School of aquatic and fisheries sciences

Mémoire de fin d'études
Pour l'obtention du Master Sciences Agronomiques et Agroalimentaires Spécialité Sciences Halieutiques et Aquacoles

Evaluating the role of fishing and environment, in determining the surplus production of the North Sea fish stocks

Présenté par : VERT-PRE, Katyana

Soutenu le : 11 Septembre 2008

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Titre :

Evaluating the role of fishing and environment, in determining the surplus production of the North Sea fish stocks

Résumé :

Comprendre l'importance relative de la pêche et de l'environnement en ce qui concerne la définition de l'abondance et de la productivité du stock, a toujours été problématique. En lien avec cette problématique émerge la question de non reconstruction de certains stocks à abondance faibles. L'intérêt étant de déterminer si ce phénomène est plutôt lié à la pression de pêche, à l'environnement ou à des mécanismes complexes. Cette étude s'est penchée sur les variations de biomasse de 12 stocks, évalués par le CIEM, dans la mer du Nord. Une confrontation de trois hypothèses en ce qui concerne la variabilité au sein des stocks est réalisée à partir de trois modèles. Ces modèles sont appliqués au surplus de production annuelle, consideré comme mesure de la productivité du stock. Le premier modèle est un modèle dynamique de biomasse représentant l'hypothèse de la pression de pêche. Comme hypothèse alternative, un modèle traduit des périodes de productivité élevée et des périodes de de basse productivité. Le dernier modèle est une combinaison des deux précédentes hypothèses. Sur 12 stocks, 6 stocks ont expérimenté un déclin entre 1960 et 2005, aujourd'hui 2 stocks demeurent a un niveau de biomasse critique. Le taux d'exploitation, pour la plupart des stocks dans les années 60 était entre 0,2-0,4 et oscille maintenant entre 0,3 et 0,5. Ces taux, trop élevés par le passé sont encore nettement supérieurs à ce que peuvent supporter ces stocks. Les données de surplus de production donnent plus de credit à l'hypothese de pression de pêche pour un stock. Les données de 5 stocks donnent credit à l'hypothese environnementalle et 4 à l'hypothese mixte. En conclusion, les stocks ne se reconstruisent pas parce qu'ils sont surexploités et généralement façonnés par des processus complexes liés aux conditions environnementales et à la pression de pêche.

Annexe 4

Abstract :

Understanding the relative importance of fishing and environment in driving stock abundance and productivity has always been a debated issue. Related to this debate is why some stocks appear not to recover from low abundance; is non-recovery linked to fishing pressure, environment or complex mechanisms. In this paper we analyze the evolution of fishing pressure as the biomass fluctuates for 12 stocks, assessed by ICES, in the North Sea. Then, using annual surplus production as a measure of stock productivity, we compare three models in order to establish what is driving stocks. We use a biomass dynamics model to represent the fishing driven hypothesis. As an alternate we consider that surplus production is driven externally and comes in regimes of higher and lower productivity. Finally we consider a mixed model that combines biomass and environmentally driven productivity. Out of 12 stocks, 6 stocks experienced a collapsed between 1960 and 2005 and 2 remain collapsed. Exploitation rate for most stocks in the 60's was between 0.2-0.4 and is now between 0.3-0.5. Such rates were too high and are still higher than most stocks can support. We found for one of the stocks the surplus production data is best explained by the fishing impacts model, for 5 of the stocks the surplus production data support the environmental hypothesis and for 4 of the stocks the mixed model is the best explanation. Finally, stocks might not recover because they are still fished too hard and moreover because most stocks are driven by environmental and fishing complex processes.

Mots-clés :

Key words: Surplus production, Fishing pressure, Regime shift, Model selection, North Sea

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Glossary

Recruitment: The number of fish added to the exploitable stock, in the fishing area, each year, through a process of growth (i.e. the fish grows to a size where it becomes catchable) or migration (i.e. the fish moves into the fishing area).

Annual surplus production: The net production a population experiences, change in biomass plus any removals from harvest

Exploitation rate: The proportion of a population at the beginning of a given time period that is caught during that time period (usually expressed on a yearly basis).

Depensation effect: Refers to the case in which rates of population growth per capita decline when population sizes fall below some threshold level of abundance

Collapsed: landings drop below 10% of the maximum catch.

Regime shift: A (medium- or long-term) shift in environmental conditions that impacts the productivity of a stock.

ICES: International council of the exploration of the seas

LME: Large marine ecosystem

Introduction

I.1 Global stock condition

The future of fisheries has been a serious concern since the last centuries and is even more nowadays. In 1884, a debate about the sustainability of stocks was ongoing. Two main views rose. The Thomas Huxley's inexhaustible theory (Huxley, 1884) : … *that the cod fishery, the herring fishery, the pilchard fishery, the mackerel fishery and probably all the great sea fisheries, are inexhaustible; that is to say that nothing we do seriously affects the number of fish. And any attempt to regulate these fisheries seems consequently…to be useless.* And the more conservative view of the situation supported by the Ray Lankester quote (Lankester, 1984): *It is a mistake to suppose that the whole ocean is practically one vast store-house, and that the place of the fished removed on the particular fishing-ground is immediately taken by some of the grand total fish, which are so numerous in comparison with man's depredations as to make his operation in this respect insignificant.*

Nowadays, most scientists have rejected the Huxley hypotheses. Fish resources have proven to be in many cases exhaustible (Casey and Myers, 1998, Gaston and Fuller, 2007). The main concern now is to define what drives fish stocks abundance. Mainly two hypotheses prevail; the first is that the fish stock abundance is mainly driven by fishing pressure; the second is that, most of the abundance of the fish stocks is environmentally driven. Many reports and studies are in favor of one or the other hypothesis. Myers et al. (1994) think that fishing can lower the biomass enough to affect recruitment and therefore affect surplus production. Some other scientist are more in favor of the environment hypotheses, like Gilbert (1997) who proposed that there are successive good and bad periods of recruitment linked to good and bad environmental conditions.

I.2 The Hutchings theory

I.2.1 The non recovery issue

Hutchings and Reynolds (2004) considered the decline and recovery of fish stocks. They found that out of 192 species examined 58% exhibited a maximum decline of 80% or more (corresponding to the IUCN definition of threatened (Baillie et al., 2004)). Hutchings (2000*b*) found that the population recovery is linked to the magnitude of the population decline. For 90 marine fish stocks examined 41% keep declining after a 15 year period. 51% exhibited some recovery and 8% fully recovered. A second interesting result is the apparent relation between the family of the species and the recovery abilities. In fact; all the stocks which have fully recovered are clupeids (Hutchings and Reynolds, 2004). These results suggest that clupeids are more resilient to decline in the long run than other taxonomic groups. Several hypotheses can be made;

the first one being that the short life cycle of these species may help them to make up for fishing pressure, the second hypothesis being that fishing methods used to fish small pelagic fishes, usually seine or mid water trawl, are less destructive for habitats than others, like bottom trawls. The alternative explanation is that the economics of clupeids is such that when they collapse fishing is no longer profitable and fishing declines, whereas for gadids and other taxa fishing remains profitable and fishing pressure doesn't decline. The declines might also be due to the fact that clupeids are more environmentally driven than others stocks (Casini et al., 2006).

I.2.2 Complex mechanism explaining the non recovery

These hypotheses brought Hutchings and Reynolds (2004) to the conclusion that, not only fishing pressure is the origin of decline and non recovery of fish stocks, but also more complex mechanisms beyond simple fishing may be responsible for the lack of recovery. Hutchings analysis (2001*a*), reveals no significant correlation between reduction in fishing mortality and rates of recovery. Nonetheless, populations seem to recover more quickly when fishing mortality is reduced after the collapse. Fishing pressure is part of the non recovery, though it might not be the only explanation for non recovery. Therefore, Hutchings and Reynolds (2004) introduced several hypotheses that might explain the non recovery of fish.

According to these authors, societal and managerial responses influence the recovery. The faster the managerial response to the population collapse, the better the chances of recovery., However; the response is usually delayed for societal or political issues. Political authorities and fishermen might first reject the decision on the grounds that there is no need to take drastic measures, as the landings remains acceptale.

Another hypothesis is related to life history traits. The common belief was that highly fecund fishes are more efficient in recovery. But in fact, two highly fecund fish, the North Atlantic cod (COSEWIC, 2003) and the Chinese bahaba (Sadovy and Cheung 2003) did not recover. On the contrary, it seems that high fecundity may be associated with low recovery (Denney et al., 2002). Fishing changes the size and age structure of the population. Indeed, fishing usually selects bigger individual are the best spawners, and thus fishing lowers the fecundity of the population.

In general, fishing selects the largest, oldest and fastest-growing individuals which trigger a genetic selection effect (Hutchings and Reynolds, 2004). The genetic selection may lead to evolutionary changes that weaken the population, like reduction in age of maturity or reduction in size (Sinclair et al., 2002). For example, the North Sea plaice and the North Atlantic cod have both shown reduction in age at maturity and smaller body size at age (COSEWIC 2003). Those modifications may increase post-reproductive mortality and smaller size at reproductive age, which reduces fecundity and produced smaller eggs (Hutchings and Reynolds, 2004).

Another hypothesis deals with "depensation" effect. "Depensation" effect refers to the case in which rates of population growth per capita decline when population sizes fall below some threshold level of abundance. Fishing is usually the variable leading, directly or indirectly, the population below this threshold.

The modification in inter-species relation ships can also be a cause of non recovery of fish.

The last hypothesis is habitat loss. Habitats are very important for all stages of development of fish. Indeed, fishing gears keep destroying and consequently reducing the available habitat (Reynolds et al., 2005). For example, bottom trawling tosses sediments and destroys the benthic life. Therefore, this gear may be an issue for recovery of demersal species. Thus, we expect the recovery to be more difficult for demersal species than for pelagics. The Hutchings complex mechanism is an alternative theory to the more traditional and simpler theories of Thompson that fish abundance drives productivity and Burkenroad that environmental changes drive productivity.

I.3 The role of environment and The Thompson-Burkenroad debate

I.3.1 The Thompson-Burkenroad debate

Initially, this debate was started when Michael Graham (1935) critized Thompson's statement that recruitment is uniform, based on yield and the relationship between growth and natural mortality (Skud, 1975). At that time, Thompson was working on Pacific halibut. He explained that changes in abundance were linked to fisheries impacts on abundance. He tried to prove statistically the existence of a high correlation between effort and CPUE (Thompson and Bell, 1934). Burkenroad 1(948), replied that Thompson and Bell estimation of the fishing mortality was too high and that the changes in CPUE are far greater than it might be explained by fishing. These results led him to the conclusion that these changes in abundance were also environmentally induced. Therefore Thompson (1950) recognize the difficulty in identifying natural versus fisheries changes: "…*So I can see that all organic life is subject to fluctuations as the environment on which it depends, an environment which determines the rate at which organisms die. Each species through its mortality rates and accumulated stocks is in balance with its environment and its own reproductive characteristics, and these form the essential core of the species. The halibut fishery disturbs these relationships, and natural factors can only be determined when these effects of the fishery are taken into account. The dynamics of the fished populations explain the major changes in the halibut stock. The changes in productivity remain to be explored.*" (Thompson, 1950).

