

Contribution to the symposium

Management Strategies for Fish Stocks in the Barents Sea

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**Capelin and herring as key species for the yield of cod
Results from multispecies model runs**

by

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Abstract

A conceptual multispecies model for the fishery of capelin, cod and herring (Systmod) in the Norwegian Sea-Barents Sea region has been developed and used in analysing the impact of different fishery management strategies on stock and yield. The study shows that the biomass production of capelin is the most important factor for the obtainable yield of cod, and the recruitment and life pattern of the herring govern the recruitment of capelin. The recruitment of herring and cod is linked to the ocean climate, which may alternate with warm and cold periods. Cannibalism is also an important factor for cod in adapting to the periodic changes of the system. Most of the production takes place in the warm periods, and capelin and cod have to be harvested when the stocks are large in order to obtain an optimal sustainable catch. The stocks cannot be accumulated in their most productive phase for the benefit of increased catches when the biomass production is low, due to the short life span of capelin, and to the stock interrelationship between the two species. The sustainable yield of herring is more dependent on climate changes than on the stock interrelationships and may be harvested with constant yearly catch quotas if the time lags between the warm periods are short. A high frequency of warm periods is favourable for the herring, but has a negative effect on the obtainable yield of capelin and cod. Long time lags between strong herring year classes in the Barents Sea provide more time for rebuilding and growth of the capelin stock, which is the condition for high biomass production of cod.

Introduction

Capelin was the dominating plankton feeder in the Barents Sea in the 1970's and first half of the 1980's. The stock formed the basis for the largest fishery in Europe with a record catch in 1977 of nearly 3 mill. tonnes, and the total biomass production is estimated to be some 8 mill. tonnes (Hamre and Tjelmeland 1982, Gjøsæter 1997). In 1983-86 a strong herring year class occurred in the southern part of the Barents Sea, and coincided with a dramatic fall in the recruitment to the the capelin stock, which collapsed in 1986. The lack of prey fishes in subsequent years caused mass mortality in the fish-eating stocks of fish, sea birds and marine mammals. It is assumed that the collapse of the capelin was associated with the occurrence of the herring (Hamre 1985, Anon., 1987, Moksnes and Øyestad, 1987, Gjøsæter and Bogstad, 1998). The present author (Hamre 1988, 1994) suggested a conceptual model, which links the observed interrelationships between herring and capelin to climatic changes in the ocean.

The stock evolution in the Barents Sea in the 1980's was the background for the development of a conceptual model for the fisheries in the Norwegian and Barents Seas (Hamre et al. 1993). The model "Systmod" was developed in cooperation between The Institute of Marine Research (IMR) and Norsk Regnesentral (Norwegian Computing Center). So far it includes herring, capelin and cod.

The conceptual hypothesis of the model presupposes that the herring has a decisive impact on the recruitment of capelin and that this stock interaction is governed by periodic changes in the ocean climate. A warm climate provides good recruitment of herring and cod, but the presence of strong year classes of herring in the Barents Sea entail mass death of capelin fry. These ecological interrelations are the most powerful dynamic factors in the system, which "Systmod" is supposed to simulate. The main evidence, which supports the hypothesis of the model, is summarised below.

1.2 The concept

The physical conditions in the Norwegian Sea - Barents Sea region are governed by the inflow of Atlantic water through the Faroe-Shetland Channel (Figure 1). Two main branches of the Atlantic Current create two separate ecosystems, one in the North Sea and one in the Norwegian Sea - Barents Sea. . In the latter area, the interface between the inflow of warm Atlantic water and the cold Arctic water, provides upwelling and the physical basis for two highly productive areas, one in the Norwegian Sea along the Polar front, and one in the marginal ice zone of the Barents Sea.

Relevant features of the general biology of the main fish stocks are illustrated in Figure 2. Most of the rich plankton production in the upwelling areas has been harvested by the adult Norwegian spring-spawning herring *Clupea harengus* in the Norwegian Sea, and the capelin (*Mallotus villosus*) in the Barents Sea. The capelin is the main plankton feeder in the Barents Sea, but in years with strong herring year classes the juvenile herring plays an important part as prey species in the area. The capelin has a short life span and most of the fish spawn only

once. Herring and capelin are the main food sources for a large variety of stocks, but the northeast Arctic cod *Gadus morhua* is the largest predator and plays a decisive role in the balance of predators and prey (Bogstad and Mehl, 1987). The stocks spawn on the Norwegian coast, and the spawning migrations of the plankton feeders transfer huge quantities of fish biomass from distant waters to the Norwegian continental shelf and to the southern parts of the Barents Sea.

The adult herring stock wintered in Icelandic waters prior to the 60's. This has changed in later years. The adult herring as well as the juveniles are now feeding in the eastern Norwegian Sea, and are wintering in Norwegian fjords.

Two large semipelagic stocks occur in the region, blue whiting and polar cod. The semipelagic stocks are however of marginal importance as prey species in this system because they spawn in other areas.

Details on stock distribution and interaction in the Barents Sea are illustrated in Figure 3. During summer the capelin feed in the marginal ice zone but accumulates in front of the south moving ice boarder during autumn. In winter the maturing stock migrates towards the coast for spawning, and it is during this spawning migration the capelin spawners become available to the immature cod (the mature cod is elsewhere for spawning). In the southern part of the Barents Sea the distribution of juvenile herring overlaps the distribution of the capelin larvae, which affects the survival of capelin fry. These stock interactions are the most powerful conceptual factors of the model and together with climate interaction determine the dynamics of the system.

The mean temperature in the Barents Sea in the period 1900-1994 is shown in Figure 4. The temperature shows abrupt increases in the about 1905, late 1910s, late 1930s, 1940s, 1950s, late 1960s and early 1970s, early 1980s and 1990s. These periods of warm climate coincide with strong year classes of herring and cod. (Marty and Federov, 1963; Sætersdal and Loeng, 1984).

In conclusion, the evidence indicates that the herring and capelin are the key prey species at fish level of the food chain in the Norwegian Sea - Barents Sea ecosystem, and the cod is the dominant predator. The abundance of immature herring determines the survival of 0-group capelin, whereas the abundance of immature cod determines the mortality of maturing capelin. The dynamics of the system are governed by the inflow of Atlantic water, which determines distribution, recruitment success and growth of the main species involved. Based on this knowledge, the structure of climate and stock interrelationships is modelled, and a technical version of the model was published in a paper by Hamre and Hatlebakk (1998): SYSTEM MODEL (Systmod) FOR THE NORWEGIAN SEA AND THE BARENTS SEA. Input data for "Systmod" are stock data and parameter data files, and the model parameters are estimated by comparing model results to data. A brief description of the model structure is outlined below.

1.6 Model structure

The model is length-based, and the growth in length per month is modelled with the following equation (von Bertalanffy, 1938):

$$dL(t) = l(t+T) - L(t) = (L_{\infty} - L(t)) \cdot (1 - e^{-KT}) \cdot M(t)$$

where t is a time variable and T an interval of fixed length. L is the maximum length of the fish. $M(t)$ is a factor, which distributes the yearly growth on the different months. K is the growth parameter, which determines the growth related to the size of the stock and environmental factors (capelin and herring). K is determined by the following equations:

$$K = (a + b \cdot e^{-d \cdot B(t)}) \cdot g$$

$B(t)$ is the stock abundance at time t . The exponential term regulates the density dependent growth. For cod the parameter K is computed according to the equation:

$$K = a(2.2 - 0.4 \cdot \frac{CCODC}{COD}) + b \cdot \frac{CCOD}{COD}$$

$CCOD$ is the food consumption for cod, $CCODC$ the consumption of capelin, and COD the stock biomass.

g is a function to regulate the growth according to environmental factors.

The juveniles are recruited to the stock in January at age 1. To describe the relation between the spawning stock in the springtime and the number of recruits in January the following year, the Beverton-Holt function is used:

$$R = \frac{M \cdot B}{H + B} e^{a \cdot T}$$

where R = recruitment; M = maximum recruitment; B = spawning stock biomass; H = the half-value; T = temperature deviation; a is a parameter. Two levels of M are used for simulating herring recruitment, one low and one high, when T exceeds a given value.

The affects of juvenile herring on the survival of capelin fry is modelled by a reduction factor proportional to the strength of the age groups 1 to 3:

$$R = R_0 \cdot (1 - (a_1 \cdot \text{HER}_1 + a_2 \cdot \text{HER}_2 + a_3 \cdot \text{HER}_3))$$

HER_1 denotes 1-group herring, HER_2 2-years herring, HER_3 3 years herring.

All the species mature at the turn of the year. The maturity ogive in each length group is computed from a logistic function (Tjelmeland, 1987):

$$M(l) = \frac{1}{1 + e^{4P_1(P_2-l)}}$$

where l denotes mean length in the length group (midpoint in length interval), P_1 and P_2 are parameters.

In computing mortality per month the following variables are used:

$$N_{i,t+1} = N_{i,t} \cdot (1 - G) \cdot (1 - M) \cdot (1 - P_i) \cdot (1 - F_i)$$

- spawning mortality (G) (capelin only)
- fishing mortality (F)
- predation (P)
- natural mortality (not including predation) (M)

A parameter in the model determines the fraction of mature capelin, which survives after spawning (1April).

The monthly mortality rate caused by the predation is computed by species. For capelin this is:

$$P_i = K \cdot (a_0 \cdot \text{COD}_{im} + a_1 \cdot \text{COD}_m),$$

for Barents Sea herring: $P_i = K \cdot \text{COD} / (1 + b_1 \cdot \text{CAP}),$

for cod: $P_i = K \cdot \text{COD} / (1 + b_1 \cdot \text{CAP} + b_2 \cdot \text{HER}_{im}),$

where

P_i	-	predation mortality rate for length group i
K	-	K is a constant
$a_i(\text{COD})$	-	weighted sum of the predator stock ($m/im =$ mature/immature)
$b_i(\text{CAP, HER})$	-	reduction in mortality rate due to preference of prey species

Parameter estimation has been effected by a step-by-step procedure based on biological knowledge of the system and experiences gained in the model runs. The impact of changes in the climate is modelled by a sine curve fitted to observed temperature anomalies in the Kola section (Figure 5). The recruitment parameters of capelin are determined by comparing modelled numbers of 2 years old to acoustic estimates of the age group in autumn, and the parameters of herring and cod by comparing modelled numbers of 3 years old to the corresponding VPA-estimates of the stocks. The stock in numbers is converted to stock biomass by observed weight by length-groups.

The predation parameters of cod are derived from the estimates of the yearly consumption of cod by prey species (Bogstad and Mehl, 1997). Such data are available from 1984 onwards. The predation parameters of cod are of basic importance and the period after 1982 is selected for fitting the model results to data. The results of fits of stock abundance in number and weight are shown in Figure 6. The fits are reasonably good whether the sine curve or the observed temperature anomalies are used as basis for the simulation. This supports the underlying theory of the dynamics of the system, that recruitment and growth are governed by the ocean climate, and that the stock interrelationship determines mortality and stock abundance. Assuming a cyclic change in the ocean climate, the model is used in analysing the impact of different fishery management strategies on stock and yield.

2 Management strategy analysis

In the model the fisheries may be regulated by the fishing mortality rate (F) and by fishing quotas by season and year. This means that for a given F the fishery is closed if and when the quota is taken. In addition the capelin winter fishery may be closed if the maturing stock is reduced to a predetermined lowest acceptable level. If no autumn fishery is allowed, this strategy is similar to the management strategy in use for capelin, and termed the conventional strategy in the text of the figures.

Warm periods with a cycle of approximately 8 years are observed in recent years and a sine curve with corresponding amplitude and frequency is chosen as basic for the first set of model runs. For the purpose of comparing model results for different time lags between warm periods, some runs are made with a cycle frequency of 11 years as shown in Figure 7. The stock estimates as of 1 January 1995 are chosen as terminal stocks, and the runs cover periods of 40 years. Output files of catch, stock biomass and recruitment are processed on spreadsheet and the results illustrated in Figures 8 to 18.

