ICES Annual Science Conference. Iceland 1996
Hydrography Committee. C M 1996/C:14: Ref. G

Systems dynamics of North arctic cod

Harald Yndestad

Aalesund College
Postboks 5104 Larsgaarden
6021 AALESUND. Norway

Abstract

Systems dynamics of North arctic cod is a non-linear time varying dynamic process dependent on the ecology and the landings systems. In this dynamic system it is detected a dynamic process closely correlated to temperature cycles of 3*18.6=55.8 years, 18.6 years and 18.6/3=6.2 years. The temperature cycles is related to changes in the earth nutation and thus expected to be deterministic. The 6.2 year temperature cycle seems to have an important influence of cod recruitment, growth rate and landings. The temperature cycle of 18.6 years and 55.8 years seems to influence the growth rate and the maximum biomass. A delay in decision a level of landing, seems to introduce an instability in the biomass. In the paper it is suggested a control strategy to control the dynamics introduces by the temperature cycles.

The deterministic dynamic properties of recruitment opens for a simplification of the dynamic modelling and forecasting of North arctic cod. In the paper it is identified a systems dynamics models that may be used for forecasting future biomass.

Keywords

North arctic cod; Systems dynamics; Stationary temperature cycles; Forecasting; Dynamic control

1 INTRODUCTION

North Arctic cod is one of the largest stock of cod in the world. During centuries this stock has been of most importance of the economic growth in the western part of Norway. People living by fishing has always known that the stock of cod has dynamic properties. Some year there is a richness of cod and some years there are less. Knowledge of dynamics in fishery resources thus always has been of most importance. Periodical variations in the biomass and the fisheries of North arctic cod has been studied by researchers for many years. Among them Otterstad in 1942 (6) and Wyatt in 1994 (7).

In 1994 a life cycle analysis of a Norwegian fishing trawler was conducted (3). By chance, it was found that the time series of the quantities for North Atlantic cod has a 6-7 years cycle in the Fourier amplitude spectrum. This cycle was found in the fry abundance and even in the quota quantities of cod. Than we raised the hypothesis of a stationary temperature cycles in the Barents Sea.

This paper is based on official data (4) and the theory of a stationary temperature cycles related to the Earth nutation of 18.6 years (9). In this paper we have found that a stationary a cycle of 18.6/3=6.2 years highly influences the recruitment of cod and the cycles of 18.6 years and 3*18.6=55.8 years cycle influences the growth and the maximum biomass.

System theory

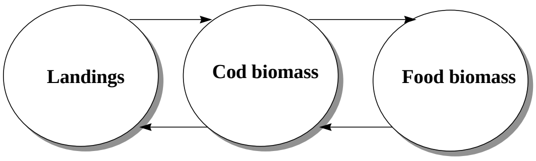

Figure 1 Dynamic system

A system is a set of organisations serving a common purpose. A general system S(t) may be expressed by

$$S(t) = \{A(t), X(t)\}$$

where X(t) is a set of organisations and A(t) is a set of relations between the organisations. In this case the set of organisations X(t) is the cod biomass system, the cod food system and the landings system. These systems are related by the time varying relations A(t). This means that the systems dynamics of cod is a dynamic process depending on the dynamics inside the organisations X(t) and the dynamic relations A(t) between the organisations.

According to the theory of systems dynamics this is a time variant non-linear dynamic system, and in this case there is a strong binding between the bio system partners. A such dynamic system may be deterministic by nature, but even if we have online access to the data of this system, the complex time varying properties introduces tremendous difficulties in predicting future development of the biomass.

There is however a possibility of simplifying this complex dynamic system. This possibility is based on there is a dominant force in the system that synchronises the dynamics of the total system. This force may be a stationary temperature cycle.

2 SYSTEM DYNAMICS

2.1 Recruit dynamics

The recruitment of cod has an important impact on the biomass. Than understanding the recruit dynamic is of most importance to understand the biomass dynamics. It has been known for years that there is a relation between the temperature and the recruitment (5). We will therefore study this relation more closely.

Temperature influences

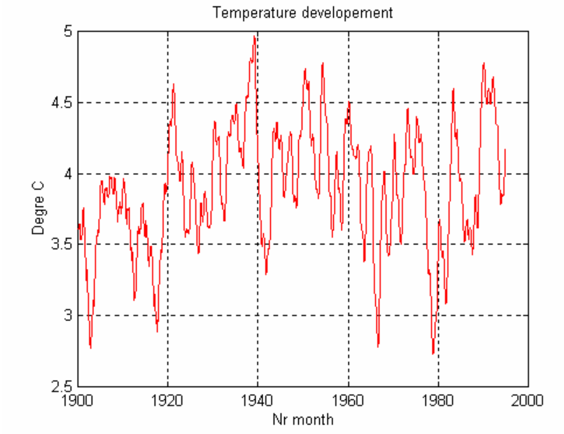

Figure 2 Temperature in the Barents Sea

The temperature in a volume of the Barents Sea has been measured each month since 1900 (1). This figure shows a 12 year moving average of the temperature time series.

