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The predestined fate

The Earth nutation as a forced oscillator on management of Northeast Arctic cod.

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Abstract

The paper presents a system dynamics theory of the influence of the Earth's nutation on management of Northeast arctic cod. According to this theory the Earth's axis dynamically behaves as a forced oscillator on a non-linear sea system that modulates a set of harmonic and sub harmonic low frequency temperature cycles in the sea system.

The paper reports a correlation between time harmonic cycles of the 18.6 year Earth nutation and the temperature system and the biological system in the Barents Sea. The influence from the Earth nutation is explained by a general systems theory where modulated temperature cycles are forced oscillators on the biological system in the Barents Sea. The system dynamics of the biological system are synchronized to the temperature cycle and amplified by a biological stochastic resonance to the food systems. A stochastic resonance of 18.6/3=6.2 yr between the management and the biomass dynamics introduces an unstable biomass.

Introduction

In the Barents Sea the inflow of warm North Arctic water meets a stream of cold Arctic water from the north and cool mixed water circulates back to East Greenland. These streams may vary in intensity and slightly in position and cause biological changes in the Barents Sea. Since the first analysis by Helland-Hansen and Nansen (1909), changes in these streams have been explained by climatic alterations in average wind and climatic variability (Loeng *et al.*, 1992; Dyke, 1996). There is, however, no clear answer as to how meteorological and oceanographic conditions influence each other (Loeng *et al.*, 1992).

Northeast Arctic cod is the largest stock of Gadus morhua cod in the world. The fishery of this stock is located along the northern coast of Norway and in the Barents Sea. For centuries this stock of cod has been the most important economic biomass for Norwegian fishermen and of vital importance for settlement and economic growth in the western part of Norway.

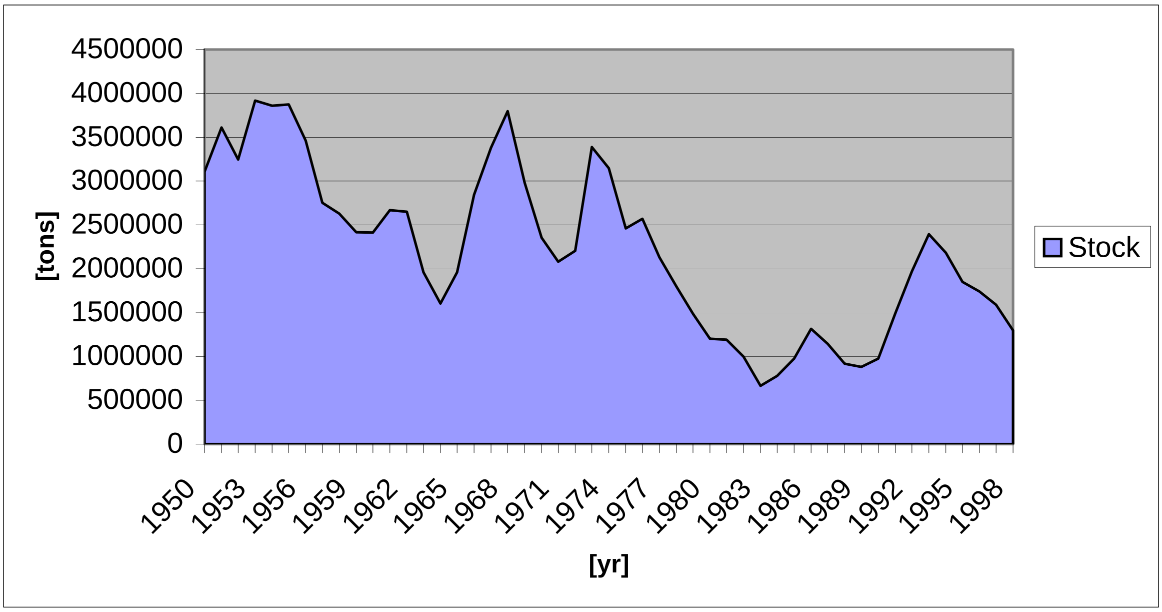


Figure 1. Time series of Northeast Arctic cod biomass stock from 1950 to 1998

The biomass of Northeast Arctic cod has always fluctuated and there have been several theories on the causes of these fluctuations. Some years the influx of cod is abundant and some years the influx may be insufficient in relation to the demand. People dependent on fishing have always known the stock of cod has a short time and long time fluctuation. These fluctuations have been explained by herring periods and cod periods, introduction of new fishing equipment and more. Better forecasting in a time span of 5-10 years, will be crucial for better planning of an economical and sustainable utilization of the cod biomass. When the Norwegian marine research started at the beginning of this century, the main task was to uncover how the nature influenced the stock of cod and the impact of fluctuation on people living by fishing (Rollefsen, 1949).