2.1 Results of runs with 8 years between warm periods

First set of runs. The first two runs compare estimated yield, stock and recruitment with and without a conventional capelin fishery, when the cod fishery is regulated by a constant F of 0.8, the herring fishery by a F of 0.2 and a yearly catch quota of 1.2 mill. tonnes, equally distributed on seasons. The simulated catches are shown in Figure 8. The capelin catches fluctuate between 0 and 0.8 mill. tonnes, with an average catch of close to 0.3 mill. tonnes. In about half the period (3-4 years) the maturing capelin stock is below the lowest acceptable level for fishing, which is set to 0.5 mill. tonnes. The fluctuation in the catches by periods is related to the pattern of the sine curve (differences in the amplitudes), and the stock interaction between the maturing capelin and the immature cod.

The cod catches fluctuate between 0.3 and 1.0 mill. tonnes with an average of some 0.55 mill. tonnes. Since this is a F -regulated fishery the catches fluctuate in relation to the stock size shown in Figure 9, and the pattern of the stock development is a combined effect of the pattern in the climatic changes and the interaction between the spawning stock of capelin and the immature cod stock. The immature terminal cod stock (1995) is relatively numerous due to recruitment of more than one abundant year class (contrary to the situation in 1983). This may delay rebuilding of the capelin stock, which has suffered from recruitment failure in several years (abundant herring year classes 1991-92). The reduced availability of capelin has consequences for the next generations of cod, for which the growth in biomass is correspondingly reduced. This will in turn result in an increased stock of capelin in the next period and so on. This alternation in stock size between a predator and its prey is a well-known phenomenon and is known as the Lotka – Volterra predator-prey relationships.

The strategy of regulating the herring fishery presupposes a yearly catch quota of 1.2 mill. tonnes, equally distributed on seasons, but not allowing F to exceed 0.2. The run shows that this strategy for managing the herring fishery may yield a constant yearly catch of 1.2 mill. tonnes, although the recruitment of herring fluctuates with 1 or 2 abundant year classes every 8 years (Figure 10).

The dotted lines in Figures 8 to 10 illustrate the estimated effects of a total band on the capelin fishery, keeping the regulating strategy of cod and herring unchanged. The simulations indicate that this restriction may have little effect on the recruitment and abundance of the stocks, but may increase the average catch of cod by about 30 000 tonnes. This is the gain in yield of cod, obtained by a corresponding loss in the yield of capelin of 300 000 tonnes.

Second set of runs. The next set of runs compares the effects of an additional constraint on the cod fishery in order to equal out the fluctuation in the yearly cod catches (Figure 8). The average yearly catch of cod in the previous runs approached 0.6 mill. tonnes, which in the present runs is chosen as the yearly catch quota of cod, keeping the fishing strategies on the other stocks unchanged. The results are shown in Figures 11 to 13. The simulation shows that

a catch quota regulation of the cod fishery, which restricts the yearly catch of cod to a level close to the optimum average sustainable yield, may create a new cycle in the abundance of cod (Figure 12), with a frequency of 16 years or twice the frequency of the cycle of changes in the climate. The catches may be kept at the quota level when the stock is abundant (half the period), but have to be reduced considerably when the stock is declining. The estimated average catch is reduced by some 5%, compared to the strategy of no quota regulation of the fishery. In addition, the accumulated stock of cod increases the predation on the stock of herring, which is slightly reduced (Figure 12).

This model result may also be explained as a Lotca-Volterra phenomenon of predator-prey relationship. The additional restriction on the catch of cod when the stock is abundant will accumulate a large immature cod stock, which may delay the rebuilding of the capelin stock. This will in turn reduce the food supply for the next generations of cod for a whole period, i.e. 8 years, and a new cycle of 16-years period may occur.

Third set of runs. These runs compare the results of the previous strategy with the same strategy but without a capelin fishery (Figure 14). The closure of the capelin fishery, which yielded some 220 000 tonnes a year on an average, may result in a slight improvement of the catch of cod, especially in prolonging the period of optimum catch. The gain in the average catch of cod is estimated to some 10 000 tonnes.

2.2 Results of runs with 11 years between warm periods

In this century strong herring year classes have occurred with periods from about 15 years in the early 1900's, to 8 years in recent time. In order to study the effect of a prolonged time lag between the warm and favourable recruitment periods of herring and cod, the model runs in this section are based on a sine curve with the same amplitude as in the previous runs, but with a cycle of 11 years (dotted line in Figure 7).

Fourth set of runs. These runs compare results of a standard management strategy with 8 and 11 years of time lags between warm periods. The strategy is defined by the conventional fishing strategy for capelin, a catch-quota-regulated cod fishery of 0.8 mill. tonnes a year and $F = 0.8$, and the herring fishery regulated as in previous runs. Results are shown in Figures 15 – 17. The effect of a longer period without interruption of the herring is favourable for the capelin, which may recruit 3 more abundant year classes to the stock and the fishery compared to the 8-years-cycle regime (Figure 17). The capelin catch may be doubled, from 0.22 to 0.44 mill. tonnes on average (Figure 15), and the impact on the cod stock is also favourable in the way that a longer period with no herring in the Barents Sea results in a more stable supply of food for the cod, and may thus level out the fluctuation in the stock abundance. The average yield of cod is however only slightly increased. The effect on the herring is on the other hand significantly negative (Figure 16) and may reinforce the fluctuation in the stock size and reduce the average yield of herring by about 20%.

Fifth Set of runs. This final set of model runs compares the estimated yield of the standard

strategy with the yield without a capelin fishery. The results are shown in Figure 18. A closure of the capelin fishery will increase the estimated average catch of cod to 0.6 mill. tonnes a year, corresponding to a gain in the yield of about 30 000 tonnes or 5 %. The corresponding loss in the yield of capelin is estimated to 440 000 tonnes. The effect on herring is an increased predation of cod, which will result in a decrease in the herring recruitment. This may reduce the average yield of herring by about 25 000 tonnes a year.

3. Discussion

In evaluating the reliability of the output from this model it should be borne in mind that in a context of multispecies interactions with a large number of mutually dependent parameters, no unique solution exists in fitting model results to data. The parameter estimates used in this study are moreover preliminary, because some are only roughly estimated and not systematically tuned to data. Slight changes in the yield estimates may also occur if or when the herring resume their traditional migration pattern. The validity of the model may thus be improved with respect to the magnitude of the estimates. However, the trends of development in stock and yield reflected by this model under different management regimes are probably more dependant on the validity of the concept on which the model is built than the accuracy of the parameter estimates. Provided that the concept is valid, the model should be a valuable tool to quantify the dynamic processes of the system. With this reservation in mind, some details of the model results will be commented on and discussed.

The goodness of fit of the temperature curve to data (Figure 5) is acceptable in the warm periods, but low in the cold period from 1993 to 1996. In spite of this the modelled stock in the past fits equally well to data, whether the simulated temperature curve or the actual temperature measurements are used (Figure 6). There is a double explanation for this, one related to the impact of the climate on the recruitment figures and one related to the survival of the fry.

The impact of the climate on capelin recruitment seems to be negligible but the effects of herring recruits on the capelin are the most powerful dynamic element in the model. This takes place in warm periods when the fits of the sine curve to data are reasonably good. The strong herring year classes are triggered by high-temperature anomaly (T), and the model selects a high maximum recruitment level (M in the recruitment formula, page 4), when T exceeds a predefined value (0.4). When 3 strong herring year classes occur, the first one is reduced by 80%. For herring the high recruitment level is determined to be 20 times higher than the low M value, and the exponential factor in the recruitment formula for herring is found to be negligible. Since the observed T in 1995 is below the value, which triggers the high-level M, the model estimates of recruitment for herring will be the same whether based on the sine curve or the observed values.

The recruitment relationship of cod to climate is different. The recruitment figures of 1-group cod seems to be closely related to the temperature and less dependent on a peak value T, which triggers a strong year class, as for herring. This relationship is modelled by selecting

relatively high parameter value in the exponent of the recruitment formula for cod. This results in good recruitment of cod in 1994-1995 as 1- group, but due to cannibalism in the subsequent years, estimated according to the formula of cod predation on cod (page 5), these age groups are depleted as 3-year olds. The cod cannibalism in 1995 and 1996 is estimated to 0.4 and 0.6 mill. tonnes of young cod, respectively (Anon. 1998), and the cod predation parameters (page 5) are tuned against these data. When the recruitment of cod as 1-group and survival of the recruits as 3-group is modelled in this way, the final results of recruitment to the stock will be approximately the same whether the sine curve or the observed values of the temperature anomalies are used as a basis for the simulation (Figure 6).

The ecological interpretation of this phenomenon is interesting and indicates that the cod has adapted to the cyclic recruitment pattern of capelin by eating its own progeny when the capelin stock is down and in a state of rebuilding. It seems obvious that if the 1 mill. tonnes of young cod eaten by older brothers and sisters in 1995-1996 had survived, this would have delayed rebuilding of the capelin stock in the subsequent years and thus threatened the food supply for the coming generations of cod.

The above interpretation of the role of cod cannibalism in the system also supports the findings that a constant yearly catch-quota regulation of cod cannot manage the cod fishery on a sustainable basis. The mechanism behind this is the same as the assumed reason for the cod cannibalism in 1995 onwards. A constant catch-quota regulation of cod will reduce the fishing mortality in periods when the stock is large, accumulating a more abundant stock during cold periods. This is after a period when the capelin has suffered from recruitment failure for several years and the spawning stock is in a state of rebuilding because the herring may have left the Barents Sea. In this situation a numerous stock of cod in the Barents Sea will increase the predation on capelin and thus delay the rebuilding of the spawning stock. This in turn will reduce the availability of food for the new generations of cod, which are expected to be recruited when the climate changes. In other words, the improved basis for the cod fishery in a cold period obtained by cutting the catches in the preceding years, may result in a low production of capelin biomass throughout the next cycle and thus reduce correspondingly the obtainable catch of cod.

In conclusion, the present study shows that the biomass production of capelin is the most important factor for the obtainable yield of cod, the former being governed by the recruitment and life pattern of the herring. The superior steering factor of the system is linked to the ocean climate, which may alternate with warm and cold periods. Most of the production takes place in the warm periods, and has to be harvested when the stocks are large in order to obtain an optimal sustainable catch. This refers especially to capelin and cod, which cannot be accumulated in their most productive phase for the benefit of increased catches when the biomass production is low. This is due to the short life span of capelin and to the stock interrelationship between the two species. The sustainable yield of herring seems to be more dependent on climate changes than on the stock interrelationships and may be harvested with constant yearly catch quotas if the time lags between the warm periods are as short as have been experienced in recent years. A high frequency of warm periods is favourable for the herring, both with respect to level and stability of the catches, but has a negative effect on the obtainable yield of capelin cod. This is because longer time lags between strong herring year

classes in the Barents Sea leave more time for the rebuilding of the capelin stock, which is the basis for high biomass production of cod.