The stationary temperature cycles is estimated (9) to be

$$Ut_1(nT) = 3.9 + 0.4 \cdot \sin(\frac{2 \cdot \pi}{3 \cdot 18.6} \cdot nT + 336T_i)$$

$$Ut_2(nT) = 3.9 + 0.6 \cdot \sin(\frac{2 \cdot \pi}{18.6} \cdot nT + 9.6T_i)$$

$$Ut_3(nT) = 3.9 + 0.4 \cdot \sin(\frac{3 \cdot 2 \cdot \pi}{18.6} \cdot nT + 12T)$$

where T is the sampling time of one month and n is the number of months from the year 1900. These cycles has a period of 6.2, 18.6 and 55.8 years. Since these cycles are correlated to a 18.6 year cycle of the earth nutation, the cycles are stationary and deterministic.

We may now study the relations between the dynamic biomass and the stationary temperature cycles. Figure 5 shows the time series $yn_3(nT)$ of the number of 3 year North Arctic Cod since 1946 (4). The estimated mean value is

$$\bar{y}n_3 = E\left[yn_3(nT)\right] = 632 \text{ mill cod}$$

This time series shows changes from 2-18 mill cod pr year. These changes may be investigated more closely by the autocorrelation and the power density spectre of the time series.

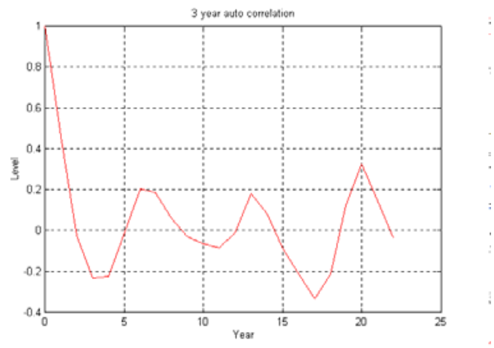

Figure 3 Autocorrelation of cod fry

The discrete autocorrelation function of the time series is computed by the estimate

$$R_{yy}(mT) = E[yn_3(nT) \cdot yn_3(nT + mT)]$$

where T is the time interval of one year and m is the number of years.

The rapid falling autocorrelation indicates that the number of 3 year cod is not a stable process. The peaks in interval of about 6 years indicates a stationary cycle of about 6 years in the time series.

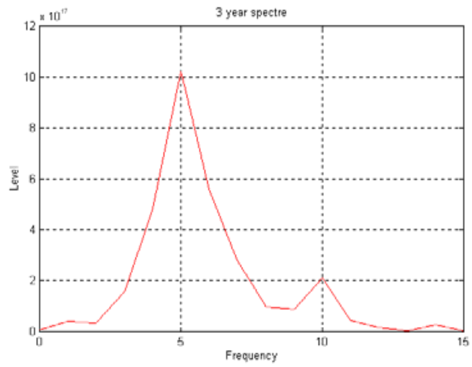

Figure 4 Power density spectrum of 3 year class

The auto power density spectre indicates stationary properties of the autocorrelation function. This spectre is computed by the inverse discrete Fourier transform

$$S_{yy}(k) = \sum_{n=0}^{N-1} R_{yy}(mT) \cdot e^{-jkmT/N}$$

Figure 4 is the power density spectre windowed by 32 points. The maximum cycle is at

$$peak = \frac{32}{5} \approx 6 \text{ years}$$

This is the same as at the temperature cycle of 6.2 years

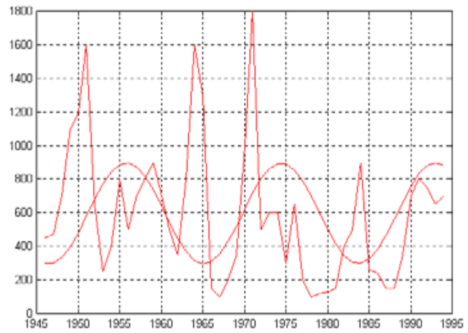

Figure 5 Number of 3 year cod and 18.6 year cycle

A time series of North arctic cod since 1946 is too short to estimate a cycle of 18.6 years. Figure 5 is a visual presentation of the 18.6 years cycle and the 3 year cod series. In this case the temperature cycle is computed from the year 1946. The figure shows that the number of 3 year cod has a low frequent component which is related in frequency and phase to the more low frequency temperature cycle of 18.6 year.

This analysis indicates that there is a close relation between the recruitment of North arctic cod and the temperature cycles of 6.2 years and 18.6 years. The 6.2 year cycle has the most influences an introduces the high peaks in recruitment. The 18.6 years cycle introduces an cycle at about the half amplitude.

Production rate

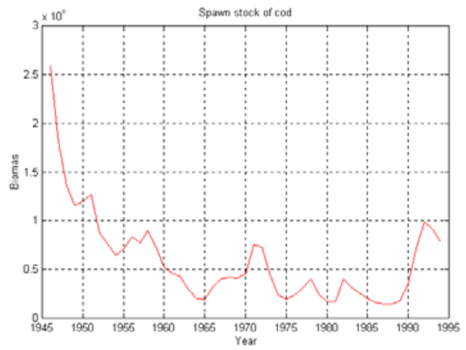

Figure 6 Biomes of 8+ year spawn cod

This figure is the time series of the biomass of cod from 1946 (4). In this case the of cod biomass is defined to be 8 years or more and characterised by the time series $y_{8+}(nT)$. The mean biomass of cod is

$$\bar{y}_{8+} = E\left[y_{8+}(nT)\right] = 600.000 \text{ tons}$$

or about 25 % of the total mean biomass.

