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# IS THE RECRUITMENT A KEY BIOLOGICAL PROCESS IN THE HYPOTHETICAL NAO-ATLANTIC TUNAS RELATIONSHIPS?

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## *ABSTRACT*

*In the recent past, it has been put forward that recruitment of the North Atlantic albacore, East Atlantic bluefin tuna and North Atlantic swordfish could be related to the North Atlantic Oscillation (NAO). In this document, the biological processes behind the NAO/recruitment relationship are further investigated. Then, the possible relationship between the East Atlantic bluefin tuna recruitment was re-investigated. The linear relationship appeared to be only due to the low frequency signal, both BFT recruitment and NAO displaying a pseudo-cyclic upward trend, but year-to-year fluctuations were not synchronous. The superposed epoch analysis, that was conducted to test for possible non-linear and non-monotonous relationship did not reveal any clear connection. In conclusion, it appears that the available data on BFT recruitment cannot support the hypothesis of an impact of the NAO on BFT recruitment. Spatially disaggregated data are needed to further investigate this hypothesis. Finally, we stressed the interest to explore other mechanisms, such as the influence of the NAO on spatial distribution, migration routes and catchability.*

## *RÉSUMÉ*

*Des travaux récents ont émis l'hypothèse que le recrutement du germon et espadon nord atlantique, ainsi que du thon rouge de l'atlantique nord-est pourraient être liés à l'oscillation nord atlantique (NAO). Ce document vise tout d'abord à expliciter les processus biologiques assumés derrière une telle hypothèse. Ensuite, l'hypothèse d'une relation entre le NAO et le recrutement du thon rouge de l'Atlantique nord-est est ré-explorée. Les relations linéaires résultent du signal basse fréquence, les séries de NAO et de recrutement étant caractérisées par une tendance croissante et pseudo-cyclique. Par contre, les variations inter annuelles des deux variables ne sont pas synchrones. L'analyse des époques superposées, qui fut menée afin de tester d'éventuelles relations non linéaires et non monotones ne met pas en évidence de liens clairs. En conclusion, les données disponibles sur le thon rouge s'avèrent insuffisantes pour confirmer une éventuelle influence du NAO sur le recrutement. Des données spatiales désaggrégées sont nécessaires pour explorer plus amplement cette hypothèse. Finalement nous mettons en avant l'intérêt d'étudier d'autres types de mécanismes, tels que l'influence du NAO sur la distribution spatiale, les routes migratoires et la capturabilité.*

## *RESUMEN*

*Trabajos recientes han presentado la hipótesis de que el reclutamiento de atún blanco y pez espada del Atlántico norte, y de atún rojo del Atlántico nordeste podría estar relacionado con la Oscilación del Atlántico Norte (NAO). Este documento profundiza en el estudio de los procesos biológicos que sustentan la hipótesis de dicha relación NAO / reclutamiento. Después, se vuelve a investigar la posible relación entre la NAO y el reclutamiento del atún rojo del nordeste. Las relaciones lineales se derivan sólo de la señal de baja frecuencia; tanto las series de NAO como de reclutamiento se caracterizan por una tendencia creciente y seudocíclica. Por el contrario, las fluctuaciones interanuales de estas dos variables no son sincrónicas. El análisis de las épocas superpuestas, que se realizó con el fin de comprobar las posibles relaciones no lineales y no monótonas no evidenció la existencia de una conexión clara. En conclusión, parece que los datos disponibles sobre el atún rojo no son suficientes para confirmar las hipótesis de una posible influencia de la NAO en el reclutamiento. Para profundizar en esta hipótesis se debe disponer de datos espaciales disgregados. Finalmente, queremos destacar el interés que tiene la exploración de otros mecanismos, como la influencia de la NAO en la distribución espacial, las rutas de migratorias y la capturabilidad.*

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*KEYWORDS*

*North Atlantic Oscillation, recruitment, bluefin, albacore, swordfish, migration patterns, time series, spatially disaggregated data*

