

# The Barents Sea ecosystem dynamics as a coupled oscillator to long tides

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## **Abstract**

The Barents Sea ecosystem has been associated with large biomass fluctuations, controlled by temperature and climate variability. This study suggests that we may understand the Barents Sea ecosystem variability as a deterministic coupled oscillation, controlled by the lunar-nodal tide spectrum. The analysis is based on wavelet spectrum transforms of a long data series from the Barents Sea. The analysis has investigated the sea temperature, the biomass of Barents Sea zooplankton, Barents Sea capelin, Northeast Arctic cod and Norwegian spring-spawning herring. The results show that the biomass life cycle period, the recruitment timing, and the biomass fluctuation periods and phase are all related to the 18.6 yr amplitude tide and the 9.3 yr phase tide. The deterministic lunar nodal tides may then serve as a reference for the Barents Sea ecosystem variability.

A wavelet analysis of data series shows that Barents Sea zooplankton biomass is negatively correlated to the 9.3 yr phase tide and the 18.6 yr amplitude tide, and the Kola section shows negative temperature fluctuation periods of about 9 and 18 years. The biomass life cycle period has adapted life cycles to about a third harmonic of the lunar nodal tide periods to optimize a long-term biomass growth. The Barents Sea capelin biomass has a mean optimum life cycle of about  $9.3/3=3.1$  years and a biomass recruitment and growth controlled by the 9.3 yr tide. Northeast Arctic cod has a mean optimum life cycle of about  $18.6/3=6.2$  years and strong recruitment in periods when the 18.6 yr tidal inflow to the Barents Sea is positive. Norwegian spring-spawning herring biomass has a mean optimum life cycle of about  $18.6/3=6.3$  years and strong recruitment in periods when the 18.6 yr tide and the 9.3 yr phase tide are becoming a positive Atlantic inflow to the Barents Sea. This relationship to the amplitude tide and the phase tide explains the fast biomass recovery after the biomass collapse

in the 1960s. Northeast Arctic cod and Norwegian spring-spawning herring had a large long-term growth beginning in 1920, controlled by a sub-harmonic temperature cycle of about 74 years.

The close relationship between the long-term tidal inflow and the ecosystem dynamic indicates that the long-term biomass oscillation is a deterministic process in which an optimum long-term growth is dependent on a few strong year classes. At the same time, a biomass collapse may desynchronize the biomass fluctuation and thus reduce the long-term biomass growth.

Keywords: lunar nodal tide; climate oscillation; eco-oscillation; coupled systems; wavelet analysis.

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## 1 Introduction

The idea of a hidden process that influences the ecosystem biomass originated in the early period of marine science. Exploration of this idea is motivated by the need to develop better long-term predictions. If there is a hidden deterministic process, we may forecast the biomass in order to control it. If there is not, we may only explain past biomass dynamics as a random chain of events. The British astronomer Edmond Halley (1656-1742) is probably the first to publish a paper on the influence of climate on biomasses in the North Sea. In 1699, he sailed in the Atlantic and made magnetic maps. In the paper *Atlas maritimus et commercialis* of 1728, he described the theory of a fluctuating herring stock between the Arctic Ocean and the North Sea that was controlled by climate conditions (Wegner, 1996). During the last hundred years, the relation between climate conditions and Barents Sea biomass fluctuations was described by Helland-Hansen and Nansen (1909), Sætersdal and Loeng (1987), Eilertsen et al. (1989), Nakken (1994) and many others. The climate and sea temperature, however, have their own complex pattern. When the cause of the climate variability is unknown, the possible hidden deterministic biomass process is unknown.

Long tides are a possible source of the hidden deterministic process that may influence climate and biomass fluctuations. George Howard Darwin recorded fluctuations of the sea level at Bombay and

was the first to draw attention to how the 18.6 yr lunar nodal cycle introduced a long-term tide as well as geological changes (History, Darwin, 1880). Otto Pettersson investigated herring catch records from Bohuslen in Sweden. He found a relationship between the sea temperature, tide periods and herring periods (Pettersson, 1905, 1915, 1930). Later, a number of Russian scientists expounded on the ideas from Otto Pettersson in the 1960s. The results were summarized by Maksimov and Smirnov (1964, 1965, 1967) and Maksimov and Sleptsov-Shevlevich (1970) and explained as a standing wave and a standing “astronomical” current in the North Atlantic and Barents Sea, which influence the climate.

Introduction of the wavelet spectrum analysis method made it possible to study each cycle period and phase in the data series. By this new analytical approach, a lunar nodal cycle spectrum was identified in data series of zooplankton, shrimps, capelin, herring and haddock in the Barents Sea ecosystem (Yndestad and Stene, 2002; Yndestad, 2003a, 2003b). The wavelet analysis confirmed the hypothesis that a hidden deterministic process influenced the biomass ecosystem. A phase reversal in the 18.6 yr tidal inflow to the Barents Sea was an indication of sub-harmonic periods in the temperature fluctuation (Yndestad, 2006).

The phase reversal limited long-term prediction and a new understanding of long-term temperature variability. A comparison of annual sea level, sea temperature and salinity in North Atlantic water and the Barents Sea Kola section identified fluctuations correlated to the astronomic 9.3 year phase tide and a 74 year sub-harmonic lunar nodal tide. This analysis indicated that the tidal correlated temperature fluctuations in the Kola section must have been introduced in a mixing process, previously identified in the Faroe-Shetland Channel (Yndestad et al., 2008). The identification of the 9.3 yr phase tide indicated that this tide may have been more important in the Barents Sea than previously expected. This paper examines the influence of the 18.6 yr lunar nodal amplitude tide, the 9.3 yr phase tide and the 74 yr sub-harmonic tide on the Barents Sea ecosystem. The result shows that we may understand the Barents Sea ecosystem variability as a deterministic coupled oscillation system, controlled by the forced lunar nodal tide spectrum.

## 2 Materials and methods

### *The data series*

The Kola section temperature data series was provided by the Polar Research Institute of Marine Fisheries and Oceanography (PINRO), Murmansk, in Russia (Vladimir Ozhigin, personal communication). The data used here are monthly temperature values from the upper 200 m of the Kola section, along the 33°30'E meridian from 70°30'N to 72°30'N in the Barents Sea (Bochkov, 1982; Tereshchenko, 1997). The temperature data series contains quarterly and annual values from the period from 1900 to 2005 and monthly values from 1921 to 2005, some of which are measured and some of which are calculated. The gaps in the time series were filled by Bochkov (1982) by means of calculations using multiple regression models.