I.3.2 Ecosystem fishing or environmentally driven

From this debate rises three hypotheses, hypothesis of a change in productivity linked with fisheries impacts on abundance, the hypothesis of those changes linked with environmental conditions. And the last, which combines the ideas, the changes in productivity linked with fisheries and environmental conditions. Each hypothesis has many arguments in favor or against them. Many studies tried to prove that fluctuations in abundance are driven by fishing. Anderson et al., (2008) compared fluctuations in abundance for the targets species to fluctuations in abundance for non-harvested species. They figured out that of 7 exploited stocks there were no evidence of correlation between the variance in fishing mortality and in abundance. Nevertheless, Jonzen et al. (2001), discovered a positive correlation between the variance in fishing mortality and the variance in abundance. These results led to the conclusion that fishing mortality might or might not lead to variability in the stock abundance.

The second hypothesis is that productivity and thus abundance variability is linked to environmental changes. Several publications described the hypothetical relationships between the size of a fish spawning stock and the consequent number of recruits present (Ricker, 1954). Hidalgo et al, (2008) present a study on hake assuming that the recruitment of these stocks is environmentally driven. They find as a result that for the adults, the abundance and biomass for the commercial fisheries did not reveal any fluctuation due to seasons. Whereas for younger individuals, for which it seems that there was a seasonal effect. Recruitment can respond to different environmental variation with different scales. The variability can be linked with regime shift or seasonal changes or climatic events like El Niño or PDO. As for Cushing (1996), there is evidence for many stocks that there is environmentally driven variability in recruitment. One of the examples is the cod in the North Atlantic. It seems that the recruitment is linked with the sea temperature for stocks located on the limit of the species distribution. In the upper limit, increasing temperature are favorable for stocks and non favorable for stocks in the lower limit (Planque and Fredou, 1999).

Gilbert (1997) proposed an alternative to the standard recruitment paradigm, involving the idea of a positive correlation between recruitment and spawning stock biomass. He presents this alternative introducing a new model. The main hypothesis is that time series of recruitment usually present successive periods of high or low values. From there, Gilbert makes the hypothesis that in a defined system, a stock can experiment several states of recruitment. These states are being driven by different environmental factors. In the model, Gilbert associates a mean recruitment to each period. Seemingly, the recruitment is on average determine by spawning stocks biomass and positively related to it at low biomass. Finally, the stock can occupy multi states in which recruitment varies around a different constant mean (Gilbert, 1997).

It is usually hard to make a distinction between fishing mortality effect and environment effect. As fishing selects bigger and larger individuals it changes the age and size structure of the population. Therefore the population is weakened and is more sensitive to environmental variability. The results of the hake studies confirm this hypothesis. Hsieh et al. (2008) find that 7 species out of 29 significatively have changed their geographical distribution, 8 species show a significant relation to a climate index like the Pacific Decadal Oscillation. This study concludes that fishing is actually the cause weakening the population by changing their spatial distribution.

I.4 Context of the study

I.4.1 Using the North Sea as an example

The North Sea is a semi-continental large marine ecosystem in Northern Europe. The North Sea as defined by the International Council of the Exploration of the Seas is the zone IV (figure 1). The climate is temperate were about 224 species of fish are found. Less than 20% species make 95% of the biomass (Ducrotoy et al., 2000).

The North Sea fishery has been one the world's most active fisheries. The greatest landings per unit area are reached there (Ducrotoy et al, 2000). This area has been overfished for years especially with beam trawling and other demersal methods. However, the total biomass seems to remain almost stable and the landings are lightly decreasing.

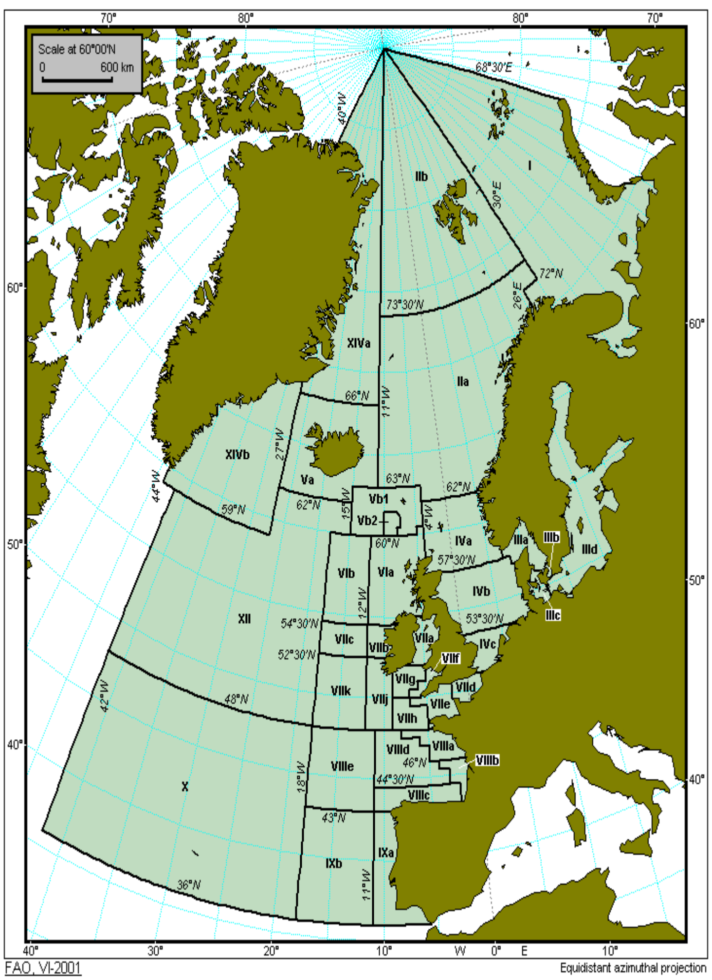

Figure 1: Fishing zone in 2001 established by the International Council of the Eploration of the Seas.

I.4.2 Fishing pressure

For the North Sea we have stock assessments of 12 species, constituting 78% of the total catch. We will use these stock assessments to assess competing hypotheses about the role of fishing and environment in driving the abundance of fish stocks.

As the ICES report, out of these 12 stocks, 2 stocks have no management plan implemented. Even so, when some stocks recover, others don't; which brings us back to the Hutchings question: why don't stocks recover? Every complex theory that Hutchings presents in Hutchings and Reynolds, 2004 are bound directly or indirectly to fishing. We must not underestimate the effect of fishing on the ecosystem. Fishing is a variable increasing the negative effect of recovery of other variables. Presently the only way we know to reduce fishing impact is management strategy.

I.4.3 Surplus production as an indicator in the Thompson-Burkenroad debate

Most of the discussion and debate about the role of environment and fishing on fish stocks (Gilbert, 1997) has concentrated on recruitment, ignoring the important role of changes in body size through somatic growth, and natural mortality rate, both of which can dramatically affect stock size and productivity. The annual surplus production (ASP) is the net production a population experiences, change in biomass plus any removals from harvest (Ricker, 1975). Surplus production is an interesting variable to work with for two main reasons. First, this variable is very informative as it is the net result of recruitment, somatic growth and mortality. Therefore, surplus production is a fundamental variable in fisheries science and fisheries management. For example, if the surplus production is negative it means that the biomass of the stock will decline, even with no catch. On the contrary, if surplus production is positive, the stock is productive. By knowing surplus production, managers have additive information on what exploitation the stock can handle. Second, surplus production captures environmental changes such as regime shift (Jacobson et al., 2001). Thus, a regime will be a period of high or low surplus production.

I.5 Analytic approach

In a first part we will try to determine, how fish stocks of the North Sea respond to fishing pressure. The second main purpose of this paper is to try and give an answer to the Thompson-Burkenroad debate using surplus production. It means determine whether stocks are fishing driven, environmental driven or both fishing and environmental driven, that is to say "combine variable driven". We are analyzing which of the 3 hypotheses proposed by the Thompson-

Burkenroad debate applying 3 models that can support the 3 scenarios of fishing, environmental and combine variable driven surplus production. These models will give us an outlook of the situation of the North Sea stocks. Nonetheless, the most interesting is that finally by knowing how many stocks are fishing or environmental or the combine variable driven, we might be able to address the Thompson-Burkenroad debate, at least for the North Sea.

II Materials and methods

II. 1 Data

II.1.1 Data sources

The North Sea is a highly exploited ecosystem counting 299 species. In this paper, Cod (*Gadus morhua*), Sole (*Solea solea*), Blue whiting (*Micromesistius poutassou*), Norway pout (*Trisopterus esmakii*), Plaice (*Pleuronectes platessus*), Saithe (*Pollachius virens*), Sandeel (*Ammodytes marinus*), Hake (*Merluccius merluccius*), Mackerel (*Scomber scombrus*), Whiting (*Merlangius merlangus*), Herring (*Clupea harengus*), Haddock (*Melanogrammus aeglefinus*) are the 12 stocks of this ecosystem we have selected to run these analyses.

The first step is to work with long time series and reliable data. Therefore we use data from two sources. On the one hand we are dealing with catch and biomass data from ICES (International council of the exploration of the seas) and on the other hand with catch data from LMEs (Large marine ecosystems). As some biomasses from ICES were missing we've estimated them with the equation (1), taken from the VPA analysis methods used in ICES (Lassen and Medley, 2001).

$$B_t = \frac{C_t}{\frac{F_t}{F_t + M} \times \left(1 - e^{(F_t + M)}\right)} \quad (1)$$

where

B_t is the biomass at year t

C_t is the landings at year t

F_t is the fishing mortality at year t

M is the natural mortality3 (Source fish base)

II.1.2 Combine stocks issue

The ICES data contain, for some species, combine stocks that gathered data from other stocks than the North Sea. To select the proportion that is allocated to the North Sea in those stocks, we use the LME data. We make the assumption that the LME data and the ICES data are equal. Then, an allocation rate is calculated by dividing the LME data by the catch data. This rate will be used to calculate the Surplus production and the production rate allocated to the North Sea for the combined stocks.

II. 2 Context of the North Sea

The first analyses are made with both LME and ICES data, in order to outline the main trends in the North Sea. From the assessments we have Biomass and Catch from 1953 to 2005. Over this same period, using the LME data we calculate the percentage of collapsed species using the definition that a stock is collapsed when landings drop below 10% of the maximum catch.

II. 3 Analyses of the Hutchings question

As the data set is operational, we can try to answer the first main question of the paper. Therefore, in a first stage features the biomass versus the annual exploitation fraction. This exploitation rate is calculated by dividing catch by the biomass.