## INTRODUCTION

The North Atlantic Oscillation (NAO) is the major source of interannual variability in the North-Atlantic atmospheric circulation (Rogers 1984, Hurrell 1996). It results from the oscillation of the subtropical high surface pressures, centred on the Azores, and of the subpolar low surface pressures, centred on the Iceland (Fig. 1). The NAO is measured by an index, that is the difference in normalised air pressures at sea level between these two poles. Although the NAO has some effects throughout the year (Alexander and Deser 1995, Hurrell and Van Loon 1997), it is mostly pronounced during the winter season, so that the index is usually calculated over December to March (Rogers 1984). The state of the NAO determines the speed and direction of the Westerlies across the North-Atlantic, as well as temperatures on both sides of this ocean. An accentuated pressure difference between the Azores and Iceland (corresponding to a high positive NAO index) is associated with a strong wind circulation in the North Atlantic, high temperatures in the western Europe and low temperatures in the East coast of U.S. and Canada and *vice versa*. The NAO could further influence the North Atlantic zooplanktonic production (especially copepods), through variations in wind stress, that can directly affect the primary production and through changes in SST (Fromentin and Planque 1996, see also Heath, et al. 1999). Because the copepods constitute the main food resource of the fish larvae in the Northeast Atlantic (Ellersten, et al. 1989, Skreslet 1989), the NAO could directly relate to the match/mismatch hypothesis, according to which the strength of a year-class depends on the timing between the fish larvae and their zooplanktonic food (Cushing 1969, May 1974).

On this background, 9 recent SCRS documents focused on the possible influence of the NAO on Atlantic tunas. At the exception of Porch at al. (2001) who concluded that the R/SSB estimates of the western bluefin tuna were uncorrelated with the NAO, the other studies put forward that the NAO could affect several temperate or sub-tropical stocks, i.e., the North Atlantic albacore (good recruitment being related to negative NAO index, Bard and Santiago 1999, Bard 2001), the East Atlantic bluefin tuna (good recruitment being related to positive NAO index, Santiago 1998, Marsac 1999, Santiago 1999) and the North Atlantic swordfish (good recruitment being related to negative NAO index, Mejuto 1999, 2000, 2001). The underlying processes that could explain such relationships appear, however, rather unclear. In most of the cases, the NAO is supposed to primarily influence the recruitment or the year-class strength of these stocks. This document aims to: (i) further investigate the biological processes behind the NAO/recruitment relationship, (ii) re-analyse the possible relationship between the East Atlantic bluefin tuna recruitment and NAO and (iii) discuss further investigations about the influence of the NAO on Atlantic tunas.

## UNDERLYING PROCESSES

A significant (positive or negative) relationship between the NAO and year-class strength of tuna populations imply that physical and biological processes have compatible scales and can match both in time and space.

The recruitment of the northern albacore (ALB) and swordfish (SWO) spread over large parts of the North Atlantic and occur during at least 3 months per year (Bard 1981, Arocha and Lee 1996), which is compatible with the spatial and temporal scales of the NAO. The western and eastern Atlantic bluefin tuna (BFT) reproduce in a more reduced spatial and temporal window than the two above species, i.e. 1 to 2 months, either in the Gulf of Mexico or around the Balearic islands and Sicily (Mather, et al. 1995), so that local environmental factors could play a more important role than for ALB and SWO.

In the same way, if the environmental conditions of the spawning sites and nursery grounds of ALB and SWO are known to be strongly influenced by the NAO, this is less clear for those of the East Atlantic bluefin tuna. Although the climate and circulation of the western Mediterranean have been recently shown to be globally related to the NAO (Hurrell and Van Loon 1997, Vignudelli, et al. 1999), this area is also strongly influenced by several regional factors, such as the depression-low center of the Ligurian Sea, the general circulation in the western basin (also related to the entrance of the Atlantic waters in the Mediterranean) and the strong local northern and southern winds that induce coastal upwellings (Millot 1979, Astraldi, et al. 1995, Pinazo, et al. 1996). The influence of the NAO being spatially heterogeneous, even in an area where it is supposed to be the most pronounced (see Fromentin and Planque 1996), a careful study would be necessary to quantify the importance of the global *versus* local factors in the areas of the East BFT spawning sites.