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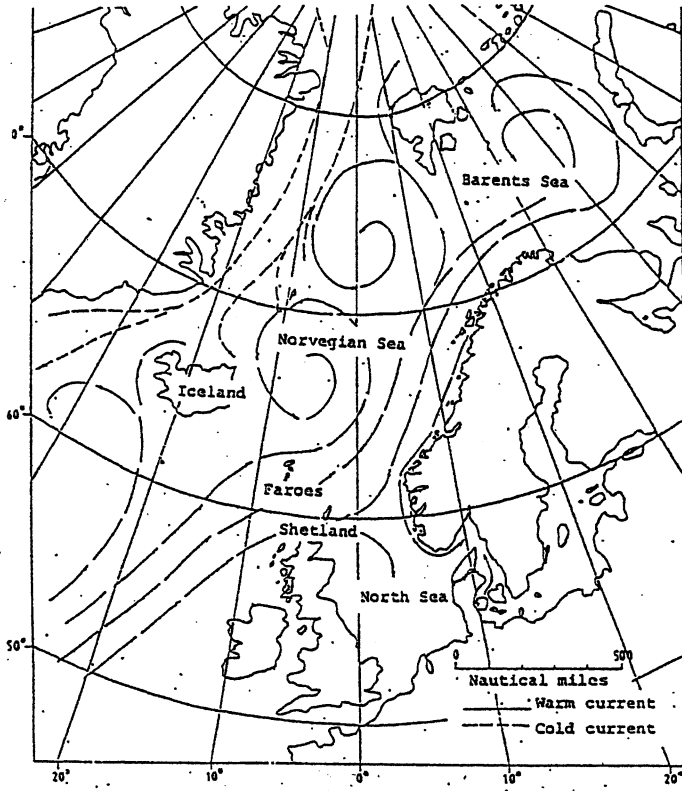


Fig. 1. The circulation of the Norwegian Sea.

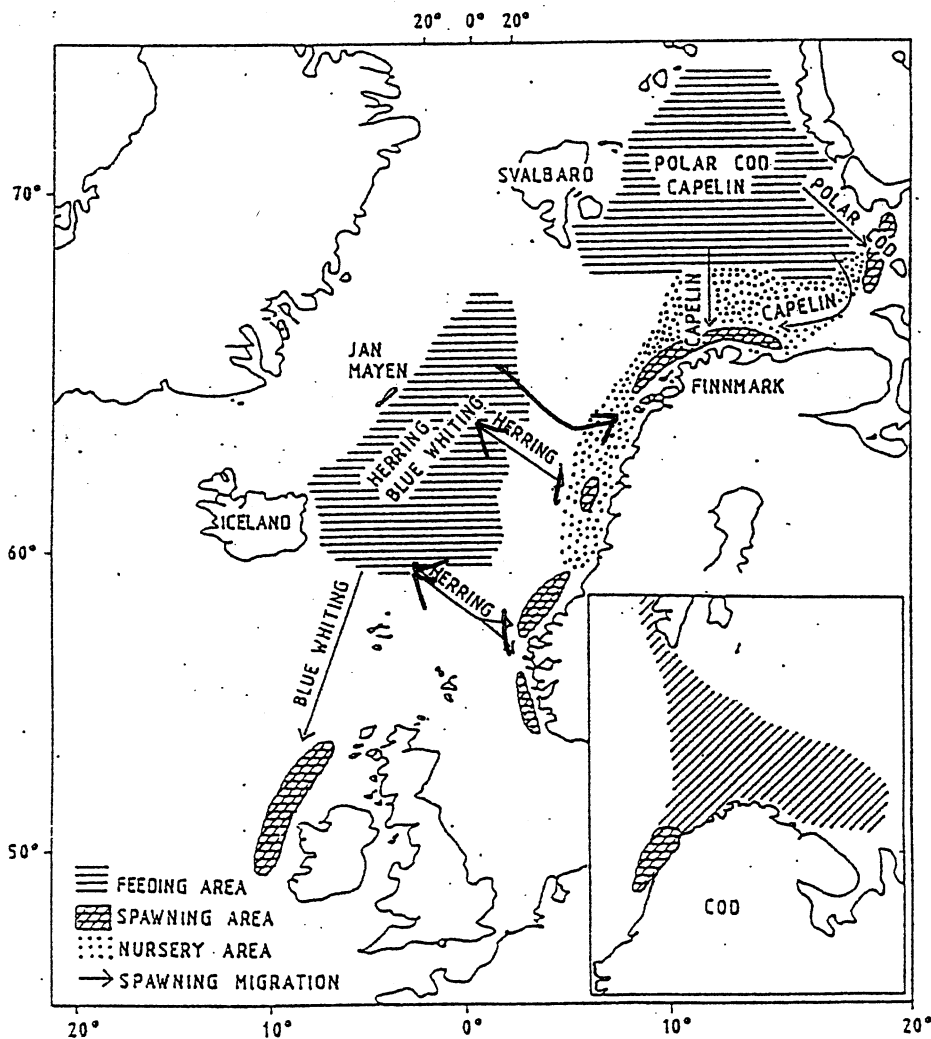


Figure 2. Distribution and migration of the most important fish stocks in the Norwegian-Barents Sea ecosystem.

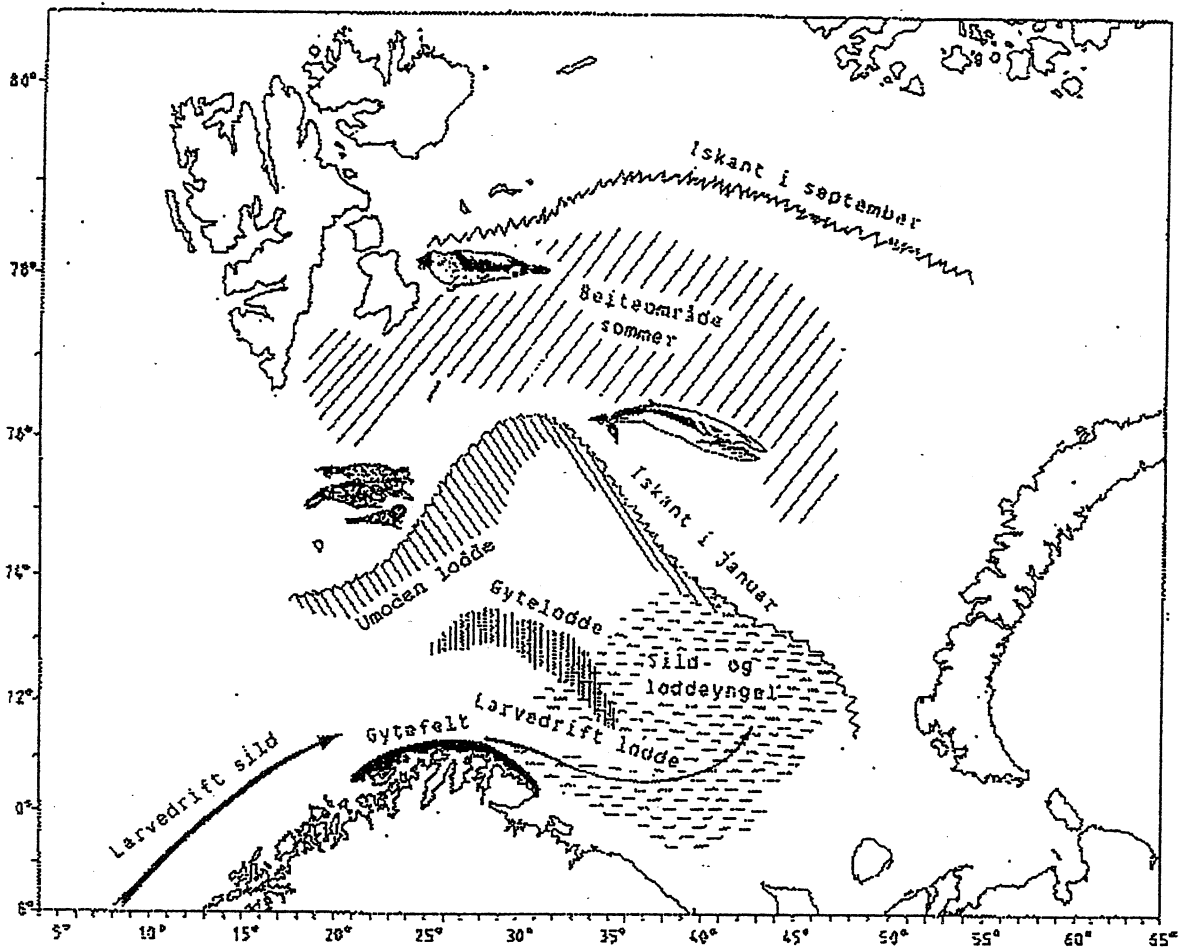


Figure 3. Stock distribution and interaction in the Barents Sea.

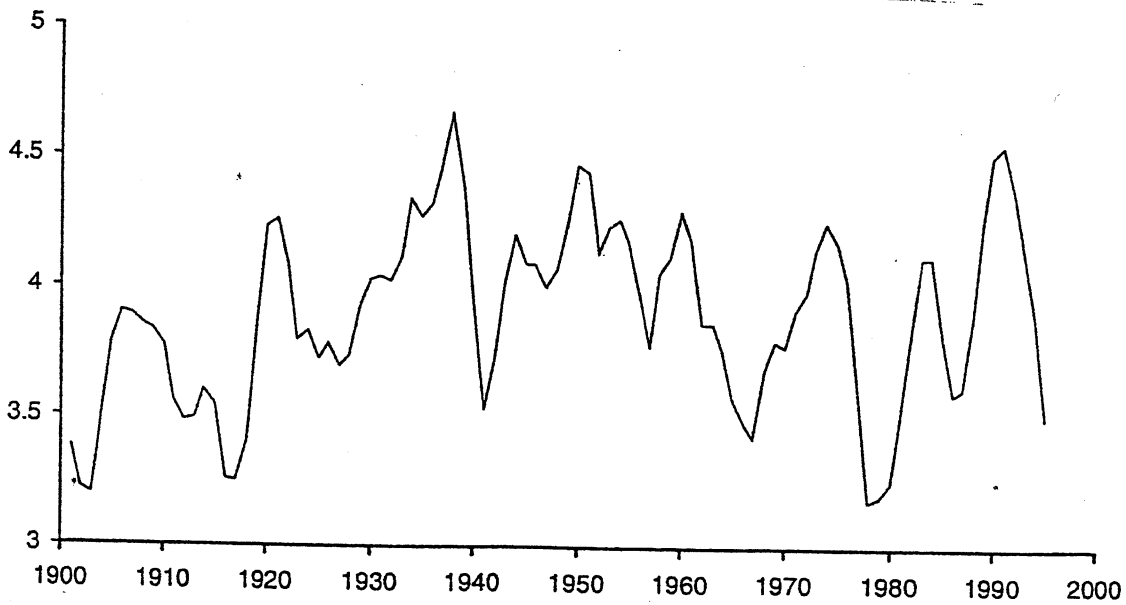


Figure 4. Mean annual temperature in the Barents Sea (Kola section), in 1900-1994 (smoothed over 3 years).

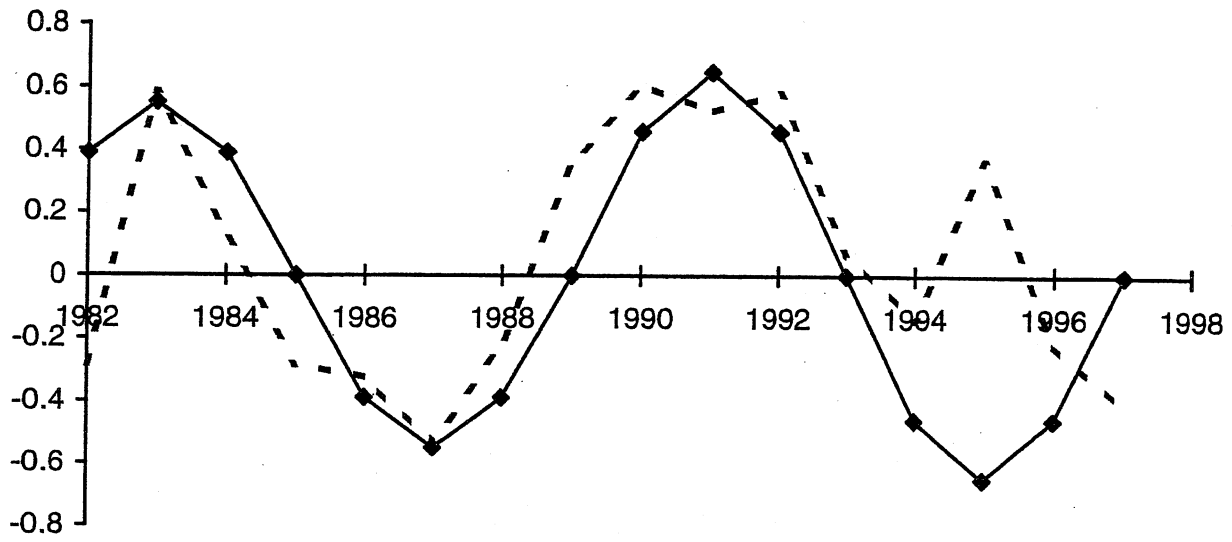


Figure 5. Simulated and observed (dotted line) temperature anomalies with 8 years between warm ocean climate periods in the Barents Sea.

