

## COMMENT

## Is there short-term periodicity in gadoid recruitment along the Norwegian Skagerrak coast?

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Fromentin et al. (1997) analysed time series of 0-group gadoid abundance data from the Norwegian Skagerrak coast and concluded that 3 gadoid species, cod *Gadus morhua* L., whiting *Merlangius merlangus* L. and pollack *Pollachius pollachius* L., exhibit periodic fluctuations of 2 to 2.5 yr in their optimal habitat. This was considered to be a result of intrinsic interactions in age-structured populations, such as density-dependent competition and cannibalism. In a more recent analysis designed to test whether the short-term cycles were indeed a result of density-dependent interaction between consecutive year-classes, I selected the 25% highest and 25% lowest cod year-classes using Fromentin et al.'s data, and estimated the average catches in subsequent years. It was assumed that, particularly after strong year-classes, one should observe year-classes well below average. Surprisingly, recruitment following strong year-classes was higher than average, and recruitment following poor year-classes was well below average. These results provide no indications of density dependence between cohorts, rather they suggest that autocorrelation in the time series resulted in the opposite result from what was expected. Because of inconsistency between this elementary analysis and Fromentin et al.'s (1997) 2 to 2.5 yr cycle, I reviewed the original analyses and found that the apparent cycles are the result of erroneous use of statistical methods. Based on new analyses, I conclude that there is no evidence of short-term periodicity (<10 yr) in recruitment of 0-group gadoids, nor is there significant density-dependent interaction between 0- and I-group cod along the Norwegian Skagerrak coast. Density-dependent interaction between 0- and I-group cod was also suggested by Bjørnstad et al. (1999), Stenseth et al. (1999) and Fromentin et al. (2000). It

should be emphasised that I was a co-author of Fromentin et al. (1997) and therefore jointly responsible for its publication.

The recruitment time series used in these analyses is derived from an annual beach seine survey carried out since 1919 (for details see Fromentin et al. 1997). Fromentin et al. (1997) applied spectrum analysis for the individual stations. Thirty-eight time series were analysed for each of the 3 gadoid species. In order to make the time series stationary, the log-transformed time series were detrended by first order differencing. This simply involves subtracting consecutive numbers in the original time series, e.g:

$$Y_i = X_i - X_{i-1}, \quad Y_{i+1} = X_{i+1} - X_i, \dots,$$

where  $x_i$  represents the elements in the original time series, and  $y_i$  the elements in the detrended time series. Obviously, consecutive numbers in the detrended time series are no longer independent, as both  $y_i$  and  $y_{i+1}$  contain  $x_i$ . In addition, because consecutive detrended observations ( $y_i$  and  $y_{i+1}$ ) depend upon  $+x_i$  and  $-x_i$ , a negative first order autocorrelation (expectation  $-0.5$ ), which can be detected as a 2 yr cycle, can be an artifact of first order differencing.

The autocorrelation coefficients of a discrete stationary process may always be interpreted as the Fourier coefficients of a non-decreasing function (Wold 1954). Because Fromentin et al. (1997) found 2 to 2.5 yr cycles to be the main cyclic signal in the time series (i.e. there was no other periodicity that could partly hide the 2 to 2.5 yr cycle), elementary methods can be applied to test whether the apparent periodicity is real. A time series with a 2 to 2.5 yr cycle transformed with first-order difference will have first-order autocorrelation significantly less than  $-0.5$  (closer to  $-1$ ), compared to  $-0.5$  in the absence of a 2 yr cycle. Estimation of first order auto-correlation coefficients of the individual station (as in Fromentin et al. 1997) and then averaged over all stations gave the following values for cod, pollack and whiting, respectively:  $-0.50$ ,  $-0.41$  and  $-0.48$ .

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Consequently, none of the 3 species shows sign of a 2 to 2.5 yr cycle (see new analyses of periodicity below).

To reveal potential patterns of periodicity, Fromentin et al. (1997) performed principal component analysis (PCA) on the spectral densities of the 3 gadoids. Each species was represented by 38 series of spectral densities (1 per station), and from each of the 38 series the spectral density values of 25 evenly distributed points along the frequency axes were selected. Hence, the PCA was performed on 3 matrices of 38 columns (variables) and 25 rows (objects). Based on this analysis Fromentin et al. (1997) concluded: 'despite important differences between species at the mesoscale, there was a relationship between the level of abundance and the evidence of a 2 to 2.5 yr oscillation (Fig. 6), especially for cod and pollack'. In other words, stations with high abundance showed a much clearer cyclic pattern.