The Barents Sea zooplankton data series represents zooplankton by average biomass (dry weight, g m<sup>-2</sup>). The data series was provided by ICES (ICES, 2007) and covers the period from 1984 to 2007. The Barents Sea capelin (*Mallotus villosus*) data series was provided by ICES (ICES, 2007) and covers the period from 1965 to 2006. The data series of Northeast Arctic cod (*Gadus morhua*) covers the period from 1866 to 2007. Data from the period 1866 to 1946 were given in Godø (2003) and Hylen (2002). The data are interpolated from catch numbers to biomass by the scaling of 3.5 tons/number. The period from 1946 to 2007 was provided by ICES (2007).

### *The forces oscillation*

The gravitational relation between the sun, the earth and the moon influences the crosspoint between the moon plane and the ecliptic plane to the sun. This crosspoint describes a *lunar nodal cycle* of 18.6134 years. The corresponding cycle of the changing inclination of the moon's orbit with respect to the earth's equatorial plane is described by the model:

$$u(t) = 23^{\circ}27' + 5^{\circ}09' \sin(\omega_T t + \varphi_T) \quad (1)$$

where  $\omega_T = 2\pi/T = 2\pi/18.6134$  (rad/year) is the lunar nodal angle frequency,  $\varphi_T = 0.90\pi$  (rad) is the lunar nodal cycle phase and  $t$  (year) is the time. The cycle amplitude has a maximum in November 1987 and a minimum in March 1996 (Pugh, 1996). The forced lunar nodal cycle introduces an 18.6 yr amplitude tide by the phase angle  $\varphi_T = 0.90\pi$  (rad) and a 9.3 yr phase tide (Pugh, 1996; Boon, 2004). The lunar

nodal amplitude tide has the estimated phase angle  $\varphi_{T/2}(t)=1.41\pi$  (rad). An analysis of the annual mean sea level at Stockholm has identified a tidal cycle of  $4*18.6*74.4$  years by the phase angle  $\varphi_{4\pi}=0.55\pi$  (rad) (Yndestad et al., 2008). Each phase angle will serve as a reference in this investigation.

### *Biomass resonance*

This paper suggests that the 18.6 yr lunar nodal amplitude tide and 9.3 yr nodal phase tide introduce a forced mean oscillating inflow to the Barents Sea. Such a long-term oscillating Atlantic inflow will have a long-term influence on the Barents Sea temperature, salinity and plankton. Species in the Barents Sea ecosystem have a life cycle from recruitment to maximum spawning biomass. Each lifecycle is a feedback loop that interacts with other feedback loops. Barents Sea ecosystem dynamics may be understood as a coupled oscillation system, with the forced tidal inflow synchronized to the Barents Sea. A single biomass feedback loop may be represented by the simple model:

$$x_b(t) = a(t)x_b(t - \tau) + v(t), \quad (5)$$

where  $x_b(t)$  represents the biomass recruitment at the time  $t$ ,  $\tau$  is the delay to maximum spawning biomass, and  $a(t)$  is the time variant recruitment rate. Equation (5) describes a nonlinear positive feedback system controlled by the recruitment rate  $a(t)$  over the time period  $T$ , and the life cycle delay  $\tau$  that controls the biomass feedback resonance period. A nonlinear dynamic system, forced by a cycle period of  $T$  years, is expected to have optimum resonance periods  $T/3$  years (Nayfeh and Mook, 1995). Barents Sea capelin has an optimum mean life cycle period of 3-4 years and indicates a resonance to the 9.3 yr phase tide (Yndestad and Stene, 2002). Northeast Arctic cod and Norwegian spring-spawning herring have an optimum life cycle period of 6-7 years. This period indicates a resonance to the 18.6 yr amplitude tide (Yndestad, 2003a).

### *Cycle period identification*

Traditional methods of spectrum analysis cannot identify cycle periods and cycle phase in time-variant stochastic processes, so, in this study, the time series have been analyzed by wavelet transformation to identify the temporary dominant cycle periods  $u_n(t)$  and the time-variant phase angle  $\varphi_{nT}(t)$ . The periodicity was identified by a three-step investigation. The first step was to compute the wavelet spectrum by the transformation:

$$W_{a,b}(t) = \frac{1}{\sqrt{a}} \int_R x(t) \Psi\left(\frac{t-b}{a}\right) dt, \quad (7)$$

where  $x(t)$  is the analyzed time series, and  $\Psi(\cdot)$  is a coiflet wavelet impulse function (Daubechies 1992; Matlab 1997).  $W_{a,b}(t)$  is a set of wavelet cycles,  $b$  is the translation in time, and  $a$  is the time-scaling parameter in wavelet transformation. The relationship between wavelet scaling ( $a$ ) and the sinus period  $T$  is about  $T \approx 1.2a$ . In this analysis, the translation is  $b=0$ ; thus, the computed wavelet transformation  $W_a(t)$  represents a moving correlation between  $x(t)$  and the impulse function  $\Psi(\cdot)$  over the whole time series  $x(t)$ . Using this wavelet transformation, it is possible to identify single, long-period cycles in a short time series. Errors at the beginning and at the end of a time series are reduced in the following manner. The time series are scaled in amplitude and to the zero mean value by the scaling transformation  $y(t)=[x(t)-\text{mean}(x(t))]/\text{var}(x(t))$ , where  $x(t)$  is the time series and  $y(t)$  is the scaled time series. Subsequently, the time series is expanded with symmetric values at the beginning and end of the time series.

The cycle periods of single dominant-wavelet cycles are identified by computing the autocorrelation for the wavelet spectrum  $R_w(\tau)=E[W_a(t)W_a(t+\tau)]$ . Dominant, stationary wavelet cycles have maximum values in the autocorrelation functions. Periodic cycles in the autocorrelation function of the wavelet spectrum demonstrate that there is a stationary cycle. The cycle period phase is identified by the optimum correlation between dominant wavelets and lunar nodal cycles by  $R_{nT}(\tau)=E[W_{an}(t)u_{nT}(t)]$ , where  $u_{nT}(t)$  is an  $nT$  lunar nodal cycle period and the phase angle  $\phi_{nT}(t)$  is a free variable.