Years of fluctuation in the biomass and the landings have been explained by limited food resources, cannibalism, changes in landings from number of cod to tons of cod, to high quota of landings (Nakken. el al., 1996) and assessment methods. Early scientific explanations of cod fluctuations were changes in food, mortality, hydrographic relations, sea temperature and positive feedback in recruitment (Rollefsen, 1949). More recently the fluctuations of Northeast Arctic cod has been described in more detail (Nakken, 1994), but the fundamental explanations are much the same.

I 1994 a modeled projection of the lifetime earning capacity of a Norwegian trawler was carried out as an item of contractual research. An autocorrelation of the biomass indicated it was not realistic to predict future biomass more than one year ahead. This motivated to look for a more fundamental cause of marine fluctuation. By chance it was found that time series of North Atlantic cod has a dominant 6-7 year cycle in the autocorrelation and the Fourier amplitude spectrum. The same dominant cycle was found in cod recruitment and landings. A next question was is this a stationary cycle? If this is a stationary cycle, this is a cause of causes that has the information we may use to estimate future biomass and future quota of landings. The income from the trawler than will be predestinated by the timing between the biomass cycle and the trawler investment. The next step was to look for the source of the stationary cycle.

The system dynamics doctrine from Newton is based on a ballistic view of reality. Energy is flowing from one object to the next and in this flow delay will introduce dynamics. This doctrine is realistic when the objects have stable relations. Free will and structural dynamics changes relations between objects in nature. When the relations between objects is changed, the dynamic property is changed and an uncertainty is introduced. This introduces an fundamental limitation in forecasting by the Newton law of system dynamics.

Aristotle had a different doctrine of system dynamics in nature. He explained the dynamics of objects by the four causes, namely the efficient cause, the material cause, the structure cause, and the predestined fate. Predestined fate was decided by the “cause of causes”; the positions of the Sun, the Moon and the stars. The Aristotle doctrine of the predestinated fate represents a dual view of the reality. By this doctrine planetary dynamics will introduce dynamics that sooner or later will influence all objects in nature.

In 1543 Copernicus associated the change of star positions with a changing direction of the rotational axis of the Earth. Isaac Newton explained in “Principia” that the Earth is a spinning object where the axis describes a circle about the North Pole. This motion is called "precession" and proceeds, in about 25 800 yrs, along a cone with a half apex angle of 23.439 degrees and moves along the elliptic by 50.291 arc s yr^{-1}. In 1754 Kant predicted that friction with tidal forces on the Earth would cause a deceleration of the Earth's rotation. Euler predicted in 1758 that the rotation of the Earth’s axis would slow the Earth's motion with respect to an Earth-fixed reference frame (polar motion). Some years later in 1776 Laplace made theoretical tidal modeling involving periodic hydrodynamics on a rotating sphere. In the eighteenth century the English astronomer Bradley discovered that the Earth’s rotational axis wobbled around the precession cone. This change was called the “nutation”. Better instrumentation slowly modified the view of the movement of the Earth as a stable dynamic process. Earth axis dynamics are now described by the four components: precession, nutation, celestial pole offset, and polar motion. The nutation has an amplitude of 9.2 arc s and a 18.6 yr cycle caused by the Moon. By new high-precision measurements more than 100 frequency components in the nutation have been discovered. The four dominant cycles of the nutation are 18.6 yrs (precession period of the lunar orbit), 9.3 yrs (rotation period of the Moon’s perigee), 182.6 d (half a year) and 13.7 d (half a month). New geodetic techniques now make it possible to detect Earth displacement influenced by the tide, the Earth core and mantle, and from atmospheric disturbance.

This predestinated dynamics may have an important influence on the ecological change in nature. In 1938 professor Petterson explained fluctuation of herring by a tidal 112 yr cycle (Rollefsen, 1949). This is an sub harmonic cycle of the Earth nutation of 18.6 yrs. In historical records of cod landings in Norway, Ottestad (1942) reported 11, 17.5, 23 and 57 yr cycles of cod. These cycles are related harmonic and sub harmonic cycle of the Earth nutation of 18.6 years (Yndestad, 1999b). There is reported a correlation between the Earth nutation and the temperature in the Barents Sea (Yndestad; 1996a; 1999a), a correlation between the Earth nutation and the biomass of Northeast Arctic cod (Wyatt et al. 1992, 1994; Yndestad, 1996b, 1999b) and a correlation to management of Northeast Arctic cod.

This paper focus on the system dynamics methods from two papers (Yndestad; 1999a, 1999b). The paper explains by general systems theory how Earth nutation influences dynamics in the food chain from planetary dynamics to management of Northeast Arctic cod.