II. 4 Fitting surplus production model

II 4.1 The SP definition

We calculate the surplus production by using the equation (2) and the production rate by using the equation (3).

$$SP_t = B_{t+1} - B_t + C_t \quad (2)$$

$$SPR_t = \frac{SP_t}{B_t} \quad (3)$$

where

SP_t is the surplus production at year t
SPR_t is the surplus production rate at year t
B_t is the biomass at year t
C_t is the catch at year t

II 4.2 Three scenarios-Three models

Then, we fit each model to a specific three scenarios. In order to represent the fishing pressure a Pella-Tomlinson model (1969) has been selected (4). In this scenario we are searching over the shape parameter (n), the maximum surplus production (m) and the carrying capacity (Binf). The m and Binf are initialized respectively with the value of the maximum surplus production and biomass. The n parameter is initialized for each species.

$$SP_t = zm\left(\frac{B_t}{B_\infty}\right) - zm\left(\frac{B_t}{B\infty}\right)^n \quad (4)$$

$$z = \frac{n^{\left(\frac{n}{n-1}\right)}}{n-1}$$

were

n is the shape parameter
B_∞ is the carrying capacity
m is the maximum surplus production

The second model is a regime shift model (5). The first step is to calculate the average surplus production over the time series. Then we determine visually break points in the data set that might correspond to regime shifts. Those break points are delimitation for different regime period. Each period is associated to a coefficient (Pi) that we multiply to the average Sp in order to calculate the average SP in each period. Each coefficient is a estimated parameter.

$$SP = \left(\overline{SP} \times P_1, \ldots, \overline{SP} \times P_k\right) \quad (5)$$

where

$\overline{SP}$ is the average of the surplus production on the time series
P_i is a parameter determine for each period
k is the number of periods

The last model is the mixed model (6) combining the first two scenarios. The parameters are the coefficient Pi and m, Binf and n.

$$SP_t = \left(zm\frac{B_t}{B\infty} - zm\left(\frac{B_t}{B\infty}\right)^n \times P_1, ..., zm\frac{B_t}{B\infty} - zm\left(\frac{B_t}{B\infty}\right)^n \times P_k \right) \quad (6)$$

For the three model the procedure is to find the set of parameters that minimizes the negative log likelihood (nll) by using a Generalized Reduced Gradient methods in excel 2003 and R 2.6.2. The negative log likelihood is the negative sum of the equation (7) for each year.

For all three models we consider an additive process error, $\varepsilon_i \sim N(0,\sigma^2)$ were σ is a function of the predicted surplus production (8). In each model we estimate the slope and the intercept like parameters for each 12 species.

$$L\left(SP_t \mid S\hat{P}_t\right) = \frac{1}{\sigma\sqrt{2\pi}} e\left(-\frac{\left[SP_t - S\hat{P}_t\right]^2}{2\sigma^2} \right) \quad (7)$$

where

SP is the observed surplus production
$S\hat{P}$ is the predicted surplus production
σ is the variance

$$\sigma_t = Slope \times SP_t + Intercept \qquad (8)$$

II 4.3 Comparing models

Finally, the comparison of the 3 models is done using the Akaike weights (9, 10, 11) (Hobbs and Hilborn, 2006). The Akaike weights will take value between 0 and 1, it can be interpreted as the probability that the model r emerge as the best model given many repetition of the model selection exercise (Royall, 1997, Hobbs and Hilborn, 2006)

$$AIC = 2nll + 2K \quad (9)$$

where

nll is the negative log likelihood at the maximum likelihood estimate
K is the number of parameters in the model

$$\Delta_r = AIC_r - \min(AIC) \quad (10)$$

$$W_r = \frac{e^{-2\Delta_r}}{\sum_{i=1}^{r} e^{-2\Delta_r}} \quad (11)$$

where

r is the model selected

II 4.4 Testing the reliability of the results

To test what rate of variability of the data is explained by each model, we used the R-squared calculated with the equation (12).

$$R^2 = 1 - \frac{\sum \left(SP_t - S\hat{P}_t\right)^2}{\sum \left(SP_t - \overline{SP_t}\right)^2} \quad (12)$$

where

SP is the observed surplus production
$S\hat{P}$ is the predicted surplus production
$\overline{SP}$ is the average surplus production

III Results and discussion

III .1 The North Sea status

As for the LME data, the North Sea ecosystem counts species out of which about 224 are fish. On this 224 species ICES assessed 12 species that represent 78% of the total catch of the ecosystem (figure 2 and figure 3). In accordance with ICES data, the total biomass is around 8 millions tons, widely dominated by Sandeel and Herring (figure 4). These two species are also the main targeted species of the ecosystem. In he North Sea ecosystem in 2005, one fifth of the biomass is being exploited (figure 5).

On the one hand, using the LME data, 45% of the 299 species of the ecosystem collapsed (figure 6). On the other hand, if we give a closure look to the ICES data, the total biomass has been rather stable around 10 millions tons since the 80's with a light diminution since 2001, leveling at 8 millions (figure 4). The total landing has been since the 80's declining from 2.5 millions tons to 1.5 millions tons mostly because of the decrease of Sandeel catches. The other stocks catches have almost be constant (figure 5). Moreover, the figure 7 reveals that only 2 stocks remains depleted out of 12, the blue whiting stock and the cod stock. Finally, when using the ICES data, the picture does not look as severe as it looks using the LME data. The North Sea system doesn't seem to be collapsing, but is clearly experiencing a very heavy exploitation. Therefore, if not collapsed, some stocks are depleted, declining or at low abundance.

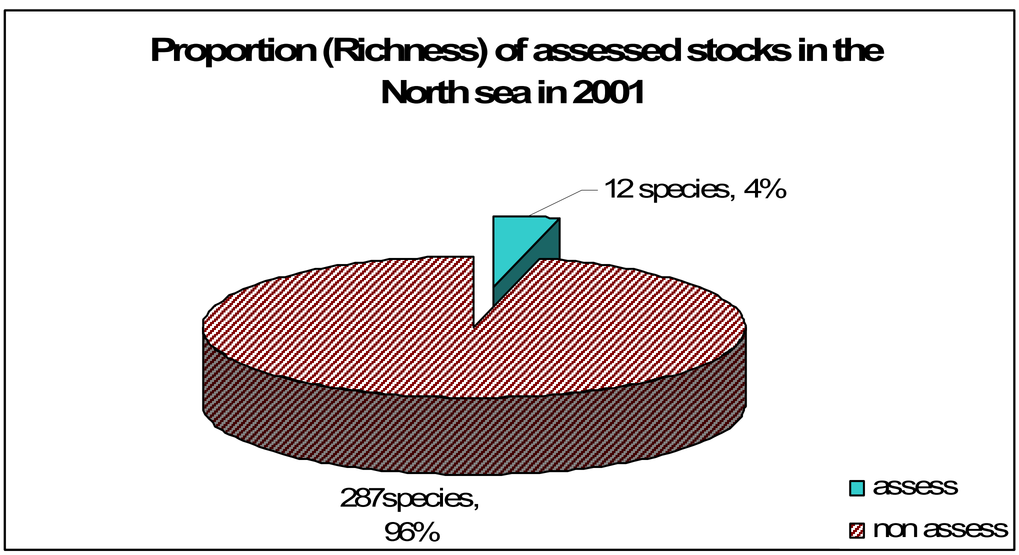

Figure 2: Proportion of number of stocks assessed by ICES present in the North Sea ecosystem. This diagram was performed with LME data.

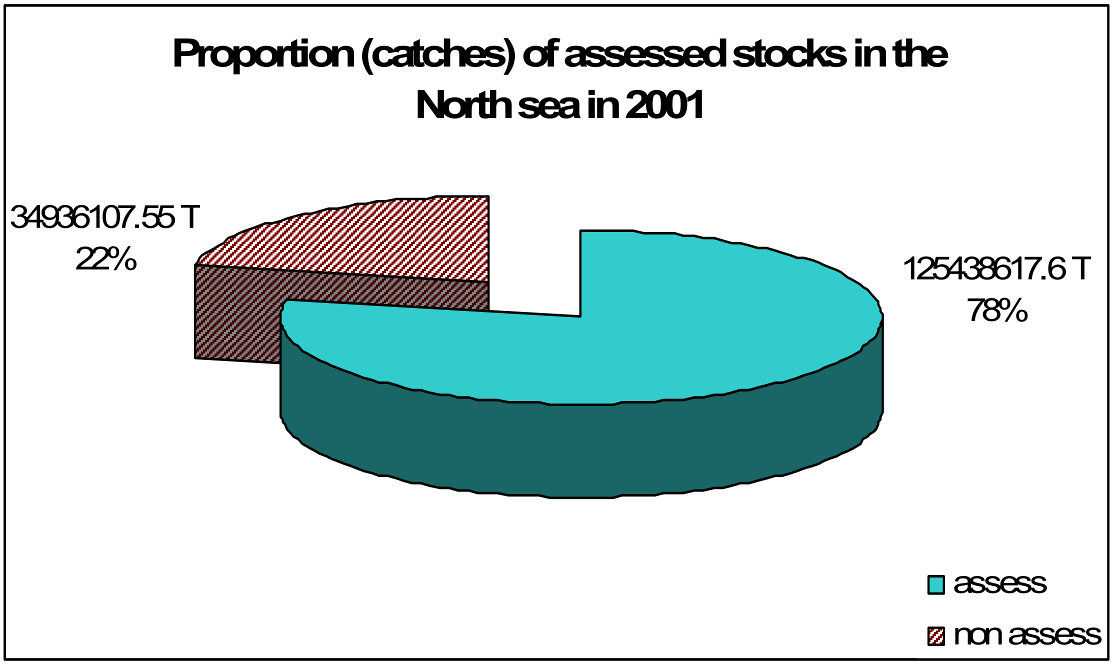

Figure 3: Proportion of landings for the 12 stocks assessed by ICES, present in the North Sea ecosystem. This diagram was performed with LME data.

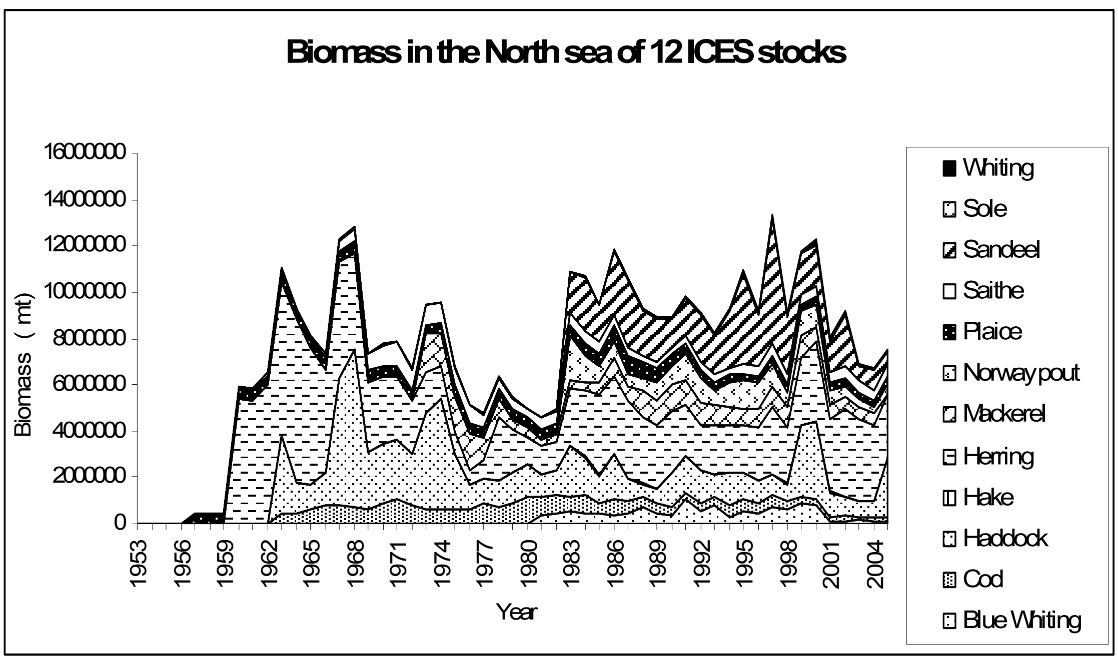

Figure 4: Total biomass in the North Sea for the 12 ICES stocks from 1983 to 2005. This graph uses ICES assessment data including combine stocks. The beginning year for each stock is different. The data are complete from 1983 except for whiting which time series starts in 1995.