As it was already mentioned by Santiago (1998), the time delay between the NAO and recruitment periods is the most problematic question. The NAO could, indeed, influence the recruitment of tunas through: (i) changes in food availability for tuna larvae during the critical period (i.e, the match-mismatch hypothesis), because the NAO influences the Atlantic zooplanktonic production, (ii) variations in the transport of tuna eggs and larvae from their nursery grounds, because the NAO strongly impacts both oceanic winds and currents, and (iii) variations in growth of tuna larvae and juveniles, because of quantitative changes in physical factors, especially the sea temperature (for more details on tuna recruitment variability, see e.g., Fromentin and Restrepo 2001). Although the effects of the NAO are perceptive throughout the year, the NAO primarily takes place in winter season (Rogers 1984, Hurrell 1995). In contrast, the recruitment of ALB, SWO and BFT occurs in spring or early summer. The above processes imply the synchrony between the NAO (or its main effects on marine environment and production) and tuna recruitment, which is not case. Because of the long memory of the marine system, one may argue that the NAO in year *t* can influence the environmental conditions, that will take place in spring-summer of the same year, i.e., during the tuna spawning season (age 0 in year *t*). However, such delayed effects are likely to be far less substantial than direct ones. The NAO is, thus, more likely to affect tuna recruitment, because the year-class strength could be established after the critical period and, even during the early juvenile stages (Peterman, et al. 1988, Myers, et al. 1993). Following this hypothesis, the NAO in year *t* could affect the survival of the Young-Of-the-Year during their first overwintering period (i.e., age 0 in year *t-1*), through food availability or variations in temperature.

## STATISTICAL CONSIDERATIONS

One classical problem with correlation and regression analysis is due to spatial and temporal autocorrelation, which is a general property of ecological and meteorological time series (Legendre and Legendre 1998). On the one hand, spatial and temporal autocorrelation in ecological time series are useful properties for the ecologist. They may be investigated to detect the pertinent spatial scales of variations or the main temporal components (trend, cycles…), which finally help to identify the underlying processes of the population dynamics (e.g., Mackas 1984, Turchin and Taylor 1992, Bjørnstad, et al. 1998, Fromentin, et al. 1998, Koenig 1999). On the other hand, autocorrelation violates the assumption of independence among observations, that is needed to test the statistical significance, so that the estimation of the number of degrees of freedom is biased (Ostrom 1987).

To correct the bias due to the autocorrelation at lag 1, one may adjust the degree of freedom with the method proposed by Bartlett (1946):

$$N' = N\frac{(1-a_1a_2)}{(1+a_1a_2)}$$

where $N$ is the number of pairs of observations in the two series and $N'$ is the adjusted number of degrees of freedom assuming an AR(1) process ($a_1$ and $a_2$ being the lag one autocorrelation coefficients of the two series). However, such a method cannot correct autocorrelation due to long-term fluctuations (i.e., at greater lags). In this case, one alternative is to compute correlation coefficient (or regression analysis) on both non-detrended and detrended time series. The comparison between both allows to distinguish whether a significant correlation is only due to the trend (i.e. autocorrelation) or not.