However, this analysis is also incorrectly applied. The spectral density depends on the standard deviations of the original time series. If, for example, a time series is multiplied by 2, both the average value of the time series and the standard deviation are doubled, and so are the values of the raw periodogram. Fromentin et al. (1997) did not standardise the periodograms to unit variance. This can be seen in Fig. 4a–c in Fromentin et al. (1997), where the values of the presented spectral densities are very different. Obviously, with non-standardised spectral densities the PCA not only depends on where the spectral density function peaks, which was the intention of the analysis, but also on the differences in the overall value of the spectral densities. Correlation analyses between the standard deviation and the average catch of the 38 stations (log-transformed data for the period 1945–1994 as Fromentin et al. 1997), gave the following Pearson correlation coefficients ( $r$ ) for cod, pollack and whiting, respectively: 0.66, 0.75 and 0.43. Consequently, stations with high abundances will have spectral densities with higher values than stations with low abundances and thereby affect the PCA results in accordance with the results in Fromentin et al. (1997).

Fromentin et al. (1997) also tested for significance of the periodic fluctuations by a permutation test. Each series was repeatedly permuted randomly, followed by recomputation of the first-order difference and spectrum analysis. This produced an empirical null distribution against which the actual periodic fluctuations were tested. For cod, pollack and whiting this analysis resulted in 61, 60 and 76% significant periodic fluctuations, respectively. However, the applied level of significance of 5% is highly disputable because the bandwidth of the periodograms corresponds to 25 frequencies, which implies that each spectral density function can peak above the null distribution at 25

positions. Consequently, we are faced with a multivariate problem, which implies that the level of significance should be much lower than 5%.

In a more recent paper Fromentin et al. (2000) tested for periodic fluctuations using a permutation test, and report a significance probability of  $p = 0.01$  for a 50 yr cycle. Despite this highly significant result obtained by the permutation test, Fromentin et al. (2000) do not seem to fully trust that the 50 yr cycle is real and state: 'The period corresponds approximately to the length of the series and therefore might be an artefact'. Indeed, this result does question the validity of the permutation test.

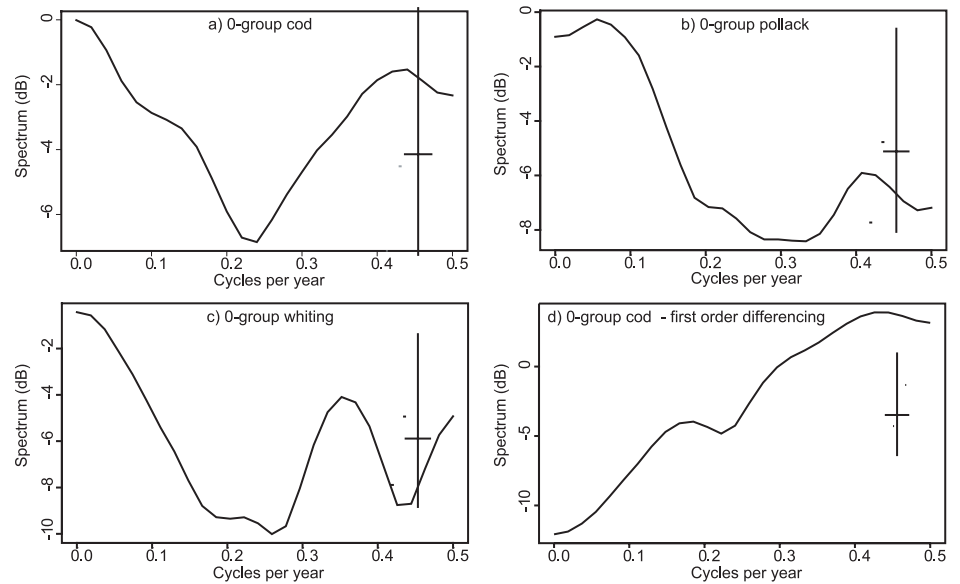
In order to study whether there actually is significant periodicity in the abundance of gadoids from the Norwegian Skagerrak coast, I performed spectrum analysis on the annual averages of cod, pollack and whiting (averaged over 38 stations and log-transformed). The log-transformed time series were detrended by a simple linear model. The first auto-correlation coefficients for cod, pollack and whiting in the detrended time series were 0.04, 0.40 and 0.25, respectively. In the case of a 2 to 2.5 yr periodicity and not other predominant periodic fluctuations, negative correlation coefficients were expected. The results of the spectrum analyses are presented in Fig. 1a–c. For cod there is no evidence of periodicity as the spectral density function varies less than the confidence limit. For pollack there is indication of 18 to 19 yr periodicity. However, there is no obvious explanation for such a periodicity, and with a time series of only 56 yr, long-term periodicity should be interpreted with caution. For whiting there is only a signal of long-term periodicity. Consequently, there is no evidence of more short-term periodicity (<10 yr) for cod, pollack and whiting, and therefore no evidence of interaction between different age groups.