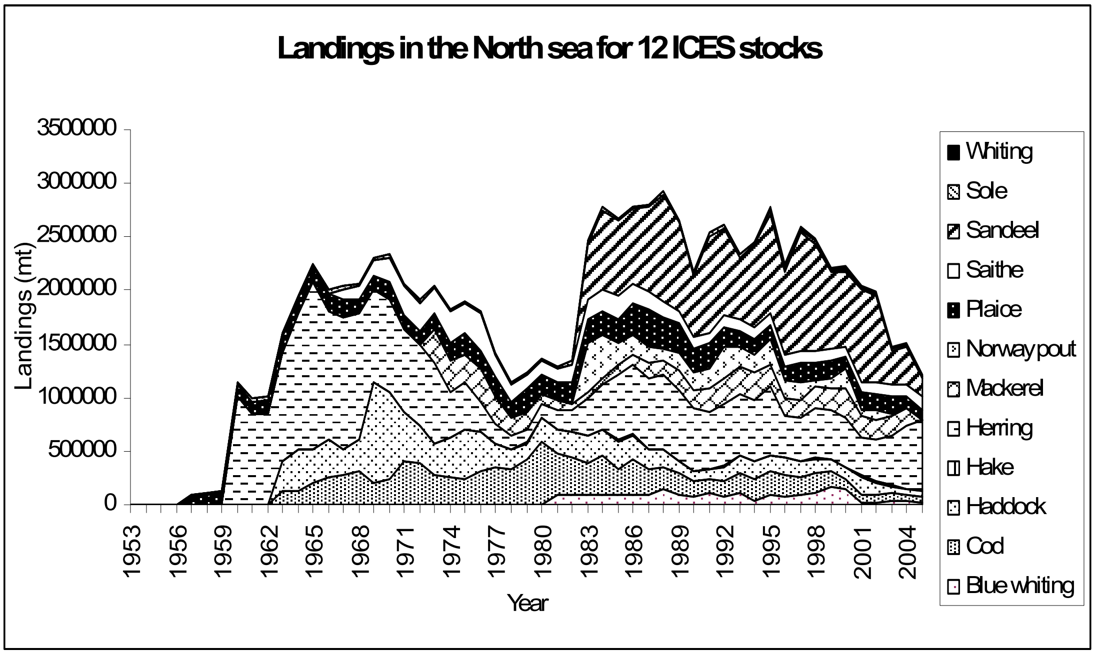

Figure 5: Total landings in the North Sea for the 12 ICES stocks from 1983 to 2005. This graph uses ICES assessment data including combine stocks. The beginning year for each stock is different. The data are complete from 1983 except for whiting which time series starts in 1995.

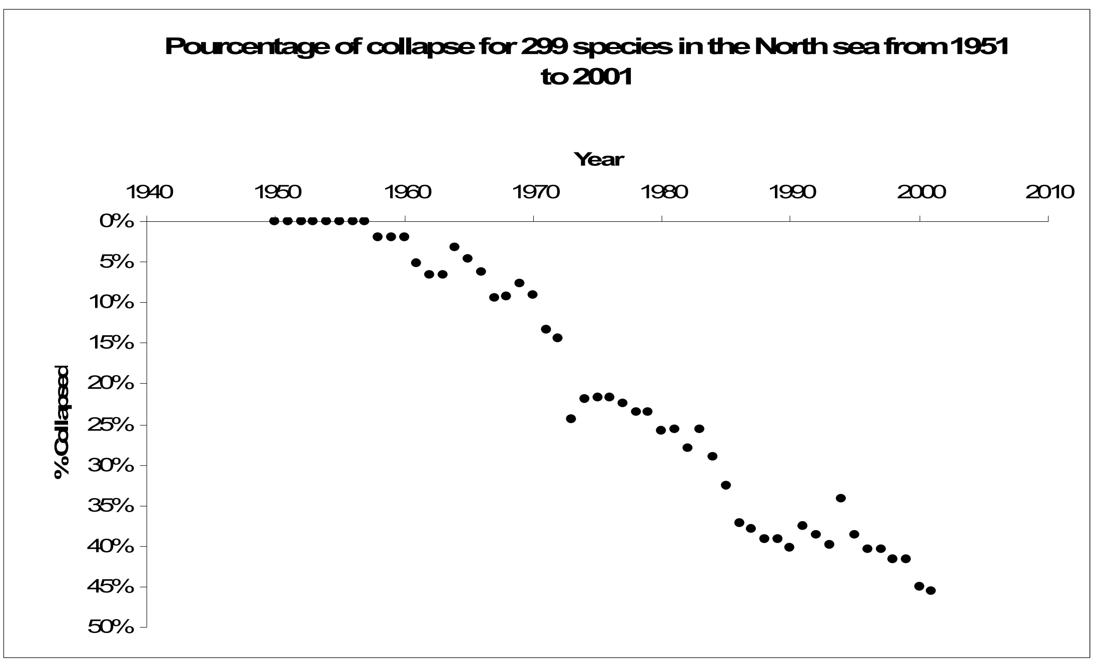

Figure 6: Percentage of collapse in the North Sea, taking into account 299 species from 1951 to 2001. This graph was performed with data landings from the LME data using the 10% standard definition of collapsed.

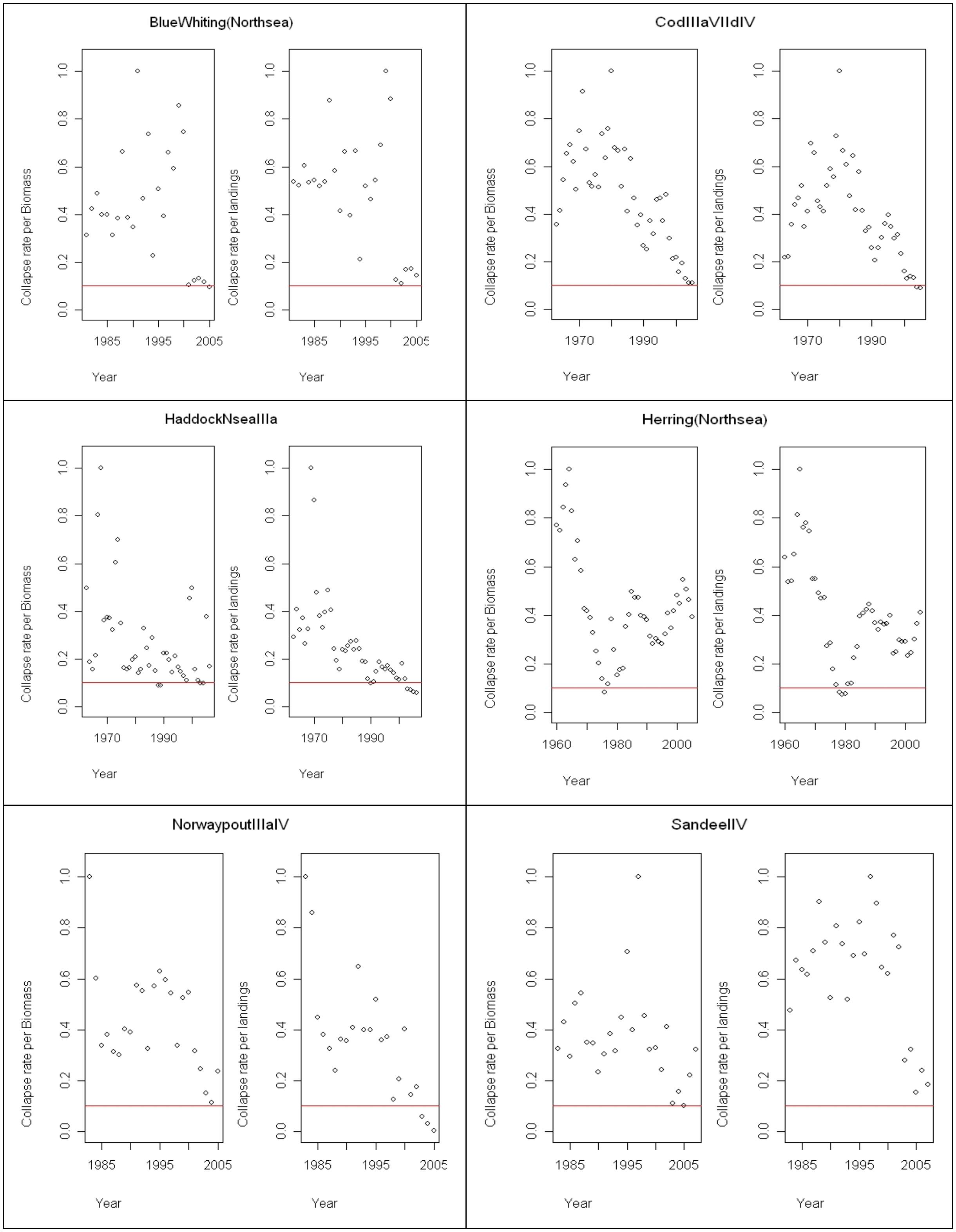

Figure 7: North Sea stocks collapsed in Biomass or in Landings between 1953 and 2005. Graph performed with ICES data.

III. 2 Surplus production, fishing, environmental, or complex process driven

The following part has the aim of clarify whether and how surplus production is shaped. The different hypotheses raised here are that the biomass is influenced by fishing or is driven by temporal changes. The last hypothesis is that surplus production is both shaped by changes in biomass due to fishing and temporal changes.

III. 2.1 Productivity Fishing driven

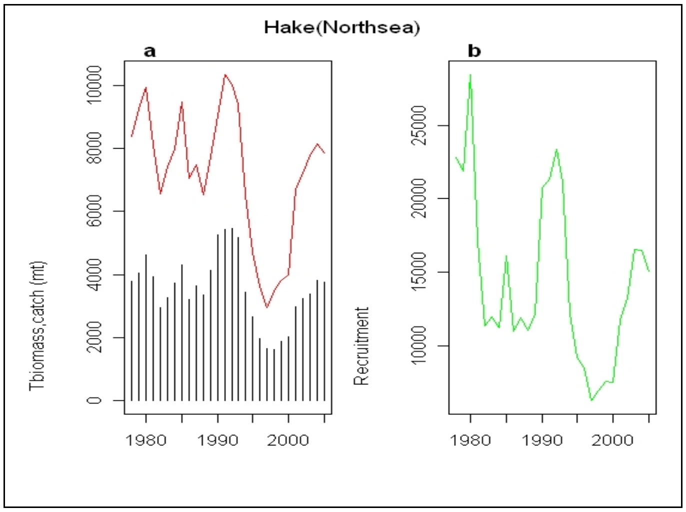

Figure 8: Hake total biomass (red line) and catch (black histogram)(a) and recruitment (b) from 1975 to 2005.