## 3 Results

### 3.1 Kola section temperature oscillations

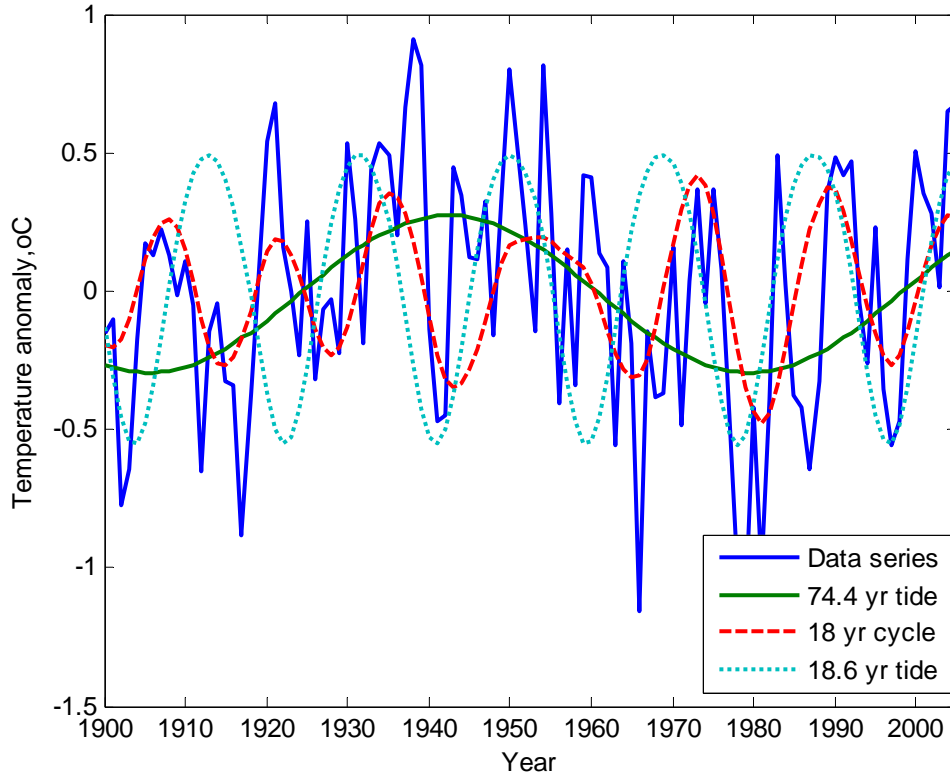


Figure 1. Temperature series from 1900 to 2007, the 18.6 yr tide, the 74.4 yr tide and the identified 18 yr cycle are shown for the Kola section of the Barents Sea. The 18.6 yr tide period has scaled amplitude on the figure to demonstrate the phase relation to the identified dominant 18 yr cycle.

The Kola section data series is believed to be a good indicator for Atlantic inflow, as well as the climate and temperature variability in the Barents Sea, and it represents one of the longest oceanographic data series in the world. Figure 1 shows the annual mean Kola section temperature series, the astronomic 18.6 yr tide cycle, the identified dominant 18 yr wavelet cycle and the identified 74.4 yr subharmonic tide cycle. The cycle phase angles are estimated to  $\varphi_{\pi/2}(t) = (1.41 - 0.90)\pi = 0.51\pi$  (rad),  $\varphi_{\pi}(t) = (0.90 - 0.20/1.20)\pi = 0.70\pi$  (rad) and  $\varphi_{4\pi}(t) = (0.55 + 0.71)\pi$  (rad). The 74 yr temperature period has a phase angle of  $0.71\pi$  (rad) before an identified 74 yr subharmonic cycle and represents the moving mean fluctuation in this time period. The 18 yr temperature cycle has a phase reversal at about 1920 when the 74 yr period is turning in a positive state (Yndestad et al. 2008). During this time, there

was a growth in the biomass of Northeast Arctic cod and Norwegian spring-spawning herring that had a maximum at about 1945 when the 47 yr period had a maximum.

### 3.2 Barents Sea zooplankton biomass oscillation

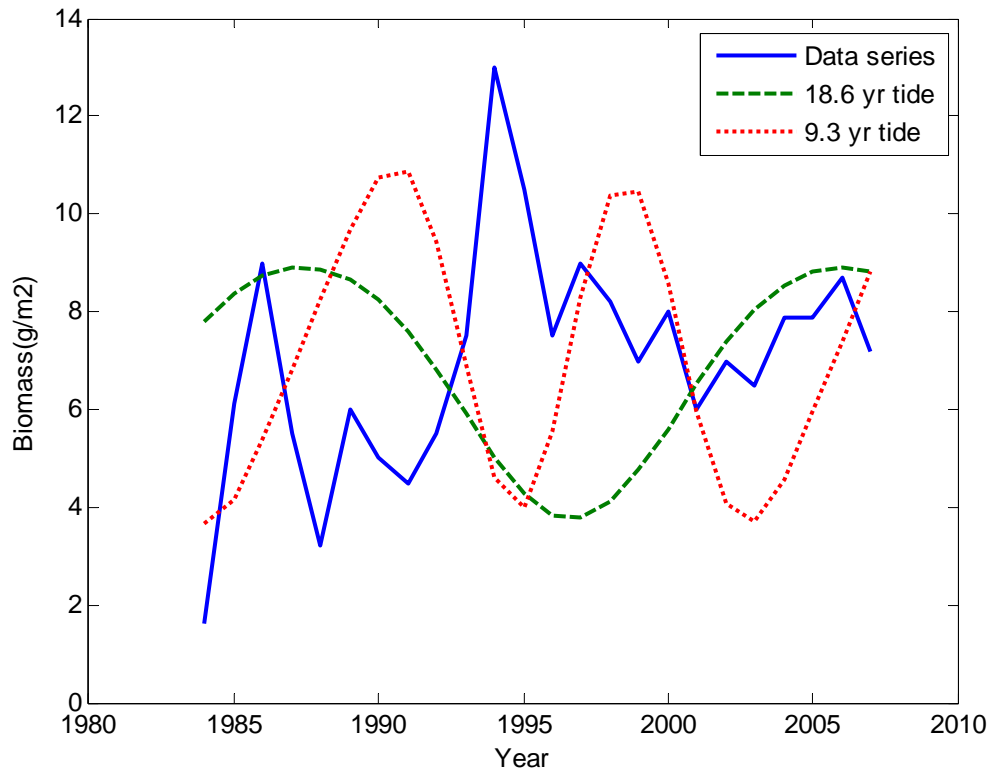


Figure 2. Barents Sea zooplankton dry weight biomass data series from 1984 to 2007 is shown, along with the astronomic 18.6 yr amplitude tide and the 9.3 yr phase tide. The 9.3 yr tide is scaled on the figure to demonstrate the phase relation to the lunar nodal tide.

