IMPLICATIONS OF ENVIRONMENTAL VARIABILITY FOR THE STOCK ASSESSMENT OF NORTH EAST ATLANTIC ALBACORE (*Thunnus alalunga*)

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The North Atlantic Oscillation

The North Atlantic Oscillation (NAO) is an index of the difference in normalised air pressures at sea level between the subtropical high surface pressure, centred on the Azores, and the sub-polar low surface pressure, centred on Iceland (Hurrell 1995; Rogers, 1990). The speed and direction of the Westerlies across the North-Atlantic as well as temperatures on both sides of this ocean are correlated with the pressure difference between the Azores and Iceland. A 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 Canada and *vice versa* (Figure 1).

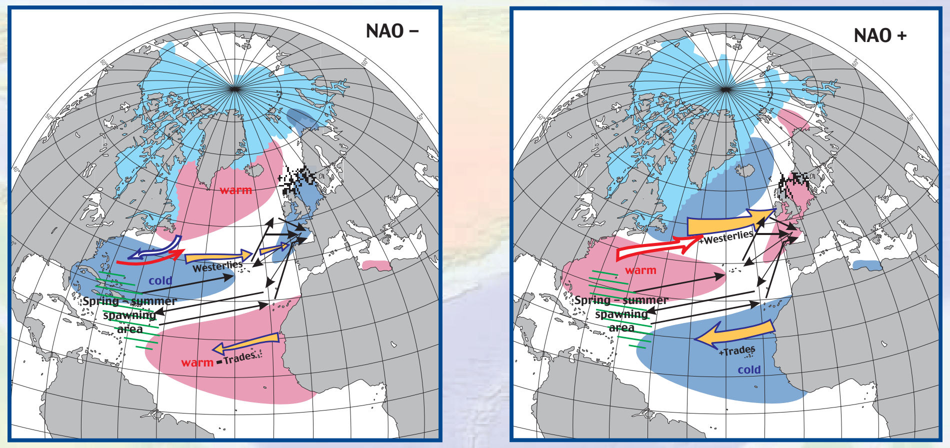

Figure 1: The migratory behaviour of North Atlantic Albacore (Aloncle et Delaporte (1973, 1979); Hue (1980), Bard (1981); Ortiz de Zárate and Cort (1998)) and the changes in large scale atmospheric and oceanographic factors associated with the +ve and –ve phases of the North Atlantic Oscillation (NAO) Dickson, R.R., 1997. From the Labrador Sea to global change. Nature 386: 649-650

Juvenile Albacore caught by trolling

Adult Albacore

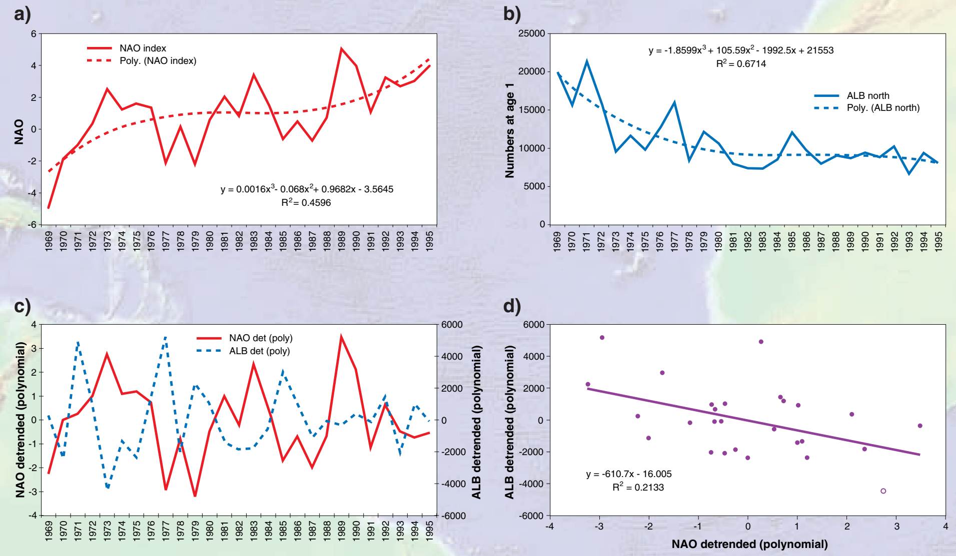

Figure 2: Correlation between North Atlantic Albacore numbers-at-age 1 and North Atlantic Oscillation winter index (NAO).
***a)** NAO and fitted trend.*
***b)** numbers-at-age 1 and fitted trend.*
***c)** detrended series of NAO and numbers-at-age 1.*
***d)** relationship between detrended series. (ICCAT 2001).*