At the light of these statistical considerations, the regression analysis between the NAO and East BFT recruitment has been re-computed. Following Santiago (1998), we approximated the BFT recruitment in year *t* by the abundance at age 1 in year *t-1* (the latter been estimated by the BFT stock assessment in 1998, Anonymous 1999). Both time series display pseudo-cyclic long-term fluctuations, being clearly highlighted by the smoothing (Fig. 2, top panels, a feature being even stronger for SWO CPUE-age1 time series, see Mejuto 1999). Let's first investigate the hypothesis that the NAO can affect BFT year-class strength by influencing BFT survival during its first overwintering period (i.e., between NAO in year *t* and age 1 in year *t*). Holding both series on a same graph would confirm a synchrony between the NAO and the BFT recruitment (Fig. 2, bottom panel). Regression analysis showed a positive effect of the NAO (more positive the NAO index, stronger the age 1 abundance) and indicated that the NAO could explain a bit more than 25% of the variations in BFT year-class strength, which is in agreement with Santiago (1998). However, the regression analysis computed on detrended time series (Fig. 3, top panels) indicated a complete lack of relationship between the NAO and BFT recruitment (Fig. 3, bottom panels). Regarding the alternate hypothesis, for which the NAO would influence the environmental conditions during the BFT recruitment period (i.e., between NAO and BFT recruitment in year *t*, so age 1 in year *t-1*), same kind of results emerged (Fig. 4). So, whatever the chosen hypothesis, the relationship is only due to the similarity of the trends, but year-to-year fluctuations of BFT recruitment are not synchronous with those of the NAO.

We could, however, hypothesize that only extreme NAO events influence BFT recruitment. Therefore, we applied the superposed epoch (Haurwitz, et al. 1981, Prager and Hoenig 1989). The null hypothesis of this test is: there is no association between extreme values of the NAO index (low or high) and the BFT year-class. To perform it, we first defined key-event years as (i) the values of the NAO index higher than the average plus one standard deviation (high NAO) and (ii) the values of the NAO index lower than the average minus one standard deviation (low NAO). Adjacent years were defined as the years before and after the key-event year. The statistics to compare abundance in key-event years with abundance in adjacent background years is similar to a *t-test* and the significance was estimated by a Monte Carlo randomisation procedure (Prager and Hoenig 1989). Considering only one year before and/or after the key-year event, the superposed epoch analysis did not reveal any clear significant association between BFT year-class strength and low NAO events ($p=0.30$, 0.33 and 0.42, for the tests assuming adjacent year as: one year before, one after and one year before and after, respectively). Although a bit closer to significance, same results emerged when considering effect of high NAO events ($p=0.11$, 0.20 and 0.075, for one year before, one after and one year before and after, respectively), as well as when we considered two years before and/or after the key-year event (low or high NAO).

## DISCUSSION

Two main difficulties, thus emerged to support the NAO-tuna recruitment hypothesis. Firstly, the underlying processes behind this relationship do not appear, from an ecological viewpoint, so obvious, mainly because of time delay between the NAO (occurring in winter) and tuna recruitment (taking place in spring-summer). It has been recently shown that the NAO could influence the recruitment of several North Atlantic populations of cod and plaice (see e.g., the review of Ottersen, et al. 2001), but it is worth noting that the recruitment periods of these northern populations match this of the NAO. To go further than simple correlation analysis (that is insufficient to assert any causal relationship), tuna biologists must clarify and develop the underlying biological processes behind this hypothesis. Doing so, it would be possible to design new tests and experiments. Secondly, the processes behind the NAO-tuna recruitment hypothesis imply that both trends and year-to-year fluctuations of tuna recruitment should be synchronous with those of the NAO. At least, the year-class strength should be affected by extreme NAO events. This is obviously not the case for the East Atlantic bluefin tuna and the highly smoothing pattern of the SWO recruitment series would tend to the same conclusion. There are two possibilities so far: (i) the recruitment data are inadequate to test such an hypothesis and (ii) there is no NAO-tuna recruitment relationship.