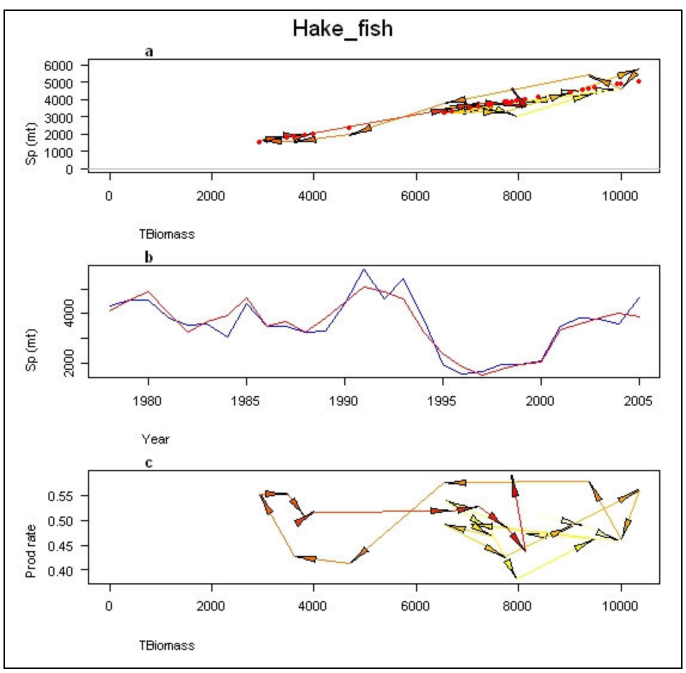

Figure 9: mixed model fitting the Hake surplus production versus biomass (a), and versus time (b), production rate versus biomass (c).

Hake surplus production seems to be influenced by fishing (figure 9a). Hake is one of the stocks that starts with a very low biomass in these time series. Surplus production for this stock is quite important. It has been constant around 4000 tons from 1978 to 1995. Then it decrease to level at 2000 tons and since then has been increasing again. In this case the surplus production follows perfectly the biomass. So, as the biomass decrease the surplus production decrease. In figure 8, it looks like the biomass is linked to recruitment. And that recruitment has periodic good year classes. This is maybe why the stock remains productive. The production rate (figure 9c) was earlier at 0.4 and nowadays levels around 0.5. Meaning that out of 2 units of biomass one unit is produced in surplus, and so this extra unit is available for the fisheries. Therefore, this stock should be able to support half of his biomass being exploited.

III 2.2 Productivity Environmental driven

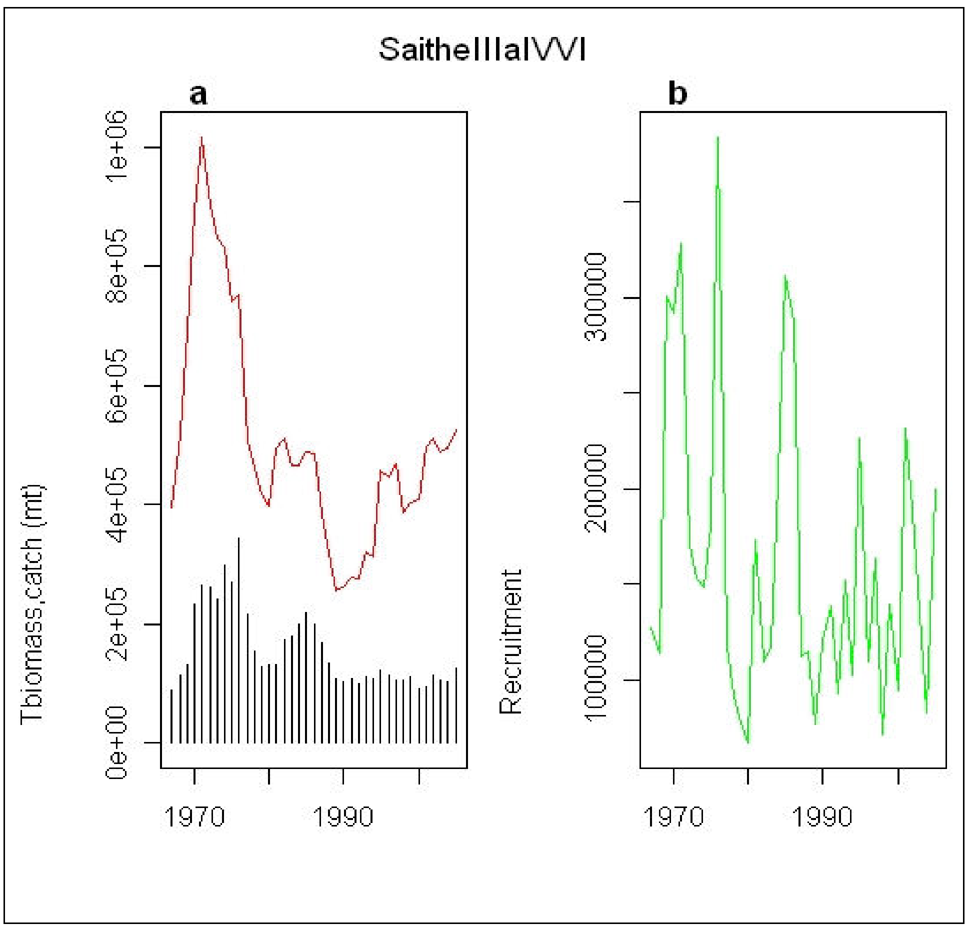

Figure 10: Saithe total biomass (red line) and catch (black histogram)(a and recruitment (b) from 1983 and 2005

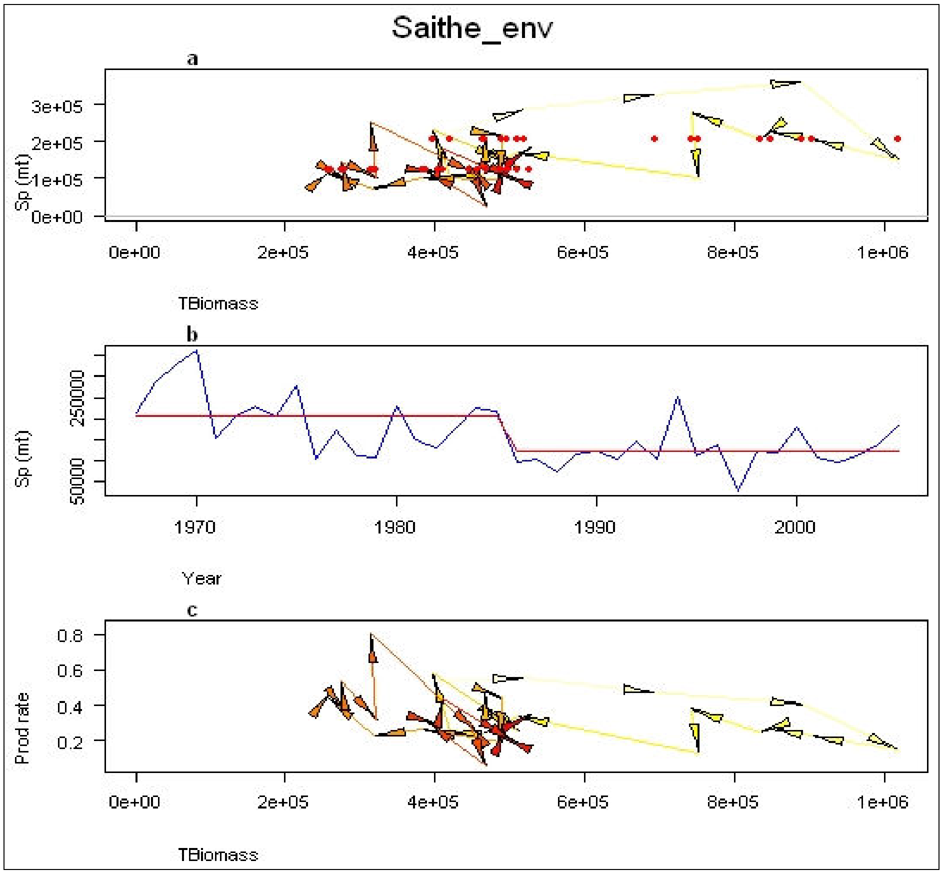

Figure 11: Gilbert model fitting the Saithe surplus production versus biomass (a), and versus time (b), production rate versus biomass (c).

Saithe is one of the species that appears to be environmentally driven. We identify one breaking point in the surplus production, which leads to the idea that there were two different regime (figure 11b). The first period spread from 1970 to the mid 80's. Conditions in this regime seem to be profitable for the productivity of Saithe stocks unlike the conditions in the 1985 to 2005 regime.

Figure 11a reveals that the surplus production is following a clock wise loop pattern. This loop might be induced by a very good year of environmental conditions. These conditions might have minimized the loss of young individuals and the recruitment and biomass therefore increased. Figure 10 reveals that in the mid 70's two years good classes in recruitment triggered an increase in biomass. In the second period, we notice that Saithe recruitment has been somehow variable throughout time, but maxima recruitments are also weaker. O'Brien and Fox (2000), found that there were recent changes in the North Sea temperature. Since 1988 the mean temperature in the North Sea has been increasing. Recruitment might be affected by this modification in temperature. As the recruitment gets weaker, the biomass keep decreasing, just like surplus production. As the biomass goes down from 1 million to 200,000 tons, the surplus production levels down from 200,000 tons to 100,000 tons. The production rate (figure 11c) levels around 0.4 in the early years of the time series and lose one unit to approximate 0.3. Meaning that out of 3 units of biomass almost one unit is produced in surplus, and so this extra unit is available for the fisheries. Therefore, this stock should be able to support one third of his biomass being exploited.

III. 2.3 Productivity Mixed model

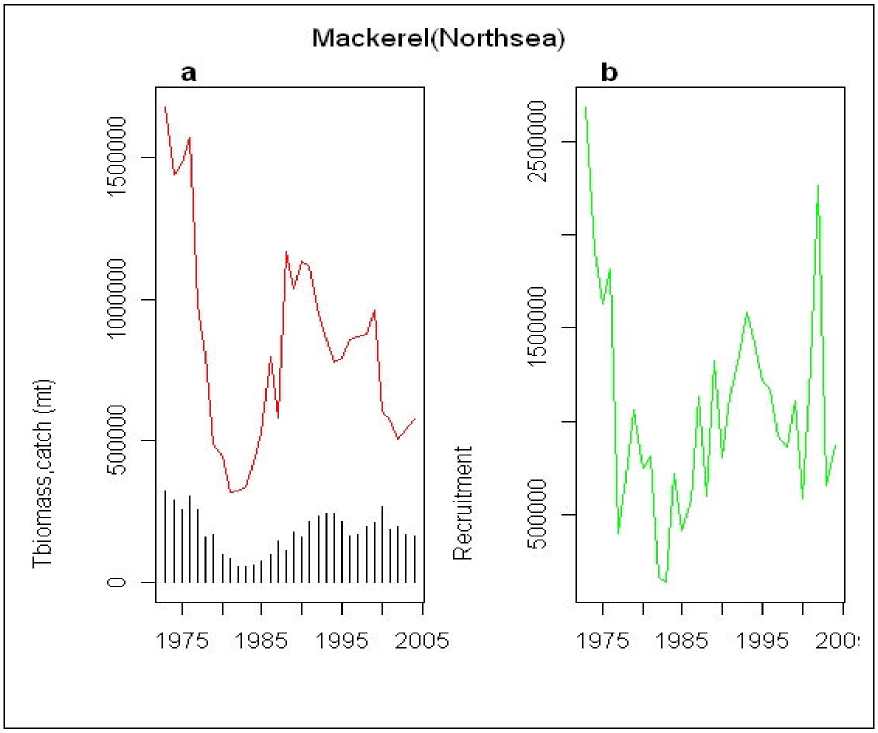

Figure 12: Mackerel total biomass (red line) and catch (black histogram) (a and recruitment (b) from 1970 to 2005.