Albacore (*Thunnus alalunga*)

North Atlantic Albacore tuna is a highly migratory species found in both temperate and subtropical waters throughout the North Atlantic. Spawning occurs in the tropical waters of the Sargasso Sea in the western Atlantic between April and September (Ueyanagi, 1971; Shiohama, 1971; Uozumi, 1996). Juvenile albacore then migrate towards the central Atlantic and at 6 months are found wintering around the Azores. Immature age classes (1 to 4 yr old) migrate in spring - within water masses of between 17° and 20°C, Havard-Duclos (1973) - towards feeding grounds in the northeast Atlantic and are subsequently found towards the south west of Ireland and in the Bay of Biscay. At the end of summer these fish return to the wintering area near the Azores and Canary Islands. On reaching maturity adult albacore migrate during spring and summer back to the spawning area in the Sargasso Sea and return to the east central Atlantic during winter months.

Albacore and NAO

Observed numbers-at-age 1 have been shown to be correlated with the winter NAO index in the previous year, Figure 2 (ICCAT, 2002). Two main hypothesises have been postulated to explain this observation (Bard and Santiago 1999), i.e. changes in the North Atlantic atmospheric circulation impact on: (1) recruitment, (2) migration patterns and consequently the availability and catchability of specific age classes to the surface fishery. To distinguish between these hypotheses, cross-correlations (Spearman because of non-normality in some series) have been computed between catches, the VPA estimates of numbers and fishing mortality-at-age and the NAO index (Table 1).

Cross-correlations appeared significant between catch and fishing mortality-at-age 1 and the NAO with lag 1. However the relationship is weaker for numbers-at-age 1 even though under the recruitment hypothesis (1) above it would be expected to be strongest.

Other strong correlations were observed. For example, there is an apparent cohort relationship between numbers-at-age 4 and the NAO at lag 0 up to numbers-at-age 7 and NAO at lag 3. There are also some positive correlations between N, F and catch of ages 4 to 8 with the NAO with a lag of 0 to 3 years respectively, which would indicate the migration/catchability hypothesis, (2) above.

Simulations

Since the cross-correlation analysis was inconclusive, simulations were undertaken to investigate the ability of virtual population analysis (VPA) to distinguish between the different hypotheses.

The simulation model modelled both the albacore population and the fishery upon it (Kell *et al*, 2003) and was used to generate data for use in a calibrated virtual population analysis. This included measurement error in the catch-at-age and CPUE series (due to sampling) and estimation error due to the use of VPA. 0 to 100% of errors were investigated, but only the scenario with 50% is presented.

Process error was modelled for natural mortality and for three scenarios corresponding to the following hypotheses:

H_1: NAO affects recruitment

H_2: NAO affects catchability of 1 and 4 year olds

H_3: NAO affects catchability of 5 to 8 year olds.

VPA Numbers-at-Age

NAO Lags	1	2	3	4	5	6	7	8
0	-0.03	-0.29	0.18	0.65	-0.08	-0.09	0.43	0.04
1	-0.29	-0.10	-0.19	0.13	0.54	0.01	-0.05	0.31
2	-0.05	-0.17	-0.17	0.07	0.01	0.42	-0.08	-0.16
3	0.20	-0.01	-0.23	-0.25	0.06	0.02	0.43	-0.21
4	0.05	0.26	0.00	-0.40	-0.12	-0.10	-0.19	0.14
5	0.18	0.16	0.03	-0.06	-0.22	-0.11	-0.08	-0.12

VPA Fishing Mortality-at-Age

NAO Lags	1	2	3	4	5	6	7	8
0	0.09	0.06	0.15	-0.08	0.00	0.17	-0.10	-0.10
1	-0.39	0.42	-0.21	0.02	-0.06	0.15	0.50	0.50
2	0.10	0.01	-0.21	-0.06	0.45	-0.14	0.19	0.19
3	0.00	-0.02	0.26	0.27	0.42	0.61	0.02	0.02
4	-0.31	0.09	0.06	0.05	-0.03	-0.01	0.17	0.17
5	0.26	0.08	0.13	-0.12	0.06	-0.06	-0.14	-0.14