Figure 2 shows the Barents Sea zooplankton dry weight biomass data series from 1984 to 2007, the 18.6 yr lunar nodal tide cycle and the 9.3 yr lunar nodal phase tide cycle. For the period from 1984 to 2005, the biomass increased from about  $2 \text{ g m}^{-2}$  in 1984 to about  $13 \text{ g m}^{-2}$  in 1994. The biomass reached a minimum at about 1990, when the astronomic lunar nodal tide cycles were simultaneously positive, and it reached a maximum in 1994, when they were negative. The wavelet analysis of the zooplankton data series has identified dominant cycles of about 9 and 18 years. The cycle phase angles are estimated to  $\varphi_{r/2}(t)=(0.51-1.00)\pi$  (rad) and  $\varphi_r(t)=(0.70-1.00)\pi$  (rad). The correlations between the



zooplankton data series and the 18.6 and 9.3 yr lunar nodal tide cycles are estimated to be  $R=-0.5$  in the period from 1984 to 2007.

The Barents Sea zooplankton biomass has a life cycle of about one year. Thus, the biomass variability is expected to be influenced by Atlantic inflow and the Barents Sea temperature. This analysis shows that zooplankton biomass fluctuations are related to the inverse 18.6 and 9.3 year tidal cycles. Compared to the 9 and 18 year Kola section temperature fluctuations, it shows that the zooplankton biomass has a maximum when the Barents Sea temperature has a minimum.

### 3.3 Barents Sea capelin biomass oscillation

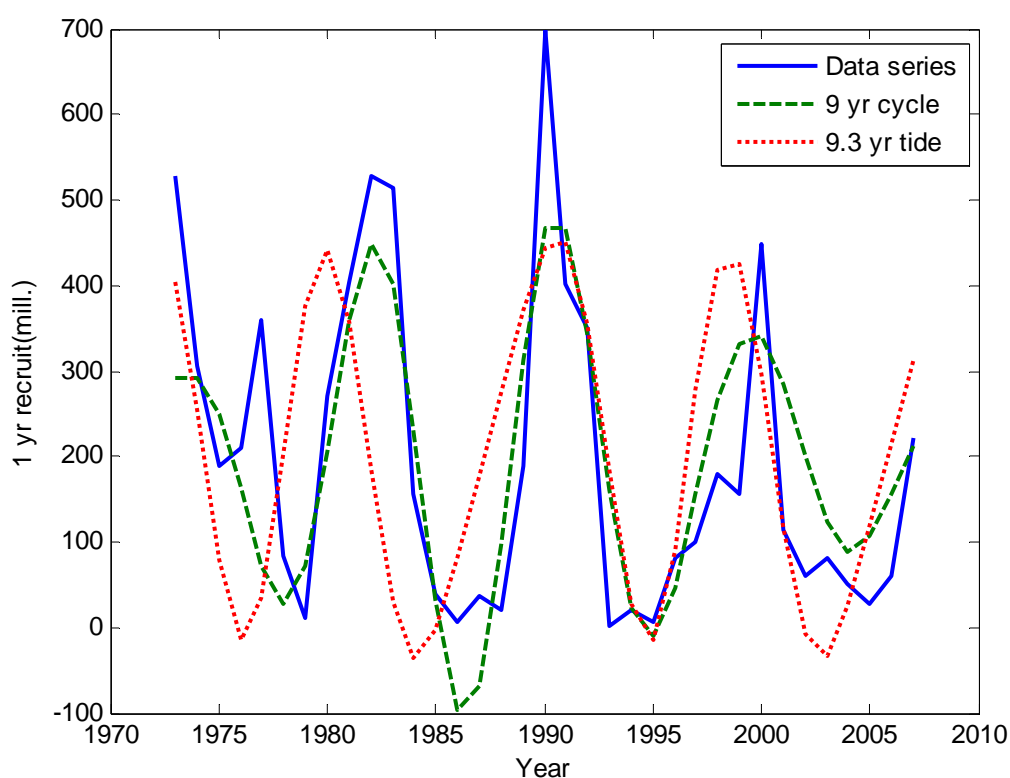


Figure 3. Barents Sea capelin 1-yr recruitment from 1972 to 2007, the estimated 9 yr tide cycle and the 9.3 yr phase tide cycle.

Figure 3 shows the Barents Sea capelin biomass between 1972 and 2005, the astronomic 18.6 yr amplitude tide and the astronomic 9.3 yr phase tide cycle. The figure shows that the dominant

recruitment period and phase are related to the 9.3 yr lunar nodal phase tide. The phase difference between the 9 yr zooplankton fluctuation and the 9 yr capelin recruitment fluctuation is about  $1.0\pi$  (rad/yr). This means that the capelin biomass has a maximum recruitment when the zooplankton biomass has a minimum level. Thus, the biomass will have an optimum timing between zooplankton growth and capelin biomass growth.