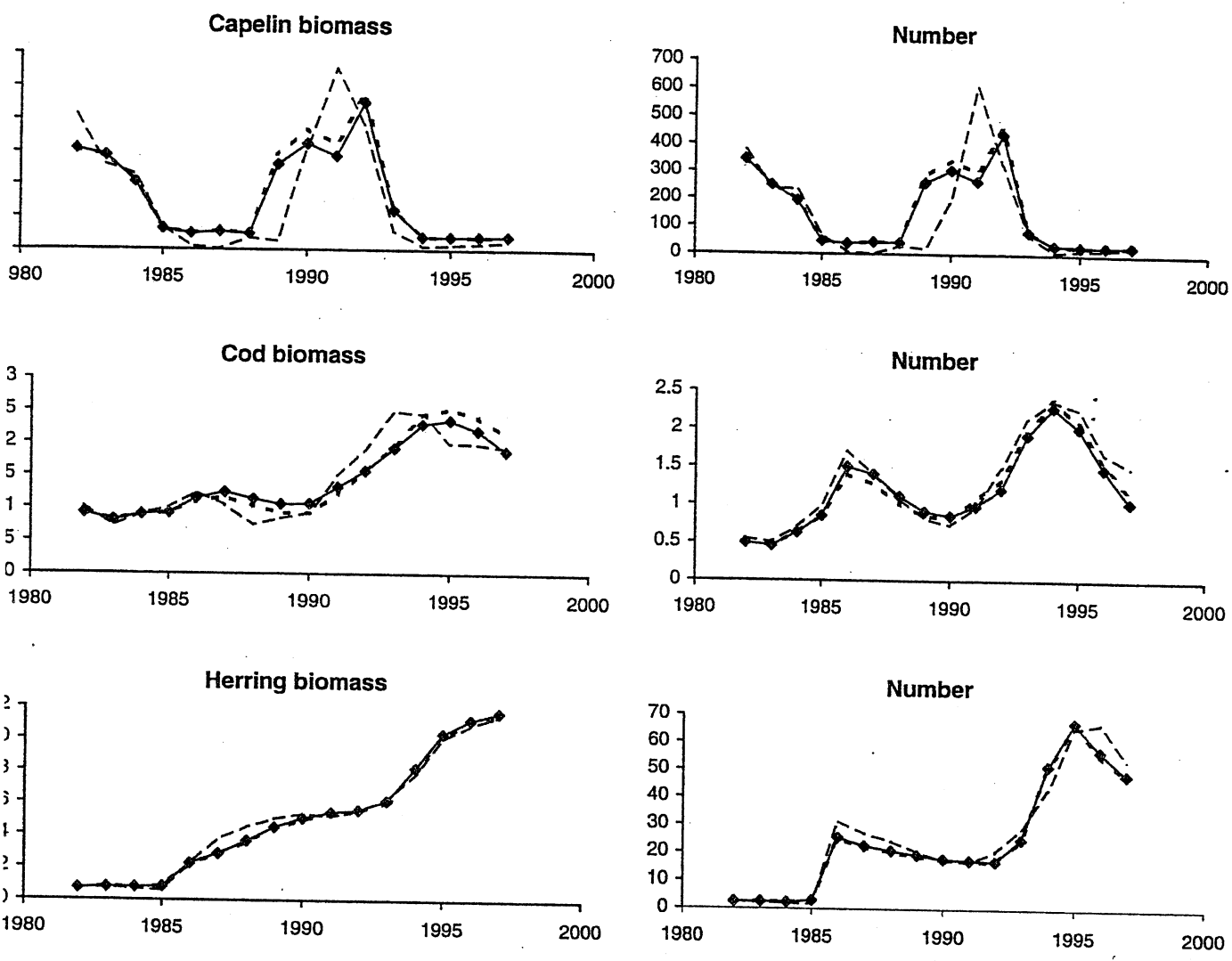


Figure 6. Simulated and observed (broken line) stocks of capelin (2+), cod (3+) and herring (3+) using the sine curve and observed temperature anomalies(dotted line) as climate control.

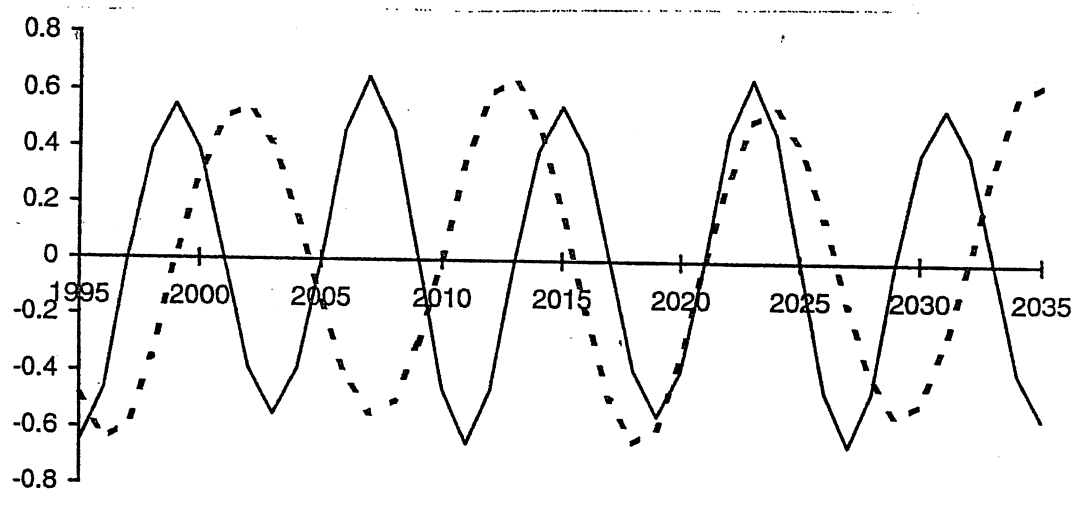


Figure 7. Simulated temperature anomalies with 8 and 11(dotted line) years between warm ocean climate periods in the Barents Sea.

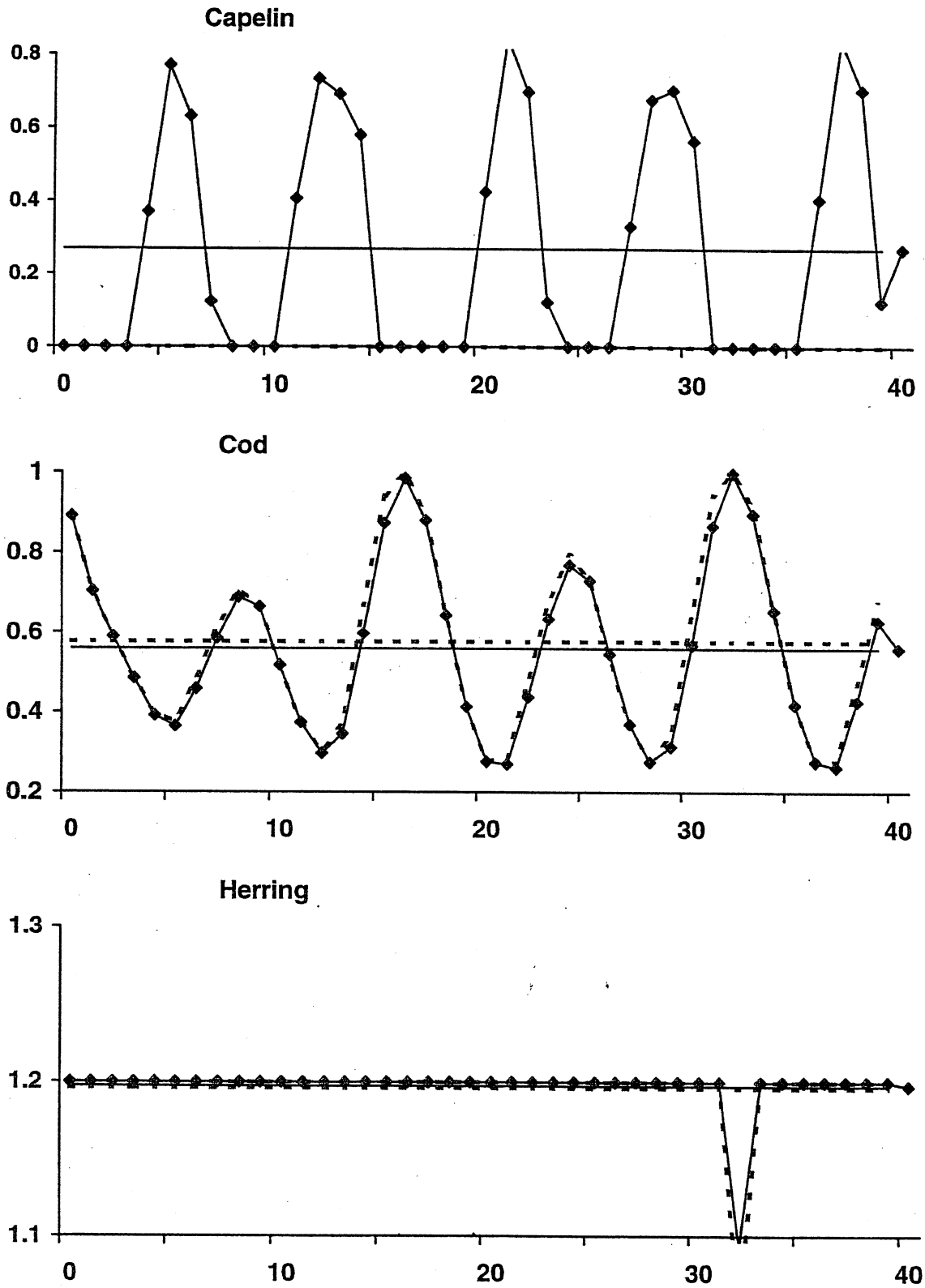
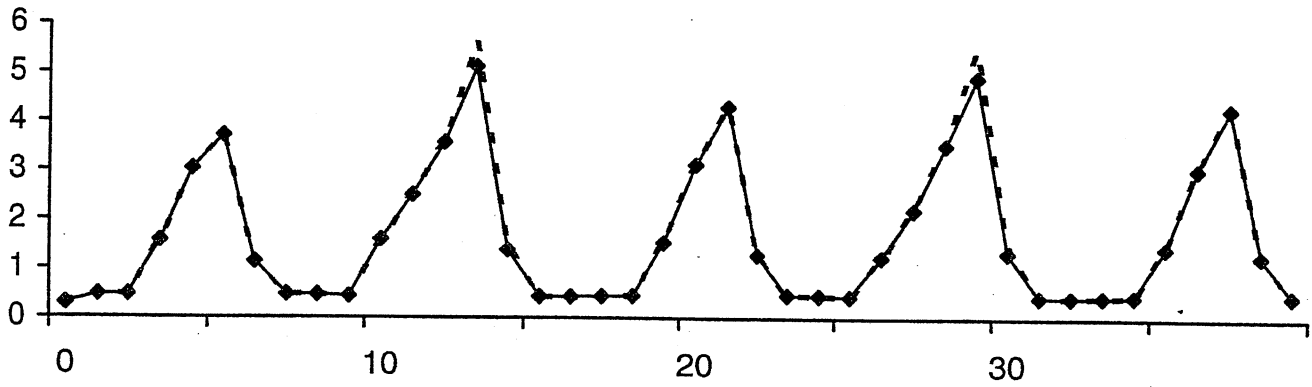
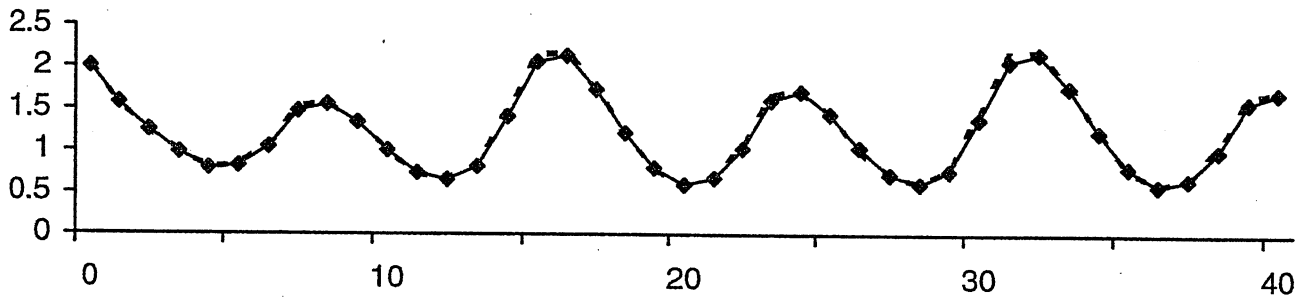


