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End-to-end modelling attempt in the North Sea to assess interactions of fishing and other human uses under climate change

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Résumé long (en français)

Le changement climatique est avéré et avec lui, les changements globaux qui impactent les écosystèmes marins. Ces impacts perturbent et modifient le fonctionnement des écosystèmes marins, comme la fonction trophique en perturbant les réseaux trophiques et les dynamiques de populations. Ces changements globaux résultant de la pression anthropique et de la variabilité climatique ont des effets directs et indirects qui se combinent. Afin de comprendre ces effets combinés et leurs impacts sur le milieu marin, nous proposons une approche écosystémique modélisant les différentes pressions via les usages (activité de pêche et structures offshores). Le cas d'étude est celui de la Mer du Nord, fortement impacté, il est un cas d'école pour ce type de questionnement.

La Mer du Nord est un écosystème très étudié en termes d'impacts climatiques et anthropiques, soumis à différentes stratégies de gestion. Le développement des énergies renouvelables avec l'implantation de champs d'éoliennes offshores crée une compétition pour l'espace marin avec les autres activités, telle que la pêche. L'objectif de cette étude est de quantifier les effets combinés entre les différents usages sur l'écosystème, ainsi que leur évolution sous changement climatique.

Afin de comprendre et estimer les impacts de cette compétition spatiale sur les dynamiques de l'écosystème, le développement d'un modèle tropho-dynamique et spatialisé est appliqué en Mer du Nord. Il s'agit du modèle OSMOSE (*Objet-oriented Simulator of Marine ecOSystem Exploitation*), un modèle individu-centré multispécifique qui représente les espèces et leurs relations trophiques ainsi que les interactions avec leur environnement.

Le développement d'un modèle intégré en Mer du Nord a pour but de définir les limites de l'écosystème, la structure du modèle et les paramètres à modéliser, définissant la phase de paramétrisation. Dans cette étude, il s'agit d'appliquer la nouvelle version du modèle OSMOSE dont la pêche est modélisée spatialement et par flottille. La seconde étape consiste à calibrer le modèle paramétré afin qu'il corresponde à l'état actuel de l'écosystème. Un problème dans l'algorithme de calibration est révélé et la calibration du modèle n'a pas été effectuée dans le temps imparti de cette étude. Néanmoins, ce problème a été identifié et sera prochainement rectifié. Le modèle ainsi paramétré et calibré pourrait permettre la simulation de différents scénarios de gestion, couplés avec différentes projections du changement climatique, qui n'a pu être réalisée durant ce stage.

Le modèle OSMOSE est un modèle individu centré spatialisé qui représente les dynamiques de cycle de vie des espèces, dont 15 sont modélisées pour la Mer du Nord. Les processus de cycle de vie tels que la reproduction, la croissance, la migration et la prédation sont modélisés. L'hypothèse principale du modèle est la prédation opportuniste. La prédation est basée sur la co-occurrence spatiale et les ratios de taille entre la proie et le prédateur. La pêche est modélisée via un effort de pêche et une capturabilité définie par flottille et pour chaque espèce. Les structures offshores sont représentées comme des zones d'exclusion à l'activité de pêche, engendrant un report d'effort de pêche. L'ensemble des processus modélisés (prédation, reproduction, pêche...) requiert des paramètres spécifiques. Les paramètres sont issus de la bibliographie et de l'analyse de données (CPUE, abondances et captures), puis sélectionnés par espèce en fonction de la zone et de la période sur lesquelles ils ont été définis ou estimés.

La paramétrisation permet de définir 29 paramètres par espèce, leur distribution spatiale ainsi que 6 flottilles de pêche sur la période 2008-2016 pour la zone correspondant à l'écosystème de Mer du Nord, soit l'ensemble de la Mer du Nord et la Manche Est (zones FAO). Les faibles niveaux trophiques sont issus du modèle hydrodynamique et biogéochimique nommé ERSEM

(*European Regional Seas Ecosystem Model*), le forçage du modèle OSMOSE par le modèle ERSEM permet l'implémentation de la variabilité climatique fournie par le GIEC (*IPCC en anglais, Intergovernmental Panel on Climate Change*). Les paramètres à calibrer – la mortalité larvaire, l'accessibilité au plancton et la matrice de capturabilité – sont estimés via un algorithme génétique.

L'algorithme génétique permet une estimation inverse des paramètres à calibrer, et est adapté aux modèles complexes, tel que le modèle OSMOSE. Cet algorithme vise à trouver la combinaison de paramètres les plus « adaptés » en référence à la théorie de Darwin, afin de reconstituer les données observées sur la période de modélisation.

Les critères de calibration ne sont pas respectés – collapses de certaines espèces – et l'efficacité de l'algorithme mesurée via la fitness n'est pas satisfaisante. En effet, l'algorithme de calibration ne permet pas d'obtenir les paramètres optimaux du modèle. Ce problème étant détecté, des scénarios de calibration sont alors mises en œuvre afin de tester l'algorithme.

Les résultats ne montrent aucun scénario de calibration satisfaisant, ce qui permet d'affirmer un problème dans l'algorithme de calibration. Toutefois, la calibration permet de mettre en évidence l'importance de la paramétrisation et l'impact des paramètres d'entrée sur les différents scénarios de calibration. La modification des paramètres de prédation et de la structure de modèle avec le nombre de bancs par espèce influence la fitness lors de la calibration, alors que la mortalité additionnelle n'a pas d'impact visible sur cette dernière. A titre d'exemple, une simulation est présentée sur 100 ans et pour 30 réplicas, mais elle ne peut être utilisée.

Suite à ce problème durant la phase de calibration, les aspects de développement du modèle en Mer du Nord et de la sensibilité des paramètres sont discutés. Les difficultés rencontrées lors de la paramétrisation, résultant de compromis entre disponibilité et conformité de l'information, mettent en évidence l'importance que cette phase pour la modélisation ainsi que la perspective de développer une méthode de validation des paramètres choisis. Le problème de calibration permet d'émettre deux hypothèses : (i) un dysfonctionnement dans l'algorithme de calibration pour cette nouvelle version du modèle OSMOSE, (ii) les paramètres d'entrée ne permettent pas de reproduire, via la simulation, les données observées.

Une fois la calibration solutionnée, les perspectives pour ce modèle sont de tester différents scénarios de gestion afin de quantifier et analyser les effets combinés de la pêche et des structures offshores, dans un contexte de changement climatique.

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1 Introduction

1.1 Global change in marine ecosystems

Induced by a rapid increase in anthropogenic emissions of greenhouse gases, global warming has been significantly observed since 1950s. Climatic variations result from a combination between natural variability and variability due to human activities (Grossmann et al. 2009) at several time scales (Holt et al. 2016). Nevertheless, the Intergovernmental Panel on Climate Change (IPCC) is now 95% certain that humans are the main cause of current global warming, with impacts observed across all continents and oceans. In addition, IPCC reports that the more human activities disrupt the climate, the greater the risks of severe and irreversible impacts on ecosystems (IPCC 2014).

Climate change disturbs different components on marine ecosystems, as hydrological and physical dynamics (e.g., thermohaline circulation is reduced and ocean surface warming is increased (IPCC 2014)). On a global scale, ocean warmed by 0.11 [0.09 to 0.13] °C in the upper 75 m, per decade over the period 1971 to 2010 (IPCC 2014). In addition, changes in ocean chemistry impact the performance and survival of many organisms (Harley et al. 2006). In consequences, biological components are affected by physical and chemical changes. For example, the reducing of primary production responds to the increasing of ocean acidification (Queirós et al. 2016; Holt et al. 2016). In fact, variations in nutrient concentrations caused by changes in ocean current patterns modify the fluctuations in primary production in coastal systems (Harley et al. 2006). These modifications impact the base of the food web which supports protected species (Queirós et al. 2016). Furthermore, ocean circulation drives larval transport and has important consequences for population dynamics (Harley et al. 2006). Coupling these phenomena, changes perturb fish species dynamics. For example, the decline of cod in North Sea during mid-1980s (Beaugrand 2009) results the combination of overfishing, plankton variations and warming reduces recruitment of North Sea cod (with a mechanism of match/mismatch).

But global warming is not the only cause of disruption of marine ecosystems. “Global change” includes climate change but also natural variability and human effects on ecosystems (Rabalais et al. 2009). These pressures can combined themselves, possibly resulting in synergistic impacts on ecosystems. Not only there is uncertainty about the separate effect of these pressures, but this uncertainty increases as we consider several pressures (i.e. due to different human activities) and their interactions. Human activities constitute, in some cases, aggravated undesired effects of natural variability and conduct to qualify this period: the Anthropocene (Emeis et al. 2015).

The recent enthusiasm for integrated ecosystem assessment is accompanied by several initiatives aiming at better characterizing ecosystem health and the various pressures they undergo. In 2010, the Oslo-Paris convention (OSPAR) commission has released an assessment of the state of the marine environment in North-East Atlantic Ocean (OSPAR 2010). Marine Strategy Framework Directive (MSFD 2008), but also the International Council for the Exploration of the Sea (ICES) through the recently released ecosystem overviews (ICES 2016), describe environmental impacts of human activities, distinguished as follows: fishing, coastal construction (ports), tourism and recreation, shipping (navigation dredging) and maritime transport, and offshore structures (oil and gas production, aggregate extraction and wind farms).

Fishing activity has been affecting ecosystems for a long time, and has been largely studied. By removing biomass from several species, with some species feeding on others, fishing has an impact on marine food webs (Pauly et al. 1998; Pauly et al. 2016). Furthermore due to the size-selective mortality of fishing, this human activity causes a decrease in the relative abundance of larger species and in mean body size within species (Jennings et al. 2002). In the North Sea, Jennings *et al.* (1998) also reported a progressive

decline in the mean trophic level of the demersal community, correlated with the increased fishery exploitation. By disrupting trophic functioning, the effects of this anthropogenic pressure have been qualified as 'fishing down the food web' (Pauly et al. 1998). When combined, overexploitation and climate change impact marine ecosystems at different levels of organization, resulting for instance in higher temporal variability in abundance for exploited species (Hsieh et al. 2006), shifts in diets of predators and depletion of top predators (Jackson et al. 2001; Baum et Worm 2009). These global changes affect the functioning of marine ecosystems (Cury et al. 2008). But others human activities have an impact on marine ecosystems, as offshore structures.

In North Sea, the synergistic consequences of coincident climate change and overfishing are demonstrated by changes in ecology of marine ecosystem (Kirby et al. 2009). These combined effects of climate and fishing made even more difficult to predict (Harley et al. 2006). Thus, the integration of offshore structures complicates the system and the resulting combined effect, which cannot be predicted from the individual effect of each. The spatial competition appears the main visible effect of fishing and wind farms constructing. By occupying the maritime space, other marine activities reduce the total area available for fishing, which results in competition for space between multiples uses (Bartelings et al. 2015).

1.2 Spatial competition between human activities: fishing and offshore structures in the North Sea

As a challenge to mitigate climate change (IPCC 2014; OSPAR 2010), an increased demand for renewable energy is observed and motivated by the reduction of carbon dioxide (contained in greenhouse gas) and as alternative use for fossil fuels. Consequently, for the past ten years the development of offshore wind farms (OWF) has conducted the scientists to study their impacts on marine wildlife. The current state of understanding on the effects of offshore wind farms on marine wildlife permits to identify different types of pressures, as acoustic disturbances, increased sediment dispersal, habitat gain, fisheries exclusion, acoustic disturbance, and electromagnetic fields (Bergström et al. 2014).

However, knowledge regarding the combined impacts of wind turbines and others human activities, such as fishing, remain scarce. The current consensus is that offshore wind farms are fishery exclusion zones, and as such constitute refuge zones (Coates et al. 2016; Bergström et al. 2014). Indeed no shipping is allowed inside wind farms (except for maintenance), which prevents fisheries activity and therefore reduces fishing mortality rates in these areas (Wilhelmsson et Langhamer 2014). With this idea, offshore wind farms management is essential for fish resources, because the fishery enclosed area can 1/ regulate fishing activities and create an ecological refugium for higher trophic levels (Coates et al. 2016), 2/ impact benthos and fish aggregation indicate a potentially "wasp-waist" controlled food web and anticipated increase in benthic invertebrate and benthos feeding fish biomass (Raoux et al. 2017), and 3/ ecosystem processes and properties are sensitive to changes generated by offshore wind farms (Burkhard et al. 2011).

With its long and documented history of fishing activity and the recent important development of offshore structure, the North Sea appears to be a suitable case study to explore combined impacts of offshore wind farms and fishing on fish species and their environment (Kooten et Glorius 2011; ICES 2016). Halpern *et al.* (2008) identify the North Sea as one of the most impacted regions. Indeed, they are studied 20 marine ecosystems, estimating the ecological impact of human activities, which is based on 17 anthropogenic drivers. So the North Sea is an environment strongly anthropized with multiple uses.

Located at mid-latitude (centered around 55°N, 4°E – Figure 1), the continental shelf of the North Sea represents an area of about 573 300 km² and a volume of 42 294 km³ (Otto et al. 1990). This shallow area has an average depth of approximately 90 m, which allows development of multiple offshore activities, but deeper area is found in the Norwegian trench

(approximately 400 m deep). The North Sea, a typical semi-enclosed continental shelf (Steele et al. 2009) is bounded by the coasts of Norway, Denmark, Germany, the Netherlands, Belgium, France and United Kingdom. The continental coastal zone covers 60 000 km² (Mackinson et Daskalov 2007), which represents 10% of the total surface area of North Sea.

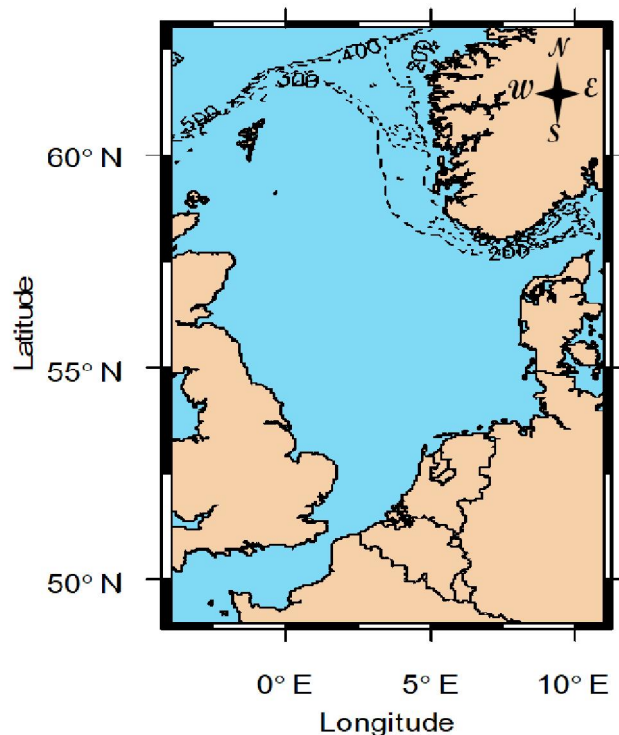


Figure 1: Map of North Sea ecosystem (with R package 'oceanmap').

The dominant activities in North Sea are fishing, shipping, oil and gas production, wind farms and aggregate extraction (ICES 2016).