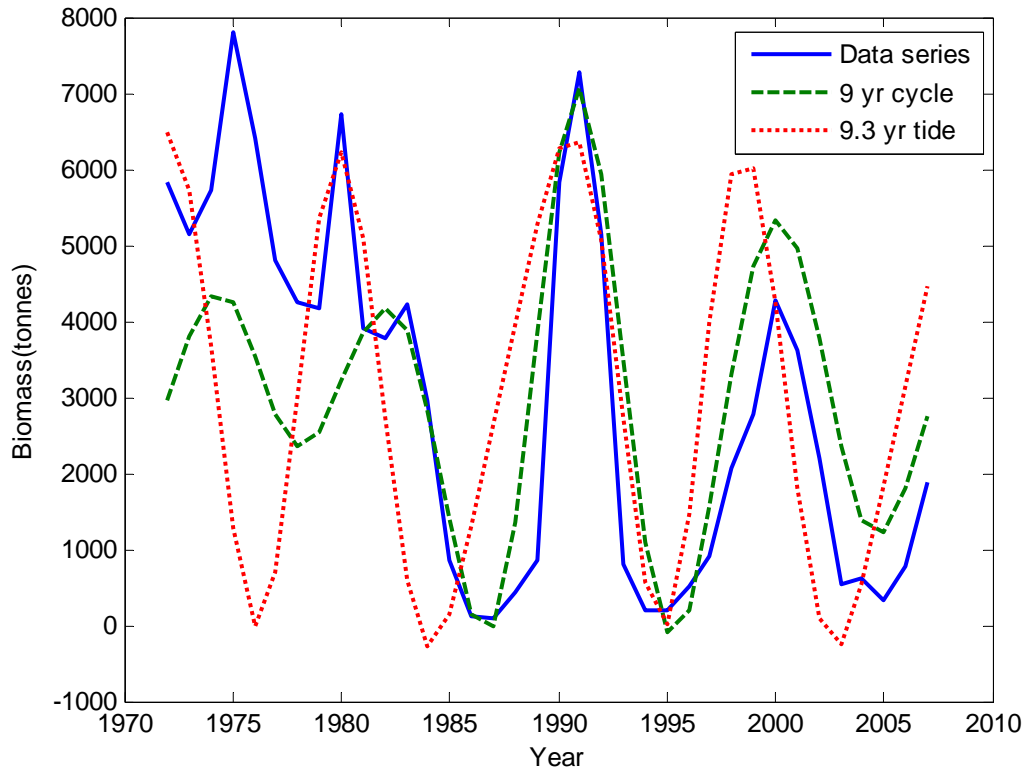


Figure 4. Barents Sea capelin biomass from 1972 to 2007, the estimated 9 yr wavelet cycle and the astronomic 9.3 yr phase tide cycle.

Figure 4 shows that the biomass has fluctuations related to life cycle periods and the 9.3 yr lunar nodal tidal phase tide. The Barents Sea capelin biomass has a mean optimum life cycle of about  $9.3/3$  or 3 years (Yndestad and Stene, 2002). The dominant 9 yr fluctuation has an estimated phase delay of  $-0.42\pi$  (rad/yr) or 2 years from the maximum 9.3 yr tide. The estimated phase delay between the zooplankton fluctuation and the capelin fluctuation is estimated to be  $(0.50+0.42)\pi = 0.92\pi$  (rad/yr) or 4.2 years. This delay between zooplankton oscillation and capelin oscillation confirms that the capelin biomass growth has a positive direction as long as zooplankton biomass fluctuation is increasing.

The figure shows the capelin biomass had peaks at about 1976 and 1980 when the biomass had a more stable level. In the period from about 1983 to 1986, the biomass collapsed, most likely due to overfishing. In this period, the 18.6 yr and the 9.3 yr tides became negative, and the recruitment was minimal. From 1985 to 1990, the 9.3 yr tide synchronized new capelin recruitment, and the biomass increased to a new maximum level. This time the biomass had about the same age distribution, and, after a life cycle period, the biomass again was reduced to a minimum level after a 3-4 yr life cycle. A new growth period occurred from about 1997 to 2000, when the 9.3 yr tidal inflow turned positive.

### 3.4 Northeast Arctic cod biomass oscillation

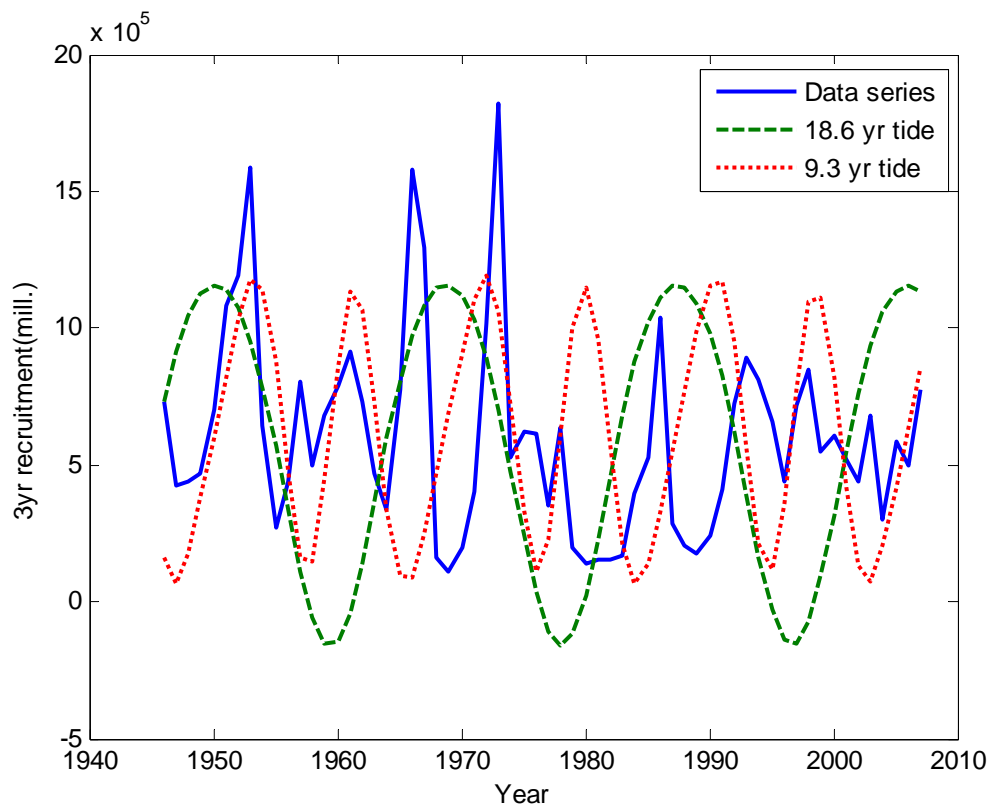


Figure 5. 3-yr recruitment of Northeast Arctic cod from 1946 to 2007, the 9.3 yr phase tide and the 18.6 yr amplitude tide.