Figure 8. Simulated catches (mill. tonnes) of capelin, cod and herring in 40 years. Parallel lines to the x-axis show average catch. Temperature cycle 8 years. Fishing strategy for capelin as conventional (see text), for cod $F = 0.8$, and for herring $F = 0.2$, catch quota = 1.2 mill. tonnes. Dotted lines show results for capelin catch quota = 0.

Capelin



Cod



Herring

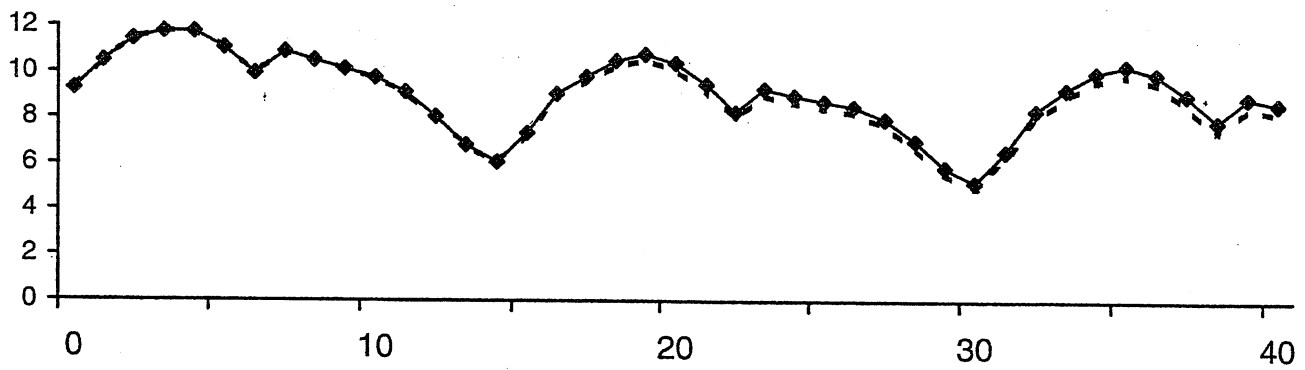


Figure 9. Stocks of capelin (2+), cod and herring (3+) in mill.tonnes. Strategy as in Figure 8.

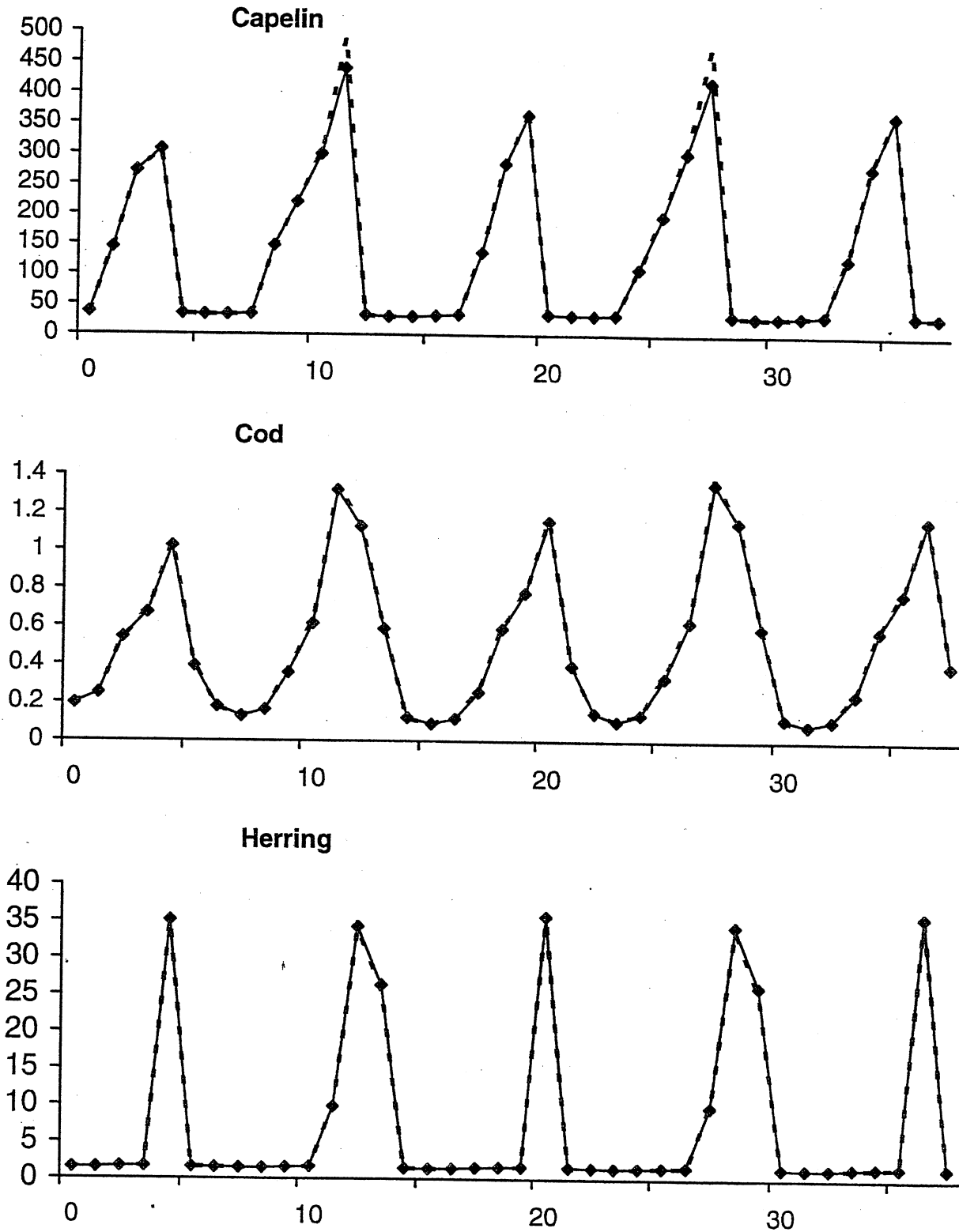


Figure 10. Simulated recruitment by year class from year 0 in bill. ind. for capelin (2-group), cod and herring (3-group). Strategy as in Figure 8.

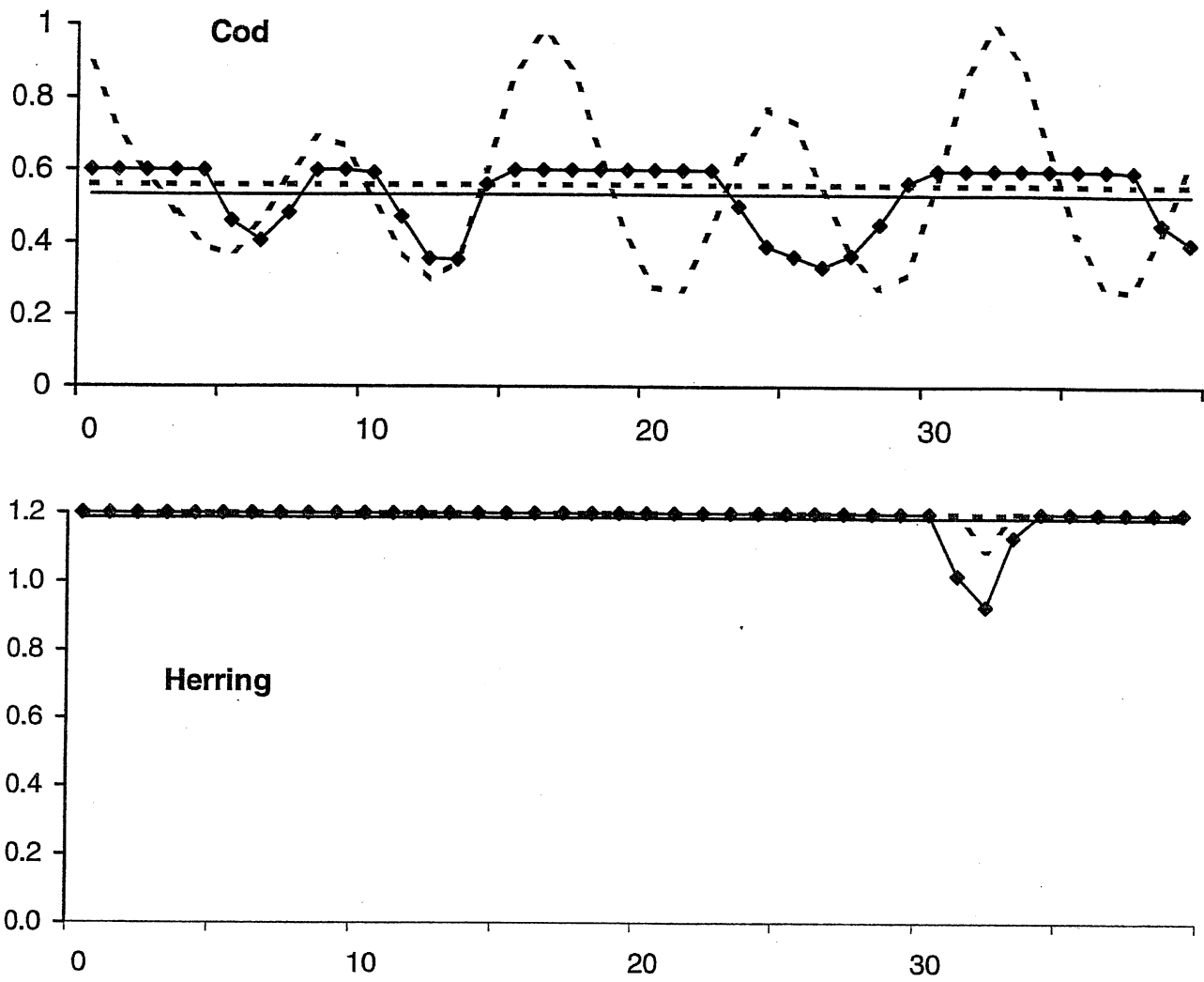


Figure 11. Simulated catches (mill.tonnes) of capelin, cod and herring in 40 years. Parallel lines to x-axis show average catch. Temperature cycle 8 years. Fishing strategy for capelin: $F = 0$, for cod: $F = 0.8$, catch quota = 0.6 mill. tonnes, and for herring $F = 0.2$. Dotted lines show fishing strategi as in fig. 8.