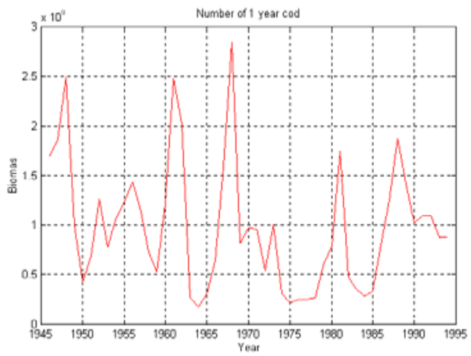

Figure 7 Number of 1 year cod

The numbers of cod at the 3 years age is known (4). The biomass of 1 year cod may be computed by the backward prediction

$$yn_i(nT) = \frac{yn_{i+1}(nT+T)}{(1-M)}$$

where M is the mean descrete mortality computed by the relation

$$e^{-F} = (1-M)$$

and F is the continuos mortality rate. The mortality is an uncertain variable and often estimated to be F=0.2 (4). In this example the mortality of cod is selected to be M=0.2 or F=0.2231. Then the number of cod at one year cod is estimated to be as shown on figure 9. In this case the mean numbers of cod is

$$\bar{y}n_1 = E\left[yn_1(nT)\right] = 986 \text{ mil cod}$$

The peeks on the estimated number of one year cod has the same frequency and phase as the 6.2 year temperature cycle.

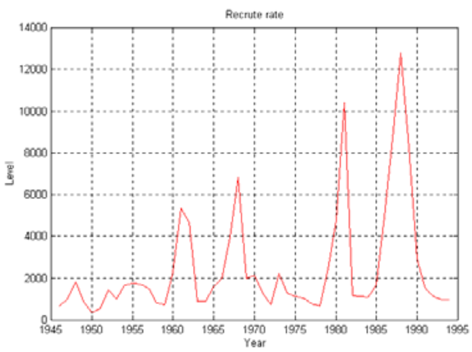

Figure 8 Production rate

The production rate of cod may be defined as the relation between the number of one year cod and the biomass of cod. This rate may be computed by

$$p(nT) = \frac{yn_1(nT)}{y_{8+}(nT)}$$

where $y_{8+}(nT)$ is the known biomass of cod and $yn_1(nT)$ is the backward estimated number of one year cod. The result is displayed on figure 8 and indicates a cyclic production rate. The mean production rate is

$$\bar{p} = E\left[p(nT)\right] = 2500 \text{ cod/tons biomass}$$

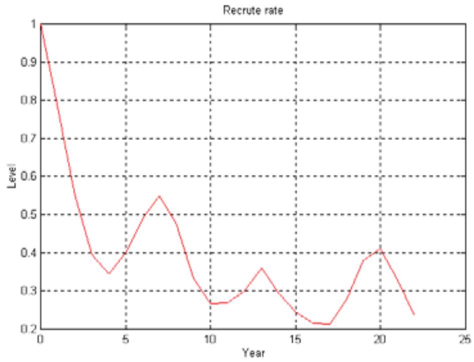

Figure 9 Autocorrelation of recruit rate

This figure is the autocorrelation of the production rate p(nT). The autocorrelation indicates there is a dominant cycle of about 6 years in the production rate. These estimates tells us the number of one year cod and the production rate is correlated to the 6.2 year cycle.

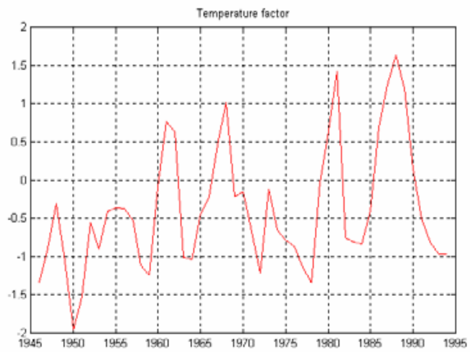

Figure 10 Exponential temperature growth rate Kt

Since each part in food chain is temperature dependent. We may expect an exponentially temperature dependent recruitment. A such relation is the model

$$p(nT) = \bar{p} \cdot \exp(Kt(nT))$$

where Kt is an exponential relation and $\bar{p}$ is the mean production rate. The exponential relation may be estimated as a time series

$$Kt(nT) = \ln\left(p(nT)/\bar{p}\right)$$

Figure 10 shows that this exponential factor Kt is changing periodically between +1 and -1.

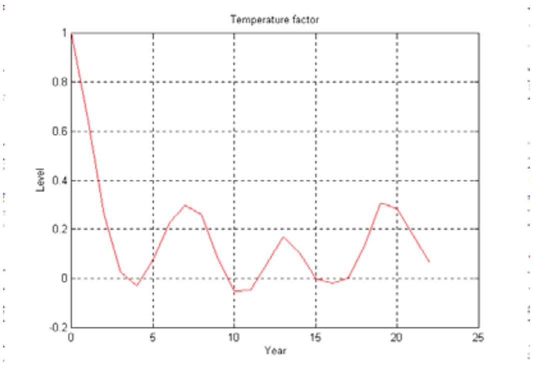

Figure 11 Autocorrelation of exponent

Figure 11 shows the autocorrelation of the exponential factor Kt. The autocorrelation shows that Kt(nT) has a dominant periodic cycle of about 6 years. This tells us that the exponential factor Kt is related to the 6 year temperature cycle. The time series is to short to estimate cycles of 18.6 and 55.6 years. Than we may modulate the production rate as

$$p(nT) = \bar{p} \cdot \exp(Kt(nT)) \approx \bar{p} \cdot \exp(Ukt(nT))$$

where $\bar{p}$ is the mean production rate and Ukt(nT) is the estimated stationary temperature cycles of 6.2, 18.6 and 55.8 years.