Figure 5 shows the data series of 3-yr recruitment of Northeast Arctic cod from 1946 to 2007, the 9.3 yr phase tide and the 18.6 yr amplitude tide. The biomass of Northeast Arctic cod has an optimum life cycle of 6 to 7 years or about  $18.6/3=6.3$  years (Yndestad, 2003a). The figure shows that the 6-7 yr life

cycle gave maximum 3-yr recruitment in periods when the 18.6 yr tide was at a positive state and minimum recruitments in periods when the 18.6 yr cycle was in a negative state.

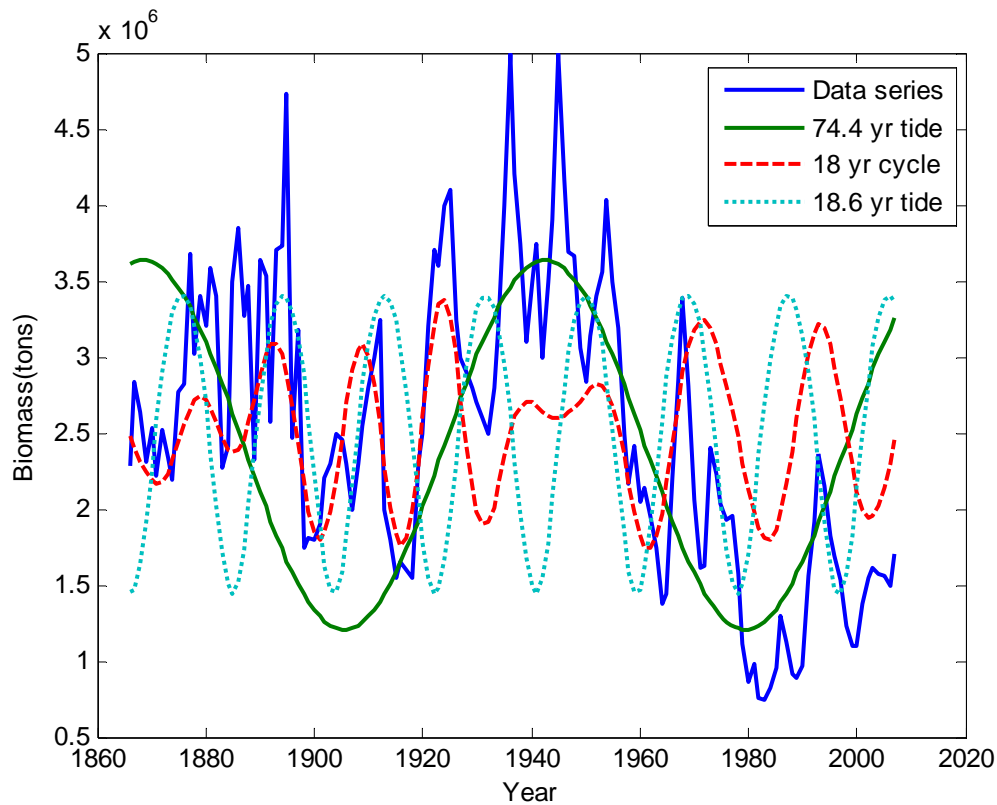


Figure 6. Data series of Northeast Arctic cod biomass from 1866 to 2007, the astronomic 18.6 yr tide cycle, dominant 18 yr wavelet cycle and superharmonic 55.8 yr cycle. The 74.4 yr and 18.6 yr periods are scaled on the figure to demonstrate the phase relation to the biomass fluctuation.

Figure 6 shows the data series of Northeast Arctic cod biomass from 1866 to 2007, the astronomic 18.6 yr tide cycle, dominant 18 yr wavelet cycle and subharmonic 74.4 yr cycle. A biomass life cycle that has the best recruitment when the 18.6 yr tide is at a positive state will introduce a biomass fluctuation of about 18 years. The figure demonstrates well the relationship between the biomass fluctuations, the identified dominant 18 yr wavelet cycles and the lunar nodal tide in a period of about 150 years.

In the period from 1866 to 1920, the biomass had two strong 18 yr fluctuations and one reduced fluctuation associated with a long-term 55 yr period. In about 1920, the 18 yr tidal inflow to the Barents Sea had a phase reversal. The phase reversal introduced a new early growth period, and the biomass increased along with the increased temperature. The large biomass stayed in two 18 yr cycles,

which represents a positive fluctuation inside the 74 yr period. This analysis indicated that long-term biomass fluctuations are related to groups of 18 yr fluctuations, controlled by a subharmonic tide.