Materials and methods

The prepared temperature series is taken from the Kola section (Bochkov, 1982). The data are measured along 33°30'E from 70°30'N to 72°30'N and have a sampling time of 1 month from 1900 to 1994. All history time series on Northeast Arctic Cod are based on the Report of Arctic Fisheries (ICES, 1999). The biomass time series from 1999 to 2020 are forecasted by the author and based on temperature dependent growth and a recruitment model (Yndestad, 1999b).

General systems theory

General system theory is a means of understanding abstract organizations independent of time and space. A system is a set of subsystems cooperating to a common purpose. This may be expressed as

$$S(t) = \{B(t),\{S_1(t), S_2,(t)\ldots, S_n(t)\}\} \in w \qquad (1)$$

where S(t) is the system, $S_i(t)$ is a subsystem, B(t) is a dynamic binding between the subsystems and w is the common system purpose. According to the general theory systems are time varying, structurally unstable and mutually state dependent.

We have a planetary system: $S(t)=\{B_p(t),\{S_e(t),S_m(t),S_s(t)\}\}$ where $S_e(t)$ represents the Earth system, $S_m(t)$ the Moon system, $S_s(t)$ the Sun system, and $B_p(t)$ is the mutual dynamic binding. In this case the planetary system represents a stable periodic system. The Earth system has the subsystems $S_e(t)=\{B_e(t),\{S_b(t),S_g(t),S_w(t),S_c(t),S_v(t)\}\}$ where $S_g(t)$ the Earth axis system, $S_w(t)$ a warm Atlantic flow system, $S_c(t)$ a cold-water stream system, $S_v(t)$ an unknown disturbance system and $B_e(t)$ the dynamic binding between the systems. The Barents Sea system $S_b(t)$ has a set of food chain sub systems where $S_{ma}(t)$ is the management system and temperature system $S_t(t)$ has a set of sub systems in the sea.

System state dynamics

The state dynamics of the system element $S_1(t)$ is described by the state space equation

$$\dot{x}(t) = A(t) \cdot x(t) + B(t) \cdot u(t) + C(t) \cdot v(t) \\ y(t) = D \cdot x(t) + w(t) \tag{2}$$

where x(t) represents the state vector at a system element $S_1(t)$, v(t) a disturbance vector from an unknown source, w(t) estimate noise, A(t) is the dynamic growth matrix, B(t) is the dynamic binding matrix to the external element and D the measurement matrix and u(t) is the state vector from an external element $S_2(t)$ In this case u(t) is the planetary dynamics where most of the energy is related to a set of stationary periodic cycles

$$u(t) = \sum_{n=0}^{M} u_n \cdot \cos(\omega_n t + \varphi_n) \tag{3}$$

where M is the number of cycles, u_n represents cycle amplitude, $\omega_n = 2\pi/T_n$ the angle frequency and φ_n a phase delay. The most important cycles are the Earth seasonal frequency $\omega_s = 2\pi/1$ (rad/yr), the Earth nutation $\omega_n = 2\pi/18.6$ (rad/yr) and the precession $\omega_p = 2\pi/26800$ (rad/yr). The autocorrelation of the periodic u(t) has the property

$$R_{uu}(\tau) = E[u(t) \cdot u(t+\tau) - E[u(t)]^2] = \frac{u_o^2}{2}\cos(\omega_i \tau) \tag{4}$$

where τ is the time displacement. This means that the autocorrelation has a stationary cycle if the time series has a stationary cycle.

Wiener spectrum

The energy E_v from the unknown source may be estimated by Parseval's theorem

$$E_v = \int_{-\infty}^{+\infty} | v(t) |^2 = \frac{1}{2\pi} \int_{-\infty}^{+\infty} \left| V^*(j\omega) \right|^2 d\omega \tag{5}$$

If the spectrum V(jω) is white noise, the spectral density is

$$S_{vv}(j\omega) = |V^*(j\omega)|^2 = V_0^{\ 2} \qquad (6)$$

where V_0^2 is the noise variance. In this case the integrated energy will be infinite. Since this is impossible, the temperature spectrum must be colored. Such process may be modulated by the first order process

$$\dot{v}(t) = -a \cdot v(t) + n(t) \qquad (7)$$

where n(t) is the none-correlated white noise. The autocorrelation of this process (5) is

$$R_{vv}(\tau) = E[v(t) \cdot v(t+\tau) - E[v(t)]^2] = \frac{V_0^{\ 2}}{2a} \cdot e^{-a|\tau|} \qquad (8)$$

where τ is a time displacement. This indicates that the autocorrelation function of the time series v(t) from an unknown source is expected to fall exponentially. The frequency transform of the first order process (5) is a non-correlated spectrum

$$V(j\omega) = \frac{V_0}{a + j\omega} \qquad (9)$$

This indicates that spectrum of the measured time series, is expected to fall by $V_0/(a+j\omega)$ and the power density spectrum will fall by $|V(j\omega)|^2$. If the system is a part of a more complex system, the measured spectrum is expected to fall by $V_0/(a+j\omega)^\gamma$.