Catch-at-Age

NAO Lags	1	2	3	4	5	6	7	8
0	0.11	-0.31	0.23	0.26	-0.08	0.12	0.26	-0.16
1	-0.45	0.17	-0.28	0.08	0.29	0.22	0.40	0.56
2	0.00	-0.13	-0.30	0.07	0.29	0.27	0.03	0.05
3	0.05	-0.06	-0.05	0.29	0.42	0.55	0.54	0.07
4	-0.29	0.36	0.04	-0.03	-0.02	-0.08	-0.19	0.39
5	0.37	0.22	0.13	-0.05	-0.03	-0.09	-0.31	-0.24

Table 1: Cross correlations from VPA and catch data (ICCAT database) and NAO

Numbers-at-age 1 correlated with NAO

VPA Numbers-at-Age

NAO Lag	1	2	3	4	5	6	7	8
0	-0.10	-0.01	0.10	0.13	0.01	0.00	0.01	-0.08
1	-0.30	-0.10	0.00	0.06	0.10	0.01	0.02	-0.03
2	0.04	-0.28	-0.06	-0.02	0.06	0.09	0.01	0.00
3	0.14	0.03	-0.19	-0.08	-0.01	0.07	0.06	0.05
4	0.04	0.05	-0.03	-0.11	-0.03	-0.01	0.02	0.11
5	0.16	0.06	0.04	-0.04	-0.10	-0.02	0.00	0.11

VPA Fishing Mortality-at-Age

NAO Lag	1	2	3	4	5	6	7	8
0	0.18	0.14	0.10	0.14	0.17	0.16	0.16	0.16
1	0.12	0.12	0.16	0.10	0.12	0.15	0.09	0.09
2	0.12	0.03	0.18	0.15	0.09	0.09	0.05	0.05
3	0.08	0.03	0.12	0.18	0.11	0.07	0.03	0.03
4	0.12	0.10	0.15	0.13	0.10	0.12	0.10	0.10
5	0.10	0.11	0.12	0.14	0.14	0.14	0.15	0.15

Catch-at-Age

NAO Lag	1	2	3	4	5	6	7	8
0	-0.03	0.01	0.07	0.10	0.05	0.03	0.00	-0.05
1	-0.14	-0.08	0.06	0.03	0.07	0.01	-0.04	-0.07
2	0.01	-0.32	0.01	0.04	0.00	0.03	-0.06	-0.08
3	0.06	-0.08	-0.21	-0.01	-0.03	-0.03	-0.01	-0.05
4	0.01	0.03	-0.01	-0.11	-0.06	0.00	0.00	0.03
5	0.05	0.03	0.03	-0.03	-0.08	-0.01	0.01	0.09

Catchability-at-ages 1 to 4 correlated with NAO

VPA Numbers-at-Age

NAO Lag	1	2	3	4	5	6	7	8
0	-0.01	-0.01	0.04	0.01	0.02	0.04	0.03	-0.02
1	-0.01	-0.12	-0.14	-0.12	-0.07	0.02	0.04	0.03
2	0.05	-0.04	-0.06	-0.10	-0.09	-0.05	0.03	0.06
3	0.08	0.03	-0.02	-0.01	-0.08	-0.06	-0.03	0.09
4	-0.02	0.01	0.03	0.02	-0.01	-0.07	-0.07	0.05
5	-0.01	0.05	0.11	0.11	0.07	-0.02	-0.06	-0.01

VPA Fishing Mortality-at-Age

NAO Lag	1	2	3	4	5	6	7	8
0	0.67	0.46	0.44	0.49	0.16	0.16	0.16	0.16
1	0.23	0.08	0.15	0.13	0.13	0.13	0.09	0.09
2	0.03	0.07	0.09	0.05	0.10	0.11	0.04	0.04
3	-0.07	-0.05	0.10	0.02	0.10	0.09	0.04	0.04
4	-0.19	-0.14	-0.07	-0.11	0.12	0.11	0.07	0.07
5	0.03	0.11	0.09	0.11	0.15	0.11	0.16	0.16

Catch-at-Age

NAO Lag	1	2	3	4	5	6	7	8
0	0.56	0.28	0.32	0.42	0.06	0.05	0.04	0.01
1	0.11	-0.12	-0.12	-0.11	-0.07	0.01	0.01	-0.02
2	-0.03	-0.08	-0.10	-0.16	-0.12	-0.07	-0.05	-0.04
3	-0.10	-0.10	-0.03	-0.16	-0.10	-0.09	-0.12	-0.04
4	-0.28	-0.20	-0.13	-0.21	-0.04	-0.07	-0.11	-0.01
5	-0.05	0.03	0.10	0.12	0.07	-0.01	-0.04	0.02