### 3.5 Norwegian spring-spawning herring

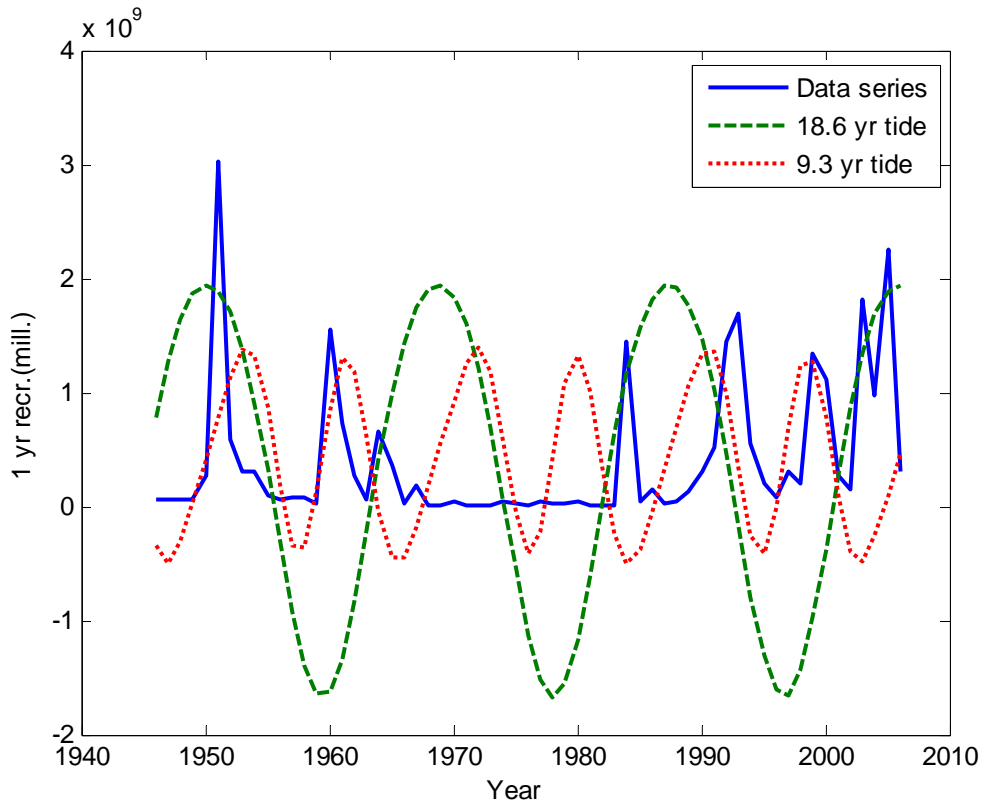


Figure 6. Data series of 1-yr recruitment of Norwegian spring-spawning herring from 1946 to 2007, the 9.3 yr phase tide and the 18.6 yr amplitude tide.

The biomass of Norwegian spring-spawning herring has an optimum life cycle of 6 to 7 or about  $18.6/3=6.3$  years. Figure 6 shows that the fluctuation of 1-yr recruitment is related to the positive growth of the 9.3 yr phase tide and the 18.6 yr amplitude tide. The exception is the period from about 1965 to 1980, when the biomass had a collapse due to overfishing. The large biomass recruitment is associated with the tidal phase angle  $\varphi_{\tau}(t)=(0.90+0.90)\pi$  (rad) and  $\varphi_{\tau/2}(t)=(1.41+0.9)\pi$  (rad). Due to this phase angle, strong recruitment periods are related to maximum tidal controlled Atlantic inflow to the Barents Sea.

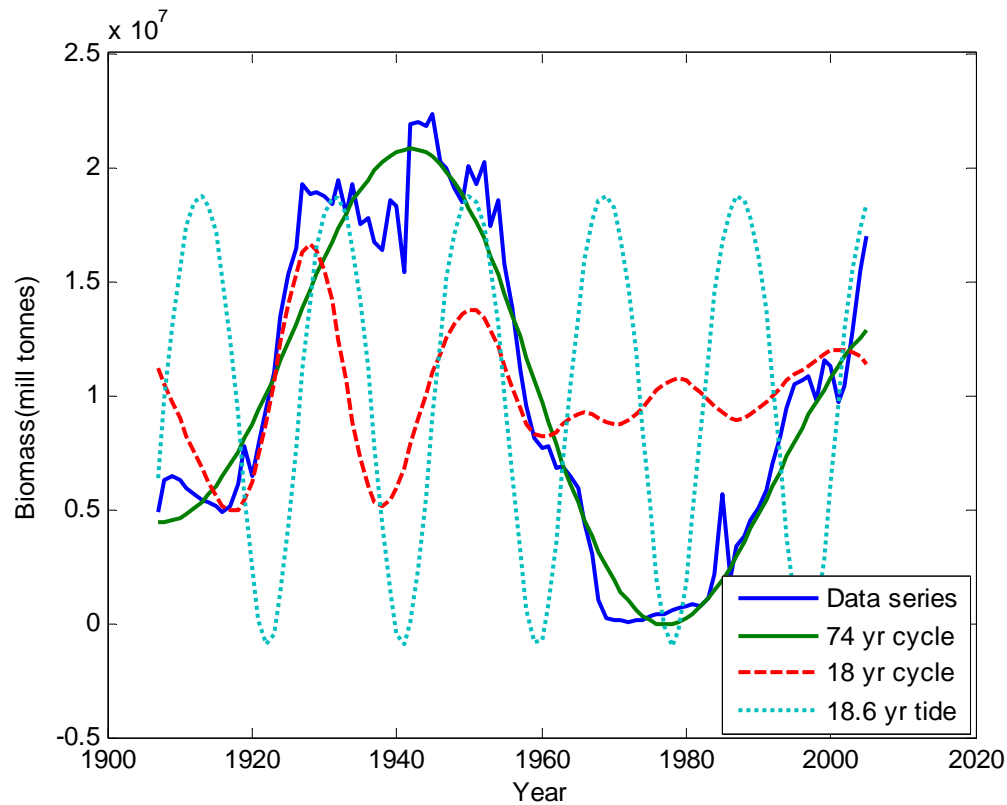


Figure 7. Data series of Norwegian spring-spawning herring biomass from 1946 to 2007, a 74 yr cycle, the identified 18 yr wavelet cycle and the 18.6 yr amplitude tide.

Figure 7 shows the data series of Norwegian spring-spawning herring biomass from 1946 to 2007, a 74 yr cycle, the identified 18 yr wavelet cycle and the 18.6 yr amplitude tide. The biomass growth started in about 1922; the growth from 0.5 to about 2 million tonnes followed the growth from two 18.6 yr tidal inflow cycles to the Barents Sea. The biomass started to be reduced from about 1958, when the second 18.6 yr cycle is in a negative state. In the 1960s, there was a collapse due to overfishing. The new growth came after the lunar nodal tide inflows in 1985 (Figure 6). In the total period from 1906 to 2007, the biomass is correlated to a subharmonic period of  $4 \times 18.6 = 74.4$  years, the same period and phase as the 74 yr Kola section temperature fluctuation.

## 4 Discussion

The present analysis is based on high quality data series. The wavelet analysis method has been used to identify single fluctuations and phase in time variant data series. The close relationship between the

known lunar nodal cycle and the identified dominant cycles confirms that the wavelet analysis is a robust method to identify cycle periods and phase in data series. At the same time, the wavelet method has limitations at the start and end of the data series. The identified long 74 yr periods therefore need to be compared with similar identifications in other data series.

### *The Barents Sea ecosystem oscillation*

This analysis suggests that we may understand the Barents Sea ecosystem dynamic as a coupled oscillating system of forced lunar nodal tide spectrum. The astronomical lunar nodal tides may then serve as a reference for the Barents Sea ecosystem fluctuations.