Frequency response

A next question is how a system element $S_1(t)$ is influenced by external sources. The external source is a forced oscillator u(t) and the non-correlated disturbance v(t). This system is linear when we have the stationary relations A(t)=A, B(t)=B and C(t)=C. In this case the Fourier transform of (6) is

$$X(j\omega) = \frac{B \cdot U(j\omega)}{(j\omega - A)} + \frac{C \cdot V(j\omega)}{(j\omega - A)} = H_u(j\omega) \cdot U(j\omega) + H_v(j\omega) \cdot V(j\omega) \qquad (10)$$

where $H_u(j\omega)$ and $H_v(j\omega)$ are the frequency transfer functions. Equation (10) indicates that a stationary cycle U(jω) is forced on a system element $S_1(t)$ it will introduce a cycle response at

X(jω) where the amplitude and phase is changed by the transfer function $H_u(j\omega)$. When a non-correlated spectrum V(jω) is forced on the transfer function $H_v(j\omega)$ it will introduce a non-correlated spectrum at X(jω) where all amplitude and phase cycles are changed.

According to the general systems theory (1) systems have a mutual dynamic binding B(t) between sub systems. We may than expect that all system are more or less non-linear by nature. It is known from non-linear theory (Moon, 1987) that non-linear system will modulate a set of harmonic and sub harmonic frequency cycles. A forced cycle $U(j\omega_0)$ on a non-linear transfer function $H_u(j\omega)$ will than introduce the frequency response

$$X_m(j\omega) = H(j\omega)x(j\omega_0) = \sum_{n,m} H_{n,m} \cdot X(j\omega - n\omega_0 / m) \qquad (11)$$

According equation (10) and (11) a non-linear system $H_{(n,m)}$ will introduce a set of harmonic and sub harmonic cycles from the forced stationary cycles U(jω) and from the non-correlated spectrum V(jω). An inverse transform of (10) and (11) gives us the general property

$$x(t) = \sum_{n,m} H_{(n,m)} \cdot \sin[\frac{n}{m} \cdot \omega_i t + \varphi_{(n,m)}(t)] + v(t) \qquad (12)$$

where ω_i is a periodic cycle, $H_{(n,m)}$ the cycle amplitude, n the harmonic number, m the sub harmonic number, $\varphi_{(n.m)}(t)$ the phase delay and v(t) a disturbance from an unknown source having a non-correlated spectrum.

Small stationary cycles may be amplified by a stochastic resonance. If we have a general system

$$S(t) = \{B(t),\{S_1(t), S_2(t)\}\} = \in w \qquad (13)$$

The system elements in S(t) may have the frequency transfer functions $H_1(j\omega)$ and $H_2(j\omega)$ and a mutual binding B(t). Mutual binding is a feedback situation. It may be shown that the total transfer function of two feedback system has the property

$$S(j\omega) = H_1(j\omega) /(1+H_1(j\omega) H_2(j\omega)) \qquad (14)$$

This system will have a stochastic resonance and a maximum amplification when

$$P_1(j\omega) P_2(j\omega) = -1 \qquad (15)$$

The system is said to have stochastic resonance when the system partners in S(t) are stochastic systems. This means that the all systems and sub systems in the food chain may have a stochastic resonance related to stationary cycles in the system.

Management of Northeast Arctic cod

Current management of Northeast Arctic cod is based on the system dynamics and the control strategy

$$\begin{aligned} \dot{x}(t) &= A(t) \cdot x(t) + B(t) \cdot u(t) + C(t) \cdot v(t) \\ y(t) &= D \cdot x(t-\tau) + w(t) \\ u(t) &= -F(t) \cdot y(t) \end{aligned} \qquad (16)$$

where u(t) is the quota of landings vector and the landing rate F(t) is the control parameter. The landings rate F(t) has been changed each year. Future estimate of the biomass is than only predictable from one year to the next. The biomass shift from one year to the next is computed from equation (16).