In the past, fishing has reduced the number of large fish in the North Sea ecosystem. In consequence, fishing effort has reduced since the 2002 Common Fisheries Policy (CFP) reforms, increasing the abundance of large fish present in assessed fish stocks (Stamoulis et Torrele 2016). Global fishing effort has fallen by approximately 50% (2004–2012) in Greater North Sea. Actually, the majority of assessed fish stocks are fished at or below MSY (STECF 2013a) fishing mortality targets (F_{MSY}). Thus, natural mortality is now the main source of mortality for many commercial species (ICES 2014). But fishing changes both community structure and functioning of the ecosystem (Daan et al. 2005), as food webs. The North Sea food web is considered as perturbed as many of these larger predatory species have depleted or present only in reduced numbers (Greenstreet et Rogers 2006). Note that flatfish are not included in the current multispecies models for the North Sea, which assess the impact of fisheries and main predators on the forage fish stocks (ICES 2016).

Concerning temperature evolution, warming of 1.1°C since 1962 (Wiltshire et Manly 2004), trends of the North Sea follow the climate change and temperature cycle of the Atlantic Multidecadal Oscillation (AMO). Primary production in the coastal zone decreased, with the decline of the phosphate input resulting from eutrophication during 1980's.

In recent years the addition of new artificial hard substrate has increased in the North Sea, as offshore wind farm development, which has started in the last decade (OSPAR 2010). Others OWF are planned for areas further offshore.

1.3 Objectives of this study

In the context of the multiple human uses of the ocean (Halpern et al. 2008), the challenge of this study is to quantify the ecosystem impacts of the interactions between different human activities in the North Sea, and their evolution under climate change. In order to estimate the wind farms' impacts of area closure on fisheries in the North Sea, it is necessary to understand the processes underlying ecosystem dynamics, such as trophic functioning. A suitable method to tackle this challenge is to use spatialized ecosystem models, which are recognized as promising decision support tools for ecosystem-based management initiatives (Holt et al. 2014).

Several ecosystem-based model frameworks exist, and some of them have been applied to the North Sea with different levels of completion. Currently in North Sea, Ecopath with Ecosim (EwE) and Ecospace models are applied for management advice (Romagnoni et al. 2015), and ATLANTIS is in progress. As this study constitutes the groundwork for an international project to come (and is thus realized with its constraints), and because of the elementary properties of the Object-oriented Simulator of Marine ecOSystem Exploitation (OSMOSE) modelling framework, it was decided to develop an OSMOSE application for the North Sea. OSMOSE is a trophodynamic model, which represents multiple species of fish and their interactions. It allows exploring fish community's dynamics and its response to fishing pressure and climate change. Because of its fundamental process of opportunistic predation and its individual-based structure, the trophic structure of the ecosystem is flexible as it emerges from the simulation, which allows the ecosystem to adapt to pressures. Furthermore, OSMOSE is spatialized, enabling the implementation of spatial management measures (e.g., offshore structures, spatialized fishing activities). Indeed in modelling, the current challenge is to integrate fisheries into marine spatial planning, developing new concepts and methods (Janßen et al. 2018).

To address the challenge presented above, this study should tackle the following tasks:

- The development of an integrated North Sea model

The aim is to define the limits of the modelled ecosystem, parameterize an OSMOSE model for the North Sea with consideration of different fishing fleets (last version of OSMOSE), and finally calibrate it to represent the current state of the ecosystem. The calibrated reference simulation will constitute a baseline to assess the effects of different pressures on the ecosystem.

- The simulation of different human activities scenarios under climate change.

The questions addressed by these simulations are as follows: How will the effects of fisheries pressure combine with climate change? What will then be the effects of spatial competition between the different uses in the ecosystem?

As a first approach, climate change scenarios will be considered through regional change of primary and secondary production (provided by Plymouth Marine Laboratory (PML)) and impacts of offshore structures will be only considered through no-take areas (spatial competition with fishing activities).

This thesis first describes the hypotheses of OSMOSE, second presents the parameterization of the model to the North Sea and then the calibration methods used. Due to the unexpected failure of the calibration, and therefore to our inability to simulate a reference ecosystem state, the scenarios initially considered for this study were not performed. The results focus on the calibration outputs and the insights gained by this study. Finally, we discuss the approach undertaken in this study and we propose future work to finally answer the questions initially asked.

2 Material and Methods

2.1 The OSMOSE modelling framework

2.1.1 OSMOSE: model overview

OSMOSE is a multispecies individual-based model (IBM). This spatially explicit IBM represents life-cycle dynamics of size-structured populations for each species, as well as their trophic interactions (Shin et Cury 2004). The main assumption of OSMOSE is the opportunistic size-based predation, with suitable size-ratio and spatial and temporal co-occurrence between predator and its prey (Shin et Cury 2001). OSMOSE allows to model the individual's future of species through life cycle processes and behavioural rules with its environment (Shin et Cury 2001). By definition, an IBM is a mechanistic model. The processes implemented in OSMOSE are: reproduction, somatic growth, migration, starvation, survival and opportunist predation.

OSMOSE has been used to model trophic dynamics and fishing impacts. It has been applied on multiple ecosystems, for example, the Strait of Georgia in Canada (Fu et al. 2013, 2017), the West Florida Shelf (Grüss et al. 2015) assessing management strategies (Grüss et al. 2016), the Southern Benguela implementing climate variability (Travers-Trolet et al. 2014) and the West Africa in Senegal including impacts of Marine Protected Area (MPA) (Brochier et al. 2013).

2.1.2 Detailed structure and formulations of OSMOSE

In this IBM, each individual is represented as a 'super-individual' (Shin 2000), which constitutes the basic interaction entity in this model and contains the abundance of a group. A group is considered as a school of fish having the same specific characteristics and same predation behaviours (Shin et Cury 2001). Therefore, a school is composed of individuals of the same species, characterized by the same age, size, life cycle parameters and local interaction between the others individuals and their environment. In view of this description, OSMOSE allows to provide a multispecies and dynamic trophic model investigating interactions of fish species.

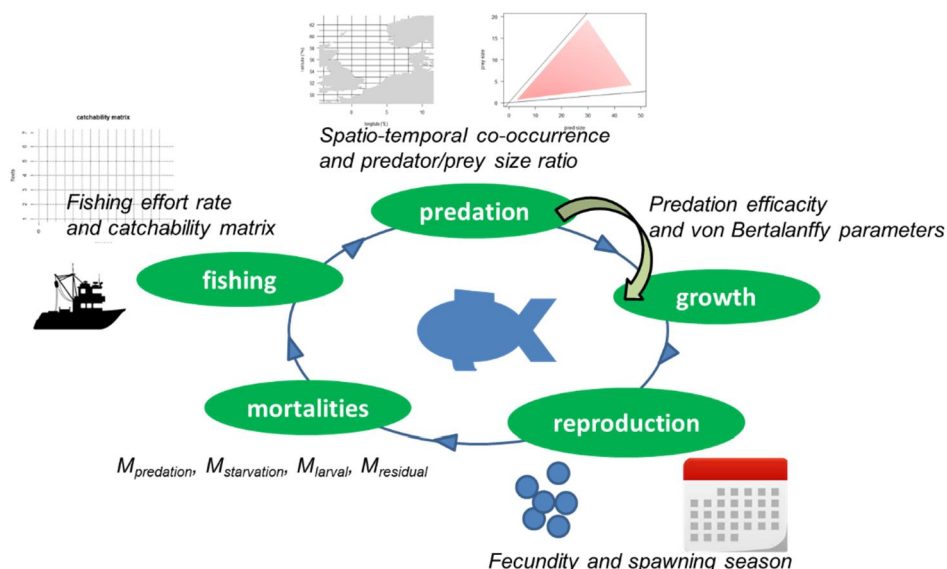


Figure 2: Scheme of OSMOSE with main processes (in green bubbles) and major parameters schematized (description is written in black).

A school of individuals undergo all the following processes for a defined time step and spatial grid (Figure 2): spatial distribution, predation, growth, reproduction and mortalities. The spatial distribution varies according to species, age and season. The predation process is

informed by predator-prey size ratio, maximum ingestion rate and plankton and vertical accessibilities. The growth process is based on the von Bertalanffy model, scaled with the predation efficiency. The reproduction is seasonal and depends on a fecundity coefficient and spawning biomass. The mortalities sources could include predation (if predated explicitly), fishing (only for recruited individuals), larval (applied at the larval stage) starvation (if predation efficiency criteria is not satisfied) and residual. These processes are modelled by different equations. The equations of predation (1) and (2), growth (3), reproduction (4) and residual mortality (5) are implemented as follows in the OSMOSE model.

The predation process is based on the size adequacy between prey and predator, and their presence in the same cell (x,y) . The feeding size range is defined by maximal and minimal predator to prey size ratios sr_{max} and sr_{min} (Travers et al. 2009). For a predator school i and the prey school j with their respective body lengths L_i ; the total biomass of available prey $AP_{i,x,y,t'}$ is defined in the equation (1) with B_j the biomass of the school j , a_j its availability coefficient and t' the duration of predation actions in t time step.

$$AP_{i,x,y,t'} = \sum_j a_j \times B_{j,x,y,t'} \left| \frac{L_i}{sr_{max}} < L_j < \frac{L_i}{sr_{min}} \right. \quad (1)$$

Predation stops if the predator has reached satiation (when prey are available) or if has depleted all available prey (2) with $PB_{i,j,\Delta t}$ the biomass of the school j preyed upon by the school i , and r is the maximum ingestion rate.

$$\begin{cases} \text{if } AP_{i,x,y,t'} > r \times B_{j,x,y,t'} & PB_{i,j,\Delta t} = a_j \times B_{j,t} \times \frac{r \times B_{i,t}}{AP_{i,x,y,t'}} \\ \text{if } AP_{i,x,y,t'} \leq r \times B_{j,x,y,t'} & PB_{i,j,\Delta t} = a_j \times B_{j,t} \end{cases} \quad (2)$$

At the end of the predation process, a predation efficiency \mathcal{E}_i is calculated, if it is higher than the critical value \mathcal{E}_{crit} (i.e, predator satiety is satisfied) then the growth process takes place. \mathcal{E}_{crit} represents the food requirement for maintenance, if predation efficiency is below this value, organisms subsist or starve (application of starvation mortality), and otherwise they grow (3) following the von Bertalanffy growth model. The growth rate ΔL of a school i is weighted by their predation success $(\mathcal{E}_i - \mathcal{E}_{crit})$. In other words, the growth depends on the quantity of food eaten, around the average increase from von Bertalanffy.

$$\begin{cases} \Delta L_{i,t} = 0 & \text{if } \mathcal{E}_i < \mathcal{E}_{crit} \\ \Delta L_{i,t} = \frac{2\Delta L}{1 - \mathcal{E}_{crit}} (\mathcal{E}_i - \mathcal{E}_{crit}) & \text{if } \mathcal{E}_i \geq \mathcal{E}_{crit} \end{cases} \quad (3)$$

When individuals reach their size at maturity, they can reproduce according to their spawning season. A spawning season is defined for each species s . The spawning season is represented by a percentage of reproductive activity for each time step. The reproduction process (4) depends on the fecundity coefficient Φ , which is the number of eggs emitted per gram of mature female (whose body mass is estimated using allometric relationships: $W_{i,t} = cL_{i,t}^b$ c and b are condition and power factors by species), and the sex ratio coefficient SR . The number of eggs produced $N_{s,0,t+1}$ is proportional to the spawning biomass $SSB_{s,t}$.

$$N_{s,0,t+1} = \Phi_s \times SSB_{s,t} \times SR \quad (4)$$

The natural mortality groups different types of mortality: predation mortality, starvation mortality, larval mortality and residual mortality. The residual mortality represents natural death due to disease, senescence (a lifespan is defined per species) and external predation mortality

from species unrepresented in this model. The residual mortality process (5) represents the exponential decrease, via a mortality coefficient M , of the abundance N of the school of fish i at the time t . Other mortalities (e.g. larval mortality) are applied in a similar way with the difference that larval mortality is applied only at the first life stage (larvae).

$$N_{i,t+\Delta t} = N_{i,t} \times e^{-\Delta t \times M} \quad (5)$$

In the most recent version of OSMOSE, different fishing fleets can be specified, with each of them targeting differently the different species (target, bycatch...). Therefore the new algorithm of fishing process (6) uses an catchability matrix $A_{s,k}$ by species s and fleet k .

$$N_{x,y,s,t+1} = N_{x,y,s,t} \times e^{(-\sum_{k=1}^K A_{s,k} E_{k,s,t,x,y})} \quad (6)$$

With $N_{s,t}$ the number of individuals of species s and $E_{s,k}$ the fishing effort rate. In the new implementation of fisheries, the fishing mortality $F_{k,s}$ is derived from a fishing effort $E_{s,k}$ variable in space (x,y) , time t and depends on the size of the targeted species (7).

$$F_{k,s,t,x,y} = R_k(t) \times S_k(s) \times Z_k(x, y, t) \quad (7)$$

With R_k the time varying effort rate, S_k the size-dependent multiplication factor and Z_k the space-dependent multiplication factor.

The process equations modelling the life cycle of fish require input parameters. These parameters can be grouped into four categories, as survival parameters (longevity, mortality rates), growth parameters (von Bertalanffy model parameters, condition factor), predation parameters (predator/prey size ratio) and reproduction ones (age at maturity, relative fecundity) that are available for many species in the literature and FishBase. The analysis of the data from Fisheries Information Dependent (FDI) allows the fishing parameters to be obtained (effort fishing rate and catchability matrix). All parameters are defined during the parameterization phase described in the following section.

2.2 Application of OSMOSE to the North Sea

2.2.1 Principle of the modelling choices to make

Setting a new configuration of OSMOSE starts with the definition of the limits of the ecosystem to model, notably regarding spatial and temporal coverage. The study area has to be represented by a 2D-grid in OSMOSE and a temporal window needs to be defined as the model will simulate an average state of the ecosystem. The ecosystem components are defined through a selection of species to be explicitly modelled, and a selection of fleets to implement fishing activity. The species are chosen according to their commercial and ecosystem representativeness. The fleets are defined as significant fisheries in this area, in term of effort and landings. All criteria (temporal, spatial, ecosystem components) are simultaneously considered for setting the OSMOSE configuration. Choosing a limited number of species achieves the compromise between the representativeness of the ecosystem and the time of computation. Definition of ecosystem limits and collection of the associated informations (biogeography, biological parameters, species distribution areas, fishing information) constitutes a key step for setting an OSMOSE application in North Sea.

2.2.2 Area and period

First, the abundant literature on the North Sea has informed us on ecosystem and hydrologic characteristics. The limitation defined by ICES (Figure 3a.) is used to collect data, which define the species to be modelled and the average state for calibration. The exclusion

of the Norwegian trench is due to two reasons: the definition of Greater North Sea ecoregion excludes the Norwegian trench (ICES 2017a) which shows a strong change in bathymetry, and the International Bottom Trawl Surveys in North Sea (NS-IBTS) does not include this area in these limitations (Figure 3b.). The particular hydrodynamic conditions – with Atlantic inflow (Turrell 1992; Winther et Johannessen 2006) – exclude the North of Shetland and Orkneys islands (Figure 3c.). The description of bathymetry, physical and habitat conditions (Mackinson et Daskalov 2007) indicates an heterogeneous environment, with variability and different fish communities. The exclusions of Norwegian trench, Shetland and Orkneys islands and the definition of North Sea by ICES provide a spatial grid for OSMOSE (Figure 3e.) to model the North Sea ecosystem.

