	793	407	17.6	9.3	118	478	2236	21.4
1990	113	96.9	8.3	732	506	17.8	7.2	103	334	1949	17.2
1991	104	53.0	13.8	610	446	24.4	10.8	29	369	1704	21.7
1992	158	25.6	19.9	503	325	27.9	16.1	2	442	1605	27.6
1993	134	34.7	11.1	476	262	20.7	6.6	61	424	1542	27.5
1994	72	25.0	4.7	464	212	27.0	10.5	172	449	1526	29.4
1995	130	50.8	8.7	491	282	38.4	10.5	59	571	1775	32.2
1996	152	44.4	7.6	576	366	50.0	18.9	3	809	2176	37.2
1997	59	23.6	18.2	712	402			268			

Table 13.2.5: Summary of results from alternative 3 (Total consumption from stomach content data included in objective function)

expected. This can also be seen in 13.2.3. Understocking is much less in alternative 6 than in the other alternatives as might be expected from the increased capelin stock.

As may be seen in 13.2.9 the estimated consumption of capelin is the same as in the other alternatives. The distribution of the consumption on mature and immature capelin is, however, quite different, with much less consumption of mature capelin according to alternative 6 as seen in Table 13.2.10 This is what is expected as the mature part is much larger according to alternative 6 and more consumption is possible. The multiplier on the selection pattern of immature capelin in 13.1.1 is much smaller than in other alternatives.

Distribution of the consumption of capelin over the year can be seen in 13.2.3. The seasonal distribution of the consumption is quite different from what can be seen in 13.1.5 falling to zero in April and May when all capelin is immature.

As may be seen from 13.2.9 and better from 13.2.4 the estimated proportion of capelin in the diet of cod here is not much different from what has been estimated in the other alternatives. This indicates that capelin stock size is not what “limits” the estimated consumption of capelin by the cod stock.

	Cod					Capelin			Consumption		
	number January 1st millions			biomass January 1st 1000 tons		biomass October 1st 1000 tons		under stock ing	1000 tons		per cent capelin
	age 3	age 6	age 8	4+	6+	total	mature		capelin	total	
1982	160	83.8	12.4	798	541	15.5	3.3	0	441	2352	18.7
1983	238	47.7	14.4	691	432	28.0	9.6	0	536	2195	24.4
1984	119	48.0	16.5	709	405	37.2	18.5	44	708	2432	29.1
1985	132	48.2	11.3	723	417	34.2	17.4	16	672	2408	27.9
1986	342	76.3	10.6	683	485	28.5	13.8	12	658	2543	25.9
1987	305	31.4	8.9	785	386	27.7	10.2	76	752	2788	27.0
1988	162	39.3	13.0	836	301	26.8	15.6	199	731	2668	27.4
1989	87	74.8	5.3	800	414	17.7	9.2	125	509	2242	22.7
1990	110	103.2	8.9	732	524	18.1	7.1	112	363	1946	18.7
1991	103	52.9	14.7	607	456	24.9	11.1	33	399	1701	23.5
1992	160	23.6	21.5	499	327	28.2	15.9	2	463	1599	29.0
1993	135	33.7	11.3	472	262	21.9	6.8	66	458	1546	29.6
1994	71	24.8	4.2	463	211	28.6	11.1	164	502	1545	32.5
1995	136	52.1	8.5	493	285	38.0	11.2	51	632	1819	34.7
1996	156	45.1	7.6	588	375	44.8	15.7	55	836	2220	37.7
1997	59	23.3	18.9	729	412			68			

Table 13.2.6: Summary of results from alternative 4 (Total consumption and length distributions from stomach content data included in objective function)

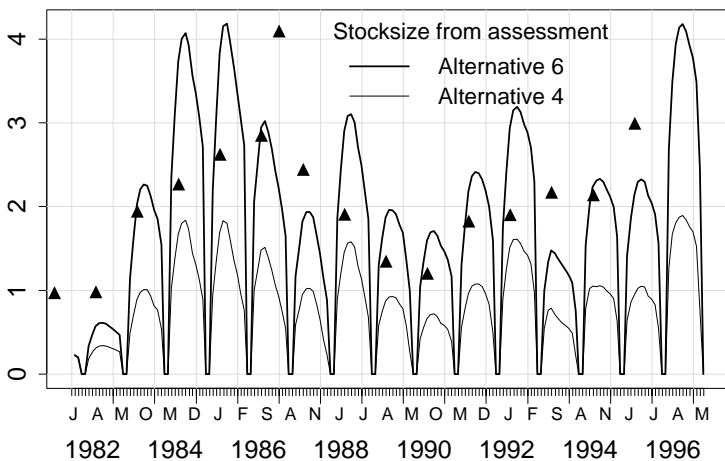


Figure 13.2.2: Biomass of the mature part of the capelin stock in alternatives 4 and 6.