Biological time series are indeed questionable for, at least, the East BFT and SWO. For the former, the stock assessment of 1998 (and so the abundance at age 1) is impaired by a large amount of uncertainty, mainly because of the quality and quantity of catch and effort data (Anonymous 1999, Anonymous 2001, Fromentin submitted). Therefore, the increase in BFT recruitment during the 80's and early 90's could simply reflect the strong increase in the catches of BFT spawners during the 90's (the available information being insufficient to correct for this bias within the VPA). SWO recruitment proxy is based on CPUE time series. However, CPUE are now known to provide a poor index of abundance, because, among other things, the catchability-abundance relationship is often complex and non-linear and the spatial distribution of fish populations is heterogeneous and density-dependent (see e.g., Hilborn and Walters 1992). It would be, thus, interesting (at least for BFT and SWO) to investigate catch data, being disaggregated by size (or age), year (month if possible), location and gear. Catch data are obviously biased, but they can be partially corrected (e.g., by selecting the most consistent gears and/or locations or selecting a given period). An advantage of such an approach is to generate several time series of 'recruitment' (coming from different locations and/or gears), that can be then compared, which make the results of the exploratory analyses more trustworthy.

Finally, we have to keep in mind that the NAO could affect tuna populations through other processes than recruitment. Because of its various effects on wind, currents, temperature and marine production (see above), the NAO is likely to affect the spatial distribution/extension of tuna populations, their migration routes and their catchability (see Marsac 1999, Bard 2001). These axes of research are, from my viewpoint, promising and deserve special attention.

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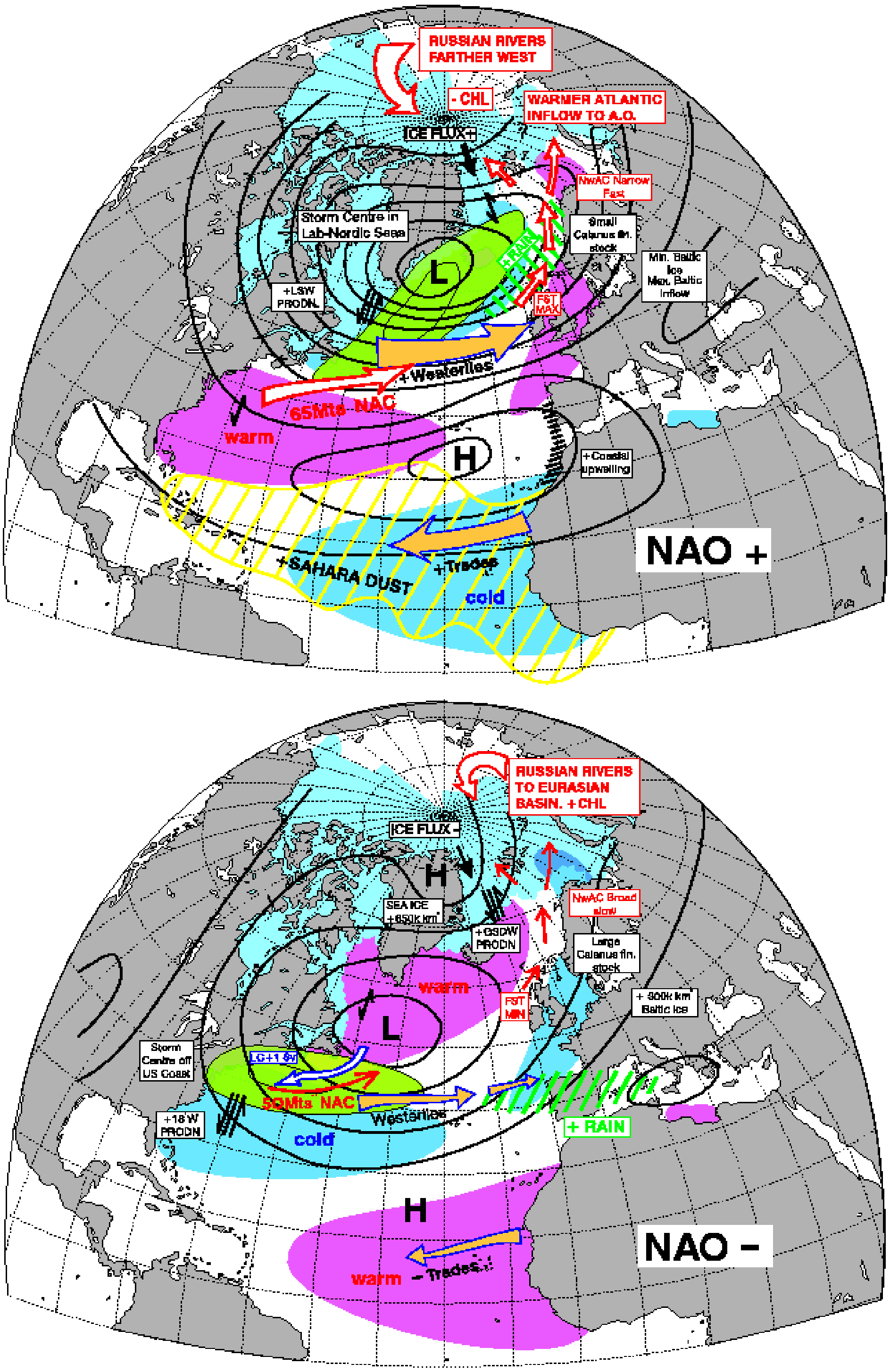