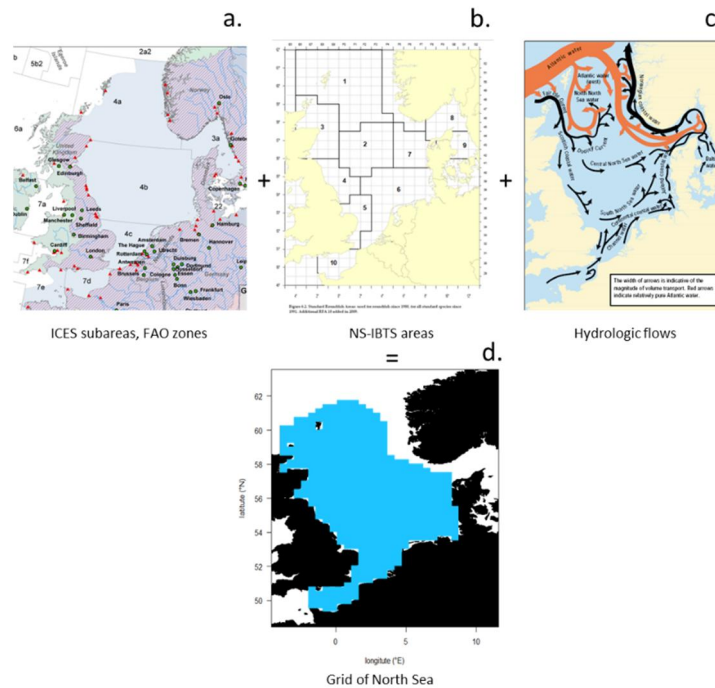


Figure 3: Main geographical characteristics of the North Sea ecosystem: management limits (a), bottom-trawl survey limits (b), hydrography (c) and spatial grid used for OSMOSE (d) with blue cells representing water areas.

The Database of Trawl Surveys (DATRAS) stores data collected from bottom trawl fish surveys, as NS-IBTS, coordinated by ICES expert groups. The NS-IBTS data, as Catch Per Unit Effort (CPUE), are covering Skagerrak, Kattegat, North Sea and English Channel.

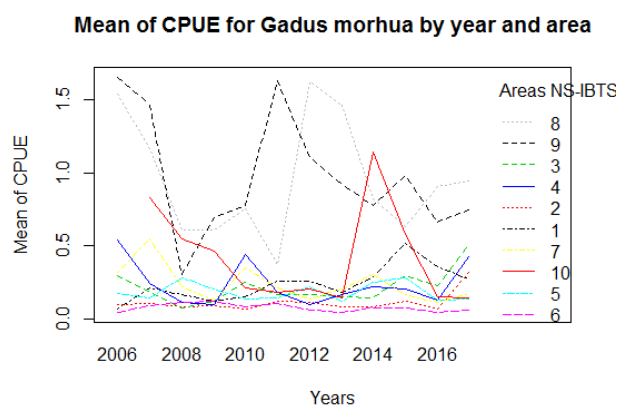


Figure 4: Evolution of annual survey CPUE per sub-areas for Cod.

The evolution of the mean CPUE, per sub-areas used by NS-IBTS (Figure 3b.), during time series 2006 to 2016 for cod, shows a high variability in CPUE for areas number 8 and 9 (Figure 4). These areas correspond to Skagerrak and Kattegat, which are excluded of study area. In addition, these areas do not provide a stable time period (variability in CPUE for cod in these two areas over the time series) and they are not integrated into studies in the North Sea (Jennings et al. 2002; Mackinson et Daskalov 2007; Emeis et al. 2015). The example of cod species is applied, because this species has a special management plan in this area. The southern limit of the North Sea ecosystem corresponds to the Eastern English Channel, represented by sub-division 7.d ICES area, for the same previous reasons to define ecosystem grid. The study area is composed of a part of Northern North Sea (Division 27.4.a), Central North Sea (Division 27.4.b), Southern North Sea (Division 27.4.c) and Eastern English Channel (Division 27.7.d).

The spatial grid of OSMOSE is divided into cells of 0.5° longitudinal by 0.25° latitudinal between (49.25°, 62° N) and (-4°, 9° E), with the average surface of a cell being 28*32 km². The coastline is defined by calculating the land/sea surface ratio of the cells bordering the countries, to determine whether the cell corresponds to the land or the sea.

Second, the period of modelling must be relatively stable. The average of log-transformed CPUE (Figure 5) shows fluctuations for only a few species, as Atlantic mackerel (corresponding to MAC in yellow) and Saithe (corresponding to POK in pink). In addition, the management strategy related to the Cod Plan has been applied from 2005 onwards, reducing the fishing pressure on this species and indirectly affecting the entire ecosystem of North Sea. The temporal window chosen to model a relative stable period is therefore 2008-2016. Regarding time discretization, the time step of OSMOSE is set to 15 days, similarly to other applications, along which the different processes occur.

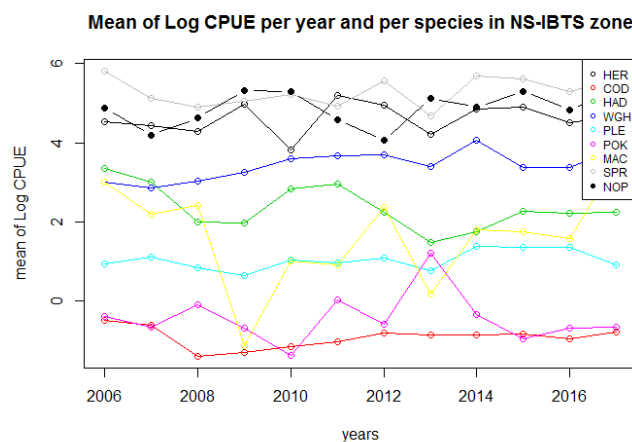


Figure 5: Time series of log CPUE for main species, derived from survey data over the NS-IBTS area. Species code are HER: Atlantic herring, COD: Cod, HAD: Haddock, WGH: Whiting, PLE: Plaice, POK: Saithe, MAC: Atlantic mackerel, SPR: European sprat and NOP: Norway Pout.

2.2.3 Selection of species and collection of their biological parameters

The explicitly modelled species are chosen in function of their abundance or biomass and landings, in order to reflect commercial importance and ecosystem dominance (an important role in ecosystem interactions associated with a high presence of individuals) in the North Sea.

From the abundance data (relative number of individuals per species) of the NS-IBTS, we select the species whose sum of individuals over the 2008-2011 period is greater than 500 individuals. Then, from the landing data and catch data, species are selected whose sum of landings and catches over the 2008-2011 period is greater than 80,000 t and 100,000 t, respectively. Landings data are based on data provided by Member States and were analyzed

during the Scientific, Technical and Economic Committee for Fisheries (STECF) Expert Working Group on Fisheries Dependent Information (FDI). Catches data correspond to official nominal catches (i.e. with discards estimation for assessed stocks) in FAO area 27 by country, species, area and year as provided by the national authorities and collected by ICES. The values chosen to select the species are arbitrary, they only make it possible to highlight the dominant species of these data. The treatment of previous data is summarized in Table 1. The number of species to select for modelling, depends on computer constraints (storage) and logistics (more complex model and longer calibration time): the choice of 15 species seems to be a reasonable compromise.

Table 1: List of the 15 most important species in term of abundance (in number of individuals per haul of trawl during NS-IBTS), landings (in tonnes derived from FDI) and catch (in tonnes derived from ICES). The species modelled in OSMOSE are indicated in bold.

	Abundances (IBTS)	Landings (FDI)	Catches (ICES)
1	Whiting	Herring	Sandeels
2	Common dab	Sandeels	Mackerel
3	Herring	Sprat	Herring
4	Plaice	Mackerel	Sprat
5	Cod	Plaice	Saithe
6	Grey gurnard	Common shrimp	Norway pout
7	Long rough dab	Great Atlantic scallop	Plaice
8	Blue whiting	Saithe	Common shrimp
9	Haddock	Haddock	Haddock
10	Sprat	Cod	Cod
11	Norway pout	Blue mussel	Blue mussel
12	Poor cod	Norway pout	Nephrops
13	Dragonet	Sole	Blue whiting
14	Horse mackerel	Nephrops	Whiting
15	Argentine	Blue whiting	Sole

Note that the study area differs slightly depending on the data. Catch data on ICES sub-areas (Figure 3a.) correspond to the Greater North Sea ecoregion, abundance data on NS-IBTS areas (Figure 3b.) correspond to the Greater North Sea with exclusions of Norwegian trench and Western English Channel and landing data on area II A and B in the Cod Plan refer exclusively to the North Sea; but they are all considered to be representative of the North Sea.

Table 1 permits to confirm the important place of the following exploited species in the North Sea: herring, mackerel, sandeels, sprat, whiting, common dab, plaice, cod and saithe, present at least once in the top five species for abundance, landings and catch. Moreover it provides a supplement information regarding the importance of grey gurnard (survey data) in the fish community abundance, which is confirmed by literature (Jennings et al. 2002; Greenstreet et Rogers 2006). Finally, the Working Group of Integrated Assessment in North Sea (ICES 2017b) includes hake in their stochastic multi-species model (SMS), as it was described as an emergent predator in North Sea (Cormon et al. 2016). As we aim at simulating the North Sea ecosystem in the future, hake was also modelled with OSMOSE.

In addition, the exploration of ICES catch data shows that the twelve most exploited species in the North Sea (Figure 6) are cod, haddock, whiting, plaice, saithe, herring, mackerel, sandeels, Norway pout, sprat, mussel and common shrimp, according to the description of fisheries (ICES Ecosystem overview 2016). These 12 species alone cover 79% of the total cumulated catches in 2015 (Figure 7).

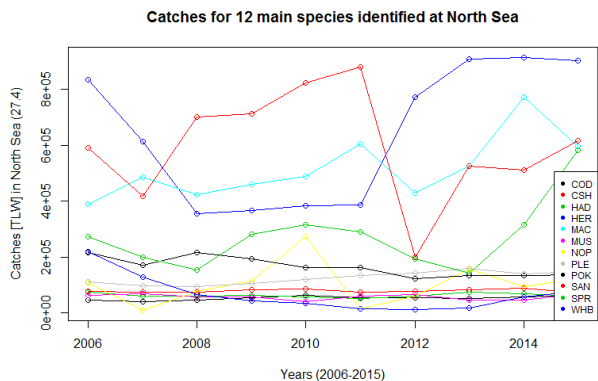


Figure 6: Evolution of catch for 12 species in North Sea during 10 years (2006-2015), from ICES. Species code are provided in appendix A.

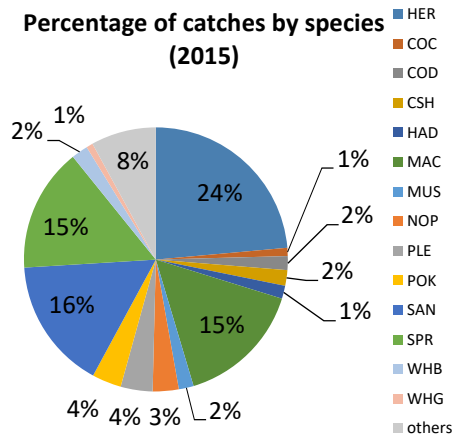


Figure 7: Pie chart of cumulated percentage for catch in 2015 (ICES data), index code of species in appendix A.

The set of species chosen to represent the North Sea ecosystem during 2008-2016 is focuses on: Atlantic herring (*Clupea harengus*), Atlantic mackerel (*Scomber scombrus*), sandeels (*Ammodytes marinus*), Norway pout (*Trisopterus esmarkii*), European sprat (*Sprattus sprattus*), Saithe (*Pollachius virens*), Atlantic cod (*Gadus morhua*), Haddock (*Melanogrammus aeglefinus*), Blue whiting (*Micromesistius poutassou*), whiting (*Merlangius merlangus*), European plaice (*Pleuronectes platessa*), Common sole (*Solea solea*), Common dab (*Limanda limanda*), Grey gurnard (*Eutrigla gurnardus*) and European hake (*Merluccius merluccius*). It should be noted that sandeels refer to a group of the same genus *Ammodytes*, but that it actually includes different species of which the most abundant in the North Sea is *A. marinus* whose specific parameters are used.

The species parameters of OSMOSE are defined in function the most recent information, the area of information and the concordance/coherence with other parameters for one species. Preferentially selected parameters are those with the most recent information (date of sampling and publication), is located in the North Sea (or including this zone) and matches with the other parameters. Information that combines the maximum of these three criteria is retained as a parameter. These informations are collected from literature and FishBase.

Biological parameters for all species are summarized in Table 2, ordered by categories of process. The references used for these parameters are listed in appendix C. For some parameters, a low sensitivity of the model to parameter values and/or poor knowledge about their values result is the use of common value for all species. These default values concern the parameters, for:

- Initialization: the number of schools per species is 50 'super-individuals' and the initial biomass corresponds to the average catch or biomass data in tonnes (see calibration),
- Mortality process: the residual mortality coefficient is 0.05 year⁻¹ (WGNOSE in ICES 2017b) and the starvation mortality coefficient is 0.3 year⁻¹,
- Predation and growth processes: the age threshold separates larvae and juvenile feeding stages and it is 0.25 year for demersal and benthic species, which have a pelagic stage during their larval phase, the predation efficiency coefficient is 0.57 and the maximum ingestion rate is 3.5 for all species, the adjustment threshold of the von Bertalanffy model is 1 year, the maximal growth in length ΔL_{max} (calculated

from a von Bertalanffy model) factor is 1.5 and it replaces the value 2 in equation (3),

- Reproduction process: the egg size is 0.1 cm, the egg mass is $5.37 \cdot 10^{-4}$ g and the sex ratio is 0.5.

In OSMOSE simulation, the time step starts with the spatial distribution of fish. Spatial distribution is defined by a presence/absence map for each species and life stage (optional season). The construction of map inputs is described below. The movement of fish is random walk. Fish move randomly among adjacent cells, when the mean spatial distribution map is the same from one time step to the next.

Table 2 : Biological parameters for growth, reproduction, survival and predation processes, for the 15 species modelled in OSMOSE. Appendix C for references.