	Cod					Capelin			Consumption		
	number January 1st millions			biomass January 1st 1000 tons		biomass October 1st 1000 tons		under stock ing	1000 tons		per cent capelin
	age 3	age 6	age 8	4+	6+	total	mature		capelin	total	
1982	160	84.5	12.4	800	543	15.5	3.4	0	451	2362	19.1
1983	238	47.8	14.5	695	435	27.9	9.5	0	541	2205	24.5
1984	123	48.1	16.8	713	409	37.3	18.6	47	713	2451	29.1
1985	128	48.4	11.4	731	421	34.0	17.2	10	676	2428	27.8
1986	340	76.8	10.8	690	491	28.5	13.8	10	655	2554	25.6
1987	303	32.8	9.1	789	397	27.5	10.1	72	751	2794	26.9
1988	162	38.3	13.4	839	307	26.7	15.4	199	723	2667	27.1
1989	86	74.8	5.6	800	417	17.7	9.2	121	503	2238	22.5
1990	109	102.7	8.7	734	527	18.1	7.2	108	363	1948	18.6
1991	102	53.1	14.7	608	458	24.6	11.0	32	396	1699	23.3
1992	160	23.4	21.8	499	328	27.9	15.7	2	453	1590	28.5
1993	135	33.5	11.4	470	261	21.8	6.8	72	452	1535	29.5
1994	71	24.6	4.2	458	209	28.5	11.1	162	499	1534	32.6
1995	134	51.9	8.4	489	281	37.8	11.2	50	630	1803	35.0
1996	158	44.8	7.5	581	370	44.9	15.5	54	833	2199	37.9
1997	59	23.3	18.7	721	406			67			

Table 13.2.7: Summary of results from alternative 5 (Proportions in stomachcontent used directly as proportions in consumption)

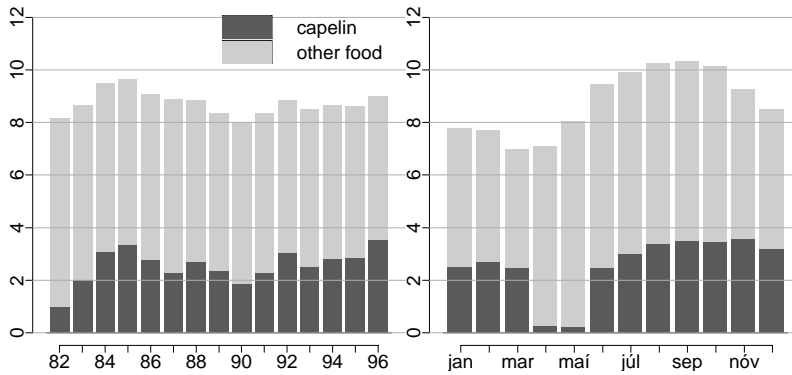


Figure 13.2.3: Consumption by the cod stock g/kg/day

13.2.5 Alternative 7. Changing the effect of capelin understocking

As discussed earlier capelin understocking is a problem in the simulations. It is as discussed earlier mostly due to difficulties in modelling the migration of mature

Name of component	Value	Percent	Value	Percent
2 c Alternative 6	Alternative 4			
Capelin acoustic surveys	8489	17.70	7624	16.92
Agedistribution of catch	3463	7.22	3373	7.48
ALK in catch	4046	8.43	3999	8.88
Mean length in catch	1960	4.10	1831	4.06
Survey indices ages 3-4	169	0.35	164	0.37
Survey indices ages 5-8	973	2.03	1000	2.22
Survey indices ages 9-11	541	1.11	551	1.22
Lengthdistribution of catch	5106	10.64	5107	11.33
Agedistribution in survey	1067	2.23	1059	2.35
ALK in survey	3169	6.60	3154	7.00
Mean length in survey	2301	4.80	2110	4.68
Length distribution in survey	2461	5.13	2407	5.34
Proportions in stomachs	6446	13.44	6446	14.30
Total consumption	5745	11.96	5754	12.82
Understocking of capelin	2024	4.22	463	1.03
Understocking of cod	14	0.03	27	0.06
Total	47973	99.99	45068	100.06

Table 13.2.8: Comparison of the objective function in alternatives 4 and 6

capelin which are both quite fast for a period of one month and variable from one year to another. Weighting understocking too much can lead to an unrealistically large capelin stock. The coefficient b in 4.7 also has large effect, higher values of b tend to give large penalty to occasional large understocking.