Catchability-at-ages 5 to 8 correlated with NAO

VPA Numbers-at-Age

NAO Lag	1	2	3	4	5	6	7	8
0	-0.04	-0.01	0.04	0.03	0.04	-0.02	-0.02	0.03
1	0.00	-0.03	0.00	0.00	0.02	-0.06	-0.14	-0.21
2	0.06	-0.03	-0.04	-0.03	0.00	0.03	-0.07	-0.25
3	0.06	0.03	-0.04	-0.05	-0.02	0.01	0.04	-0.10
4	-0.03	0.00	0.02	-0.01	-0.03	0.00	0.02	0.01
5	-0.01	0.00	0.00	0.01	-0.01	0.03	0.08	0.17

VPA Fishing Mortality-at-Age

NAO Lag	1	2	3	4	5	6	7	8
0	0.18	0.13	0.15	0.13	0.56	0.57	0.63	0.63
1	0.17	0.15	0.19	0.16	0.15	0.17	0.18	0.18
2	0.15	0.15	0.19	0.17	0.04	0.02	-0.07	-0.07
3	0.10	0.09	0.20	0.18	0.00	-0.01	-0.14	-0.14
4	0.13	0.11	0.13	0.14	-0.14	-0.18	-0.26	-0.26
5	0.09	0.12	0.14	0.13	0.11	0.10	0.07	0.07

Catch-at-Age

NAO Lag	1	2	3	4	5	6	7	8
0	0.02	-0.01	0.05	0.03	0.45	0.45	0.30	0.45
1	0.03	-0.02	0.05	0.03	0.06	0.00	-0.13	-0.12
2	0.05	-0.03	0.05	0.03	-0.07	-0.06	-0.20	-0.31
3	0.03	-0.02	0.01	0.01	-0.14	-0.14	-0.13	-0.31
4	0.02	-0.01	0.00	0.00	-0.25	-0.26	-0.19	-0.27
5	-0.02	-0.01	0.01	-0.01	-0.03	0.02	0.08	0.09

Table 2: Cross correlations from simulated data according to hypotheses H1, H2 and H3

Numbers-at-age 1 correlated with NAO

VPA Numbers-at-Age

NAO Lag	1	2	3	4	5	6	7	8
0	0.24	0.17	0.25	0.31	0.21	0.21	0.23	0.31
1	0.61	0.22	0.15	0.22	0.28	0.21	0.23	0.31
2	0.23	0.57	0.18	0.14	0.21	0.27	0.21	0.32
3	0.34	0.24	0.39	0.23	0.18	0.23	0.25	0.32
4	0.14	0.16	0.17	0.26	0.17	0.18	0.18	0.32
5	0.28	0.16	0.18	0.16	0.24	0.17	0.16	0.35

VPA Fishing Mortality-at-Age

NAO Lag	1	2	3	4	5	6	7	8
0	0.19	0.18	0.20	0.23	0.20	0.20	0.27	0.27
1	0.19	0.18	0.20	0.20	0.21	0.21	0.24	0.24
2	0.24	0.27	0.21	0.19	0.20	0.18	0.28	0.28
3	0.22	0.27	0.20	0.22	0.19	0.22	0.30	0.30
4	0.14	0.16	0.18	0.18	0.18	0.16	0.23	0.23
5	0.17	0.16	0.18	0.18	0.17	0.19	0.18	0.18

Catch-at-Age

NAO Lag	1	2	3	4	5	6	7	8
0	0.21	0.19	0.21	0.24	0.23	0.24	0.19	0.23
1	0.30	0.22	0.22	0.20	0.23	0.22	0.19	0.21
2	0.21	0.67	0.18	0.20	0.18	0.19	0.22	0.21
3	0.27	0.23	0.42	0.21	0.18	0.22	0.21	0.22
4	0.15	0.13	0.16	0.24	0.20	0.18	0.19	0.17
5	0.19	0.15	0.16	0.18	0.22	0.16	0.16	0.21

Catchability-at-ages 1 to 4 correlated with NAO

VPA Numbers-at-Age

NAO Lag	1	2	3	4	5	6	7	8
0	0.19	0.20	0.21	0.24	0.22	0.22	0.22	0.30
1	0.17	0.25	0.28	0.25	0.25	0.19	0.20	0.33
2	0.28	0.19	0.18	0.21	0.22	0.22	0.19	0.33
3	0.29	0.26	0.19	0.19	0.20	0.20	0.23	0.33
4	0.15	0.15	0.18	0.17	0.20	0.19	0.19	0.27
5	0.12	0.18	0.23	0.24	0.19	0.19	0.17	0.27