**Figure 1.** Graphical summary of the two extreme phases of the North Atlantic Oscillation (NAO), as measured by the NAO index. Top graph: positive phases, bottom: negative ones
(see: http://www.cgd.ucar.edu:80/cas/climind/)

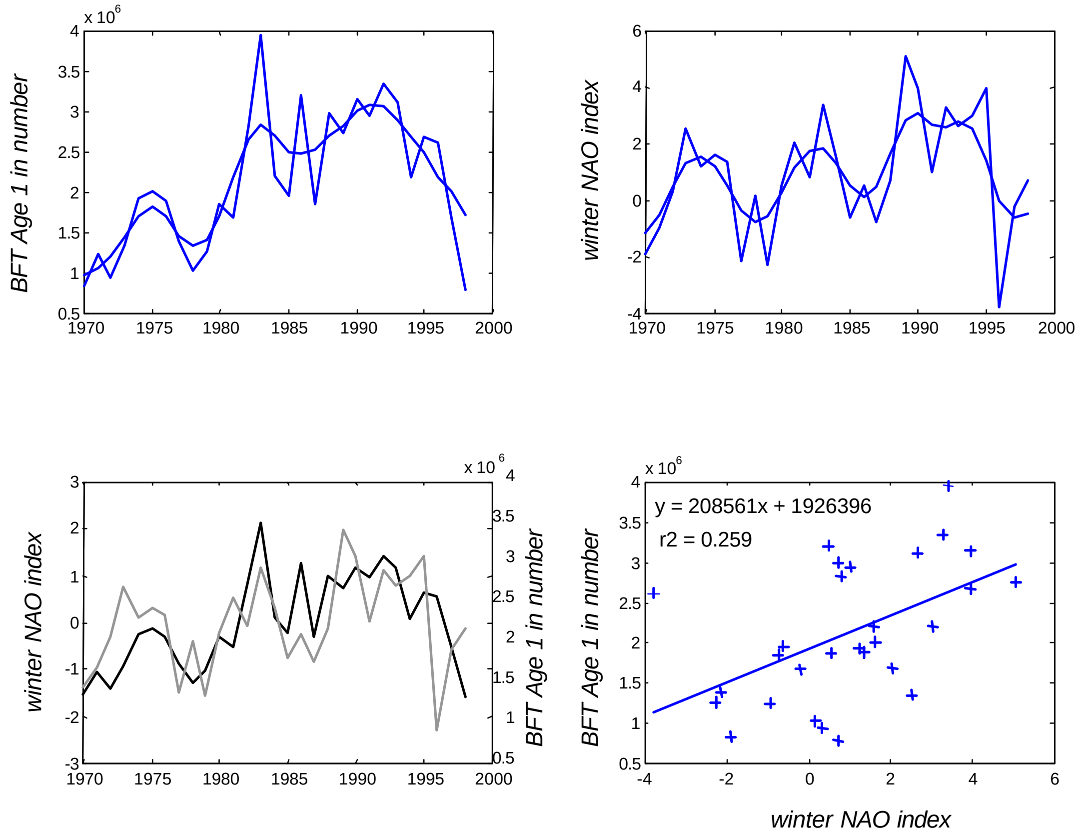


**Figure 2.** Considering the relationship between the NAO and age1 in year *t*. Top panels: age 1 abundance estimated by VPA and NAO time