The impact of first order differencing on the spectral density is illustrated in Fig. 1d for 0-group cod. In Fig. 1a there is no evidence of periodicity, whereas first order differencing resulted in a significant 2 to 2.5 yr cycle (notice the different scales of panels a and d).

In this Comment it has been shown that statistical errors resulted in faulty conclusions regarding important ecological mechanisms. Fromentin et al. (1997) refer to Bjørnstad et al. (1996), who applied the same statistical procedures to study periodicity in voles (first order differencing followed by spectrum analysis and PCA). Also in Bjørnstad et al. (1996) 2 yr cycles were a predominant feature of periodicity. Hence, in the light of what has been presented here, it is recommended that this paper should also be reanalysed.

Errors in published papers are probably unavoidable, even with the strictest refereeing process. The possibility of making mistakes is, in my opinion, a risk that scientists have to take to extend methodology in

Fig. 1. Smoothed periodogram of year-class indices of cod, pollack and whiting along the Norwegian Skagerrak coast 1945–1999, with indication of approximate 95% confidence interval (vertical line of cross) and band-width (horizontal line of cross). The spectrum analyses were carried out using S-Plus (Spector 1994), on the log-transformed annual averages of the same 38 stations as in Fromentin et al. (1997). The time series were detrended using (a–c) a simple linear model, (d) by first order differencing. Taper was set to 0.1 in all panels and the periodogram smoothed by a modified Daniell filter,  $m = 5,5$  (see Bloomfield 2000)



the pursuit of scientific progress. However, because user-friendly statistical packages make statistical analyses available for everybody, one should be particularly alert when advanced statistical methods are being applied. Authors should test results obtained with elementary methods whenever possible, as unfortunately was done too late in this case.

From the analyses of the present time series Bjørnstad et al. (1999) and Stenseth et al. (1999) reported density-dependent forces between different cohorts in juvenile cod, 'most likely due to asymmetrical competition and probably cannibalism of the I-group on the 0-group' (Stenseth et al. 1999). Both papers applied sophisticated statistical analyses. A simple way of testing whether I-group cod actually have an impact on survival and the subsequent year-class strength of 0-group cod is by performing Pearson correlation analysis, as a negative correlation should appear between the 2 year-classes. In the more recent paper Fromentin et al. (2000) did correlate the annual 0-group and I-group abundance and reported  $r = 0.32$  ( $p < 0.01$ ) for the mean temporal pattern and  $r = 0.1$  (ns) for the detrended series, 'indicating that 0- and I-group fish exhibited similar trends but non-synchronous year-to-year fluctuations'. This result is in agreement with the present analyses of individual stations as the average of the first order auto-correlation coefficients was not less than  $-0.5$  for the first ordered differenced series (0-group abundance can be considered an approximation of I-group abundance the following year). The consistent lack of correlation between 0- and I-group abundance does not support density-dependent interactions between 0- and I-group cod. However, Fromentin et al. (2000) failed to comment on the obvious discrepancy

between their correlation analysis and their suggestion of density dependent mortality between 0- and I-group cod based on spectrum analysis, which also in this paper involved first order differencing.

From the analyses presented here I conclude that there is no evidence of short-term periodicity ( $< 10$  yr) in recruitment of 0-group gadoids, nor is there significant density-dependent interaction between 0- and I-group cod along the Norwegian Skagerrak coast.

#### LITERATURE CITED

- Bjørnstad ON, Champely S, Stenseth NC, Saitho T (1996) Cyclisity and stability of grey-sided voles, *Clethrionomys rufocanus* of Hokkaido: evidence from spectral and principal component analyses. *Phil Trans R Soc Lond B* 351: 867–875
- Bjørnstad ON, Fromentin JM, Stenseth NC, Gjøsæter J (1999) Cycles and trends in cod populations. *Proc Natl Acad Sci USA* 96:5066–5071
- Bloomfield P (2000) Fourier analysis of time series. An introduction. John Wiley & Sons, New York
- Fromentin JM, Stenseth NC, Gjøsæter J, Bjørnstad ON, Falck W, Johannessen T (1997) Spatial patterns of the temporal dynamics of three gadoid species along the Norwegian Skagerrak coast. *Mar Ecol Prog Ser* 155:209–222
- Fromentin JM, Gjøsæter J, Bjørnstad ON, Stenseth NC (2000) Biological processes and environmental factors regulating the dynamics of the Norwegian Skagerrak cod populations since 1919. *ICES J Mar Sci* 57:330–338
- Spector P (1994) An introduction to S and S-Plus. Duxbury, London
- Stenseth NC, Bjørnstad ON, Falck W, Fromentin JM, Gjøsæter J, Gray JS (1999) Dynamics of coastal cod populations: intra- and intercohort density dependence and stochastic processes. *Phil Trans R Soc Lond B* 266:1645–1654
- Wold H (1954) A study in the analysis of stationary time series. Alquist & Wiksell, Stockholm