Now we know that the exponential factor Kt is direct related to the stationary temperature cycles. This is of most importance because the changes of these cycles is expected to be deterministic (10). The next is identifying the periodic temperature amplitude relation.

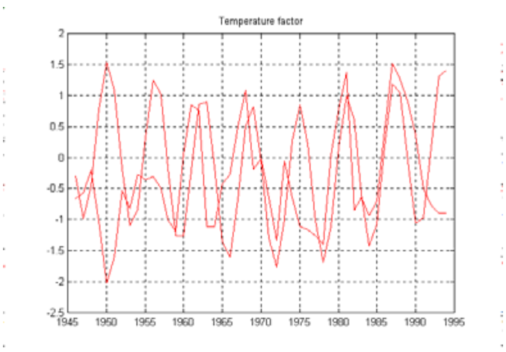

Figure 12 Measured exponent Kt and temperature cycle Ukt_3

By adjusting the amplitude of the 6.2 year cycle, we found the optimal cyclic exponential temperature parameters

$$Ukt_3(nT) = 1.2 \cdot \sin\left(\frac{3 \cdot 2 \cdot \pi}{18.6} \cdot nT + 12T\right)$$

where n = 1,2,3…. From the year 1900.

The correlation between these cycles are surprisingly good. The exceptions are the years 1950 and 1956 when the biomass was at a high level.

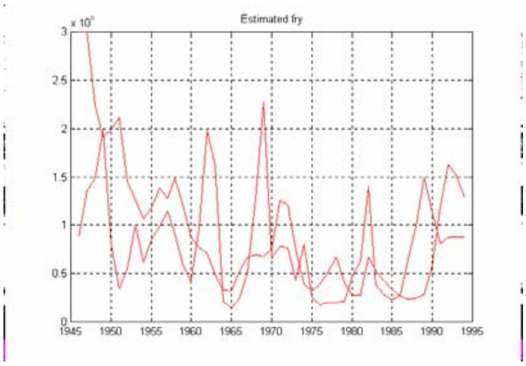

Figure 13 Estimated 1 year cod form the 3 cod and from the biomass

Knowing the estimated production rate, we may now estimate the number of one year cod from the estimated production rate model

$$\hat{y}n_1(nT) = y_{8+}(nT) \cdot \bar{p} \cdot \exp(Ukt(nT))$$

Figure 13 shows the estimated number of one years cod in two ways. The first is estimated backwards from the 3 year biomass $y_3(nT)$ and the second is predicted from the recruitment model. The figure shows a good relation between the two estimates.

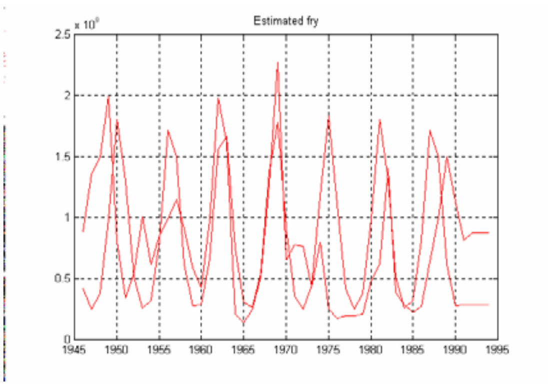

Figure 14 measured and estimated production

To test the sensitivity of the temperature cycles, the estimated production of one year cod may be modulated by the simplified model

$$\hat{y}n_1(nT) = \bar{y}_{8+} \cdot \bar{p} \cdot \exp(Ukt(nT))$$ where

$\bar{y}_{8+} = E\left[y_{8+}(nT)\right]$=590.000 tons

$\bar{p} = E\left[p(nT)\right] = 1660$ fry/ton spawn cod

$$Ukt(nT) = -0.38 + 1.0 \cdot \sin(\omega_3 nT + \phi_3)$$

In this case only the 6.2 year cycle is used in the temperature parameter Ukt(nT). The figure shows there are a surprisingly close relations between the estimates by the production and backward prediction from 3 year cod. This time there are a phase shift error in 1950 and in 1987.

The model may easily be tuned some more. The phase error is related to a known phase shift in temperature cycle (10) which is not adjusted in this estimate. If we introduces the temperature 18.6 year cycle in the model, the amplitude error will be further reduced.

These estimates indicates that the recruitment is exponentially dependent on the temperature cycle and less dependent on the biomass. If this estimate and the hypothesis of stationary temperature cycles is confirmed, it opens for a deterministic prediction of future recruitment of North arctic cod.

2.2 Biomass Dynamics

The dynamics of the total biomass may be modulated by knowledge of the mean recruitment, individual growth in weight, landings and mortality.