series from 1970 to 1998. Smoothing was performed by the eigen vector filtering. Bottom panels: superimposition of both time series (NAO and age 1 in year *t*) and linear regression plot between these two series

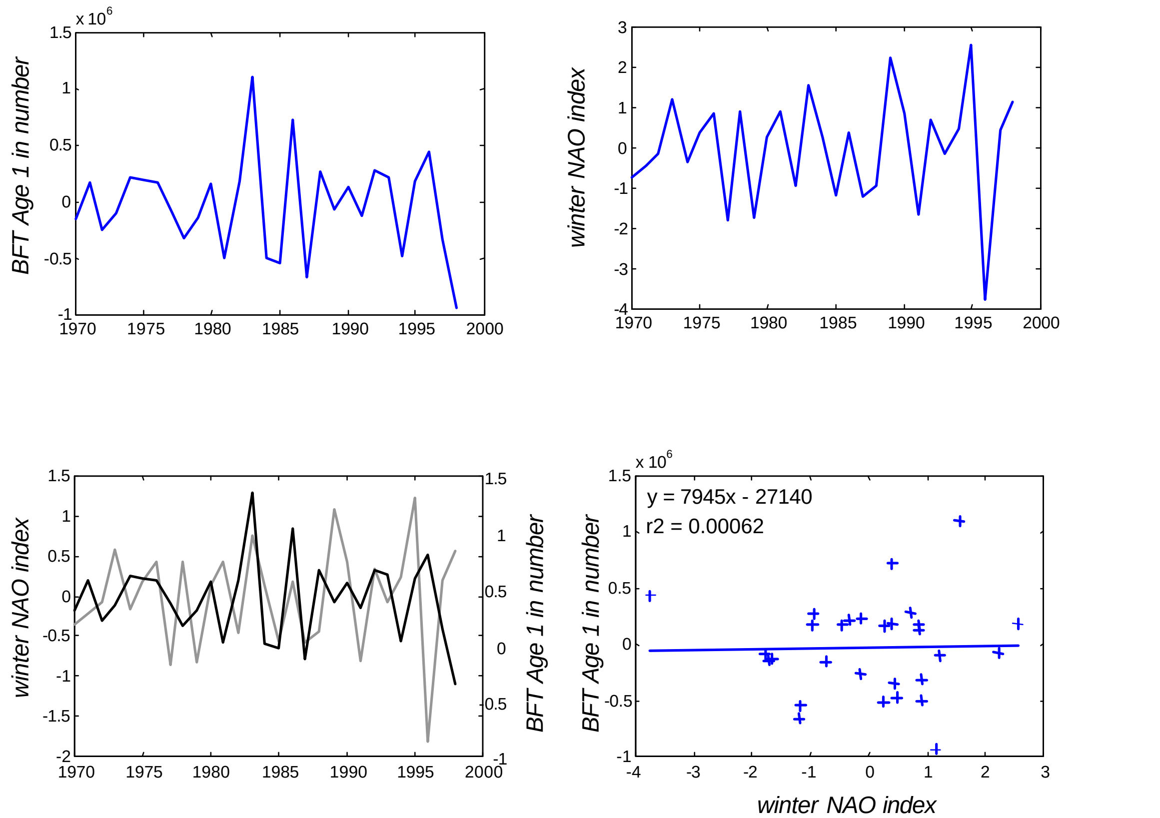


**Figure 3.** Same as Figure 2, but time series have been detrended (i.e., original series minus the trend estimated by the eigen vector filtering)