$$\begin{aligned} x(t_1) &= e^{A(t_0)T} x(t_0) + \int_{t_0}^{t_1} e^{A(t_0)(t_1-\tau)} \cdot u(t_0) d\tau = A(t_0)^{-1}[e^{A(t_0)} - I]u(t_0) \\ x(t_1) &\approx [I + A(t_0)]Tx(t_0) + Tu(t_0) \\ x(t_1) &\approx [I + A(t_0)]Tx(t_0) - T \cdot F(t_0)[D \cdot x(t_0 - \tau) + w(t_0)] \end{aligned} \qquad (17)$$

where v(t)=0, a one year time interval $T=t_1-t_0$ and I is an identity matrix. Equation (17) describes how this control strategy influences the biomass dynamics. The control of the biomass is based on choosing a proper quota of landing $u(t_0)$ that moves the biomass to the wanted state $x(t_1)$. There are some fundamental problems related to this control strategy. The growth matrix A(t) has time variant stationary cycles of 6.2 yr, 18.6 yr and 55.8 yr due to the Earth nutation influence on the Barents Sea temperature. Estimates of the growth matrix will than change each year and biomass dynamics will introduce errors in the estimated data. The estimate delay τ of 2-3 yr will introduce a phase error in the estimate. A combination of the phase error τ and the stationary cycle of about 6 yr in the growth matrix A(t), will introduce an instability in the biomass. This means that the current control strategy will introduce three different types of instabilities.

Results

Sea temperature dynamics

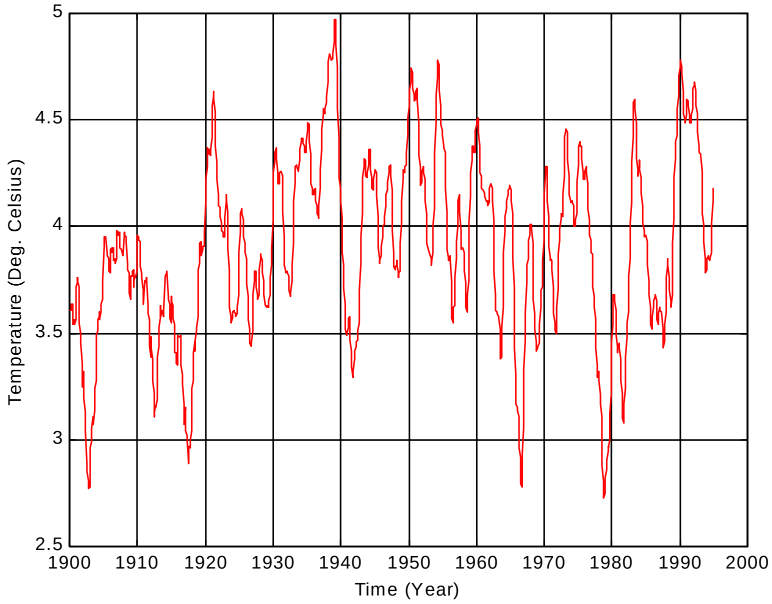
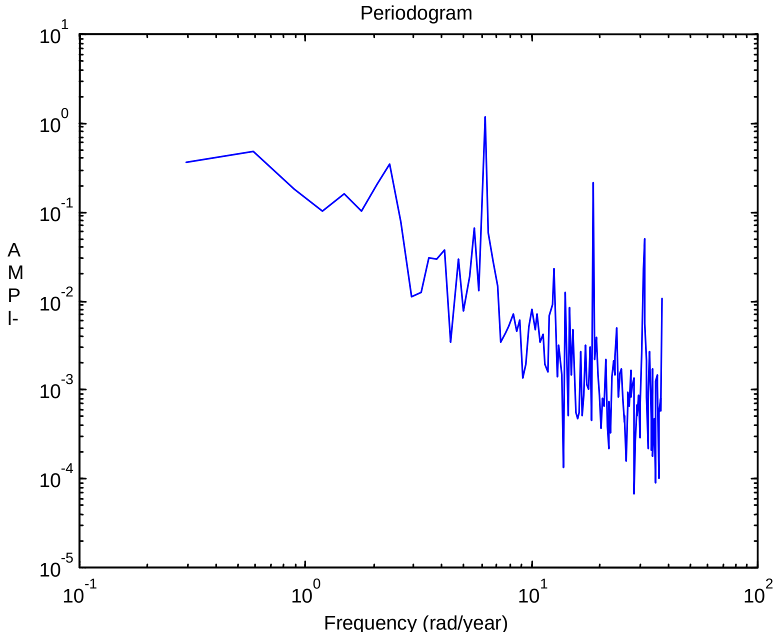


Figure 2: Temperature time series from the Barents Sea

Figure 2 shows the low pass filtered time series of the temperature from the Kola section in the Barents Sea from 1900 to 1994 (Yndestad; 1994). The figure shows fluctuations where the



temperature is changing +/- 0.5 degree Celsius.