Species	Growth					Reproduction			Survival	Predation		
parameter	L_{∞}	K	t_0	a	b	ϕ	a_{mat}	L_{mat}	a_{max}	sr_{min}	sr_{max}	ecology
unit	cm	y^{-1}	year	$g.cm^{-3}$		eggs.g ⁻¹	y	cm	year			
Atlantic Herring	30.5	0.44	-0.69	0.00322	3.22	503	2.73	22.1	8	500	2.5	pelagic
Atlantic Mackerel	33.6	0.837	-0.18	0.002	3.401	1275	2	30	17	500	2.5	pelagic
Sandeel	18.5	0.36	0	0.001	3.44	8140	1.51	13.5	10	50	1.5	demersal
European Sprat	15	0.503	-0.49	0.00289	3.36	400	2	11.5	6	500	2.5	pelagic
Norway Pout	22.6	0.52	0	0.0039	3.202	980	1.35	15	5	50	1.5	demersal
European Plaice	48	0.16	-1	0.0107	2.97	265	2.9	22.1	25	125	5	benthic
Common Sole	40	0.148	-3	0.00497	3.2	800	1.2	18.8	26	125	5	benthic
Saithe	87.7	0.211	-0.04	0.0049	3.133	750	4.75	55.4	25	50	1.5	demersal
Atlantic Cod	116	0.208	0.08	0.00587	3.14	700	2.1	37.8	25	50	1.5	demersal
Haddock	61.4	0.25	-0.25	0.005	3.176	500	2.5	33.5	20	50	1.5	demersal
Blue Whiting	35	0.24	-1.58	0.0073	2.893	600	2.35	22	8	50	1.5	demersal
Whiting	38.1	0.432	-0.5	0.0045	3.162	1700	1.5	20.2	20	50	1.5	demersal
Common Dab	33	0.21	-0.89	0.0068	3.14	482	2.3	13	12	125	5	benthic
Grey Gurnard	46	0.16	0	0.0112	2.877	255	4.5	25	21	50	1.5	demersal
Hake	127.5	0.073	-1.13	0.004	3.13	426	3.8	40	20	50	1.5	demersal

2.2.4 Mapping species distribution

The construction of the species distribution maps is based on CPUE data per haul from the NS-IBTS survey (DATRAS), average over 2008-2016. CPUE are aggregated by statistical rectangles (via geographical coordinates) and by species and their stage of development (juveniles or adult, depending on their size).

Then, the OSMOSE grid is overlaid on the CPUE distribution map by statistical rectangles, and the values are extrapolated by OSMOSE rectangles of 1/4 resolution of a statistical rectangle. These values are adjusted according to the limitations of the OSMOSE grid and converted into presence/absence factor of 0 to 5 (no presence to high presence) and reported as matrices.

The differentiation between the juvenile and adult stage comes from the length at maturity by species found in the literature (Table 2). This value is previously adjusted with the age at maturity and the von Bertalanffy model (with specific parameters) by species and provide the selection size L_{mat} used for the maps.

These matrices of spatial distribution are established for each species by age according to their juvenile or adult stage for one year (Figure 8).

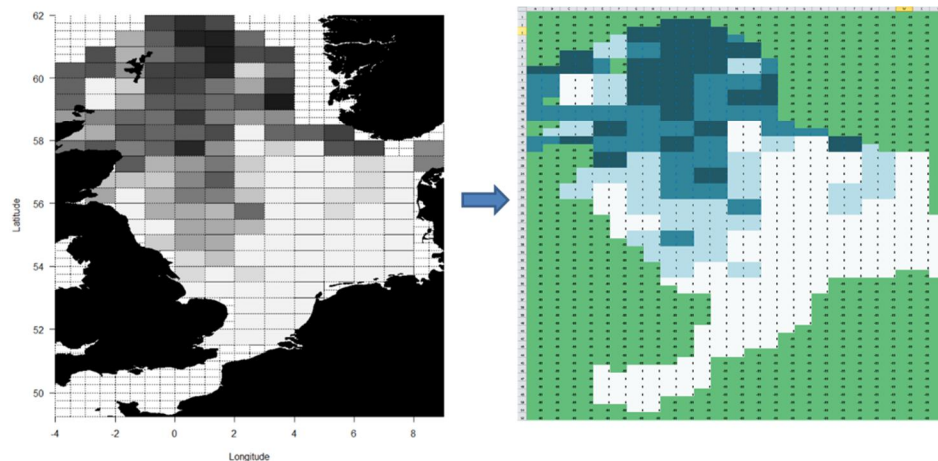


Figure 8: Example of distribution maps, for juvenile herring. A: mean CPUE per statistical rectangle derived from survey data, and B: corresponding distribution map used in OSMOSE, with 0 to 5 level of abundance (in scaled colors from white to blue).

Seasonal differentiation could not be achieved, via quarters 1 and 3 (from January to March and from July to September) due to a missing data in quarter 3 and computer problem during the time allowed for the internship.

2.2.5 Setting the fishing fleets

Implemented in early 2018, the new fishing process is defined by fisheries. The fishing effort data (derived from FDI) allows selection of a moderate number of fisheries. These fisheries must represent the main patterns of exploitation in the North Sea. To determine these patterns, fishing effort is analysed first by vessel and spatial distribution, second by gear and finally by species landed.

The average of fishing effort over 2008-2016 shows the temporal variability of fishing effort by vessel types (Figure 9). The temporal variability of fishing effort indicates the dominance of three types of vessel over the modelled area and period. These three length classes of vessel represent the major fishing effort.

In order to capture most of the fishing effort, vessels can be grouped using the 15 meters limit. The result is two length classes of vessel with those less than or equal to 15 m

and those greater than 15 m. This limit also broadly correspond to coastal fishing (<15m) and offshore fishing (>15m).

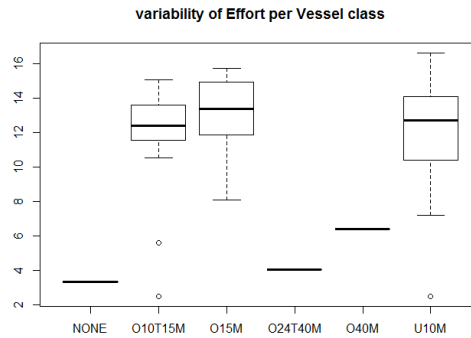


Figure 9: Boxplot of fishing effort aggregated by class of vessel length and averaged over 2008-2016.

The gear used depends on targeted species and, more precisely on the species ecology. In Figure 10, the relative dominance of the different gears is illustrated for 2 species, with a benthic species represented by plaice and a pelagic species by herring. The dominance of gear are beam trawl and bottom trawl (BT and TR for different mesh) for benthic species, and pelagic trawl and seine (PEL_TRAWL and PEL_SEINE) for pelagic species.

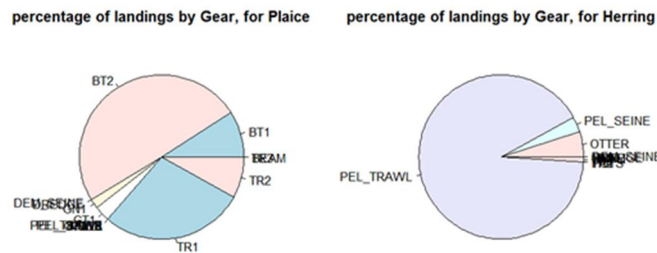


Figure 10: Percentage of landings in 2015 (for example) by gears, for Plaice and Herring.

Among the species exploited and modelled, the grouping (Figure 11) of landings by fishing gear according to vessel length distinction (15m) enables us to identify the main fleets for each species and thus, the exploitation patterns to define the fisheries.



Figure 11: Histogram of landing percentage by species (Cod, Plaice, Herring and Norway pout), gears et vessels (length >15 m on the left and length ≤15 m on the right).

The patterns observed from grouping landing in different ways shows that a distinction can be made between two groups of vessel (limit of 15 meters) and “pelagic or benthic” gears.

The size of the vessels coupled with the distribution of gear by species allows the following fisheries to be defined, reflecting different spatial distribution of effort (Figure 12). These matrices of fishing effort distribution map are established for each fisheries for one year, similarly to the spatial distribution matrices of species. The fishing distribution map is defined into effort/no effort factor of 0 or 1.

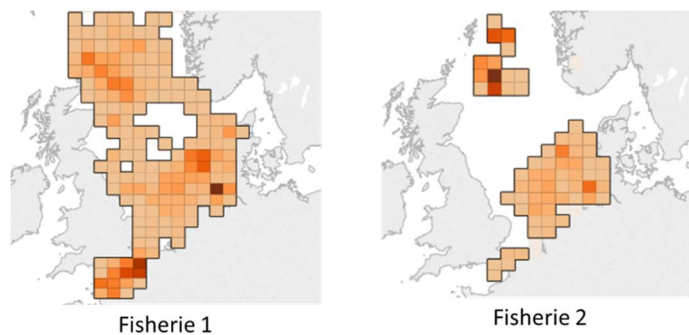


Figure 12: Fishing effort distribution maps for fisheries 1 and 2 (FDI data).

Six fisheries are defined: 1/offshore pelagic fleets (>15m) with targeted species are herring, mackerel, sandeel, sprat, blue whiting and Norway pout, 2/ coastal fleets (<15m) with bottom trawl (fine mesh) and targeted species are sandeel, sprat, Norway pout, whiting, grey gurnard and saithe, 3/coastal fleets (<15m) with longline and targeted species are mackerel, cod and haddock, 4/ coastal fleets (<15m) with bottom trawl (large mesh) and targeted species are plaice, sole, cod, haddock, whiting, and common dab, 5/ coastal fleets (<15m) with gillnets

and targeted species are plaice, sole, dab, cod, haddock, hake, herring, mackerel and sprat, 6/ offshore benthic-pelagic fleets (>15m) with beam and bottom trawls for species hake, cod, haddock, saithe, whiting, plaice, dab, sole, mackerel and herring.

Once the fisheries have been determined, the percentage catchability $A_{s,k}$ of a species s by a fleet k (within the fishery) is estimated. This value is approximated by the $\log(\text{CPUE})$. First, the average effort per fleet is calculated (Table 3) and corresponds to E_k the fishing effort rate (in equation 6). Second, average landings by fleet and for each species are calculated. The following equation (8) gives the catchability, which is divided by the number of cells with fishing effort.

$$A_{s,k} = \log \left(\frac{L_{s,k}}{E_k} + 1 \right) / n_{cell} \quad (8)$$

Table 3 : Fishing parameters by fisheries.

fishery number	n_{cell}	$E_k (\text{h}^{-1} \cdot \text{cell}^{-1})$	selectivity curve
1	505	0.21	step
2	173	1.06	step
3	184	3.56	gauss
4	288	2.48	step
5	113	5.05	step
6	632	0.62	step

2.2.6 Plankton prey field derived from ERSEM model

The European Regional Seas Ecosystem Model (ERSEM) is used to represent lower trophic levels of the marine food web (Butenschön et al. 2016). It is composed two parts: pelagic and benthic. ERSEM includes explicitly the cycles of major chemical elements of ocean and models the microbial food web (Figure 13). In addition, ERSEM integrates parameters of physical driver in the environment. Consequently, it is a generic model for marine biogeochemistry and ecosystem dynamics. The dynamics respond to abiotic variations (simulated by scenarios of climate change by IPCC). Thus, ERSEM represents the marine ecosystem in contrasting environments.

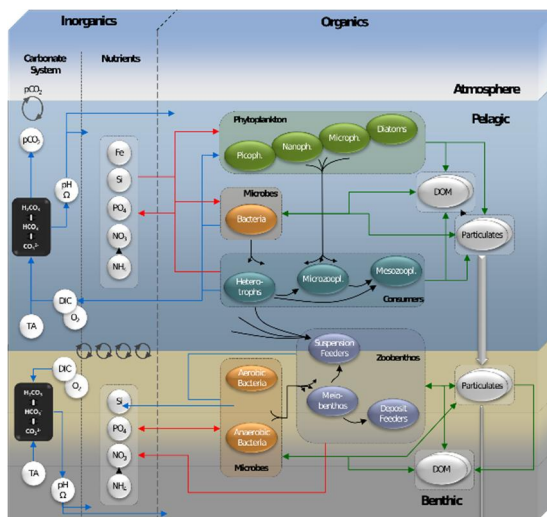


Figure 13: A schematic of the ERSEM model (Butenschön et al. 2016).

ERSEM provides input biomass for lower trophic levels (LTL) in OSMOSE. The organisms in the ERSEM are grouped by ecosystem functions. The used groups of LTL in OSMOSE are microphytoplankton, diatoms, heterotrophic flagellates, microzooplankton, mesozooplankton, suspension feeders, deposit feeders and meiobenthos. The biomass data for LTL forcing (i.e., input files) are generated by the PML. These files are already integrated over 15 days (OSMOSE time step). The biomass values are averaged over the years 2008-2016 and grouped by cells to match the OSMOSE grid. ERSEM and OSMOSE are coupled through the predation process.

Two scenarios of LTL forcing are simulated in response to climate change. These scenarios correspond to projections of IPCC, which defines the Representative Concentration Pathways (RCPs) with intermediate scenarios (RCP4.5) and one scenario with very high greenhouse gas (GHG) emissions (RCP8.5) (IPCC 2014). ERSEM permits to implement the climate variability for OSMOSE application in context of climate change.

2.3 Calibration and simulation

2.3.1 Principle and algorithm of calibration

The calibration of the individual-based model OSMOSE is conducted by the inverse parameter estimation. An evolutionary algorithm (EA) is applied to calibre the parameter uncertainty. The uncertainty depends on high stochasticity and numerous non-linear interactions between parameters in complex IBM. This method is automated estimates the calibrated parameters of complex and stochastic IBM, as OSMOSE (Duboz et al. 2010). It provides an estimation of parameters from observed data with process to compare (look like) model and “reality”. The EA is adapted to stochastic and multimodal likelihood surfaces in complex IBM. And EA permits to solve complex combinations of parameters via the processes of Darwinian evolution.

The evolutionary algorithm is inspired by Darwin’s theory of evolution and the aim is to find the best adapted individual, in other words the optimal parameters. The principle is to create a population of parameters, evaluate this population with OSMOSE and select the best individuals to produce the next generation, and start the evolution process in order to find adapted individual (Figure 14). The evolutionary algorithm needs a fitness function associated to target values to estimate the parameters. Target values are biomass and landing of species, associated with thresholds (minimal and maximal). The convergence of the algorithm is verified by the diminution of the fitness function (here to be minimized). It is possible to choose a sequential calibration method in several phases (Oliveros-Ramos et al. 2017), but in our case only one phase is used.

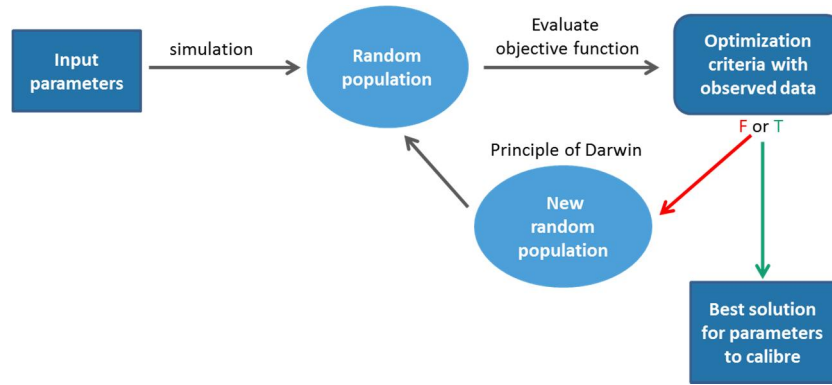


Figure 14: Scheme of steps to calibre OSMOSE with EA.

In this case, we have chosen to calibrate the following parameters: larval mortality, plankton accessibility to fish and fishing catchability matrix. Larval mortality regulates the number of individuals right after eggs are released, plankton accessibility is the quantity which is available for predation and fishing catchability matrix link species to fleets.

2.3.2 Target values

Target values are extracted from assessment reports from ICES for all species in North Sea, during modelled period (values are averaged over 2008-2016). When biomass values are not available for the study area only but for a wider, then a calculation is applied, involving the catch ratio (9).

$$B_i = \frac{L_i}{L_s} \times B_s \quad (9)$$

With B the biomass and L the landing of a species, i indicating the North Sea area and s the entire stock area. More specifically, when the estimate of discards is given in the stock assessment, L actually corresponds to the catch values, which are used as a target.