Individual growth

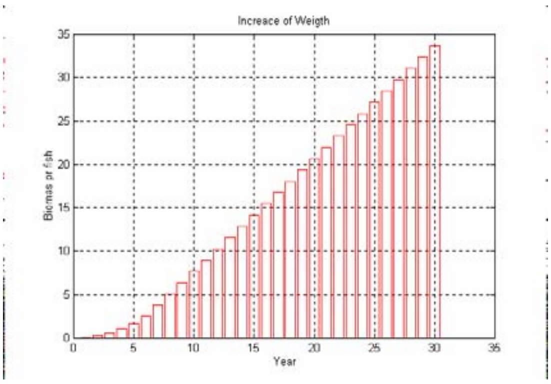

Figure 15 Mean individual growth in weight

The individual growth of North arctic cod is well documented (2), (4). Using these data, the mean growth in weight of a cod fish may be modulated as

$$x_{i+1}(nT + T) = x_i(nT) + u_i$$

where x_i is the biomass at the age i and u_i is the incremental growth at the same age.

The mean growth is

$$\bar{u}_i = E\left[\frac{x_{i\,\max} + x_{i\,\min}}{2}\right] = 1.04 \text{ kg/year}$$

and the mean weight in a life time of 30 year is

$$\bar{x} = E[x_i] = 14 \text{ kg}$$

Figure 15 shows the weight growth of one fish. This model indicates a deterministic view of growth where the growth is small the first years and than there is a steady growth.

The growth factor

The growth factor is the mean growth form one year to the next. The estimated growth factor at each age is

$$a_i = \frac{x_{i+1}}{x_i}$$

Using the growth factor, we may describe the life cycle incremental growth of one fish as

$$x_{i+1}(nT + T) = a_i \cdot x_i(nT)$$

In this model the mean growth from 9 to 30 years is expected to be the same as from 7 to 8 year. This indicates that the mean growth in weight is constant, and the relative weight is decreasing. In this case the mean growth rate is:

$$\bar{a} = E[a_i] = 1.33$$

This means in an uniform distributed biomass, the maximum mean growth of biomass is about 33 % pr year. The growth of one cod has probably an S-shape. The mean growth of 1.33 than is probably a maximum estimate.

Temperature dependent growth

If we look at the data of mean growth (2), the growth has a maximum at the year 1990 a minimum at the year 1987. When subtracting the delay of growth, there is a phase relation between the growth of cod and the 6.2 year temperature cycle. This indicates a correlation between the growth and the stationary temperature cycle of 6.2 years. Using a priori information on the temperature cycle, we may estimate a temperature dependent growth that is related to the temperature cycle of 6.2 years. This means that the this temperature cycle influences the growth rate of the biomass in cycles of 6.2 years.

Biomass dynamics

The dynamics of the biomass is dependent on the individual growth rate, mortality and landings. To understand more about the biomass dynamics, we may first study what will be the maximum biomass if the landings are zero.

Knowing the mean number of 3 year cod and the mean mortality rate, we may compute the mean number of each age by

$$xn_{i+1} = (1-M)xn_i \cdot = a_n \cdot xn_i$$

where the age i = 1,2,3… 30. And knowing the mean numbers of cod at each year class and the mean weight at each year class, we may now compute the mean biomass at each year class by

$$x_{i+1} = mv_i \cdot xn_i$$

where mv_i is the mean biomass on a fish at the age i. We may now compute the maximum growth of the biomass in a cod life span when there are no landings. This accumulated biomass may be computed by

$$xb_{i+1} = xb_i + x_i$$

where xb_i is the accumulated biomass at the age i and x_i is the biomass at the year class i. From known sources (4) the mean number of 3 year cod since 1946 is estimated be 632 mill cod per year and the mean mortality is expected to be F=0.2. The mean accumulated biomass, without landing, than is estimated to be 22.000.000 tons.

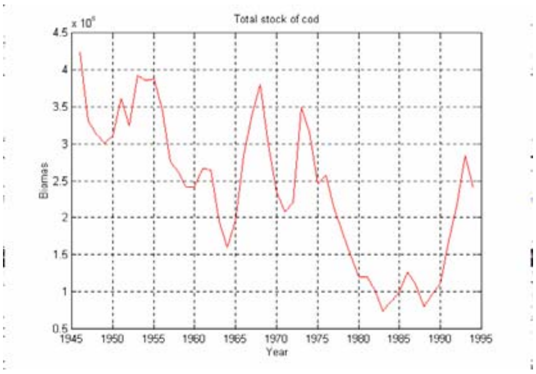

Figure 16 Total biomass $y_{3+}(nT)$

This figure shows the development of the total biomass the last 50 years (4). In 1945 the estimated biomass was about 4.000.000 ton. The time period 1940-50 had optimum conditions cording to the 55 years temperature cycle and there was less landing the years 1940-45. If this growth model is right, there must be a mush more biomass in the Barents Sea or there must be much higher mortality.

If the years 1940-50 had optimum conditions, a 50 % higher than the estimated 4.000.000 tons seems to be more realistic. This means the maximum biomass is about 6.000.000 tons on optimum conditions. If this is correct, the mortality must be higher than F=0.2.