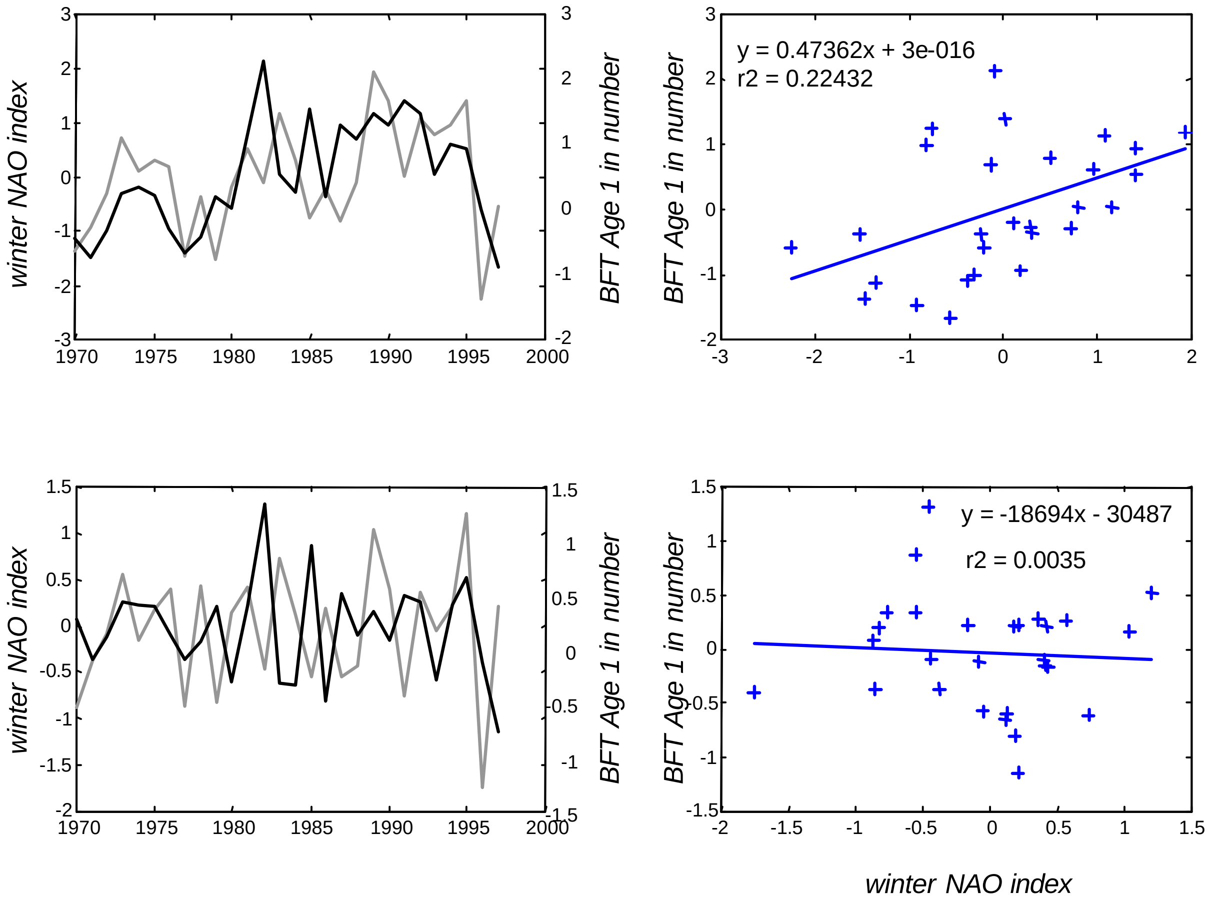


**Figure 4.** Considering the relationship between the NAO and BFT recruitment in year *t*, i.e. age 1 in year *t-1*. Top plots: same as bottom plots of Figure 2, bottom plots: same as bottom plots of Figure 3