The target values from the literature provide the bold values in the Table 4. Other values, such as biomass and thresholds are estimated. In our data, catches represent on average 10% of the biomass. This ratio is applied so that the thresholds can then be constructed. The thresholds are calculated by multiplying the biomass by a factor. This factor is determined arbitrarily in order to homogenize the threshold values, with 0.25 for the minimum value and 1.25 for the maximum value. In an effort to obtain a reliable calibration, the estimated biomass data are not used as targets.

Table 4: Target values of biomass, landing and thresholds (minimal and maximal values) calculated as 0.25 and 1.25 of biomass.

species	biomass	landings	minimal	maximal
Atlantic Herring	3 372 649	344 119	843 162	5 902 135
Atlantic Mackerel	1 378 279	270 223	344 570	2 411 988
Sandeel	1 661 545	278 191	415 386	2 907 704
European Sprat	2 430 820	152 274	607 705	4 253 935

Norway Pout	422 827	57 699	105 707	739 948
European Plaice	1 098 018	118 354	274 504	1 921 531
Common Sole	58 478	17 638	14 619	102 336
Saithe	870 000	87 212	217 500	1 522 500
Atlantic Cod	225 932	44 387	56 483	395 381
Haddock	446 831	37 814	111 708	781 955
Blue Whiting	197 354	25 219	49 339	345 370
Whiting	483 419	29 102	120 855	845 983
Common Dab	450 000	45 754	112 500	787 500
Grey Gurnard	60 000	6 361	15 000	105 000
Hake	31 889	17 666	7 972	55 806

2.3.3 Scenarios of calibration

The calibration of OSMOSE in North Sea can involve several back-and-forth between the evolutionary algorithm and adjustments of other parameters. Therefore, additionally to the first attempt of calibration with the parameters described above, other scenarios of calibration are run. Five scenarios are defined and named according to their modification. Changes occur in input parameter values or the calibration configuration. The scenarios are ordered and described in the following Table 5.

Table 5: Scenarios of calibration and associated parameters.

scenario number	scenario name	scenario description
1	mortality	The residual mortality parameter is set to zero for all species.
2	predation	Predation ratio parameters are modified from other bibliographic sources for some species.

3	nschools	The number of schools is modulated according to the spawning period and the distribution area of the species.
4	calibrated predation	Predation ratios are integrated into the calibration configuration and are calibrated parameters.
5	without thresholds	Biomass threshold values are removed from the target values of the calibration.

3 Results

3.1 First attempt of calibration

A first attempt of calibration was realized on the IFREMER cluster DATARMOR (using 28 cores), by launching the evolutionary algorithm for 250 generations with 28 “individuals” per generation. An individual in calibration process corresponds to a combination of parameters, which selected in a probability law centred (in function of the variable) on the value of the parameter to calibrate and bounded by a range of values indicted in configuration. Each individual is tested to fit with observed data. Only the best individual is saved. This best individual decreases the fitness value during the calibration.

Conversely to expectations, the global fitness of the best individual at each generation does not decrease along generations (Figure 15).

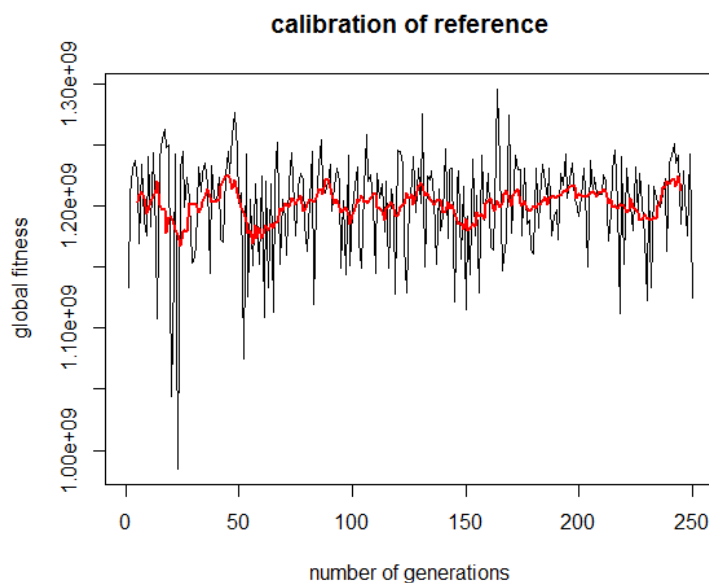


Figure 15: Evolution of the global fitness of the best individual at each generation (black line) with its moving average (red line) for the first attempt of calibration.

In fact, the global fitness corresponds to the sum of partial fitness multiplied by the index of confidence in the variable (weight). In details/precisely, the evolution of partial fitness per each variable of calibration, as biomass, landings, and thresholds shows very high variations (Figure 16+appendix D). To illustrate this case, the example of herring is used (Figure 16).

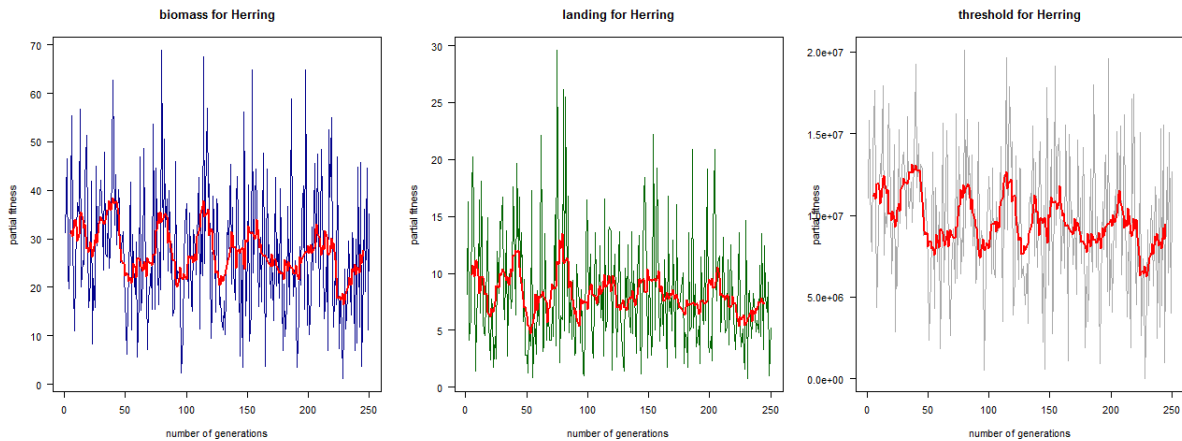


Figure 16: Evolution of the partial fitness of the best individual per variable (biomass: blue line, landing: green line, threshold: grey line) at each generation with their moving averages (red line) for the first attempt of calibration, and with the example of herring.

The fluctuations between biomass and threshold are similar, only the scale has changed. The thresholds correspond to the boundaries of biomass values, which are informed in the configuration of calibration. The common variability between these two variables appears evident. The variations of threshold variable present a higher amplitude than variations of biomass variable. The variations of landing variable are very large too. Previously, the global fitness shows the same patterns (Figure 15) and the important variation is captured by the threshold variable (Figure 16). / As global fitness is equal to the weighted sum of partial fitness, orders of magnitude show that it is threshold variable which contributes the most to global fitness.

For information, the moving average observed, for this example (Figure 16), decreases slightly. Indeed, it is one of the only species for which a minor improvement is noted (appendix D). For collapse species, evolution of fitness is linear and it is difficult for the algorithm to escape from this situation.

A light downward trend is also observed for the moving average of the partial fitness for all variables. This trend is explained by the link between landing and biomass via fishing mortality. As fishing mortality is applied to the biomass present in the system, and the landings result from this fishing mortality, excluding species below the minimum catch size. With the idea that variables and parameters are related and interact in calibration, an exploration of calibration scenarios is then described.

3.2 Further attempts of calibration

Secondly, the changes inside input parameters illustrate the impacts of the parametrization phase through scenarios of calibration.

The evolution of global fitness for the different scenarios is shown in Figure 17. No trend of decrease is observed, but changes of fluctuations illustrates the impacts of modified input parameters.

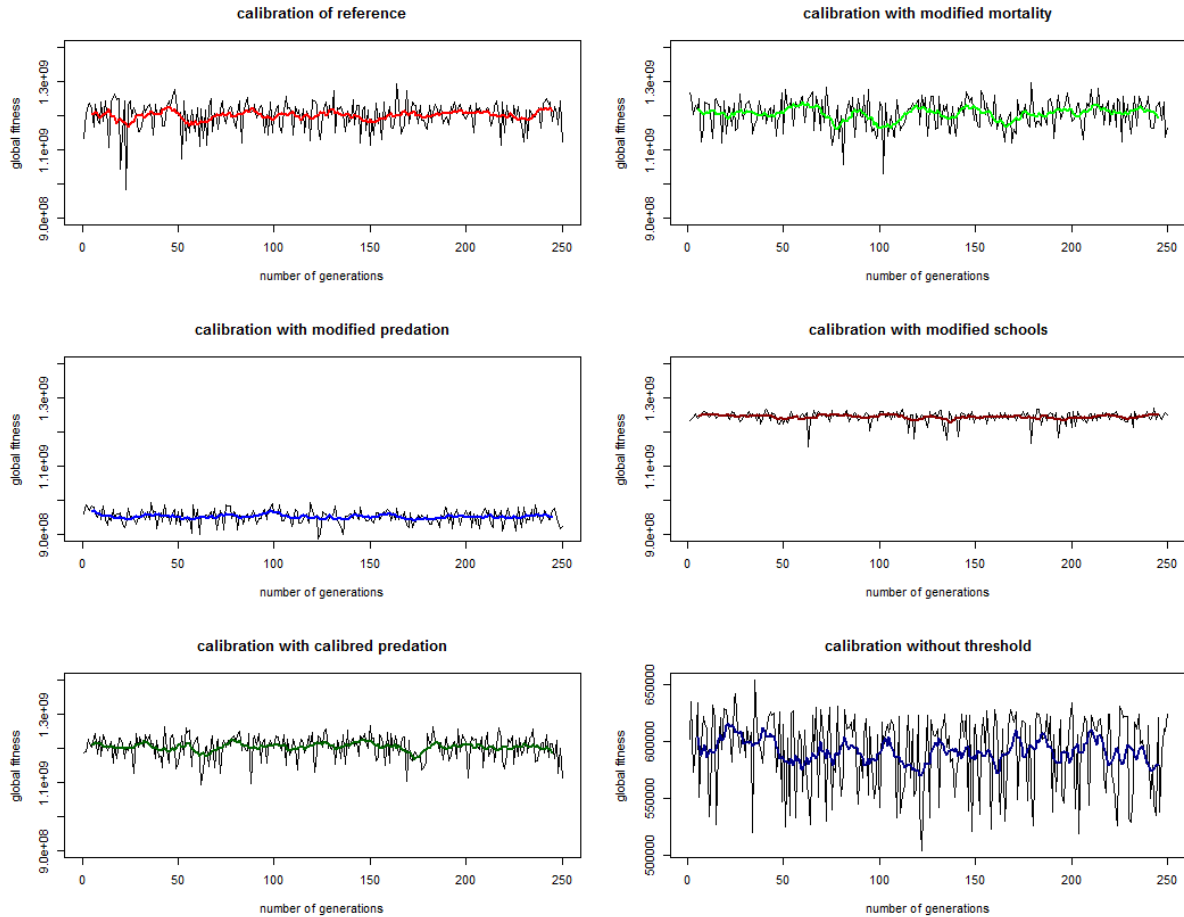


Figure 17: The evolution of global fitness for scenarios of calibration. Colored lines represent the moving mean and black line represents the global evolution during generations. The colors are following scenarios : reference (red), mortality (green), predation ratios (blue), number of schools (dark red), predation to calibre (dark green) and calibration without threshold values (dark blue).

Between scenarios of “reference” and “mortality”, the evolution of fitness is similar. Few pics of variation are different, reflecting the stochasticity of model. Between scenarios “predation” and “schools” the global fitness is lower for “predation” and variations are moderated for “schools”. Note that the number of schools in OSMOSE imposes a computer memory constraint.

Contrary to expectations, the global fitness of “calibrated predation” is not decreased. While the scenario “predation” reveals that predation ratio is a sensitive parameter. A better calibration is expected by letting the calibration algorithm “choose” in a lognormal around the initial value, but fitness does not decrease.

Regarding the scenario of “without threshold” no decreasing in the fitness is observed, and it is associated to an important variability. This scenario remains unsatisfactory and does not comply with the calibration criteria either (the decreasing of fitness to assess convergence of algorithm and best parameters found, and no collapse species for a stable system). Nevertheless, the last scenario is not comparable to previous scenarios, because the targeted values of calibration are different.

In this panel of calibration scenarios, the minimal fitness is attributed the “predation”, with the lower fitness for the best individual (Table 6). In addition, only four species are collapsed during the calibration process, corresponding to Sandeel, European Sprat, Norway Pout and Grey Gurnard. Others scenarios of calibration show higher global fitness and more collapses of species than “predation”. Calibration scenario of “predation” is considered as

“least worst/bad”, thus its calibrated parameters are used for the example of simulation (Table 8).

Indeed, different values for calibrated parameters are obtained by calibration (Table 7).

Table 6: Global fitness values per each scenarios of calibration, values are corresponding to optimal parameters.

calibration	reference	mortality	predation	nschools	calibrated predation	without threshold
global Fitness	1.31E+09	1.26E+09	9.73E+08	1.26E+09	1.34E+09	7.23E+05
number of collaspe	6	7	4	7	7	7
Names of species are collapsed	Sandeel	Sandeel	Sandeel	Sandeel	Sandeel	Sandeel
	European Sprat	European Sprat	European Sprat	European Sprat	European Sprat	European Sprat
	Norway Pout	Norway Pout	Norway Pout	Norway Pout	Norway Pout	Norway Pout
	European Plaice	European Plaice		European Plaice	European Plaice	European Plaice
		Blue Whiting		Blue Whiting	Blue Whiting	Blue Whiting
	Common Dab	Common Dab		Common Dab	Common Dab	Common Dab
	Grey Gurnard	Grey Gurnard	Grey Gurnard	Grey Gurnard	Grey Gurnard	Grey Gurnard

Table 7 shows a large variability in potential parameters. No similarity in distribution of parameters is observed. The algorithm has explored many combinations of parameters without finding the best ones for which fitness would have decreased. Calibrated values of catchability matrix are associated to each scenarios.

In the example of simulation, using calibrated parameters of “predation” scenario, simulated biomass provide a value to check if it is in interval of threshold (Table 8). Only Sandeel biomass is in the interval, other specific biomasses that do not collapse, are above the threshold (Norway Pout, European Plaice, Common Sole, Haddock, Grey Gurnard and Hake). A preliminary exploration of this simulation is then described and it represents the reference simulation.