Adjusted mortality

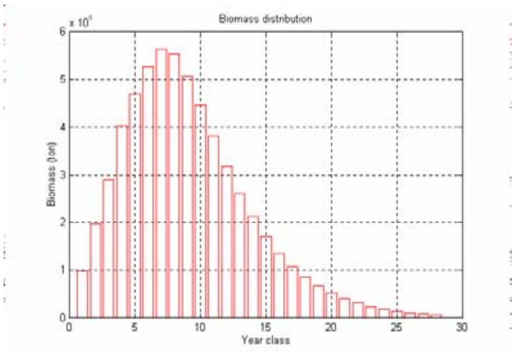

Figure 17 Biomass distribution when F=0.31

This figure is an estimate of the biomass distribution when the mortality F=0.31 and M=0.27. In this case the peak of the biomass is at the 7 years class.

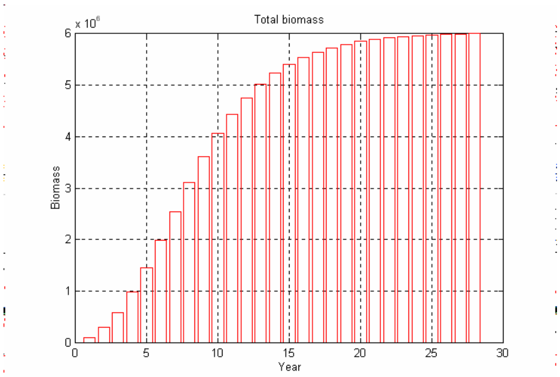

Figure 18 The growth of total biomass when mortality rate F=0.31

Figure 18 shows the growth of the total biomass when the discrete mortality rate M=0.27. In this case the biomass is growing to 6.000.000 tons and most rapidly between 500.000 and 4.000.000 tons.

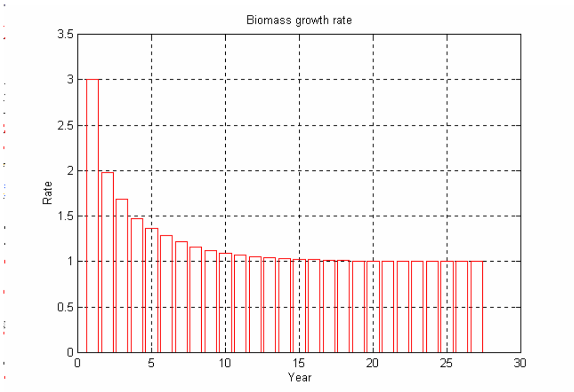

Figure 19 Biomass growth rate

Knowing the growth of the total biomass xbi and the mortality rate M, we may now compute the biomass growth rate by

$$ab_i = \frac{xb_{i+1}}{xb_i}$$

The result on figure 19 shows that the growth rate is decreasing exponentially. This means the biomass is an highly non-linear system. In the past 50 years, the biomass has changed between 1.000.000 and 4.000.000 tons. In this area the growth rate is changing between

ab_{1-4} = 1.5 and 1.2

This means the biomass has a growth of 50% when the biomass is 1.000.000 tons and 20 % when it is 4.000.000 tons. The mean growth rate is: $\bar{a}b = 1.3$ or about 30 % a year.

3.3 Landings dynamics

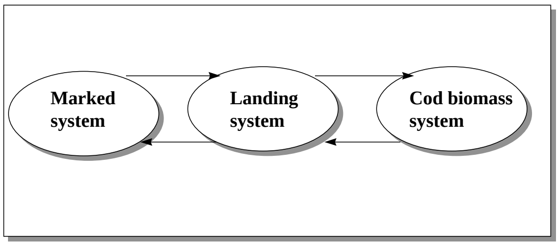

Figure 20 Landing system

The landings system regulates the quota of cod. This system is related to its context. The dynamics of this system is on one side related to the dynamics and the binding to a marked system. On the other side it is related to the dynamics and the binding to the cod biomass system. Thus the marked system, the landing system and the cod biomass system is a part of a common value chain system where each sub system will influence the dynamics of the other. For better understanding the total dynamics, we will now study some fundamental properties of the landing dynamics.

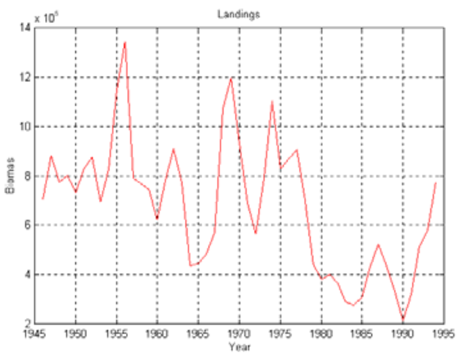

Figure 21 Landings of cod

This figure shows landings of cod since 1946. The mean landing is

$\bar{u} = E\left[u(nT)\right]$ = 677.000 tons pr year

This is 28 % of the biomass. If we use the landings as an input to the biomass model, we will have the state space difference equation

$$x(nT+T) = A(nT)\cdot x(nT) + B\cdot u(nT) + C\cdot v(nT)$$
$$y(nT) = D\cdot x(nT) + w(nT)$$

where u(nT) is the biomass of landings and B is a (m x m) matrix that distributes the landing on each yeas class. The state vector v(nT) is the loss of biomass from an unknown source.