Alternative 7 is based on alternative 4 with the change that the value of b was changed to 1 which means that the penalty for understocking is proportional to the sum of understocking at all areas and all periods.

13.2.12 shows a summary of the results. Compared to alternative 2 the understocking of capelin is larger and the capelin stock smaller. The size of the cod stock and its capelin consumption are similar.

13.2.5 compares the distribution of the objective function in alternative 4 and alternative 7. The value is a little lower in alternative 7 mainly due to improved fit to capelin acoustic indices.

13.2.6 Future work on modelling

The simulations described in the last sections all give the proportion of capelin in the diet of cod just below 30%. This is much less than has been found by other authors. Different methods of treating stomach data and capelin indices are tested but these all give similar results.

Having investigated the stomach content data and acoustic indices leaves only

	Cod					Capelin			Consumption		
	number January 1st millions			biomass January 1st 1000 tons		biomass October 1st 1000 tons		under stock ing	1000 tons		per cent capelin
	age 3	age 6	age 8	4+	6+	total	mature		capelin	total	
1982	137	83.6	12.4	813	540	28.0	6.1	0	265	2239	11.9
1983	241	53.6	14.4	667	436	56.0	22.7	0	496	2113	23.5
1984	125	49.8	15.9	676	402	74.6	40.7	1	771	2388	32.3
1985	147	42.0	12.0	699	386	70.2	41.8	0	854	2469	34.6
1986	325	75.9	10.3	690	467	50.2	28.9	0	794	2590	30.7
1987	279	32.3	7.6	792	387	46.7	19.4	33	686	2672	25.7
1988	155	42.9	12.9	805	312	50.3	31.0	48	785	2574	30.5
1989	87	70.2	5.3	765	403	35.6	19.6	71	627	2201	28.5
1990	110	94.6	9.4	715	503	36.6	17.1	16	452	1931	23.4
1991	102	48.2	13.3	594	440	46.8	24.2	20	455	1681	27.0
1992	160	23.3	19.9	489	314	49.8	31.9	1	552	1608	34.3
1993	136	34.1	9.7	471	253	37.6	13.7	28	442	1508	29.3
1994	70	24.6	4.0	453	203	52.5	23.3	37	483	1490	32.4
1995	130	51.3	8.5	478	273	71.8	23.3	26	566	1708	33.1
1996	147	45.5	7.4	553	354	96.9	41.8	2	818	2084	39.2
1997	58	22.5	18.1	681	386			93			

Table 13.2.9: Summary of results from alternative 6 (All capelin abundance indices assumed to be proportional)

tmp	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96
Alternative 6	212	432	699	795	737	608	721	585	417	420	521	403	439	498	730
Alternative 3	109	167	279	313	292	244	316	245	142	162	236	182	187	192	313

Table 13.2.10: Estimated consumption of mature capelin for alternatives 3 and 6 1000 tons

cod growth. The growth of cod is calculated from its consumption of food and temperature. If the percentage of capelin in the diet of the cod becomes too high the variability in growth with changes in the capelin stock increases.

In all the simulations presented so far in chapter 15 the reference-length-weight curve of the cod has not been allowed to change. (See chapter 8). This means that all observed changes in the mean weight of cod are changes in length multiplied by length-weight relationship. It is very likely that fish of the same length are lighter in period of food shortage than in periods when there is enough food. Ignoring this will probably reduce the estimated consumption of capelin.

	baserun	alt 1	alt 2	alt 3	alt 4	alt 5	alt 6	alt 7
	28.5	29.5	29.8	25.8	27.3	27.2	29.1	27.8

Table 13.2.11: Proportion of capelin in the diet of cod for the various alternatives investigated