Table 7: Values for calibrated parameters per each scenario of calibration.

species	parameters to calibre	reference	mortality	predation	nschools	calibrated predation	without threshold
Atlantic Herring	larval mortality (calibrated, 15 days ⁻¹)	8.50	18.36	11.33	3.97	7.66	11.62
Atlantic Mackerel		1.44	1.65	17.20	18.30	15.18	11.35
Sandeel		10.67	14.02	5.65	1.73	12.63	17.24
European Sprat		4.97	8.31	18.97	7.69	17.34	15.92
Norway Pout		8.36	6.95	1.82	1.43	14.45	13.37
European Plaice		5.52	8.03	2.74	3.18	7.42	13.15
Common Sole		10.27	17.08	1.97	9.34	10.52	8.45
Saithe		3.98	7.46	13.57	9.64	11.01	17.63
Atlantic Cod		15.00	7.59	12.59	3.70	5.21	5.60
Haddock		8.81	16.16	5.76	4.68	14.78	5.57
Blue Whiting		3.37	12.33	3.77	17.37	12.00	11.84
Whiting		17.68	12.80	14.12	10.70	1.67	4.97
Common Dab		7.09	7.73	5.55	11.03	10.58	11.00
Grey Gurnard		9.06	4.43	2.68	3.85	18.81	9.69
Hake	12.26	17.62	5.51	12.26	13.39	7.84	
Micro Phytoplankton	plankton accessibility (calibrated, log ₁₀)	0.48	2.95	3.34	3.24	2.78	0.38
Diatoms		1.50	2.51	3.00	0.93	1.30	2.16
Heterotrophic Flagellates		0.59	1.30	2.17	3.41	1.97	2.30
Microzooplankton		1.38	1.65	1.02	2.55	3.52	1.06
Mesozooplankton		0.90	1.37	1.29	2.88	1.81	1.23
Suspension Feeders		1.92	0.94	3.27	2.73	2.51	1.96
Deposit Feeders		2.65	2.11	2.59	1.80	0.89	1.32
Meiobenthos		3.65	2.19	3.45	0.79	3.00	0.44

Table 8: Simulation of biomass during last ten years with parameters of "predation" scenario and values thresholds (min and max) associated species biomass (mean).

predation	Common names							
Time	Atlantic Herring	Atlantic Mackerel	Sandeel	European Sprat	Norway Pout	European Plaice	Common Sole	Saithe
91	0.00E+00	0.00E+00	2.13E+06	0.00E+00	7.96E+05	6.59E+06	6.81E+09	0.00E+00
92	0.00E+00	0.00E+00	1.90E+06	0.00E+00	9.95E+05	6.75E+06	6.71E+09	0.00E+00
93	0.00E+00	0.00E+00	1.65E+06	0.00E+00	1.01E+06	6.45E+06	6.81E+09	0.00E+00
94	0.00E+00	0.00E+00	2.19E+06	0.00E+00	1.40E+06	6.03E+06	7.41E+09	0.00E+00
95	0.00E+00	0.00E+00	3.28E+06	0.00E+00	2.19E+06	5.16E+06	7.89E+09	0.00E+00
96	0.00E+00	0.00E+00	2.52E+06	0.00E+00	5.54E+06	7.50E+06	8.73E+09	0.00E+00
97	0.00E+00	0.00E+00	2.76E+06	0.00E+00	7.73E+06	7.92E+06	8.71E+09	0.00E+00
98	0.00E+00	0.00E+00	4.10E+06	0.00E+00	1.75E+07	9.38E+06	8.74E+09	0.00E+00
99	0.00E+00	0.00E+00	4.19E+06	0.00E+00	1.65E+07	1.38E+07	9.41E+09	0.00E+00
100	0.00E+00	0.00E+00	4.23E+06	0.00E+00	1.88E+07	1.42E+07	1.06E+10	0.00E+00
mean	0.00E+00	0.00E+00	2.90E+06	0.00E+00	7.25E+06	8.38E+06	8.18E+09	0.00E+00
min	8.43E+05	3.45E+05	4.15E+05	6.08E+05	1.06E+05	2.75E+05	1.46E+04	2.18E+05
max	5.90E+06	2.41E+06	2.91E+06	4.25E+06	7.40E+05	1.92E+06	1.02E+05	1.52E+06
predation								
Time	Atlantic Cod	Haddock	Blue Whiting	Whiting	Common Dab	Grey Gurnard	Hake	
91	0.00E+00	2.75E+07	4.46E+08	0.00E+00	0.00E+00	1.91E+09	4.81E+08	
92	0.00E+00	1.98E+07	5.36E+08	0.00E+00	0.00E+00	1.83E+09	4.85E+08	
93	0.00E+00	1.37E+07	4.32E+08	0.00E+00	0.00E+00	1.66E+09	4.57E+08	
94	0.00E+00	1.08E+07	4.02E+08	0.00E+00	0.00E+00	1.43E+09	4.61E+08	
95	0.00E+00	8.49E+06	3.38E+08	0.00E+00	0.00E+00	1.23E+09	4.22E+08	
96	0.00E+00	1.06E+07	2.81E+08	0.00E+00	0.00E+00	1.12E+09	3.58E+08	
97	0.00E+00	4.56E+07	2.44E+08	0.00E+00	0.00E+00	9.99E+08	3.49E+08	
98	0.00E+00	5.14E+07	1.96E+08	0.00E+00	0.00E+00	8.91E+08	3.32E+08	
99	0.00E+00	4.19E+07	1.96E+08	0.00E+00	0.00E+00	8.67E+08	3.32E+08	
100	0.00E+00	4.71E+07	4.68E+08	0.00E+00	0.00E+00	7.73E+08	3.98E+08	
mean	0.00E+00	2.77E+07	3.54E+08	0.00E+00	0.00E+00	1.27E+09	4.08E+08	
min	5.65E+04	1.12E+05	4.93E+04	1.21E+05	1.13E+05	1.50E+04	7.97E+03	
max	3.95E+05	7.82E+05	3.45E+05	8.46E+05	7.88E+05	1.05E+05	5.58E+04	

3.3 Details of set of simulations

For illustrative purposes, a set of simulation was performed with the least bad calibrated parameters (corresponding to "predation" calibration scenario). The parameters used for this simulation are the input parameters described in Material and Methods section, except for predation ratios for which modified values are used, and calibrated parameters from Table 7. As OSMOSE is a stochastic model, 30 replicates were runs for 100 years.

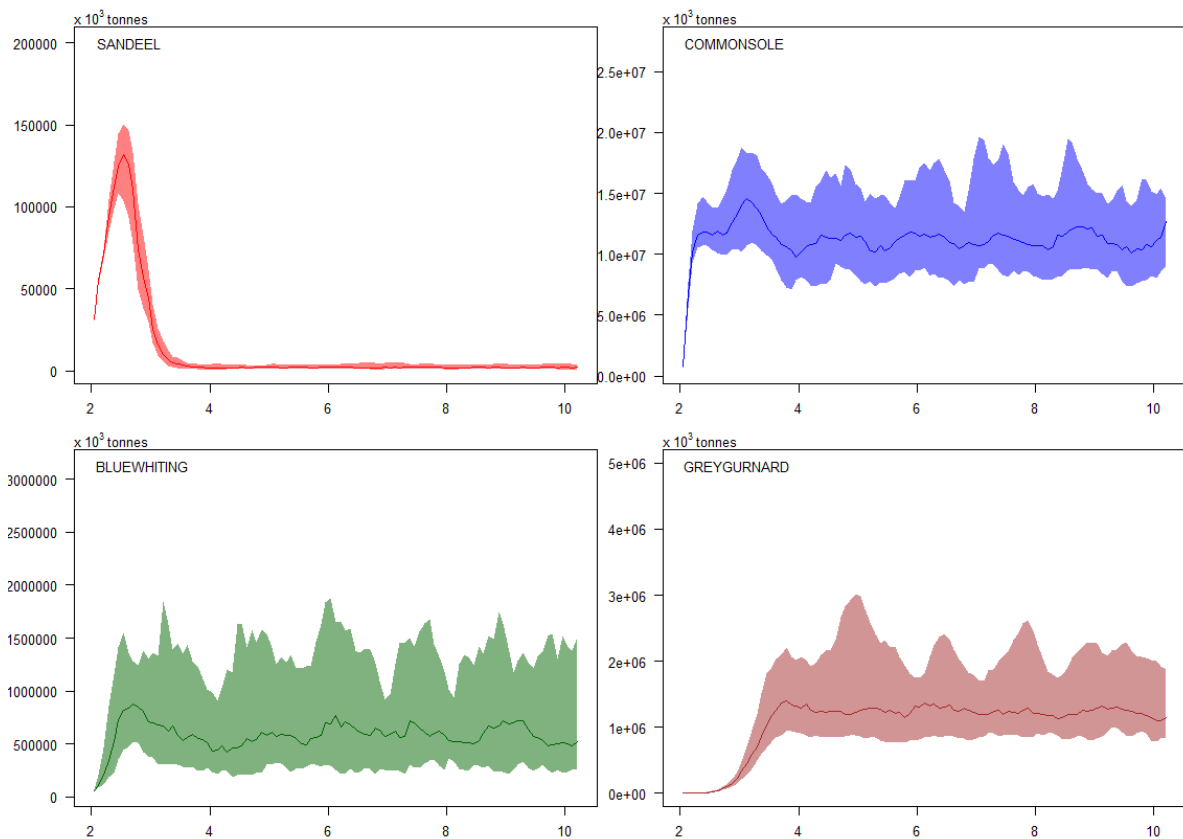


Figure 18: Evolution of simulated biomasses (in tonnes) with 30 replicates, for four species (sandeel, common sole, blue whiting and grey gurnard). Time is expressed in ten years

Evolution of simulated biomass is shown for some species in Figure 18. The variability of biomass between replicates is significant. However, the average is reached quickly and is stable over time. After a brief increase, biomass of sandeel collapses early in the simulation, for all replicates. Others biomasses show the variability in projections of 100 years. Indeed, the variability of biomass between replicates is significant. However, the average is reached quickly and is relatively stable over time.

In addition, the evolution of biomass and catch for hake shows the synchronic trend between these two variables (Figure 19).

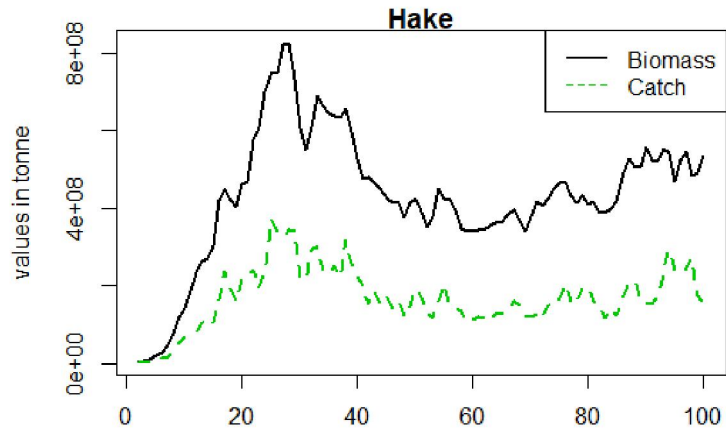


Figure 19: Evolution of biomass and catch for Hake (one replicate).

Finally, this simulation permits to present some simulated indicators available. For example, the mean trophic level (TL) of catches can be compared between species, or averaged over all species to inform on the community dynamics. Figure 20 presents the variability of this indicator for Norway pout, Common sole, haddock and hake. Hake has the higher TL, while Common sole has the lower TL, which is coherent with their ecology. However, these results won't be explored further as the simulation is not representative of the current state of the ecosystem (no calibrated model).

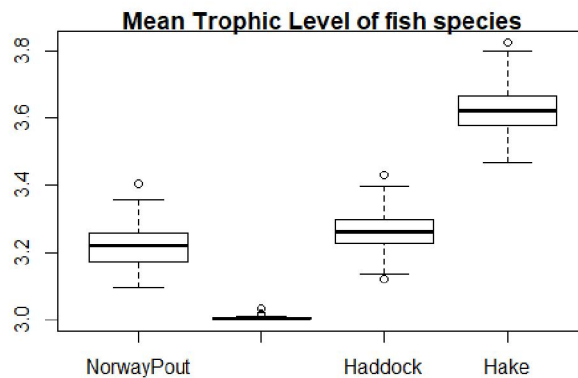


Figure 20: Boxplot over 100 years within a unique replicate representing the mean trophic level for Norway pout, Common sole, haddock and hake fish species in the catches.

4 Discussion

4.1 Developing a new model for the North Sea

The trophic modelling in the North Sea has long been conducted, notably with the development of the ecosystem model Ecopath (Polovina 1984; Christensen et al. 1992). Modelling studies in the North Sea have investigated regulation of populations by competition and prey-predator interactions (Volterra 1928; Lotka 1932; Holling 1959), trophic structure with stable isotopes and size structure (Jennings et al. 2003) and the concept of fishing down marine food webs (Pauly et al. 1998). The North Sea ecosystem is one of the most documented ecosystems worldwide, resulting in the existence of several estimations for most of the parameters required for OSMOSE. But for our study, the parametrization requires recent data and information from literature.

Regarding biological parameters, some inconsistencies can be observed between growth parameters and size/age at maturity: the size at maturity does not always correspond to the size computed from the growth parameters applied to the age at maturity. For example (Figure 21), the parameters of maturity match with growth curve for saithe. While the size at maturity corresponds to a higher age than that found (or conversely) for Norway pout.

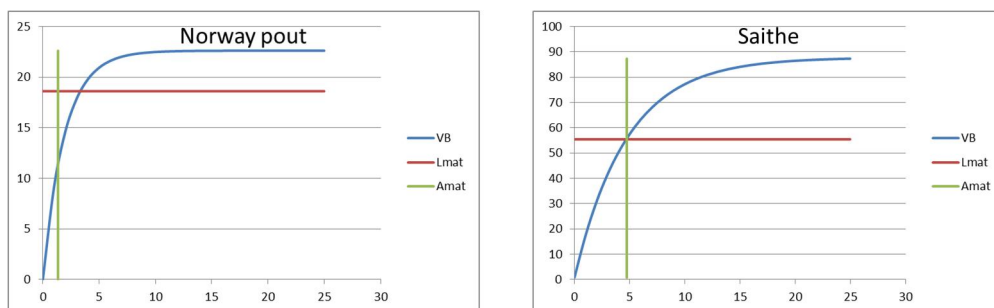


Figure 21: Graphs illustrating von Bertalanffy model (growth curve in blue) with associated specific parameters and projections of age (line in green) and size (line in red) at maturity.

Indeed, data used to estimate these parameters do not always come from the same author and/or the same period, since we made a compromise between recent and provided information in the North Sea. Moreover biological parameters in literature are available at different spatial and temporal scales depending on the conducted studies. An example of compromise between area and time, the lifespan of sprat is available in the North Sea for 1963, the period is old but the area corresponds to our study. And the reverse is true for the length at maturity for Grey Gurnard, in Irish Sea during the year 2003.

Concerning the predation process, it appears that predation parameters – and notably the size ratios informing on the adequacy between predator and prey size – are difficult to find in the literature. Because these data are derived from analysis of stomach contents, for which the prey are at different degrees of digestion and therefore difficult to measure. Some information coming from outputs of other models are available but to be rigorous, the uncertainty associated with these values should be incorporated into our model. Moreover these parameters are sensitive in OSMOSE, as shown by the scenario of “calibrated predation” during the calibration step. These parameters are sensitive in our model and difficult to find. One solution would therefore be to implement an equation defining the size ratio between prey and predator. This relationship (Hansen et al. 1994; Scharf, et al. 2000) could be established by multivariate analysis on different species from different ecosystems.