Figure 3. Power density spectrum of the temperature time series from the Barents Sea.

Figure 3 shows the power density spectrum of temperature time series in Figure 2. The figure confirms some fundamental properties from the general system theory. The power density spectrum of the temperature is falling by $k/(a+\omega)^2$. This confirms the theory of energy distributions from equation (9). Most power density is concentrated at the 1 yr seasonal angle frequency ω_e = 6.28 (rad/yr) forced from the Sun. The seasonal 1 yr cycle from the Sun generates the harmonics $2\omega_e$ and $3\omega_e$ and there is a trace of the sub harmonics $\omega_e/2$ and $\omega_e/4$. This is according to the modulation theory (10) and (11). At the lower end of the spectrum there are some indications of the nutation harmonics frequency $\omega_e/2$ = 0.6 (rad/yr) or 9.3 yrs, $\omega_e/3$ = 1.1 (rad/yr) or 6.2 yrs, and at $\omega_e/4$ = 1.3 (rad/yr) or at 4.6 yrs. This confirms the modulation theory (11) and (12). The time series is dominated by the 1 yr seasonal cycle. The correlation between time series and the Earth cycles of 18.6/3=6.2 yr, 18.6 yr and 3*18.6=55.8 yr is found to be about 0.5 (Yndestad; 1999a). This indicates there is a relations between harmonic cycles of the Earth nutation and the temperature series in the Barents Sea and thus confirms the relation described is equation (11) and (12). If this theory is confirmed, there is a stochastic resonance in the flow of water that amplifies the cycles from the Earth nutation. This cycle is a deterministic process that will change the climate and ecological system in the Barents Sea.

This confirms there is a binding B(t) in the system $S(t) = \{B(t),\{S_p(t), S_t(t)\}\} = \in w$ where $S_p(t)$ is the planetary system and $S_t(t)$ is the temperature system in the Barents Sea.

Cod biomass dynamics

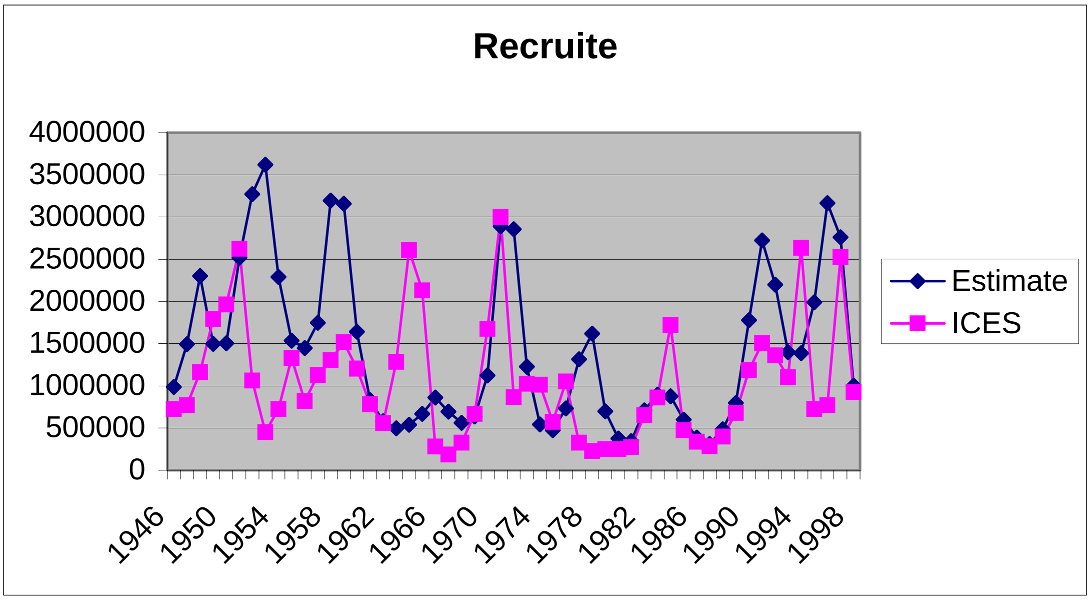


Figure 4. Number of recruitment of Northeast Arctic cod (ICES) and estimated recruitment from 1946 to 1998.