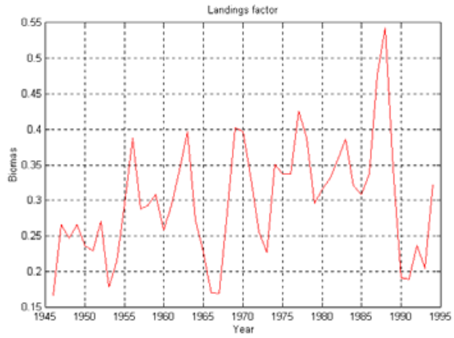

Figure 22 The landings rate

A landings rate is an policy index that indicates how much of the biomass of cod that are landings to the marked. The landings ratio may be defined as

$$L(nT) = \frac{u(nT)}{y_{3+}(nT)}$$

The landings rate function is shown on figure 22. The mean landings rate is

$\bar{L} = E\left[L(nT)\right]$ = 0.3 or 30 %

Earlier in this paper we found the mean growth was about 30 % and it was changing between 20 % and 50 %. This indicates the that if the mortality rate F=0.31, as indicated in this paper, the landing rate is the main force in controlling the dynamics of the biomass and the landings rate is at a critical level. The non-linear properties of the growth rate will force the biomass in the direction of cod at smaller ages. In the next years the Barents Sea is expected to be cooled down by the 55.8 year cycle (10). This will influence the biomass growth rate. If the landings rate still is 0.3, the biomass will be more reduced.

A mean landing ratio of 0.3 tells us that the landing will have much impact on the dynamics of the cod biomass. Understanding the dynamics of the landings rate is of most importance for understanding the dynamics of the cod biomass.

The landings rate and the analysis of the landings rate indicates that there has been a steady growth of landings ratio from 1965 to 1985. There was a change in the policy in 1985-90 when the biomass collapsed. Since than the landings rate has been growing to the levels of the 1970-80.

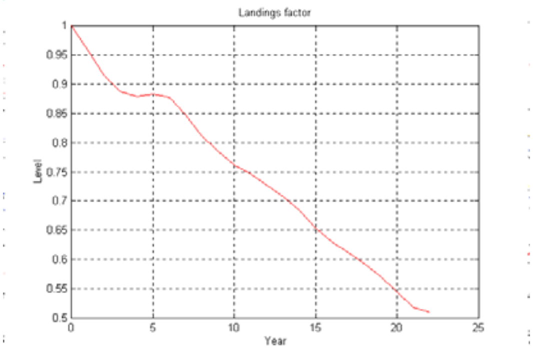

Figure 23 Autocorrelation of landings ratio

The autocorrelation function of the landings rate L(nT) is shown on figure 25. The slow decline of autocorrelation indicates a steady landing policy.

An analysis of the landings function u(nT) indicates that the landings also has a cycle of about 6 years, but compared to the biomass function $y3_{+}(nT)$, the landings has a phase delay of 3 years. The effect of this phase delay is introduction of instabilities in the biomass. This instability will lead to a minimum quota of landing when the biomass has a maximum and a maximum landing quota when the biomass has a minimum level.

Systems dynamics control

Instabilities in the biomass may be reduced and controlled to a chosen level. Knowing the dynamics of the biomass and the recruitment, the biomass may be controlled to a wanted level by feedback control and a feed forward control. A discrete representation of the biomass may be modelled by

$$X(nT+T) = A(nT)\cdot X(nT) - B\cdot U(nT) - \cdot V(nT)$$
$$Y(nT) = D\cdot X(nT) + W(nT)$$

where X(nT) is the biomass vector for each age, A(nT) the growth matrix, U(nT) the landings vector, V(nT) is mortality from an unknown source, Y(nT) is the Kalman-estimated vector of biomass and W(nT) is an uncertainty in the measurement.

Low frequent dynamics may be controlled by the feedback control

$$U(nT) = (R(nT) - Y(nT))\cdot K$$

where R(nT) is the wanted biomass level and K is the control strategy. A well known control strategy is a proportional and an integration property.

If the biomass is controlled to a low level, the recruitment from 3 year class and the growth of the biomass in a year will be of importance. We may than introduce a feed forward control strategy.

$$U_f(nT) = y_3(nT) + dX(nT)$$

where $y_3(nT)$ is the estimated mean biomass of 3 year cod and dX(nT) is the estimated growth in a year. The estimated landing by feedback and feed forward control will than be

$$U(nT) = (R(nT) - Y(nT))\cdot K + U_f(nT)$$

This control will suppress dynamic in the biomass that is introduced by the high frequent cycle of 6.2 years and the more low frequent cycles of 18.6 and 55.8 years.

2.4 Uncertainty

Analysing the uncertainty we will know more of the quality of the data and models in this paper. The system dynamics of the each age in the total bio system may be modulated by the state space equation

$$X(nT+T) = A(nT)\cdot X(nT) + B\cdot U(nT)$$
$$Y(nT) = D\cdot X(nT) + W(nT)$$

where X(nT) is a vector of biomasses A(nT) is the matrix that regulates the growth, U(nT) the landings and W(nT) the uncertainty in the measured biomass.

We will now analyse the uncertainty in measuring the biomass. If the mortality is incorporated in the growth model, we may now use this dynamic biomass model based on known data (4).

$$x_{3+}(nT+T) = \bar{a}b\cdot x_{3+}(nT) - u(nT)$$
$$y_{3+}(nT+T) = x_{3+}(nT) + w(nT)$$

Than the uncertainty w(nT) may than be formulated as

$$w(nT) = y_{3+}(nT+T) - \bar{a}b\cdot y_{3+}(nT) + u(nT)$$

where u(nT) is the landings and ab is the estimated mean growth rate and mortality estimated in this paper.