Furthermore, even if recent data were used, the multiple sources of data available (ICES, NS-IBTS survey, and FDI management program) are associated with different sampling biases and confer technical problems. For fisheries, VMS or Logbook data (FDI) do not always correspond to the same statistical rectangle. As a result, the sum of catches on all gears in the

fishing effort database does not correspond to the sum of catches in the landing database. Given this problem, the sandeel fishery was not explicitly modelled although it is important in the North Sea (ICES Advice 2017). For target values used in calibration, discrepancies in landings are noted, which depend on data collection by national authorities. Regarding the biomass values, different ICES working groups assesses the stock status for some species in North Sea, according to the stock distribution. But this distribution of stock is not the same as the OSMOSE grid. This can complicate the search and especially the conversion of data.

Indeed, the application in the North Sea (whose configuration is complete) demonstrates that (i) for the main species the difficulty was to choose a limited number of species, whereas (ii) for the less important species (e.g., grey gurnard, sandeel and hake) the difficulty was to find the parameters. But it is better to have a lot of data with periods and areas that do not match exactly, rather than little data for an ecosystem that fits perfectly. Because having a lot of parameters leaves the possibility to judge the quality of the data, as well as the possibility to make analyses, by averaging the values by examining their trends etc...

Moreover, the orders of magnitude of the parameters are valid and could make it possible to construct a "confidence range" based on the variability of the parameters. This range could be used for parameterization validation or sensitivity analysis.

4.2 Calibration of OSMOSE in the North Sea

The analysis of calibration results reveals that the algorithm of calibration has not converged to a suitable state. Comparison of diverse scenarios for calibration provides different information, such as fitness value and the sensitive of parameters. At the end of the time dedicated to this study, the evolutionary algorithm has not permitted to calibrate the OSMOSE configuration for the North Sea. Two assumptions can be proposed to explain such outcome:

- (i) the algorithm used for calibration is not working properly. The version of the algorithm used is a new one, and has not been tested previously. Furthermore, the collapsing species are not the same between the algorithm outputs and the OSMOSE model run with the optimal parameters as input, which indicates a malfunction of the algorithm
- (ii) the input parameters set for the North Sea OSMOSE configuration do not permit to reach a simulated state close to observations.

To remedy to the latter, we could propose to systematically use a checking method, such as a sequential procedure to validate the parameterization before performing the calibration. For example, if parameters of plankton accessibility are fixed to zero and the parameters of larval mortality are set at a high value, the specific abundances are projected to collapse as plankton food and recruitment are extremely reduced. To test the assumption (i), about the validity of the algorithm, a solution could be to use the latest version of the algorithm on a configuration already calibrated (i.e. for which we are sure that the fixed parameters allow reaching the target state).

This study shows the influence of model structure (i.e. interactions among variables and the sensitive of parameters) and calibration configuration (i.e. integration of catchability matrix in calibrated parameters affects the genetic algorithm) on the dynamic trophic modelling. In fact, results show that by applying the same calibration settings, but by modifying the input parameters (e.g. predation size ratio) and parameters to calibrate (e.g. calibrated predation scenario), the fluctuations in fitness are changed. Nevertheless, these modifications are not sufficient to affect the convergence state. Maybe, the solution is to use a larger dataset for the target values, which improved the accuracy of the calibrated parameters (Hua et al. 2018).

The success of the calibration and the values of the calibrated parameters depend on the other fixed input parameters. To address this, a Bayesian calibration could be used to combine information from multiple sources (such as experimental data and prior knowledge) and comprehensively quantify the uncertainty in the model parameters (Absi et Mahadevan 2018).

Advances in trophic modelling are improving the calibration process, but uncertainties about data (effort, catches, survey data and biological parameters from the literature and database analyses) remain. These data could be verified by the “confidence range” described in previous section. The aim is to accurately inform parameterization to minimize parameters uncertainty. Because uncertain parameters are parameterized, it is necessary to minimize the accumulation of uncertainty between these parameters. Moreover parameter optimization via genetic algorithms imposes severe time constraints due to the running time of the algorithm (several individuals and several generations). A rigorous calibration requires a large number of generations and so a long time to run the algorithm.

4.3 Perspectives

Improvement of trophic dynamic modelling is primordial in the current context of climate change. The intensification of uses and global warming are pushing decision-makers to propose solutions for managing marine resources. Trophic models could be used as a decision support tool for ecosystem-based management, and particularly for marine spatial planning (MSP). To be able to propose OSMOSE as such a tool in the North Sea, further work should be undertaken.

First, the calibration methodology needs to be improved, using for example sequential methods to check the validity of the parameters set from literature. Indeed, the current configuration and the current implementation of the algorithm does not allow OSMOSE to be calibrated for the North Sea. In fact, the new implementation of fisheries is not entirely debugged for the moment. In addition, the catchability matrix of fleet has confused the configuration of calibration. Additionally, this work is the first attempt of specifying fleets within OSMOSE. Again, a sequential approach could be to first calibrate the model only using a classic fishing mortality rate (F), and in a second step to complicate the representation of the fishing activity.

Second, once OSMOSE is calibrated for the current state of the North Sea, implementation of offshore wind farms can be established, by identification of grid cells where the effort is set to 0 in the input fisheries maps.

Management scenarios for multiple uses can be constructed in the following way: a first scenario represents offshore wind farms currently present (with 0 on the fishing map, and a second scenario that corresponds to the future extension of offshore wind farms, for example offshore wind around Great Britain that is being planned (Figure 22), this wind farm would be represented by increasing the area of 0 on the fishing map associated with a shift of effort in fishing parameters. Offshore wind farms and climate change scenarios are based on offshore wind map and ERSEM projections. Fisheries parameters could be modified (e.g. corresponding to ICES advice) and combined with these scenarios to observe interactions between fishing, uses and climate.

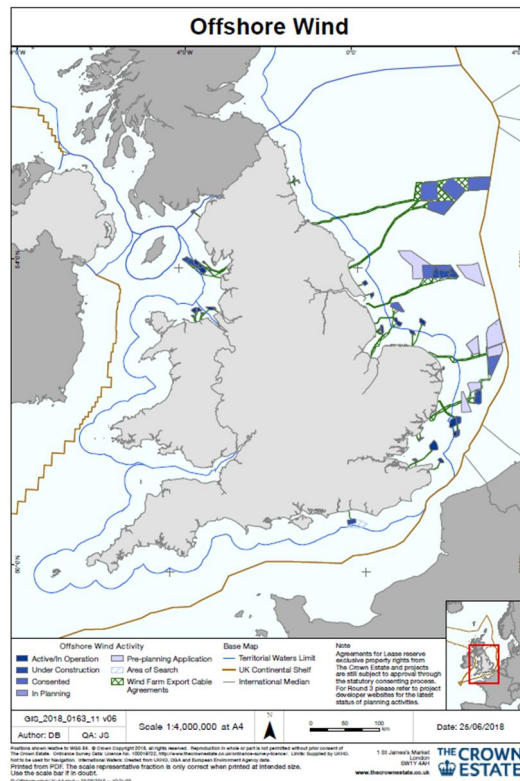


Figure 22: Map of offshore wind in ZEE of Great Britain, with wind farms active (dark blue) and in planning (light blue) (www.thecrownestate.co.uk).

Changes in an ecosystem state result from the interplay between management strategies and environmental conditions. Trophic models can inform on the ecosystem state and drivers, e.g: the application of Ecopath with Ecosim and EcoTroph for the interaction between fisheries management and occurrence of good recruitments (Moullec et al. 2017). Moreover, EwE and Ecospace food-web model was used to examine spatial alternatives and management strategies hypothetical planning process of Marine Spatial Planning (MSP) (Shabtay et al. 2018). As Ecospace food-web model, OSMOSE is dynamic and spatialized food web. OSMOSE with implementations of offshore and fishing effort maps could be used in marine spatial planning (the potential usefulness of food web models for MSP and aim to promote ecosystem-based management and marine conservation goals).

Indeed, in the North Sea the challenge is to be able to combine all the different uses, in accordance with the different management policies. For example, the development of business model for oil and wind offshore structures (Legorburu, Johnson, et Kerr 2018) combines the biological and economic models in context of offshore uses.

Concerning, fisheries management the idea of managing to obtain Maximum Sustainable Yields by setting Total Allowable Catch limits gained hold worldwide, and now the EU has changed the target to limiting fishing intensity to some level less than would be needed to obtain MSY. These targeted values are still poorly and ambiguously defined (Holt et Raicevich 2018). Thus, these complicate the decision-maker and the integration in model.

The understanding interactions between wild species and their environment, climate change and anthropogenic pressures with human uses, can be permit to define a best value for management decision. For a good governance of marine resources and sustainable fisheries.

5 Conclusion

In conclusion, the attempt to calibrate a complex model, such as OSMOSE, reveals the multitude of interactions that exist between the different variables and the sensitivity of some parameters.

This work highlighted the need to develop a test phase for parameters validation in the new version of model. Moreover, the implementation of fishing could be simplified in terms of input files, easing its parameterization.

However, assumptions related to calibration problems could be made and will be tested subsequently.

At this stage, no scenario results could be provided. Nevertheless, the challenge would be to evaluate different management strategies in order to provide a decision support tool, in the context of marine spatial planning.

Finally, from this scenario simulation perspective, climate is currently forcing the biomass of low trophic levels from ERSEM. The impacts of climate change on processes such as reproduction, growth, spatial distribution, mortality, etc... are well known. Climate change could be forced differently, but the risk is to complicate an already complex model.

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Appendices

Appendix A : Species codes and their signification.

FAO code	scientific name	english name	french name
PLE	<i>Pleuronectes platessa</i>	European plaice	Plie d'Europe
DAB	<i>Limanda limanda</i>	Common dab	Limande
SOL	<i>Solea solea</i>	Common sole	Sole commune
COD	<i>Gadus morhua</i>	Atlantic cod	Morue de l'Atlantique
HAD	<i>Melanogrammus aeglefinus</i>	Haddock	Églefin
POK	<i>Pollachius virens</i>	Saithe(=Pollock)	Lieu noir
NOP	<i>Trisopterus esmarkii</i>	Norway pout	Tacaud norvégien
WHB	<i>Micromesistius poutassou</i>	Blue whiting(=Poutassou)	Merlan bleu
WHG	<i>Merlangius merlangus</i>	Whiting	Merlan
SAN	<i>Ammodytes spp</i>	Sandeels(=Sandlances) nei	Laçons nca
HER	<i>Clupea harengus</i>	Atlantic herring	Hareng de l'Atlantique
SPR	<i>Sprattus sprattus</i>	European sprat	Sprat
HKE	<i>Merluccius merluccius</i>	European hake	Merlu européen
MAC	<i>Scomber scombrus</i>	Atlantic mackerel	Maquereau commun
CSH	<i>Crangon crangon</i>	Common shrimp	Crevette grise
MUS	<i>Mytilus edulis</i>	Blue mussel	Moule commune
EQE	<i>Ensis ensis</i>	Pod razor shell	Couteau-sabre
SCE	<i>Pecten maximus</i>	Great Atlantic scallop	Coquille St-Jacques atlantique
COC	<i>Cerastoderma edule</i>	Common edible cockle	Coque commune
WHE	<i>Buccinum undatum</i>	Whelk	Buccin
CRE	<i>Cancer pagurus</i>	Edible crab	Tourteau
JAX	<i>Trachurus spp</i>	Jack and horse mackerels nei	Chinchards noirs nca
NEP	<i>Nephrops norvegicus</i>	Norway lobster	Langoustine
GUG	<i>Eutrigla gurnardus</i>	Grey gurnard	Grondin gris

Appendix B : Gear and vessel codes and their signification.

Effort Regime	Code in data table	Regulated Gears
Multi-annual plan for Cod Stocks in the Baltic Sea (Reg. (EC) 1098/2007)	R_OTTER R_DEM_SEINE R_PEL_TRAWL R_PEL_SEINE R_GILL R_TRAMMEL R_BEAM R_LONGLINE	<ul style="list-style-type: none"> • OTTER (≥ 90 mm) • Danish Seine (≥ 90 mm) • Pelagic trawl (≥ 90 mm) • Pelagic seine (≥ 90 mm) • Gill net (≥ 90 mm) • Trammel net (≥ 90 mm) • Beam trawl (≥ 90 mm) • Longlines (all)
Long term management plan for Cod stocks (Reg. (EC) 1342/2008) ¹	<p>TR1</p> <p>TR2</p> <p>TR3</p> <p>BT1</p> <p>BT2</p> <p>GN1</p> <p>GT1</p> <p>LL1</p>	<ul style="list-style-type: none"> • Bottom trawls and seines (OTB, OTT, PTB, SDN, SSC, SPR) of mesh: <ul style="list-style-type: none"> TR1 equal to or larger than 100 mm, TR2 equal to or larger than 70 mm and less than 100 mm, TR3 equal to or larger than 16 mm and less than 32 mm; • Beam trawls (TBB) of mesh: <ul style="list-style-type: none"> BT1 equal to or larger than 120 mm BT2 equal to or larger than 80 mm and less than 120 mm; • Gill nets, entangling nets (GN); • Trammel nets (GT); • Longlines (LL)

Effort Regime	Code in data table	Length category
Multi-annual plan for Cod Stocks in the Baltic Sea (Reg. (EC) 1098/2007)	U8M O8T10M O10T12M O12T18M O18T24M O24T40M O40M NONE	<ul style="list-style-type: none"> • Vessels less than 8 m length • Vessels ≥ 8 m BUT < 10 m length • Vessels ≥ 10 m BUT < 12 m length • Vessels ≥ 12 m BUT < 18 m length • Vessels ≥ 18 m BUT < 24 m length • Vessels ≥ 24 m BUT < 40 m length • Vessels ≥ 40 m length • Vessel length not given
Celtic Sea		
Deep Sea and Western Waters		
Long term management plan for Cod stocks (Reg. (EC) 1342/2008) ¹	U10M O10T15M	<ul style="list-style-type: none"> • Vessels less than 10 m length • Vessels ≥ 10 m BUT < 15 m length

1342/2008) ¹	O15M NONE	<ul style="list-style-type: none"> • Vessels ≥ 15 m length • Vessel length not given
Recovery Plan Southern Hake and Norway Lobster in the Cantabrian Sea and Western Iberia (Reg. (EC) 2166/2005)		

Appendix C : Biological parameters and their associated references.