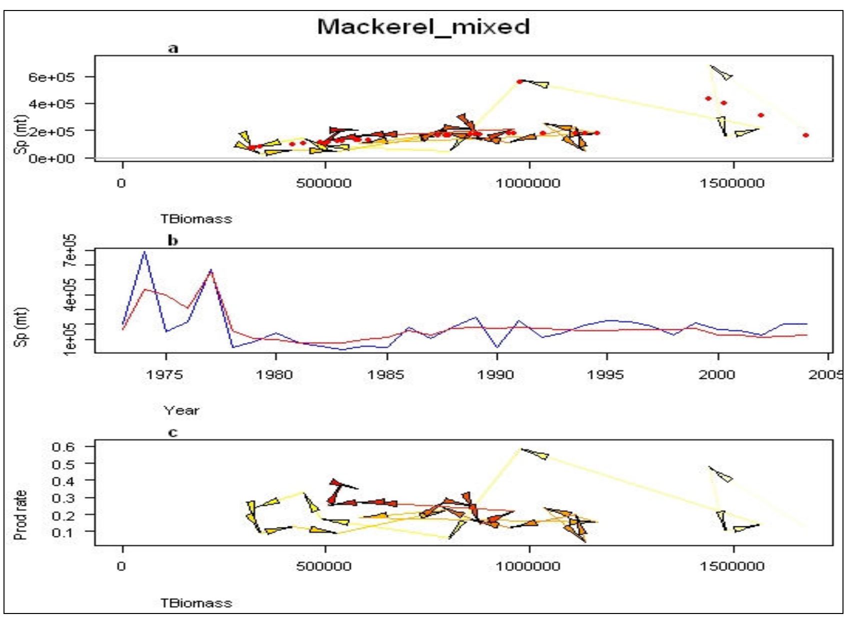

Figure 13: mixed model fitting the Mackerel surplus production versus biomass (a), and versus time (b), production rate versus biomass (c).

Atlantic mackerel is a pelagic, therefore we expect this stock to be environmentally driven. However, it is not only environmentally driven but also fishing driven. None only that the Atlantic mackerel stock is environmentally driven it is also fishing driven at the same time.

As we well know the Atlantic mackerel stock has been intensively exploited. Thus, it is the mixed model that suits the mackerel surplus production (figure 13a). The baseline available for the Atlantic mackerel in this study is 1970. In that year the Atlantic mackerel starts with a moderate biomass compared to some other stocks. This, because at that time, the stock had already been largely exploited which might explain the reason why fishing is driven the surplus production. As shown in figure 13b, surplus production experiences two different environmental regimes. Like for Saithe the former period (1970-1978) is a more favourable than the later period (1980-2005), certainly linked to the temperature of the North Sea. In this case, the stock experienced a high recruitment in the early 70s (figure 12). This good year classes generate a high surplus production with a mean of 600,000 tons. In the second period, the surplus production leveled at 200,000 tons though there is still some high recruitment. Even though there are some good year classes, the biomass has been steadily decreasing, which is probably due to increasing fishing pressure. Figure 13c reveals that the mackerel stock can support one fifth of his stock being exploited whereas earlier it could afford half.

III. 2.4 Helping the Burkenroad and Thomas debate

We are comparing the 3 models in order to evaluate the power of the alternative hypotheses to explain the changes in surplus production. As surplus production and catch drive the abundance of the stocks this question is essential.

As lots of author, such as Hsieh, Reiss and Hewitt thought, the biological dynamic of the species is mainly driven by complex processes including both fishing and environmental conditions. The AIC weighted table (Table 1) shows that for the Cod, the data provides 47% support for the hypotheses that both fishing and environmental drive the surplus production, 27% gives support for the hypothesis of abundance influenced by fishing and 25% for the hypothesis of temporal changes in abundance. Blue whiting, Mackerel and Whiting data give support for the mixed hypothesis respectively at 98%, 100% and 94%. For Blue whiting, the data provide 0.02% support for the hypothesis of abundance influenced by fishing and for Whiting the data provide 0.06% support for the hypothesis of temporal changes in abundance. Mackerel is a small pelagic highly exploited. Small pelagics are known to depend on environment. The study reveals that this stock is under the influence of environment but also of fishing.

Saithe, Plaice, Sandeel and Herring stocks are environmentally driven. The data provide respectively 100%, 77%, 58% and 95% support for the regime shift hypothesis (table 1). When a stock is environmentally driven the data provide 0% support for the fishing model, the complementary explanation is attributed to the mixed model. Two of those 4 stocks experienced a collapse, Sandeel and Herring. Herring did recover thanks to high recruitment years (figure 15a). As this stock is environmental driven we can make the hypothesis that the stock did not recover mainly because of management measures, but due to good year classes. Sandeel was a stock maintain at good level until 2000 (figure 7), until then the stock was sustained by a really strong year classes occurred in 1995. Then, as the recruitment was very low, the stock started to collapse. The recruitment seems to be very variable (figure 15a), and to control the biomass variability. When the stock collapsed management measure were taken to maintain the stock. This decision may not have help the stock to recover but maybe helped so that the situation did not get worse. Plaice and Saithe have never experienced a collapse in the North Sea. Their recruitment is very variable but what is interesting is Saithe and Plaice recruitment are in opposition of phase, which confirms that their recruitment is driven by environmental conditions.

Hake is the only stock fishing driven. Hake surplus production the data provide 98% support for the hypothesis that abundance is influenced by fishing. The Hake is still a very productive stock and so is interesting for fisheries.

In conclusion, figure 14 reveals that the data suggest 14 % support the fishing hypothesis, whereas the data provide 40% and 46% support respectively for the environmental and the mixed model. The data provide by these 12 stocks do not support the Thompson hypothesis of the abundance driven b fishing. Instead these data support the Burkenroad hypothesis that the surplus production might as well environmental induced.

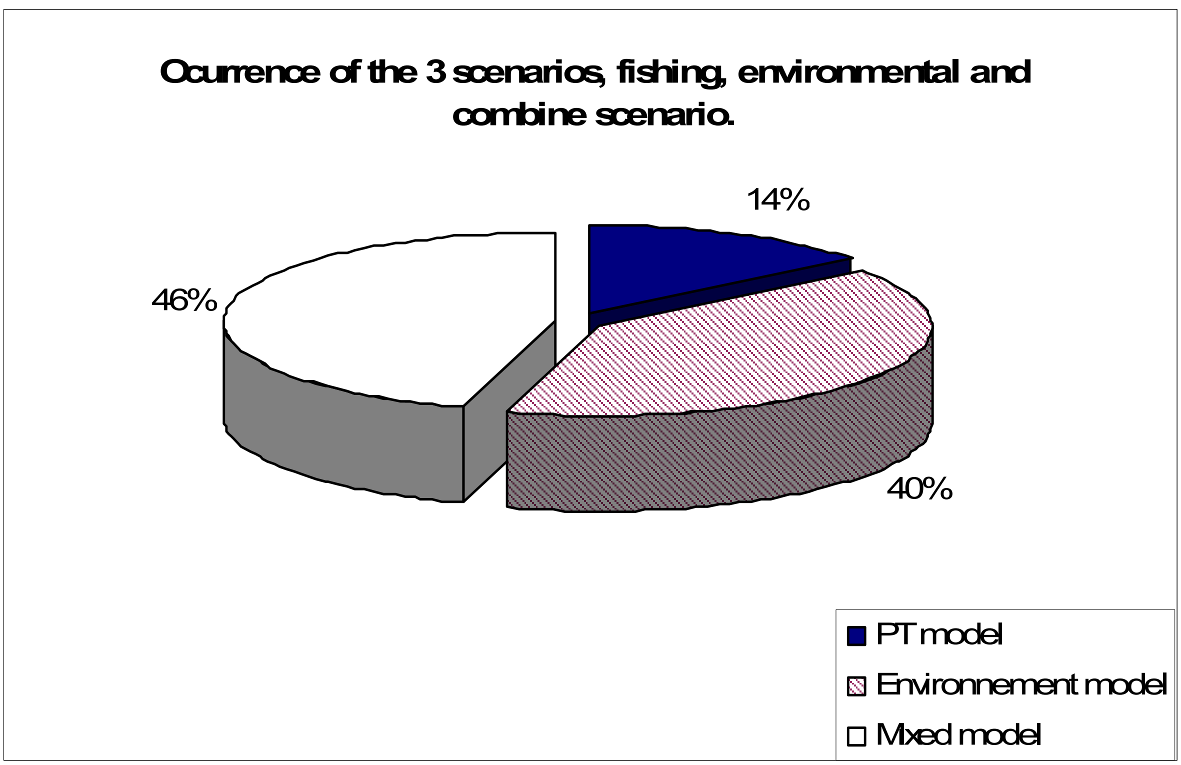

Figure 14: Comparison between the three models applied on the 12 main stocks of the North Sea using the AIC weighted

Table 1 : AIC weighted assigned to the alternative hypothesis of abundance driven by fishing or temporal changes or the by the mixed hypothesis, for the 9 stocks of the North Sea

	Pella-Tomlinson	Environment	Mixed
Cod	0.27	0.25	0.47
Blue Whiting	0.02	0.00	0.98
Plaice	0.02	0.77	0.21
Saithe	0.00	1.00	0.00
Sandeel	0.00	0.58	0.42
Hake	0.98	0.00	0.02
Mackerel	0.00	0.00	1.00
Whiting	0.00	0.06	0.94
Herring	0.00	0.95	0.05