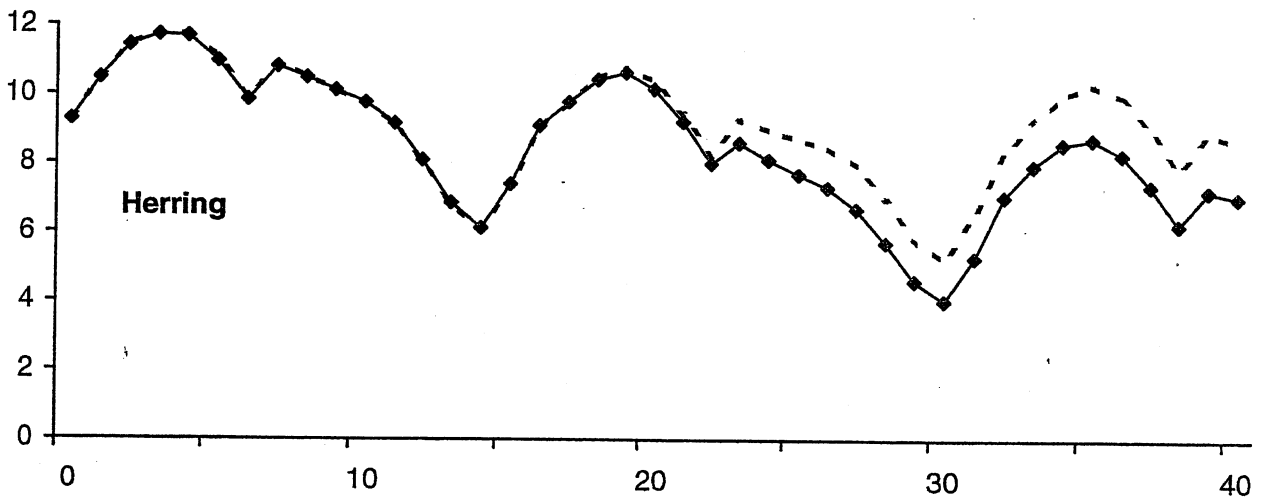
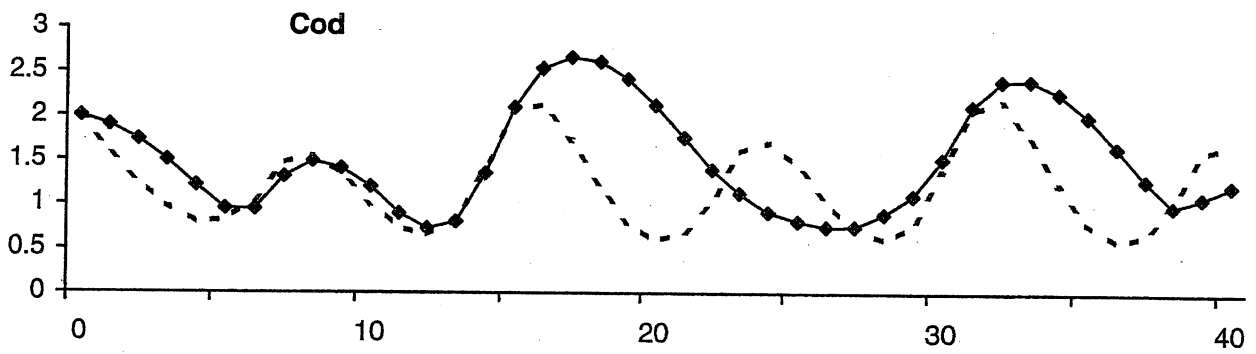
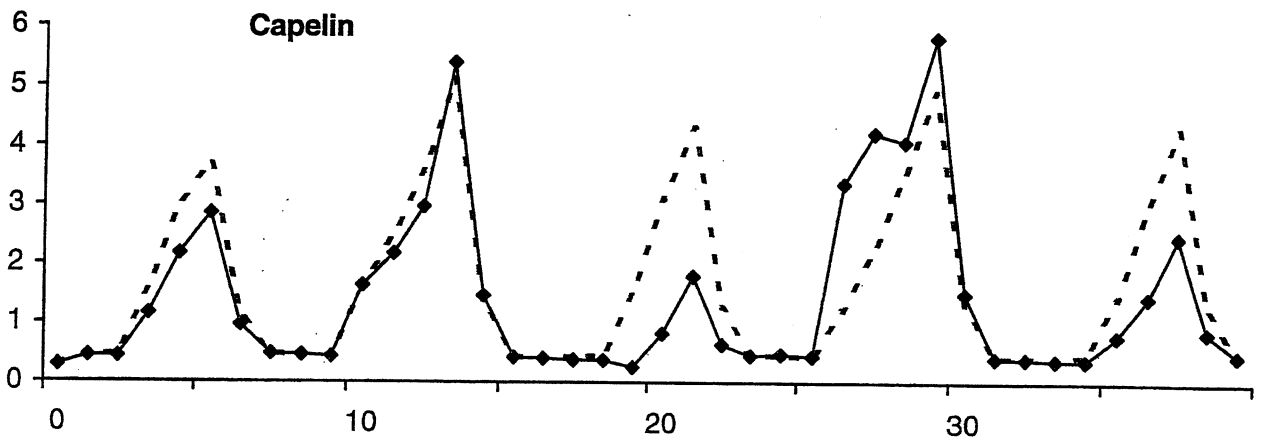


Figure 12. Stocks of capelin (2+), cod and herring (3+) in mill.tonnes. Same strategy as in Figure 11

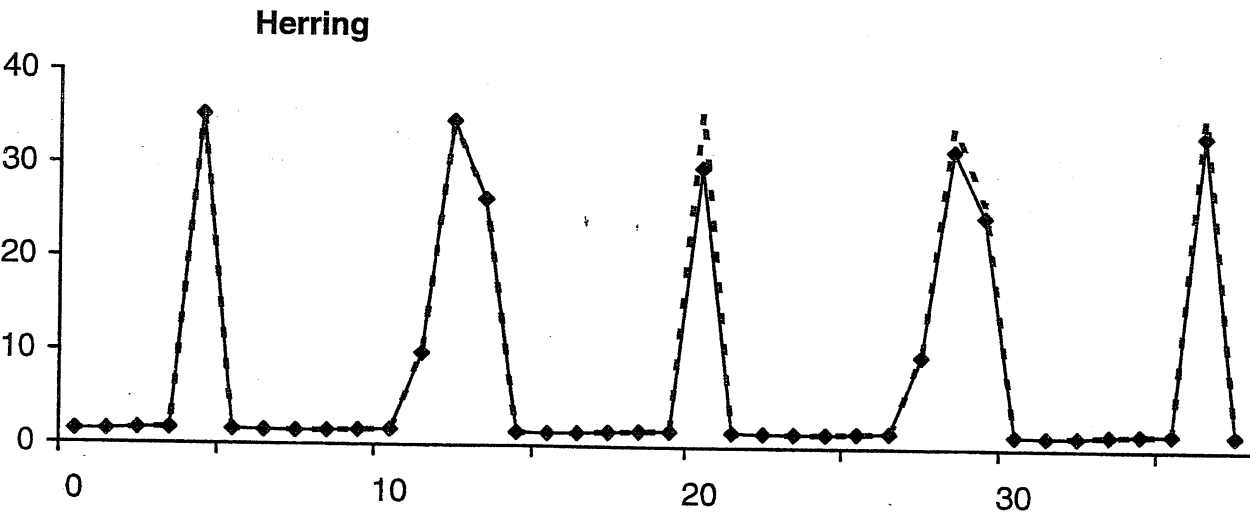
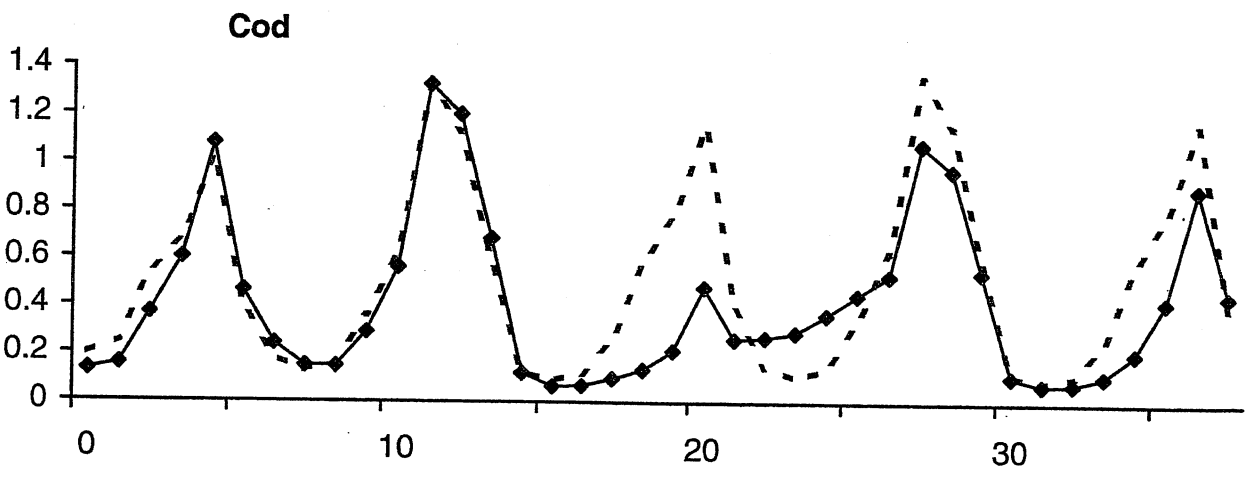
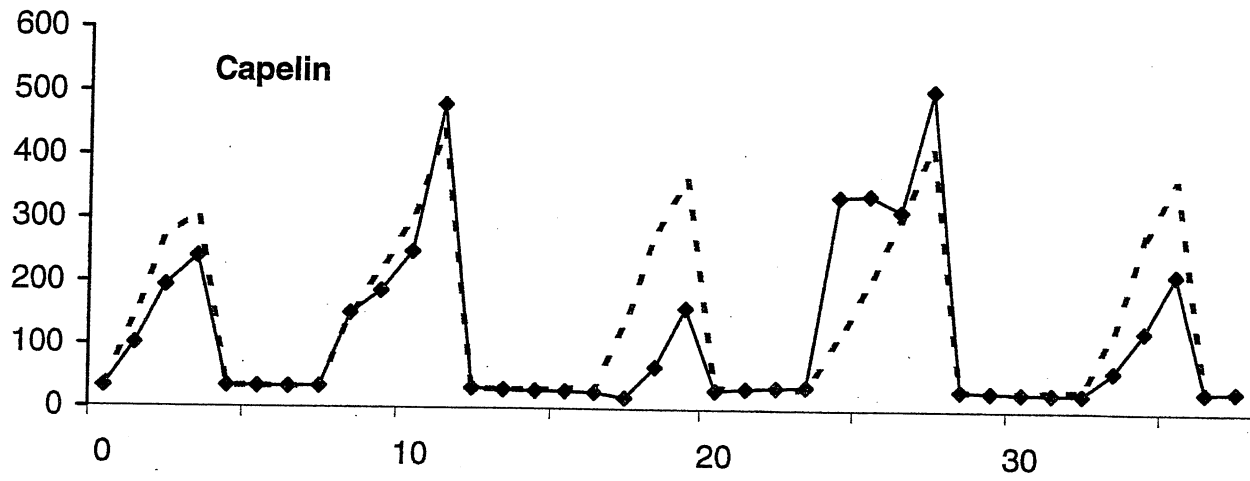


Figure 13. Simulated recruitment by year class from year 0 in bill. ind. for capelin (2-group), cod and herring (3-group). Strategy as in Figure 11.