Figure 4 shows the time series of the number of 3 year Northeast Arctic cod since 1946 to 1998. The ICES data shows the time series from the official ICES reports (ICES, 1999). A spectrum analysis of this data indicates this time series is correlated to the Earth nutation cycles of 18.6 years and 18.6/3=6.2 yrs (Yndestad, 1999b). This correlation indicates a relations between harmonic cycles of the Earth nutation and the recruitment and the biomass growth of Northeast Arctic cod in the Barents Sea. This relation is connected to the food chain in the Barents Sea and thus confirms the relation described is equation (11) and (12). This fluctuation may be explained by a chain of reactions. First the Earth nutation is a forced oscillator on the sea temperature system. Than the temperature system is a forced oscillator on the food chain in the Barents Sea. This fluctuations is amplified by a stochastic resonance between the cod biomass and the food chain in the Barents Sea. This confirms there is a binding B(t) in the biomass system $S(t) = \{B(t),\{S_p(t), S_c(t), S_f(t), S_t(t)\}\} = \in w$ where $S_p(t)$ is the planetary system, $S_c(t)$ is the cod system, $S_f(t)$ is the food chain system and $S_t(t)$ is the temperature system in the Barents Sea.

The deterministic property of the nutation cycle may be used to tune a dynamic biomass model of growth and recruitment. This is shown in Figure 4 where the estimated time series is computed from a biomass growth model and the Earth nutation cycles are parameters (Yndestad, 1999b).

Management dynamics

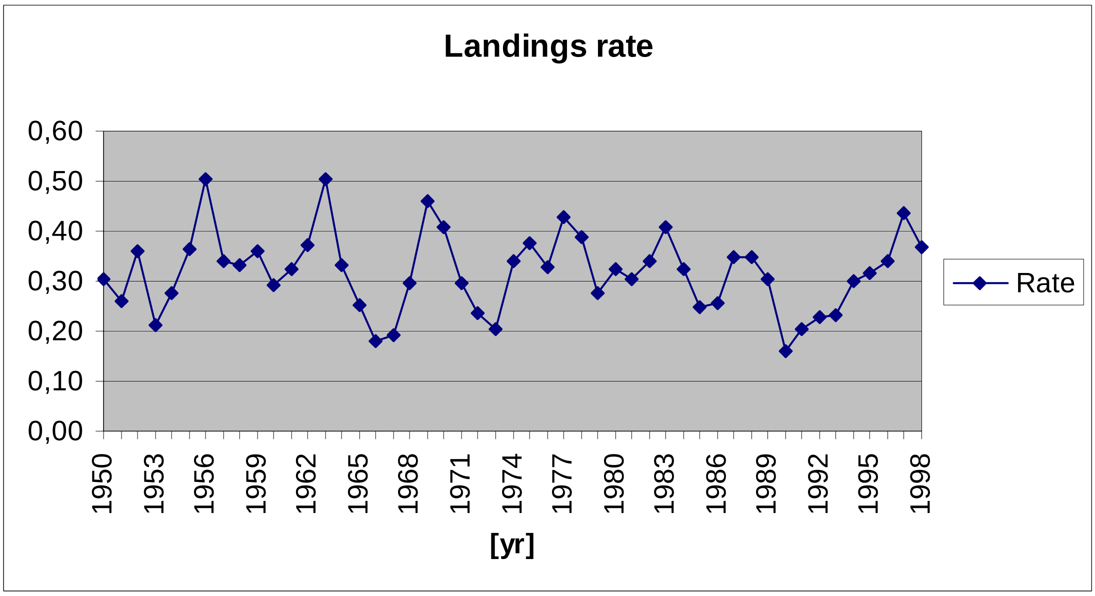


Figure 5. History of current landings rate from 1950 to 1998.

The biomass level is controlled by the quota of landings. The landings rate F(nT) is a control parameter has the relation

$$F(nT) = \frac{u(nT)}{y(nT)} \qquad (15)$$

where u(nT) is the quota of landings at the year n and y(nT) is the ICES estimated total biomass at the year n. The biomass is sustainable when the landings rate about F(nT) <0.3 (Yndestad, 1999b). Figure 5 shows the landings rate from 1950 to 1998. The landings rate F(nT) has a 6-7 year cycles. This fluctuation demonstrates an unstable situation. The harmonic cycles from the Earth nutation do not stop at the biomass system as described in equation (11). The management of Northeast Arctic cod has a relation to the biomass and this relation will influence the cod management. In this case there is a stochastic resonance between cod management and the 6.2 yr nutation cycle that make the system unstable. This confirms there is a binding B(t) in the biomass system $S(t)=\{B(t),\{S_p(t),S_{ma}(t),S_c(t),S_f(t),S_t(t)\}\} = \in w$ where $S_p(t)$ is the planetary system, $S_t(t)$ is the temperature system in the Barents Sea, $S_f(t)$ is the food chain system, $S_c(t)$ is the cod system and $S_{ma}(t)$ is the management system.