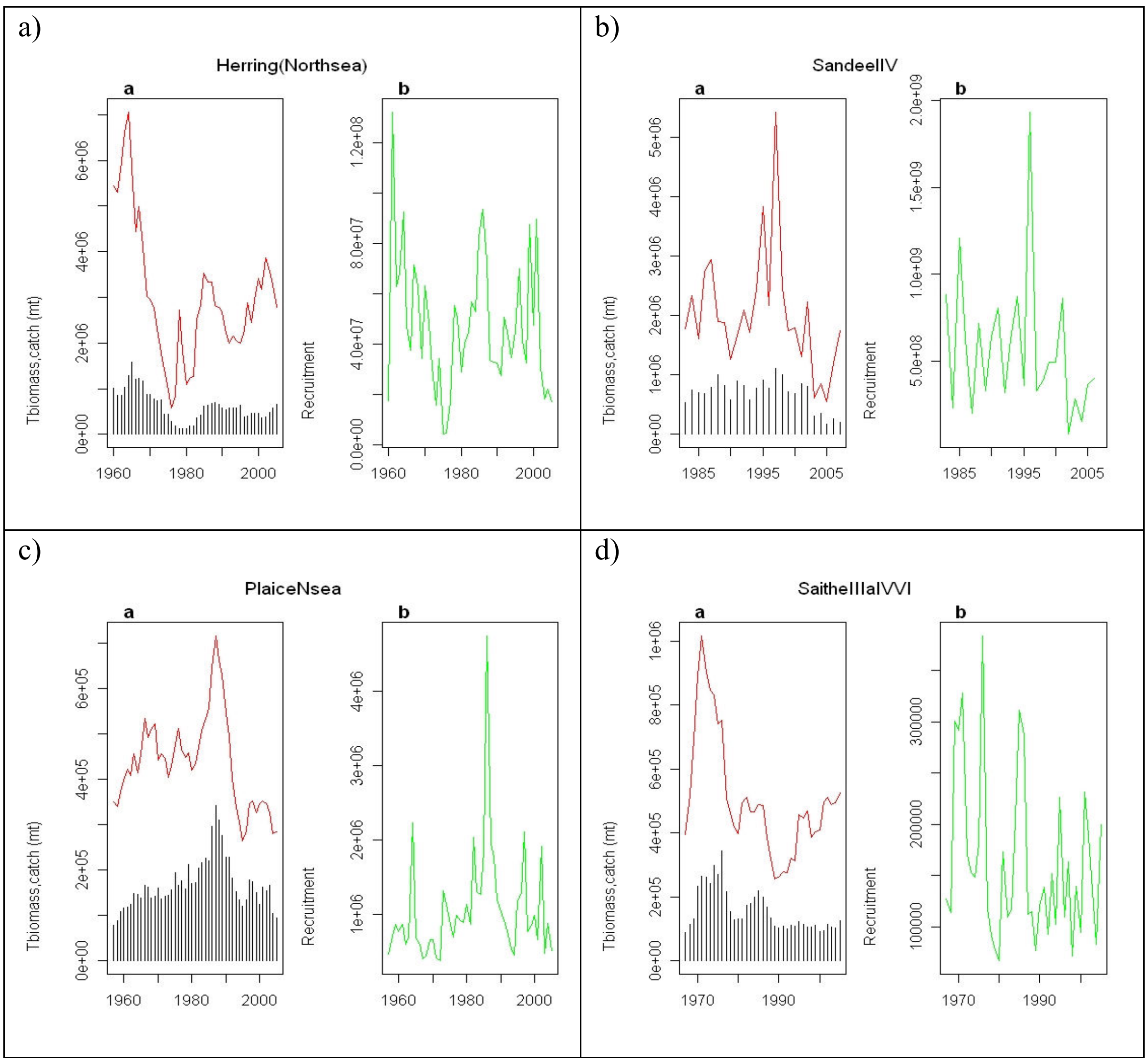

Figure 15: Herring(a), Sandeel (b), Plaice (c), Saithe (d) total biomass (red line) and catch (black histogram) and recruitment (green line) from 1970 to 2005.

III. 2.5 Limitation in the analyses

While we have framed the discussion around the three hypotheses, abundance driven, environmentally driven or a mixed explanation, there remains a fourth hypothesis that is that none of these three hypotheses explain the data. When we look at the percentage of the variation in surplus production explained (table 2), we have decided to discard the Sole, Norway pout and Haddock from the results. None of these models explain more than 20% of the variability present in the data. For Haddock and Norway pout and Sole, it seems that the environment and the mixed model have problems to fit those surplus production data because the surplus production is variable around an average almost with the same variance (figure 16). The Pella-Tomlinson model does not capture a great deal of variability of the Norway pout and Haddock data either. Around 20% of the variability is explained by the fishing model for both stocks.

Except for these three stocks, in general the three models capture the variability present in the surplus production data. Most of the models explain more than 50% of the variability of the surplus production data.

The AIC weighted are not always in accordance with the R-squared for example the Hake R-spared indicates that all three models explain the same variation in the data, when the AIC weighted give all the credit to the Pella-Tomlinson model, this because the Pella-Tomlinson model have less parameters.

Table 2: Proportion of the variation in surplus production explained by each alternative model, Pella-Tomlinson, Gilbert and mixed model.

	PT model	**Environmental model**	**Mixed model**
Cod	0.22	0.33	0.35
Sole	0.00	0.00	0.00
BW	0.52	0.03	0.74
Norway pout	0.22	0.08	0.16
Plaice	0.36	0.51	0.49
Saithe	0.20	0.33	0.31
Sandeel	0.56	0.72	0.79
Hake	0.88	0.79	0.89
Mackerel	0.28	0.37	0.62
Whiting	0.04	0.45	0.75
Herring	0.07	0.38	0.33
Haddock	0.21	0.00	0.00

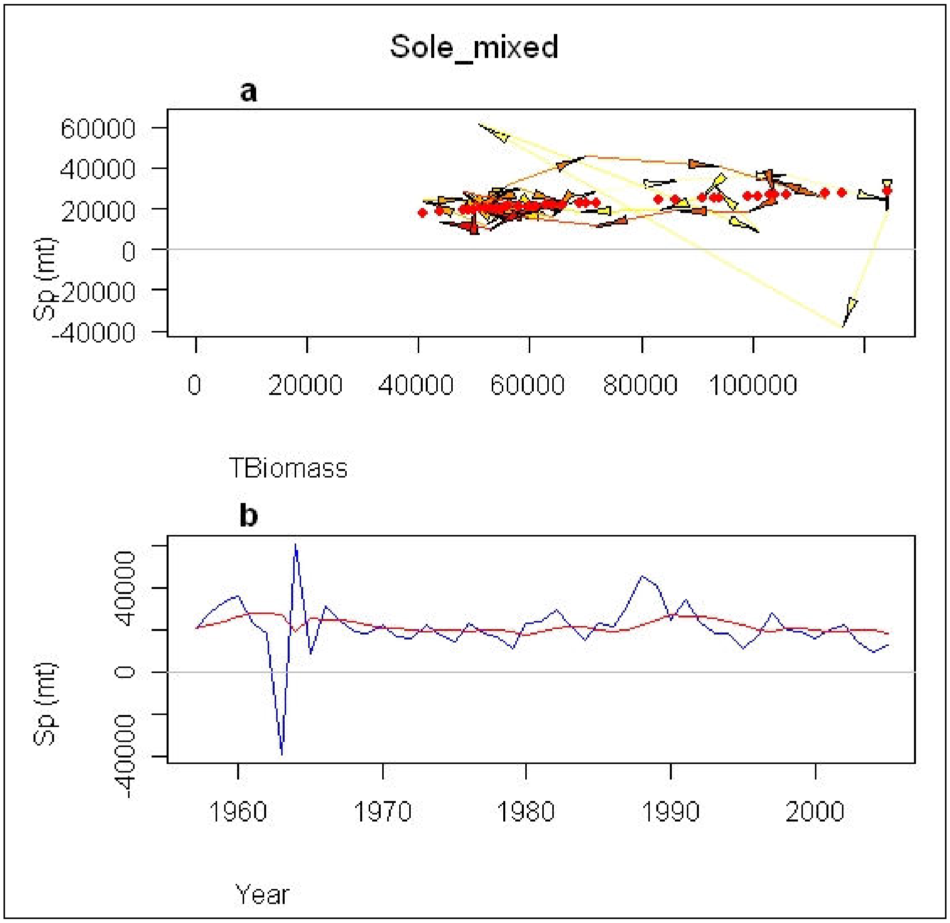

Figure 16: Pella-tomlinson model fitting the Sole surplus production versus biomass (a), and versus time (b)

III.3 Stock recovery issue and answering the Hutchings question

Hutchings thinks that, not only fishing pressure is the origin of decline and non recovery of fish stocks, but also more complex mechanisms beyond simple fishing may be responsible for the lack of recovery. In this section we will try to understand what influence decline and recovery and why some stocks recover when others don't.

In response to depletion and collapse of those stocks, ICES took some management decisions. In the end 70's moratoria were implemented on the North Sea Herring. Other management decisions were taken for the Mackerel (Henrik Sparholt et al., 2007). Seems those harvest control rules led to the recovery of the Herring stock but were not efficient for the Mackerel stock.

III. 3.1 Herring, a successful recovery

The Herring stock has been highly exploited for centuries in the North Sea. The exploitation rate on the Herring stock has been increasing in the 60's and the 70's as the stock was collapsing (figure 17a). The rate increased from 0.1 to 0.5 as the biomass went down from 7 million tons to 1 million ton. A moratorium was implemented in 1978. The exploitation rate was decreased almost to zero but not totally due to bycatch. Indeed, the Herring stock recovered rapidly thanks to a strong year classes in the early 1980's (Bjorndal and Lindroos, 2004). The Herring is a clupeid, it's a short live, r strategy pelagic. Therefore the response to a strong year class is pretty instant. Those results are sustained by the Hutchings paper saying that all stocks that were fully recovered were clupeids (Hutchings and Reynolds, 2004). Those strong year classes were a good stepping stone for the recovery of the stock, although the recovery was possible because of the moratorium. Since the moratorium, the exploitation rate of the Herring has been increasing to reach 0.3 and then, leveled at 0.2 nowadays.

III.3.2 Mackerel, remains depleted

While the Mackerel's exploitation rate has been slowly increasing from 0.2 to 0.35, the biomass was at low abundance from 1.6 million tons to 400 thousand tons (figure 17b). Then as the rate was lowed the stock started to rebuilt. The rate has been increasing since then to reach 0.4 in 2005, which is the highest exploitation rate the stock has suffered. In fact, if this stock has difficulties to recover it might be because the exploitation rate is way too high. We have proved that the stock can support one fifth of its biomass being exploited, so obviously the exploitation rate is higher than what the stock can produced.

III.3.3 The Atlantic cod, a collapsed stock

The Atlantic cod (*Gadus Morhua*) is one of the stock that has been depleted between 1960 and 2005. This stock abundance seemingly did not recover (figure 17c), even worse, it has now collapsed by the 10% standard (figure 7). The stock is well below the limit B_{pa} level of 70,000t below which ICES considers productivity of the stock impaired (Horwood,et al., 2006). The exploitation rate was around 0.3 in the 60's and is now stabilized at 0.45 (figure 17c). As the biomass levels down the exploitation rate gets a little higher which, is meaningless in terms of management. So, it is obvious that this rate is way too high for the stock and a recovery can hardly be expected.