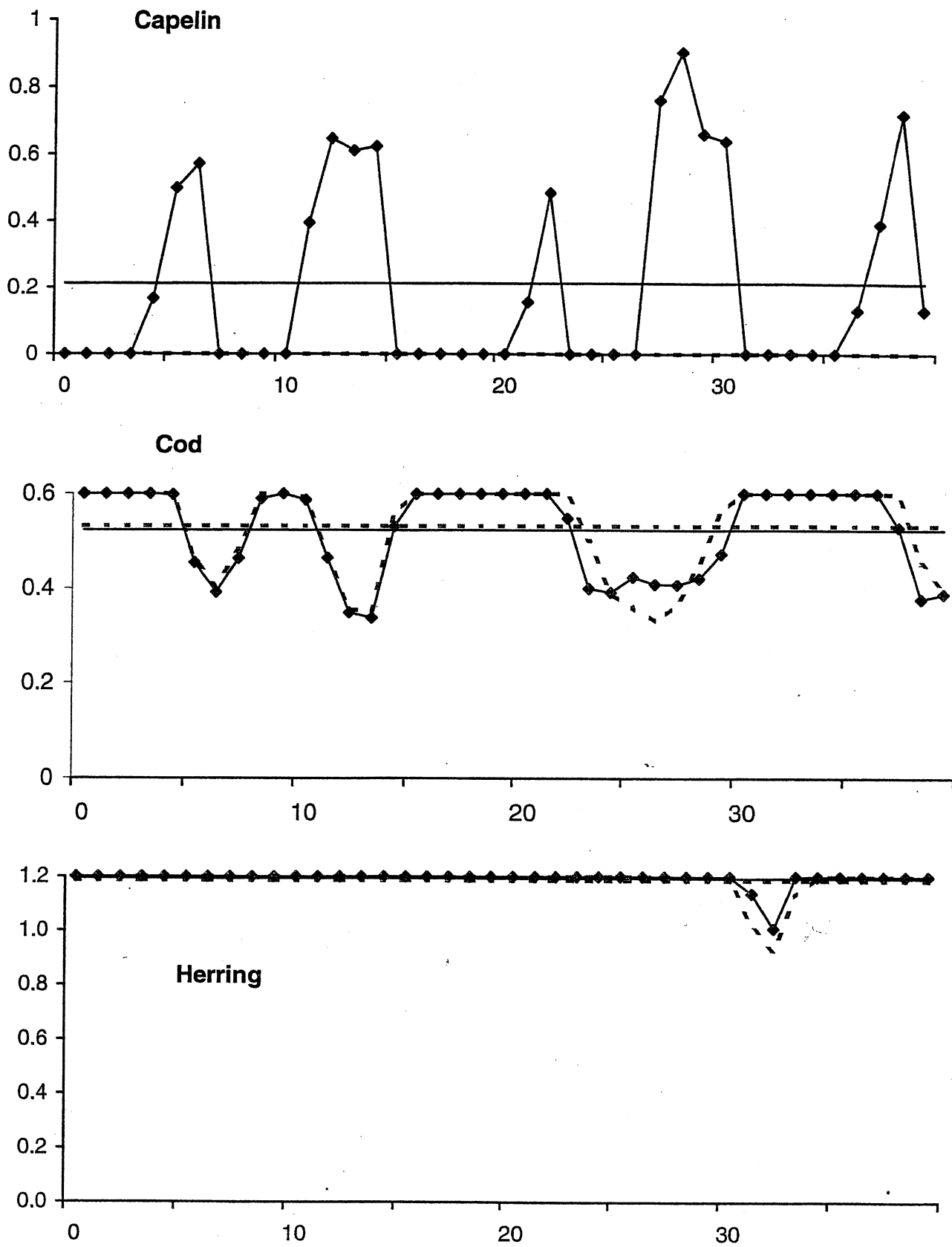


Figure 14. Simulated catches (mill. tonnes) of capelin, cod and herring in 40 years. Parallel lines to x-axis show average catch. Temperature cycle 8 years. Fishing strategy for capelin: $F = \text{conventional}$, for cod: $F = 0.8$, catch quota = 0.6 mill. tonnes. Herring: $F = 0.2$, catch quota 1.2 mill. tonnes. Dotted lines show the same strategi but capelin $F = 0$.

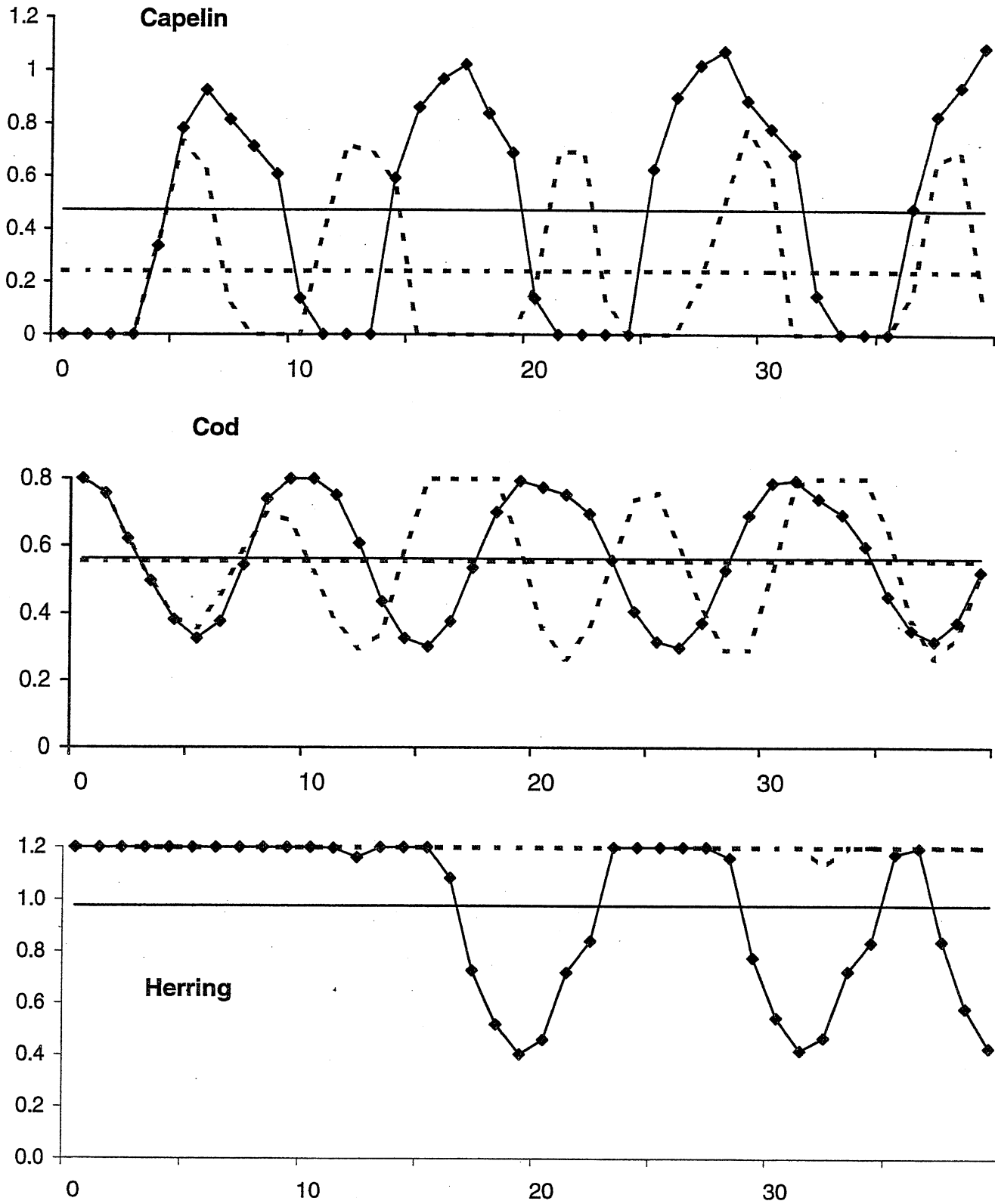


Figure 15. Simulated catches (mill. tonnes) of capelin, cod and herring in 40 years. Parallel lines to x-axis show average catch. Temperature cycle 11 years. Fishing strategy for capelin: conventional (see text), for cod: $F = 0.8$, catch quota = 0.8 mill. tonnes. Dotted lines show results for 8 years cycle.

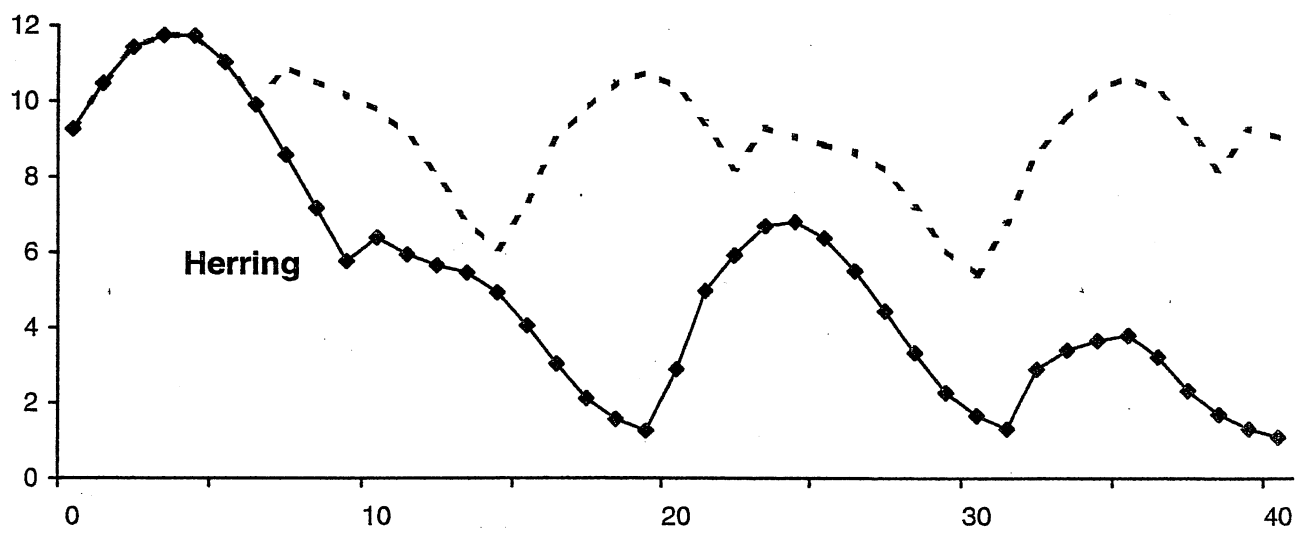
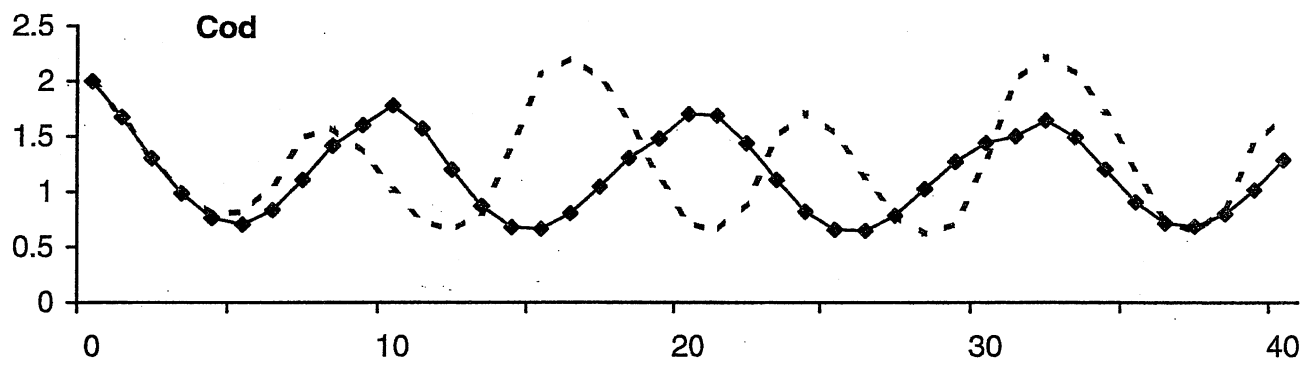
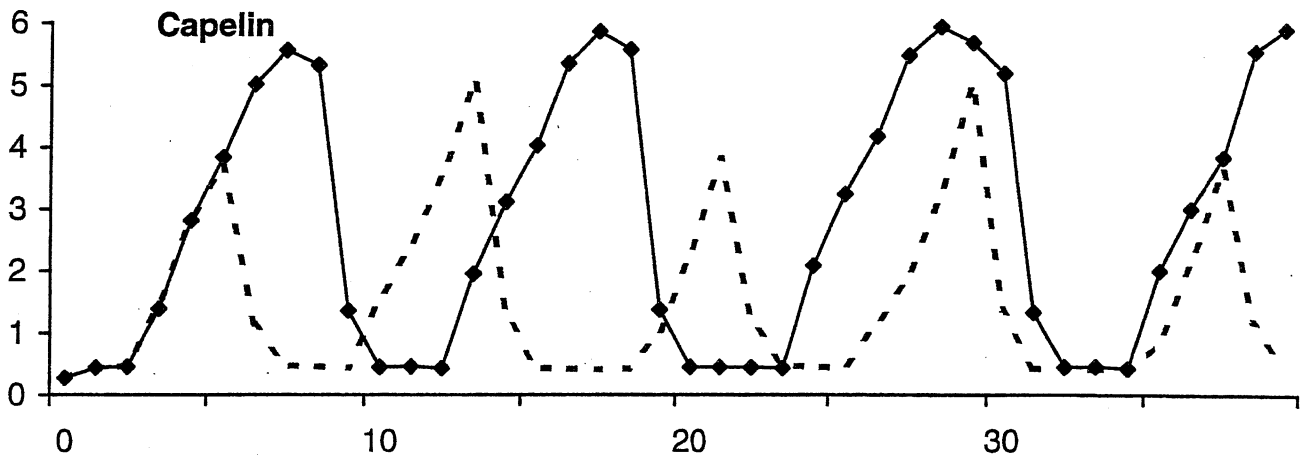