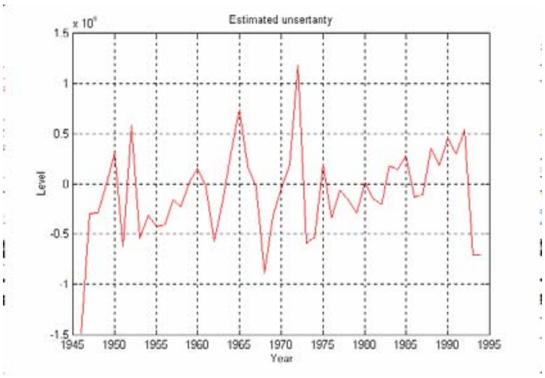

Figure 24 Estimated uncertainty of mortality and measurement

The estimated uncertainty function w(nT) is shown on figure 24. The figure shows that the uncertainty has some positive and negative values. Positive values indicates there must be more biomass in the system than expected and negative there is less. The mean value of uncertainty is

$\overline{w} = E\left[w(nT)\right]$ = -90.000 tons

This is only 3.7 % of the total biomass. The estimated error is mostly positive when the biomass has a low value and negative when it is high. In this estimate the growth rate is not adjusted for changes in the biomass, if this had been done, the uncertainty w(nT) should be even lower.

Estimation of uncertainty is test of the quality of measured data (4) and the estimated parameters of growth rate and discrete mortality in this paper. In this estimate the mortality rate was F=0.31. If the right mortality is F=0.2, there should be mush more biomass than measured.

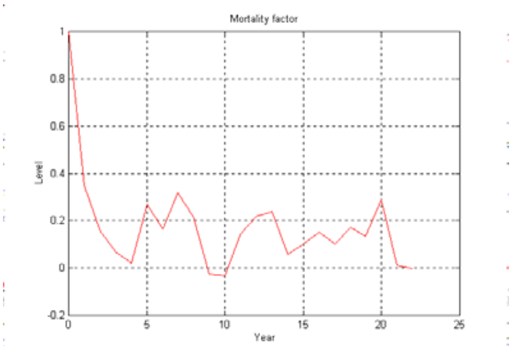

Figure 25 Autocorrelation of the uncertainty

This is the autocorrelation function of the uncertainty function w(nT). It shows that the autocorrelation function is falling rapidly to about 0.3 and than there is a peak at about 6 years repeating in periods of about 6 years. This indicates there are much noise in the data as expected. This confirms the estimates of data and parameters in this paper.

3 CONCLUTION

Systems dynamics of North arctic cod is a non-linear time varying dynamic process dependent on the ecology and the landings systems. In this dynamic system it is detected a dynamic process closely correlated to temperature cycles of 3*18.6=55.8 years, 18.6 years and 18.6/3=6.2 years. The temperature cycles is related to changes in the earth nutation and thus expected to be deterministic. The 6.2 year temperature cycle seems to have an important influence of cod recruitment, growth rate and landings. The temperature cycle of 18.6 years and 55.8 years seems to influence the growth rate and the maximum biomass. A delay in decision a level of landing, seems to introduce an instability in the biomass. In the paper it is suggested a control strategy to control the dynamics introduces by the temperature cycles.

The deterministic dynamic properties of recruitment opens for a simplification of the dynamic modelling and forecasting of North arctic cod. In the paper it is identified a systems dynamics models that may be used for forecasting future biomass.

References

1. Bochkov, Y.A: Water temperature in the 0-200 m layer in the Kola-Meridian in the Barents Sea, 1900-1981. Sb. Nauchn. Trud. PINRO, Murmansk, 46: 113-122 (in Russian).
2. Havforskningsinstituttet: Ressursoversikt 1995. Bergen.
3. Helgessen Ø, Yndestad H, Walde P, m.fl.: Livssyklusanalyse for tråler. 1994 HIÅ. Ålesund.
4. ICES: Report of the arctic fisheries working group. ICES Headquarters. Copenhagen. Denmark. August 1995
5. Loeng H, Blindhein J, Ådlandsvik B, Ottersen G: Climatic variability in the Norwegian Barents Seas. ICES mar. Sci. Symp.. 195: 52-61. 1962
6. Ottestad, Per: On Periodical Variations i the Yield of the Great Fisheries and the Possibility of establishing Yield Prognoses. Fiskeridirektoratets skrifter. 1942. Bergen
7. Wyatt T, Cyrrie R G, Saborido-Rey: Deterministic signals i Norwegian cod records. ICES mar. Sci. Symp., 198: 49-55. 1994
8. Yndestad H: Sammenheng mellom temperatur og yngel for norsk arktisk torsk. HIÅ/AEA/F-95/02. Ålesund. 1995.
9. Yndestad H: Stasjonære temperatursykluser i Barentshavet. Årsakenes årsak. HIÅ/AEA/F-95/01. Ålesund. 1995
10. Yndestad H: Stationary temperature cycles in the Barents Sea. The cause of causes. ICES. Annual Science Conference. Iceland. Sept. 1996