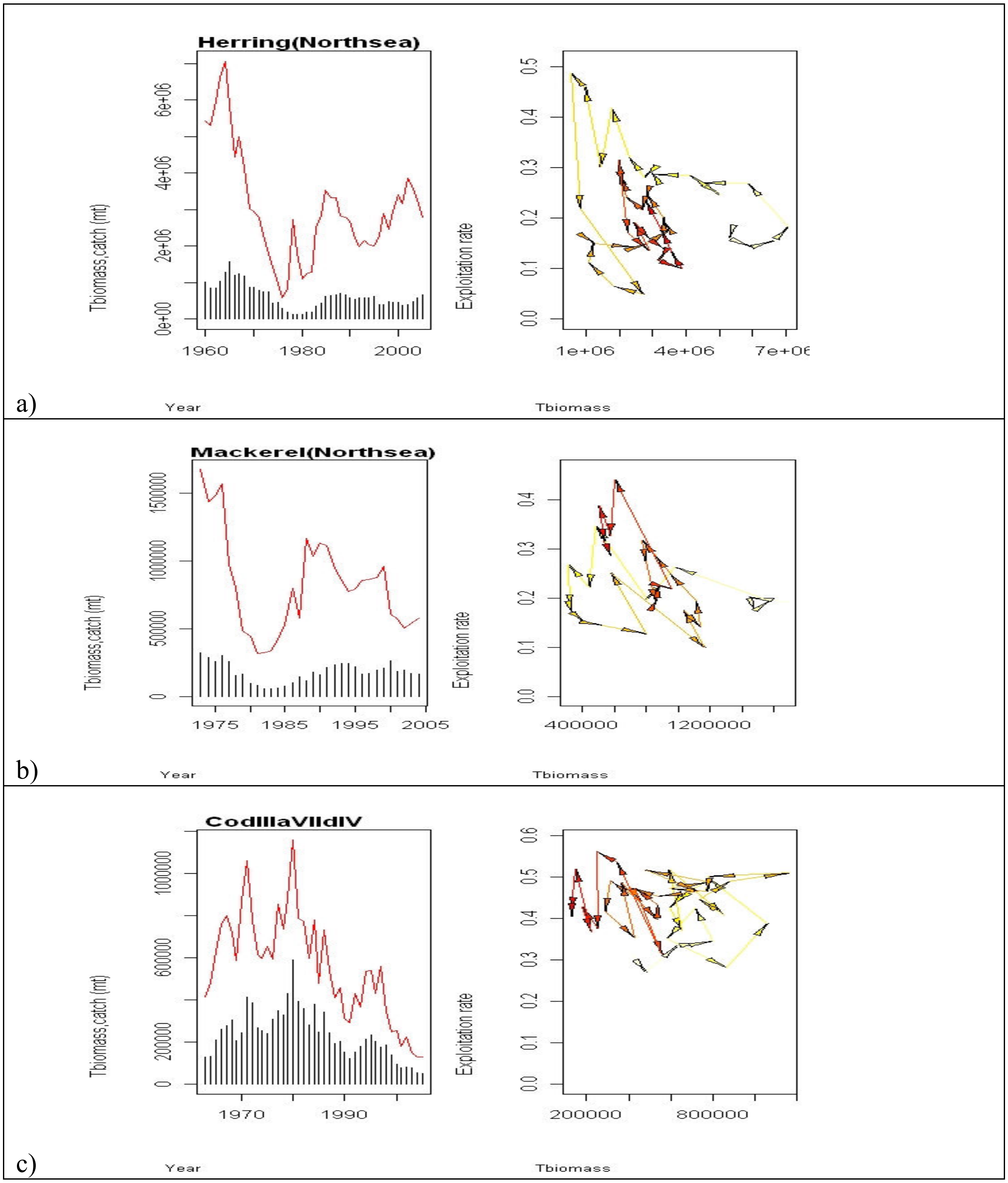

Figure 17 : Total biomass (red line) and catch (black histogram) in million of tons and exploitation rates evolution, for the Herring (a), the Atlantic mackerel (b) and the Atlantic cod (c),in the North Sea, between 1960 and 2005. Exploitation rate versus biomass is represented with arrows from white to red as the years are more recent.

III.3.4 A link between high exploitation rate and collapse

Four other stocks have collapsed in the last 5 years, Sandeel, Blue whiting, Haddock and Norway pout. The biomass of the Sandeel collapsed in 2005 but is now recovering to reach 30% of the maximum biomass (figure 7). As the biomass was decreasing the exploitation rate was lowered so the stock starts recovering (figure 18a). The biomass of Blue whiting remains collapsed and, the catch that collapsed in 2002, increased slightly to reach 15% of the maximum catch, which is close to the threshold (figure 7). The exploitation rate applied on the Blue whiting (figure 18b) is actually twice higher than it was 20 years ago, which explains that the landings increase, even though the biomass keeps decreasing and remains collapsed. This example reveals that even if the landings remains at a sustainable level for the fisheries, it doesn't mean the stock is in good shape. Managers could always take into account the biomass of the stock to implement management plans. For the Norway pout the exploitation rate had to be set down almost to zero so that the stock can rebuilt (figure 18c).

Exploitation rate, for most stocks in the 60's was between 0.2-0.4, after implementing management strategies on lots of stocks, lots of stock did rebuild. But, nowadays, exploitation rate is, higher than it was in the 60's, between 0.3-0.5. Such rates may not be the only cause of the non recovery of these stocks; nevertheless the exploitation rate in the North Sea, for most stocks remains too high considering the exploitation rate and the productivity of each stock. Finally, we can try and give a first answer the Hutchings question: (Hutchings and Reynolds, 2004) why don't stocks recover; by pointing out that in general the stocks are still fished too high. It is true that usually stocks surplus production is influenced at the same time by fishing and temporal changes, meaning that surplus production is influence by complex phenomena. But even if the stocks are influenced by complex phenomena, when the exploitation rates lower, the stocks start rebuilding.

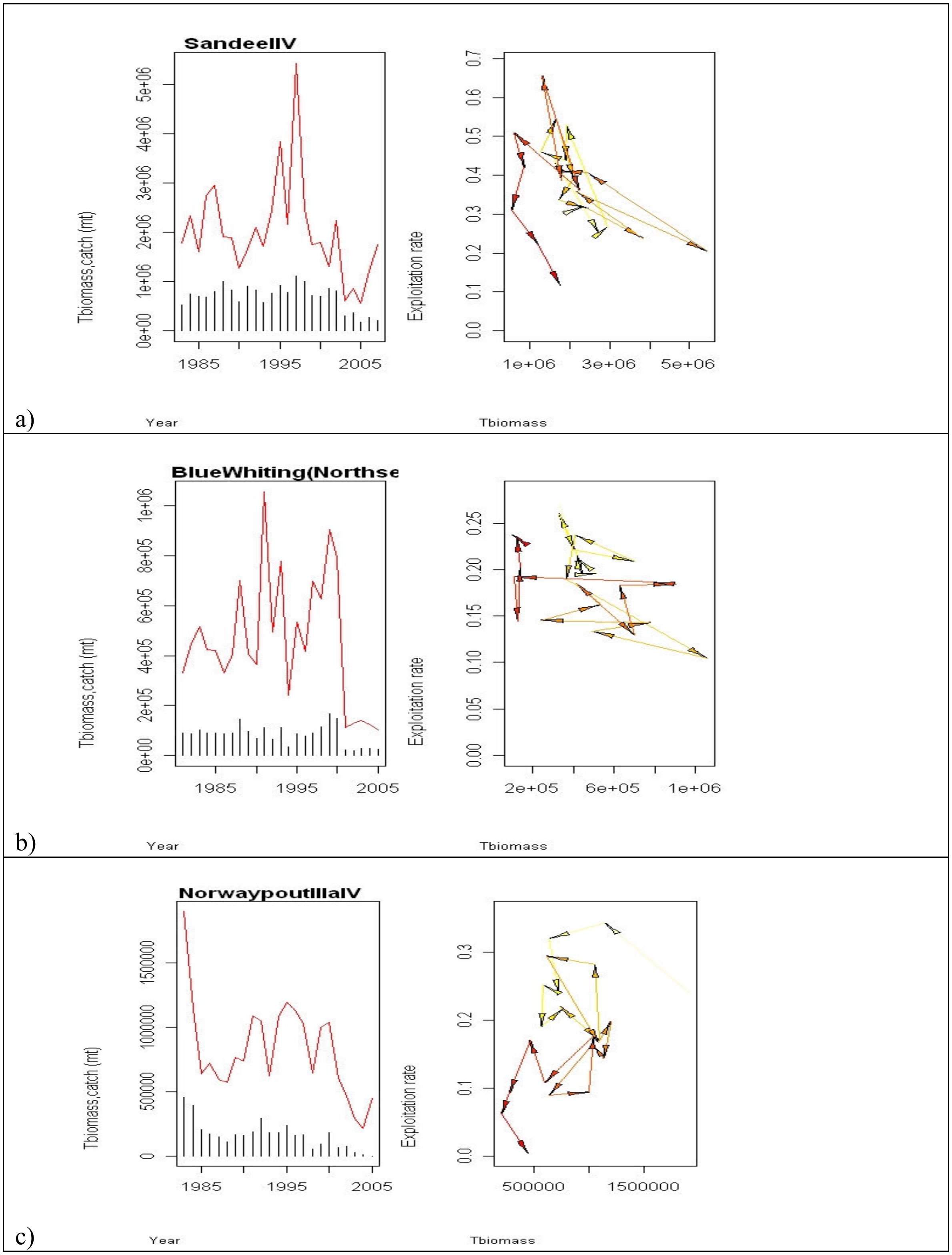

Figure 18: Total biomass (red line) and catch (black histogram) in million tons and exploitation rates, for Sandeel, BlueWhiting and Norway pout, in the North Sea, between 1983 and 2005. The exploitation rate versus biomass is represented with arrows from white to red as the years are more recent.

IV Conclusion

These results lead to the conclusion that, in fact few stocks of the North Sea are primarily fishing driven. Most of stocks are driven by both fishing and environmental conditions, which support the Burkenroad hypothesis. Apparently it is more difficult for these stocks to rebuild after a collapse. This provides an answer to Hutchings question: why don't stocks recover? We have noticed though that the exploitation rates for most of those stocks remains high. The management decisions might be more restrictive on exploitation rate. It might be a benefit for the stocks if the management plan were associated to environmental conditions. It will consist in lowering the exploitation rate in a bad environmental periods and allowed higher exploitation rate in good environmental periods. Environmental driven stocks are another issue as the status of the stock depends only on non control variable. In the North Sea like in other ocean of the world we are witnessing environmental changes that might affect the surplus production of the stocks positively or negatively and thus weaken the ecosystem. As the recovery is only a matter of good recruitment year, some stocks might not recover even if management measures are considered. Fishing driven stocks apparently have experienced no collapse and if they do they recover when the fishing pressure is released.

While we have framed the discussion around the three hypotheses, abundance driven, environmentally driven or a mixed explanation, there remains a fourth hypothesis that is that none of these three hypotheses explain the data. For some stocks none of the Pella-Tomlinson, Gilbert or Mixed model explain more than 20% of the variability present in the data.

In general the three models capture the variability present in the surplus production data. Most of the models explain more than 50% of the variability of the surplus production data. But even though the AIC weighted are not always in accordance with the R-squared. The AIC weighted might not represent the best what real proportion of the data support the hypothesis.

The third main problem of this study is also a method problem. In fact, the environmental model traduces regime shifts that may or may not be link to environmental changes. Moreover as we find the break points arbitrarily, they might not correspond to an environmental change.

First in this kind of model we could use analytic methods using the variance to determine the break points (Pawlowski and Cabezas, 2008). Even further, the same analyses could be run using an environmental model that depends on effective environmental factors like SST, or that corresponds to climate changes like the PDO (O'Brien and Fox, 2000).

Extra analysis could be run on fishing pressure and on production rate to find tendencies respectively in fishing pressure and in production rate versus biomass. Concerning the Hutchings hypothesis, we didn't pay too much attention at other explanation than fisheries combine with environmental changes. It would be interesting to integrate genetics, habitat loss into a more complex model and make a comparison to see which variable has more weight than the other. Moreover, theses results concern only the North Sea; it would be interesting to extrapolate the analysis to other stocks, to see whether we find the same trends.

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