A coupled oscillating system is expected to have optimum third harmonic and third subharmonic oscillations (Strogatz and Stewart, 1993; Nyafeh and Mook, 1995). This mechanism is similar to resonance in physics. The physical explanation of ecosystem oscillation as a small tidal oscillating Atlantic inflow to the Barents Sea has a powerful influence when it is integrated in time and space, in the same direction. The long-term mean inflow thus influences zooplankton production, biomass recruitment and biomass growth in the food chain. In a very long period of tidal inflow, biomass life cycle periods are optimized by the periods of tidal inflow. The biomass grows in periods when the amplitude tide and the phase tide grow. This observation supports a previous theory from Hjort (1914), as well as many later observations, that biomass growth is dependent on matching of recruitment and zooplankton fluctuation. This analysis shows, however, the importance of life cycle matching. It is the optimum recruitment cycle time, related to optimum growth that makes an optimum long-term biomass growth. This means that an optimum long-term biomass growth is dependent on a few strong year classes.

### *Barents Sea zooplankton oscillation*

The wavelet analysis of the Barents Sea zooplankton data series shows that the dominant biomass fluctuations are related to the inverse 18.6 and 9.3 year lunar nodal tidal cycles and the inverse 9 yr and 18 yr temperature fluctuations in the Kola section. This means the zooplankton biomass increases with decreased temperature. The cause of this relation is unclear. The close relation to the 9.3 yr phase tide and the 18.6 yr amplitude tide indicates that the long tides may serve as a deterministic reference for the zooplankton biomass fluctuations.

### *Barents Sea capelin biomass oscillation*

The Barents Sea capelin is a zooplankton predator. We may then expect an inverse relation between the zooplankton biomass variability and the capelin biomass variability, as identified in this investigation. If predation was the major effect in a dynamic system, we might expect a random unstable dynamic relationship between the zooplankton biomass fluctuation and capelin biomass fluctuation. The capelin biomass dynamics has, however, a stable life cycle of about  $9.3/3=3.1$  years (Yndestad and Stene, 2002). This investigation shows that the capelin biomass fluctuation is synchronized to the 9.3 yr phase tide after the biomass collapse in 1985. This indicates that the 9.3 yr tide is the main trigger event for the capelin biomass growth. We may then understand the 3-4 yr biomass life cycle as a coupled oscillator to the 9.3 yr phase tide.

Figure 4 shows that the biomass has a problem recovering after the collapse in 1985, and it demonstrates that there is no linear relationship between temperature, zooplankton and capelin biomass growth. This situation is most likely caused by a uniform age distribution after the biomass collapse. When there is a distance of about three life cycles between the large recruitments periods, it may take many decades to restore the biomass.

### *Northeast Arctic cod biomass oscillation*

The biomass of Northeast Arctic cod has a mean optimum life cycle of about  $18.6/3=6.3$  years (Yndestad, 2003a). This analysis has shown that this life cycle time gives two strong year classes in periods when the 18.6 yr tide is positive and less recruitment when the 18.6 yr tide is negative. Three 6-7 yr biomass life cycles thus will introduce a biomass fluctuation of about 18 years, as shown in Figure 6. The 6-7 yr life cycle recruitment of Northeast Arctic cod is a third harmonic of the 18.6 yr cycle and thus represents an optimum cycle period in a nonlinear dynamic system (Nyafteh and Mook, 1995). We may then understand the dynamic variability of Northeast Arctic cod biomass as a coupled oscillator, to the forced 18.6 yr tidal cycle inflow to the Barents Sea.

The recruitment at about 1992 had a delay that influenced the expected new 3-yr recruitment at about 2002. A possible explanation is the biomass overfishing in the 1980s. This overfishing reduced the age



distribution and introduced a decoupling between biomass oscillation and tidal Atlantic inflow and thus reduced the biomass from the 1990s onward.

The long-term fluctuation of Northeast Arctic cod is associated with a group of 18 yr fluctuations. The synchronization to the 74 yr temperature beginning in 1920 indicates that the long-term growth is controlled by a subharmonic 74 yr tidal controlled period. The long-term stability of this 74 yr cycle is, however, unclear.

### Norwegian spring-spawning herring biomass oscillation

Norwegian spring-spawning herring has the same optimum life cycle of about  $18.6/3=6.3$  years (Yndestad, 2003a). The analysis has shown that the herring biomass has strong year classes in periods when the 18.6 yr amplitude tide and the 9.3 yr phase tide have a maximum state. Strong year classes at the 18.6 yr and the 9.3 yr tide reduce the 18 yr oscillation as estimated in the biomass of Northeast Arctic cod and introduce a more stable growth as shown in Figure 7.

The long-term biomass fluctuation had the same growth period from 1920 to 1956 as noted for Northeast Arctic cod. This indicates that long-term biomass fluctuation of Northeast Arctic cod and Norwegian spring-spawning herring are controlled by the same 74 yr subharmonic temperature cycle. Norwegian spring-spawning herring has, however, the ability to recruit strong year classes at the 9.3 yr tidal inflow to the Barents Sea and thus is able to grow more rapidly.

## 5 Conclusion

The present investigation has identified long lunar nodal tides as a hidden source that has a temporary deterministic influence on the temperature fluctuation in North Atlantic water and the Barents Sea ecosystem. The explanation is that a small tide may have a major influence on the ocean's thermohaline circulation system and the Barents Sea ecosystem, when the tides are integrated in time and space over a long period.

The Barents Sea zooplankton biomass fluctuation grows in cold periods when the 9.3 and 18.6 yr tides have less Atlantic inflow to the Barents Sea. The Barents Sea capelin has a life cycle of about  $9.3/3=3.1$  and a biomass growth controlled by the 9.3 yr phase tide. Northeast Arctic cod and Norwegian spring-spawning herring have optimum life cycles of about  $18.6/3=6.3$  years. The cod life cycle period gives two strong recruitment periods when the 18.6 yr tide is at a positive state. The result is a biomass fluctuation of about 18 years. A tidal controlled subharmonic temperature cycle of about  $4*18.6=74.4$  years introduced a long-term biomass growth period, beginning in 1920. The herring life cycle period gives two strong recruitment periods when the 18.6 yr tide is positive and when the 9.3 yr tide is positive. This relationship to both tides explains the biomass ability to have a fast biomass growth. The herring biomass has the same 74 yr biomass fluctuation beginning in 1920, controlled by the 74 yr temperature fluctuation. These results suggest that we may understand the Barents Sea ecosystem dynamics as a deterministic coupled oscillation system to the forced lunar nodal tide spectrum.

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