Forecasting Northeast Arctic cod

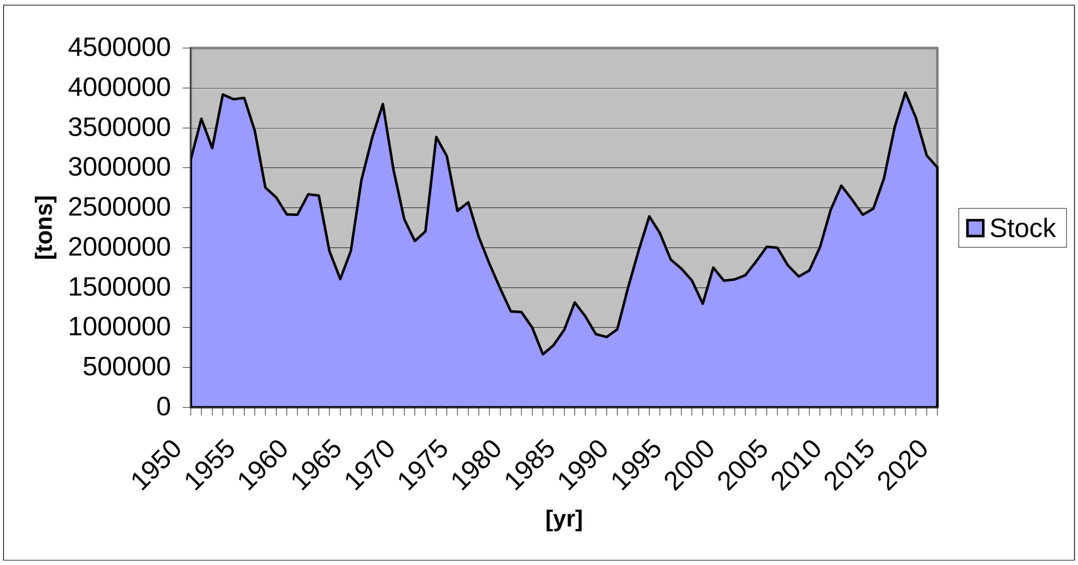


Figure 6. History (1950-1998) and forecasted (1999-2020) total biomass, spawning stock biomass and landings by feedback control.

When the source of changes in recruitment and growth is identified, we may introduce this source in a dynamic biomass model. In this case the cause is a deterministic fluctuation. This information is useful to forecast future biomass recourses. Management of Northeast Arctic cod is not a deterministic process. But if the landings rate F(nT) = 0.25 the next 20 years, we will have a better ability to forecast future biomass resources.

Figure 6 shows the time series of historical records of total biomass from 1950 to 1998 and a forecasted biomass from 1999 to 2010. The forecasted biomass is based on a temperature dependent growth model (Yndestad; 1999b) and a constant landings rate F(nT) = 0.25. Figure 6 shows that the it takes about 20 years to build up the biomass and the deterministic 6.2 yr fluctuations will increase when the biomass is growing.

Discussion

The Newton system dynamics doctrine is based on the law of energy flow and the law of energy balance in nature. When relations between system elements are changing we have a non-linear system where small changes in the relations may lead to large changes in the system states. This limits the ability of long time forecasting dynamics in nature.

A Fourier transform of a time series represents a dual view of nature where we are looking for frequency properties. In most cases a Fourier spectrum has information about the past and little information about the future. A frequency transform of time series often has a Wiener spectrum as shown in equation (9) and figure 3. This does not mean the future time series is predicable. The phase of the spectrum is changed in the next time series. There are however exceptions. If a stationary cycle is forced on a system element in nature, the system element will respond by a stationary cycle as in equation (10). Planetary dynamics are stationary cycles in nature. This paper indicates there may be some truth in the Aristotle doctrine on the predestinated fate.

Correlation analysis indicates there is a binding B(t) between the system elements $S(t)=\{B(t),\{S_p(t),S_{ma}(t),S_c(t),S_f(t),S_t(t)\}\} = \in w$ where $S_p(t)$ is the planetary system, $S_t(t)$ is the temperature system in the Barents Sea, $S_f(t)$ is the food chain system in the Barents Sea, $S_c(t)$ is the cod biomass system and $S_{ma}(t)$ is the cod management system. This relations are explained by a chain of reactions. The Earth nutation is a stationary forced oscillator on the sea system, the sea system is non-linear and introduces a set of harmonic and sub harmonic temperature cycles amplified by stochastic resonance. The temperature cycles is a forced oscillator on the food chain and introduces a stochastic resonance that amplifies the impact from the temperature cycle. The biomass of Northeast Arctic cod is a forced oscillator on biomass management. A stochastic resonance of 18.6/3=6.2 yr between the management and the biomass dynamics introduces an unstable biomass.

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