Figure 16. Stocks of capelin (2+), cod and herring (3+) in mill. tonnes. Same strategy as in Figure 15

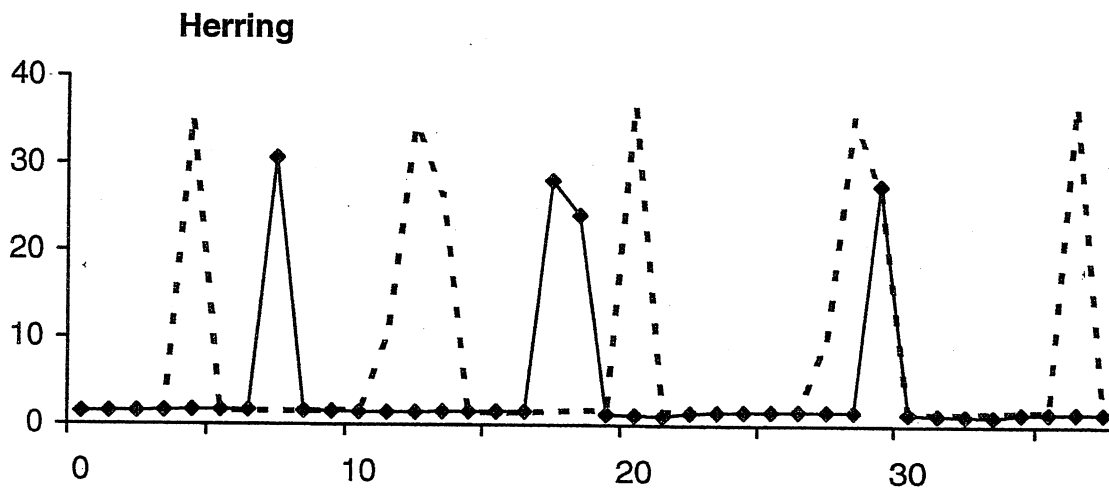
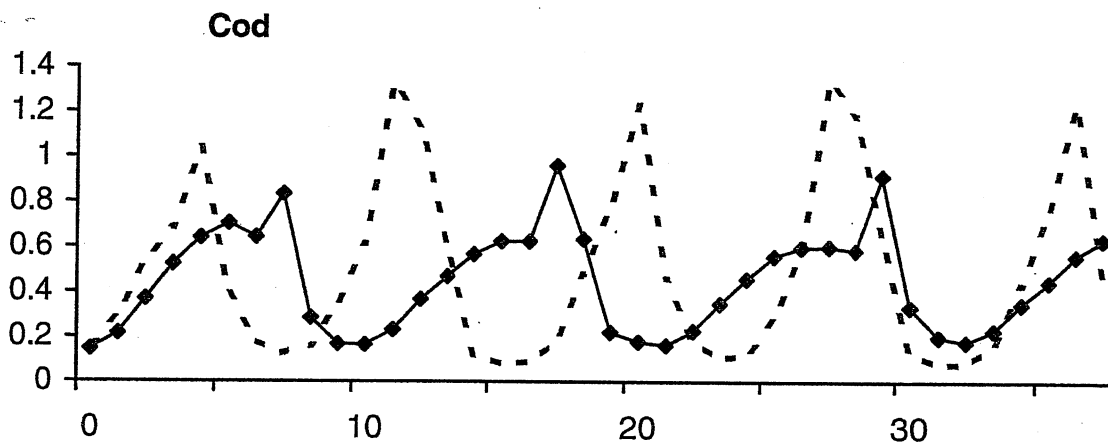
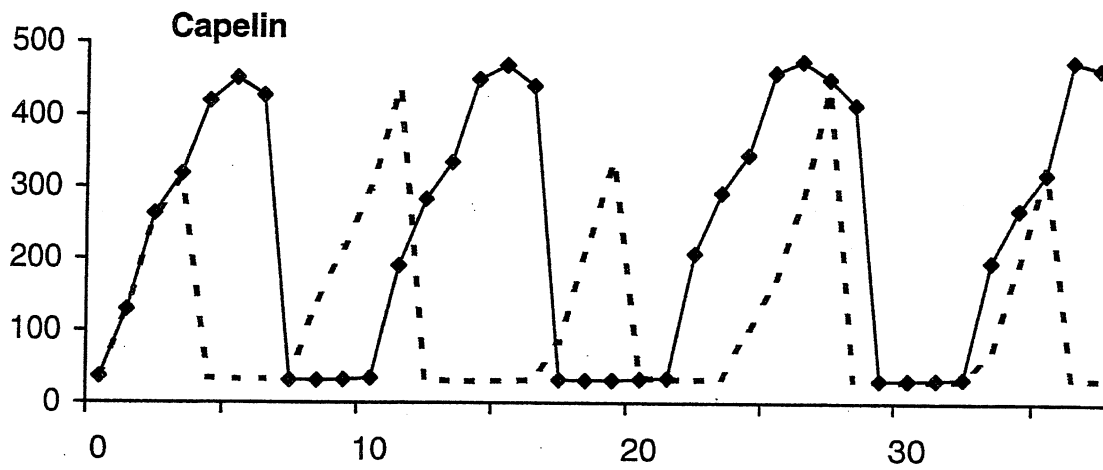


Figure 17. Simulated recruitment by year class from year 0 in bill. ind. for capelin (2-group), cod and herring (3-group). Strategy as in Figure 15.

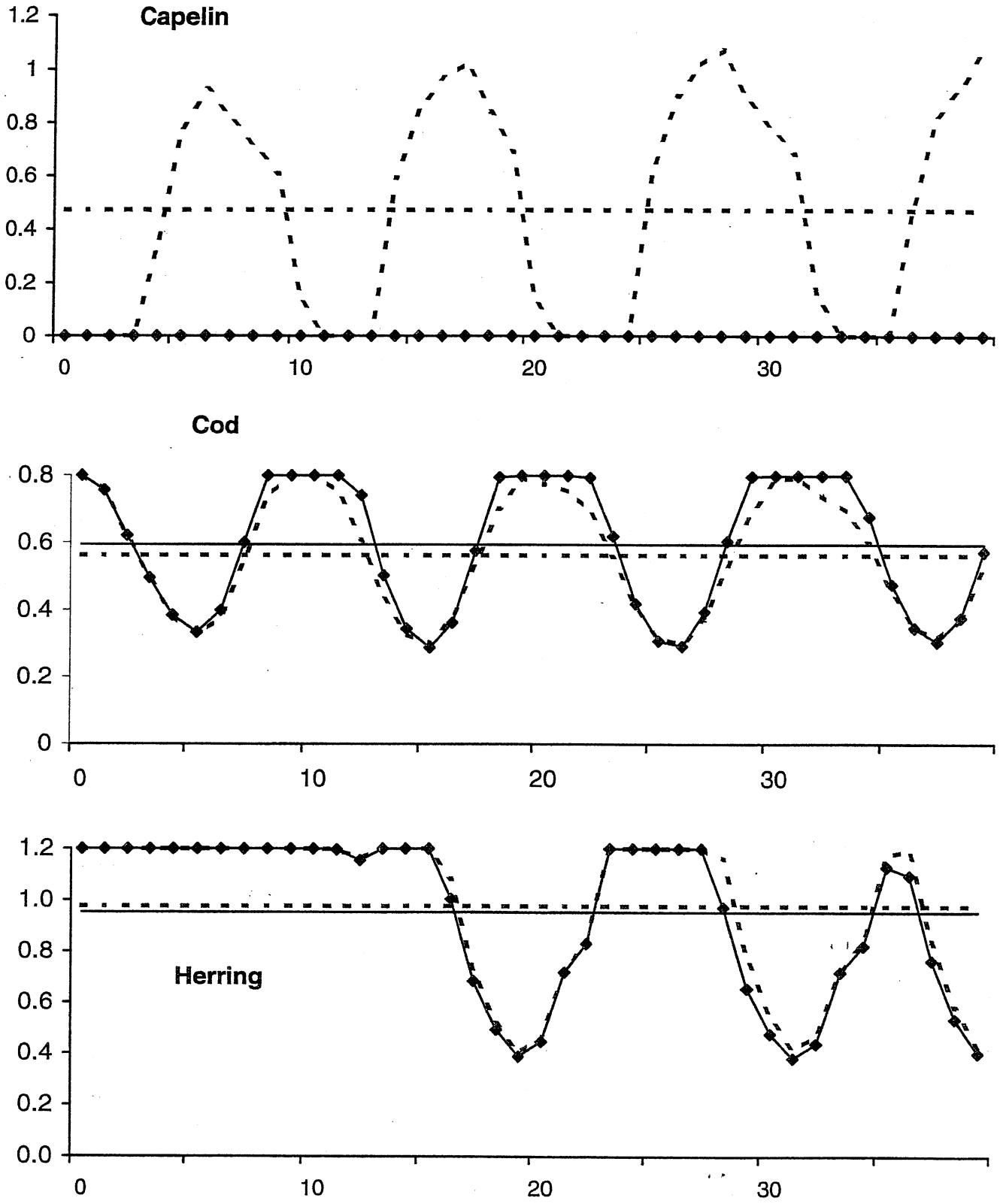


Figure 18. Simulated catches (mill.tonnes) of capelin, cod and herring in 40 years. Parallel lines to x-axis show average catch. Temperature cycle 11 years. Fishing strategy as in Figure 15. Dotted lines shows results for capelin $F = 0$