	Cod					Capelin			Consumption		
	number January 1st millions			biomass January 1st 1000 tons		biomass October 1st 1000 tons		under stock ing	1000 tons		per cent capelin
	age 3	age 6	age 8	4+	6+	total	mature		capelin	total	
1982	157	83.5	12.4	787	523	15.4	3.4	0	463	2334	19.9
1983	243	49.3	12.1	680	422	27.5	9.3	0	563	2189	25.7
1984	118	47.8	15.9	704	398	36.4	17.9	61	748	2443	30.6
1985	129	46.9	11.5	723	409	33.3	17.1	42	712	2425	29.4
1986	340	77.4	10.5	685	487	26.4	13.0	18	681	2557	26.6
1987	300	31.1	8.7	788	390	25.4	9.0	93	726	2768	26.2
1988	159	38.6	13.2	831	303	25.3	14.4	256	709	2633	26.9
1989	86	74.5	5.2	789	411	17.4	8.8	149	518	2221	23.3
1990	107	101.3	8.6	727	520	18.1	7.1	132	387	1946	19.9
1991	102	51.2	14.4	603	453	24.3	11.0	37	424	1704	24.9
1992	160	23.3	21.3	498	326	26.0	15.2	15	478	1601	29.9
1993	137	32.9	10.8	472	260	19.2	5.7	106	441	1534	28.8
1994	71	24.6	4.1	460	208	26.1	9.5	227	487	1532	31.8
1995	134	52.0	8.2	490	280	35.8	10.3	119	635	1813	35.0
1996	155	45.6	7.5	584	372	41.9	14.4	111	848	2216	38.3
1997	59	23.3	18.8	726	411			109			

Table 13.2.12: Summary of results from alternative 7 (Different penalty for capelin understocking)

As described in chapter 8 the model includes the possibility to let the reference length-weight relationship move with the food ratio so the effect of letting the reference length-weight relationship move up in periods of abundant food and down in periods of food shortage need to be investigated. In connection with this work mean weight at length should be incorporated in the objective function.

Another thing that might affect the estimation of the proportion of capelin in the diet is a change in the selection of fishing gears with food availability. In periods of food shortage fish of the same length have a smaller diameter making it easier for it to get through meshes of fishing gears. This could lead to increased mean-length at age compared to what would be obtained if the length-based selection of the gear was constant.

Name of component	Value	Percent	Value	Percent
	Alternative 4		Alternative 7	
Capelin acoustic surveys	8217	15.72	7757	14.93
Agedistribution of catch	3434	6.57	3435	6.60
ALK in catch	4050	7.75	4042	7.77
Mean length in catch	1978	3.80	2013	3.89
Survey indices ages 3-4	154	0.29	160	0.31
Survey indices ages 5-8	987	1.88	966	1.85
Survey indices ages 9-11	549	1.05	560	1.08
Lengthdistribution of catch	5026	9.62	4960	9.55
Length distribution in stomachs	5301	10.14	5303	10.21
Agedistribution in survey	1058	2.03	1064	2.05
ALK in survey	3167	6.06	3158	6.08
Mean length in survey	2257	4.32	2239	4.31
Length distribution in survey	2429	4.65	2460	4.74
Proportions in stomachs	6446	12.33	6446	12.41
Total consumption	5676	10.86	5848	11.24
Understocking of capelin	1515	2.90	1518	2.92
Understocking of cod	13	0.02	15	0.03
Total	52256	99.99	51942	99.97

Table 13.2.13: Comparison of the objective function in alternatives 4 and 7

Prey switching may possibly be an important factor in the modelled ecosystem considered in this report. The function that has been used in previous sections to describe the consumption of capelin by cod is a type II functional feeding relationship. When the feeding level is low the food increases linearly with the “catchable biomass” of prey stocks and no prey switching takes place. When the feeding level approaches one prey switching does on the other hand occur. Typically the feeding level of cod in the simulations was around 0.5 which means that prey switching does not occur. Implementing other types of feeding functions of trying to make the feeding level higher by lowering maximum consumption would be interesting.

13.2.7 Programming concerns

The solutions presented here are obtained through the use of the Hookes and Jeeves minimization algorithm. The typical number of parameters is large (58) and some of the parameters are heavily correlated. The objective function is the sum of a number of different components which means that it could have many local optima and the optimum found might depend on the starting value.

The program implementation includes an optimization algorithm (simulated annealing) which is better at finding global optima in cases where there are many optima. Unfortunately this algorithm uses orders of magnitude more function

evaluations than the Hooke and Jeeves algorithm which makes it infeasible to use in this cod-capelin simulation where each function evaluation takes approximately 1:30 minutes on an UltraSPARC computer.

This clearly leaves room for considerable experimentation in terms of intelligent minimization algorithms, including parallel algorithms. Many optimizations need to be done iteratively using only different weights in the objective function. In this case a large number of function evaluations may be available, but at prespecified points and an algorithm which could take such information into account might be a major improvement in terms of making the model more suitable for common use.

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