VPA Fishing Mortality-at-Age

NAO Lag	1	2	3	4	5	6	7	8
0	0.99	0.76	0.65	0.75	0.20	0.21	0.26	0.26
1	0.21	0.15	0.16	0.16	0.20	0.20	0.23	0.23
2	0.16	0.21	0.20	0.16	0.20	0.19	0.29	0.29
3	0.32	0.34	0.20	0.25	0.19	0.22	0.29	0.29
4	0.58	0.50	0.36	0.42	0.18	0.16	0.21	0.21
5	0.10	0.13	0.17	0.15	0.20	0.17	0.20	0.20

Catch-at-Age

NAO Lag	1	2	3	4	5	6	7	8
0	0.97	0.56	0.65	0.83	0.22	0.24	0.21	0.18
1	0.21	0.27	0.26	0.22	0.22	0.19	0.19	0.21
2	0.14	0.22	0.19	0.31	0.26	0.22	0.19	0.21
3	0.24	0.29	0.19	0.31	0.25	0.25	0.30	0.22
4	0.57	0.37	0.26	0.40	0.14	0.20	0.23	0.18
5	0.13	0.15	0.21	0.22	0.21	0.16	0.18	0.18

Catchability-at-ages 5 to 8 correlated with NAO

VPA Numbers-at-Age

NAO Lag	1	2	3	4	5	6	7	8
0	0.19	0.19	0.24	0.27	0.23	0.23	0.22	0.30
1	0.19	0.17	0.18	0.22	0.24	0.24	0.31	0.45
2	0.26	0.19	0.18	0.19	0.21	0.24	0.24	0.51
3	0.27	0.24	0.25	0.22	0.21	0.24	0.23	0.37
4	0.18	0.15	0.17	0.18	0.18	0.16	0.19	0.25
5	0.13	0.16	0.15	0.17	0.17	0.19	0.21	0.38

VPA Fishing Mortality-at-Age

NAO Lag	1	2	3	4	5	6	7	8
0	0.22	0.23	0.25	0.23	0.88	0.91	0.96	0.96
1	0.22	0.21	0.22	0.20	0.15	0.16	0.20	0.20
2	0.23	0.23	0.22	0.21	0.14	0.14	0.36	0.36
3	0.19	0.24	0.23	0.24	0.26	0.25	0.50	0.50
4	0.17	0.16	0.15	0.16	0.53	0.58	0.76	0.76
5	0.20	0.18	0.16	0.18	0.16	0.16	0.16	0.16

Catch-at-Age

NAO Lag	1	2	3	4	5	6	7	8
0	0.23	0.25	0.22	0.24	0.87	0.89	0.63	0.88
1	0.24	0.20	0.22	0.20	0.16	0.14	0.26	0.18
2	0.25	0.21	0.21	0.20	0.13	0.15	0.39	0.63
3	0.24	0.22	0.21	0.22	0.27	0.27	0.27	0.64
4	0.17	0.16	0.16	0.18	0.51	0.54	0.35	0.55
5	0.19	0.17	0.18	0.15	0.14	0.13	0.18	0.17

Table 3: The probabilities of getting an R value> 0.25 or less than –0.25, the intention is to show the probability of getting spurious correlations

Results

1) H1 induces significant but not very strong cross-correlations between the numbers-at-age 1 and 2 or the catch at age 2 and the NAO
2) H2 and H3 induce significant and higher cross-correlations between F, catch and NAO, but without any cohort effects.
3) H2 and H3 induce no significant cross-correlations between N and NAO (probably because of the algorithm of the VPA in which errors are cumulated for N but not for F)

When comparing Table 2 to Table 1, it is difficult to explain all the observed correlations in Table 1. To check for this, the probability of obtaining a correlation greater than 0.25 are presented in Table 3:

4) The probability of obtaining significant correlations as a result of chance is large.
5) Short-time series (30 yrs), observation errors and autocorrelation in the NAO time series also increase the probability of spurious correlations.

Conclusion

The probability of detecting spurious correlations between a given environmental variable, such as the NAO and VPA outputs appears to be strongly related to the level of error in the stock assessment, due to both the observations and assumptions made within the assessment procedure. VPA assumes that catch-at-age and natural mortality are known without error and that the data corresponds to a discrete stock. However in general, data used in VPA suffer from moderate to large observation errors (due to non random sampling strategies, approximations in length and age procedures etc.). Thus correlations based solely on VPA outputs may not be conclusive.

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