species	growth			ref
names	Linf	K	t0	
AtlanticHerring	30.5	0.44	-0.69	Kienzle, M., 2005. Estimation of the growth parameters of von Bertalanffy growth function for the main commercial species of the North Sea. Fisheries Research Services Internal Report No 05/05, Fisheries Research Services Marine Laboratory, Aberdeen, UK. 30 p + Figs.
AtlanticMackerel	33.6	0.83	-0.18	Nedelec, C. , 1958. Biologie et pêches des maquereaux. Rev. Trav. Inst. Pêches Marit. 22(2):121-134
Sandeel	18.5	0.36	0	Gislason, H., N. Daan, J.C. Rice and J.G. Pope , 2008. Does natural mortality depend on individual size?. ICES CM 2008/F:16
EuropeanSprat	15	0.50	-0.49	Froese, R. and A. Sampang , 2013. Potential indicators and reference points for good environmental status of commercially exploited marine fishes and invertebrates in the German EEZ. http://oceanrep.geomar.de/22079/
NorwayPout	22.6	0.52	0	Jennings, S., J.D. Reynolds and S.C. Mills , 1998. Life history correlates of responses to fisheries exploitation. Proc. R. Soc. London B 265:333-339
EuropeanPlaice	48	0.16	-1	Froese, R. and A. Sampang , 2013. Potential indicators and reference points for good environmental status of commercially exploited marine fishes and invertebrates in the German EEZ. http://oceanrep.geomar.de/22079/
CommonSole	40	0.14	-3	Froese, R. and A. Sampang , 2013. Potential indicators and reference points for good environmental status of commercially exploited marine fishes and invertebrates in the German EEZ. http://oceanrep.geomar.de/22079/
Saithe	87.7	0.21	-0.04	Pauly, D. , 1978. A preliminary compilation of fish length growth parameters. Ber. Inst. Meereskd. Christian-Albrechts-Univ. Kiel (55):1-200
AtlanticCod	116	0.20	0.08	Froese, R. and A. Sampang , 2013. Potential indicators and reference points for good environmental status of commercially exploited marine fishes and invertebrates in the German EEZ. http://oceanrep.geomar.de/22079/
Haddock	61.4	0.25	-0.25	Jones, R. , 1983. An investigation of north sea haddock, (<i>Melanogrammus aeglefinus</i>) length-at-age data, with particular reference to the effects on growth of the outstanding year classes of 1962 and 1967. J. Cons. Int. Explor. Mer. 41(1):50-62
BlueWhiting	35	0.24	-1.58	Magnussen, E. , 2007. Interpopulation comparison of growth patterns of 14 fish species on Faroe bank: are all fishes on the bank fast growing?. J. Fish Biol. 71:453-475
Whiting	38.1	0.43	-0.5	Pauly, D. , 1978. A preliminary compilation of fish length growth parameters. Ber. Inst. Meereskd. Christian-Albrechts-Univ. Kiel (55):1-200

CommonDab	33	0.21	-0.89	Froese, R. and A. Sampang , 2013. Potential indicators and reference points for good environmental status of commercially exploited marine fishes and invertebrates in the German EEZ. http://oceanrep.geomar.de/22079/
GreyGurnard	46	0.16	0	Jennings, S., S.P.R. Greenstreet and J.D. Reynolds , 1999. Structural change in an exploited fish community: a consequence of differential fishing effects on species with contrasting life histories. <i>J. Animal Ecol.</i> 68:617-627
Hake	127.5	0.073	-1.13	Piñeiro, C. and M. Sainza , 2003. Age estimation, growth and maturity of the European hake (<i>Merluccius merluccius</i> (Linnaeus, 1758)) from Iberian Atlantic waters. <i>ICES J. Mar. Sci.</i> 60:1086-1102

species	maturity		ref	
	Lmat	Amat		
AtlanticHerring	22.1	2.73	Froese, R. and A. Sampang, 2013. Potential indicators and reference points for good environmental status of commercially exploited marine fishes and invertebrates in the German EEZ. http://oceanrep.geomar.de/22079/	
AtlanticMackerel	30	2	Lockwood, S.J. and J.G. Shepherd, 1984. An assessment of the western mackerel stock. <i>J. Const. int. Explor. Mer</i> 41:167-180	Vasilakopoulos, P., F.G. O'Neill and C.T. Marshall, 2011. Misspent youth: does catching immature fish affect fisheries sustainability? <i>ICES J. Mar. Sci.</i> 68(7):1525-1534.
Sandeel	13.5	1.51	Boulcott, P., Wright, P. J., Gibb, F. M., Jensen, H., & Gibb, I. M. (2006). Regional variation in maturation of sandeels in the North Sea. <i>ICES Journal of Marine Science</i> , 64(2), 369-376.	Vasilakopoulos, P., F.G. O'Neill and C.T. Marshall , 2011. Misspent youth: does catching immature fish affect fisheries sustainability? <i>ICES J. Mar. Sci.</i> 68(7):1525-1534
EuropeanSprat	11.5	2	http://www.ifremer.fr/maerha/life_history.html	
NorwayPout	15	1.35	ICES FishMap	Lambert, G., J.R. Nielsen, L.I. Larsen and H. Sparholt , 2009. Maturity and growth population dynamics of Norway pout (<i>Trisopterus esmarkii</i>) in the North Sea, Skagerrak, and Kattegat. <i>ICES J. Mar. Sci.</i> 66:1899-1914
EuropeanPlaice	22.1	2.9	Froese, R. and A. Sampang , 2013. Potential indicators and reference points for good environmental status of commercially exploited marine fishes and invertebrates in the German EEZ. http://oceanrep.geomar.de/22079/	
CommonSole	18.8	1.2	Froese, R. and A. Sampang , 2013. Potential indicators and reference points for good environmental status of commercially	

			exploited marine fishes and invertebrates in the German EEZ. http://oceanrep.geomar.de/22079/	
Saithe	55.4	4.75	Jennings, S., J.D. Reynolds and S.C. Mills , 1998. Life history correlates of responses to fisheries exploitation. Proc. R. Soc. London B 265:333-339	ICES , 2012. Report of the Working Group on the Assessment of Demersal Stocks in the North Sea and Skagerrak (WGNSSK), 27 April - 03 May 2012, ICES Headquarters, Copenhagen. ICES CM 2012/ACON:13. 1346 p
AtlanticCod	37.8	2.1	Froese, R. and A. Sampang , 2013. Potential indicators and reference points for good environmental status of commercially exploited marine fishes and invertebrates in the German EEZ. http://oceanrep.geomar.de/22079/	
Haddock	33.5	2.5	Jennings, S., J.D. Reynolds and S.C. Mills , 1998. Life history correlates of responses to fisheries exploitation. Proc. R. Soc. London B 265:333-339	
BlueWhiting	22	2.35	estimated	Vasilakopoulos, P., F.G. O'Neill and C.T. Marshall , 2011. Misspent youth: does catching immature fish affect fisheries sustainability? ICES J. Mar. Sci. 68(7):1525-1534
Whiting	20.2	1.5	Jennings, S., J.D. Reynolds and S.C. Mills , 1998. Life history correlates of responses to fisheries exploitation. Proc. R. Soc. London B 265:333-339	
CommonDab	13	2.3	Jennings, S., S.P.R. Greenstreet and J.D. Reynolds , 1999. Structural change in an exploited fish community: a consequence of differential fishing effects on species with contrasting life histories. J. Animal Ecol. 68:617-627	
GreyGurnard	25	4.5	ICES FishMap	Magnussen, E. , 2007. Interpopulation comparison of growth patterns of 14 fish species on Faroe bank: are all fishes on the bank fast growing?. J. Fish Biol. 71:453-475
Hake	40	3.8	Bouaziz, A., A. Bennou, F. Djabali and C. Maurin , 1998. Reproduction du merlu <i>Merluccius merluccius</i> (Linnaeus, 1758) dans la région de Bou-Ismaïl. p. 109-117. In J. Lleonart (ed.) Dynamique des populations marines. Cahiers Options méditerranéennes No. 35	Vasilakopoulos, P., F.G. O'Neill and C.T. Marshall , 2011. Misspent youth: does catching immature fish affect fisheries sustainability? ICES J. Mar. Sci. 68(7):1525-1534

species	allometric relation		ref
	a	b	
AtlanticHerring	0.003 2	3.22	Froese, R. and A. Sampang, 2013. Potential indicators and reference points for good environmental status of commercially exploited marine fishes and invertebrates in the German EEZ. http://oceanrep.geomar.de/22079/
AtlanticMackerel	0.002	3.401	Wilhelms, I. , 2013. Atlas of length-weight relationships of 93 fish and crustacean species from the North Sea and the North-East Atlantic (No. 12). Johann Heinrich von Thünen Institute, Federal Research Institute for Rural Areas, Forestry and Fisheries, 552 p
Sandeel	0.001	3.44	Wilhelms, I., 2013. Atlas of length-weight relationships of 93 fish and crustacean species from the North Sea and the North-East Atlantic (No. 12). Johann Heinrich von Thünen Institute, Federal Research Institute for Rural Areas, Forestry and Fisheries, 552 p
EuropeanSprat	0.002 8	3.36	Froese, R. and A. Sampang , 2013. Potential indicators and reference points for good environmental status of commercially exploited marine fishes and invertebrates in the German EEZ. http://oceanrep.geomar.de/22079/
NorwayPout	0.003 9	3.202	Wilhelms, I. , 2013. Atlas of length-weight relationships of 93 fish and crustacean species from the North Sea and the North-East Atlantic (No. 12). Johann Heinrich von Thünen Institute, Federal Research Institute for Rural Areas, Forestry and Fisheries, 552 p.
EuropeanPlaice	0.010 7	2.97	Froese, R. and A. Sampang , 2013. Potential indicators and reference points for good environmental status of commercially exploited marine fishes and invertebrates in the German EEZ. http://oceanrep.geomar.de/22079/
CommonSole	0.004 9	3.2	Froese, R. and A. Sampang , 2013. Potential indicators and reference points for good environmental status of commercially exploited marine fishes and invertebrates in the German EEZ. http://oceanrep.geomar.de/22079/
Saithe	0.004 9	3.133	Wilhelms, I. , 2013. Atlas of length-weight relationships of 93 fish and crustacean species from the North Sea and the North-East Atlantic (No. 12). Johann Heinrich von Thünen Institute, Federal Research Institute for Rural Areas, Forestry and Fisheries, 552 p
AtlanticCod	0.005 8	3.14	Froese, R. and A. Sampang , 2013. Potential indicators and reference points for good environmental status of commercially exploited marine fishes and invertebrates in the German EEZ. http://oceanrep.geomar.de/22079/
Haddock	0.005	3.176	Wilhelms, I. , 2013. Atlas of length-weight relationships of 93 fish and crustacean species from the North Sea and the North-East Atlantic (No. 12). Johann Heinrich von Thünen Institute, Federal Research Institute for Rural Areas, Forestry and Fisheries, 552 p

BlueWhiting	0.007 3	2.893	Wilhelms, I. , 2013. Atlas of length-weight relationships of 93 fish and crustacean species from the North Sea and the North-East Atlantic (No. 12). Johann Heinrich von Thünen Institute, Federal Research Institute for Rural Areas, Forestry and Fisheries, 552 p
Whiting	0.004	3.162	Wilhelms, I. , 2013. Atlas of length-weight relationships of 93 fish and crustacean species from the North Sea and the North-East Atlantic (No. 12). Johann Heinrich von Thünen Institute, Federal Research Institute for Rural Areas, Forestry and Fisheries, 552 p
CommonDab	0.006 8	3.14	Froese, R. and A. Sampang , 2013. Potential indicators and reference points for good environmental status of commercially exploited marine fishes and invertebrates in the German EEZ. http://oceanrep.geomar.de/22079/
GreyGurnard	0.011 2	2.877	Wilhelms, I. , 2013. Atlas of length-weight relationships of 93 fish and crustacean species from the North Sea and the North-East Atlantic (No. 12). Johann Heinrich von Thünen Institute, Federal Research Institute for Rural Areas, Forestry and Fisheries, 552 p
Hake	0.004	3.13	Wilhelms, I. , 2013. Atlas of length-weight relationships of 93 fish and crustacean species from the North Sea and the North-East Atlantic (No. 12). Johann Heinrich von Thünen Institute, Federal Research Institute for Rural Areas, Forestry and Fisheries, 552 p

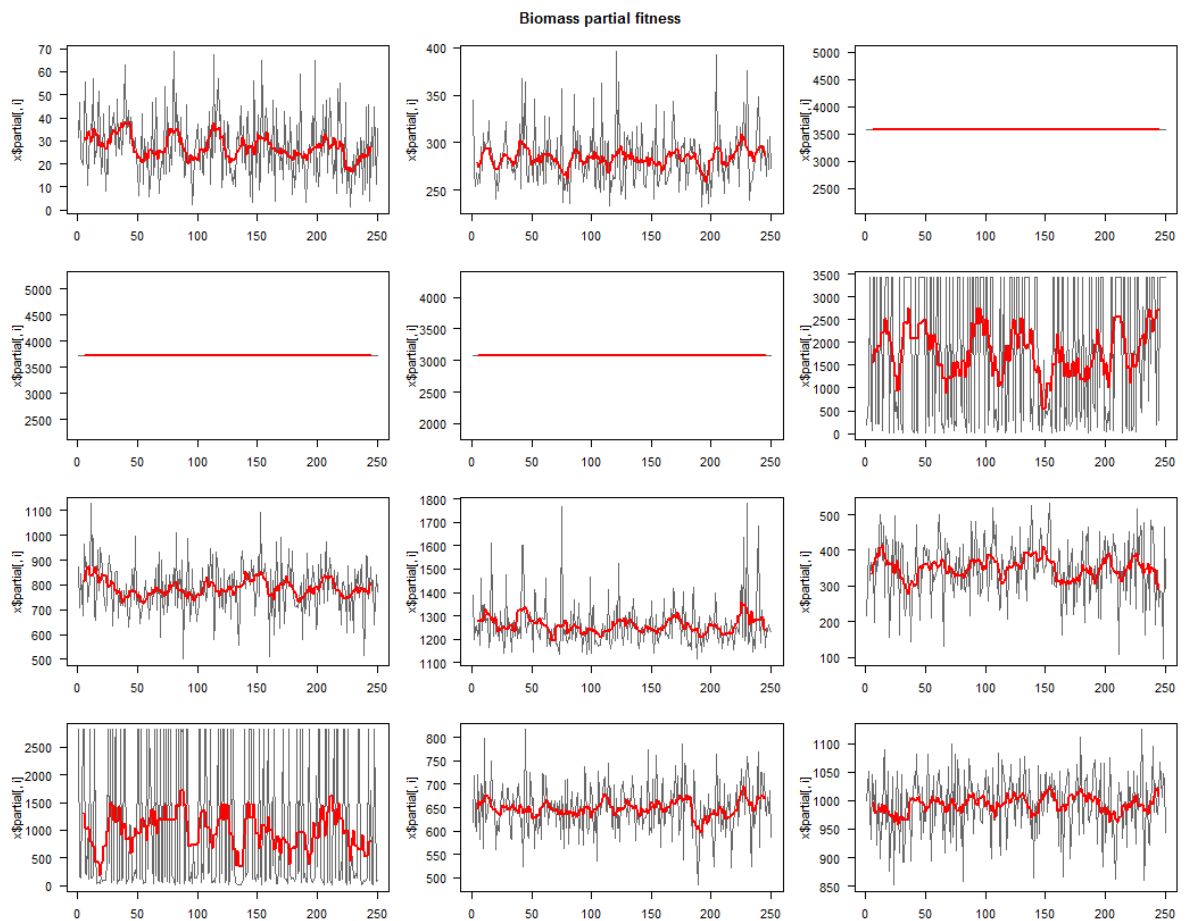
species	relative fecundity	ref
names	phi	
AtlanticHerring	503	Anokhina, L.E. , 1960. Some data on fecundity of Salaka (<i>Clupea harengus membras</i> L.). ICES: C.M. 210:21.
AtlanticMackerel	1275	ICESFishMap
Sandeel	8140	Muus, B.J. and J.G. Nielsen, 1999. Sea fish. Scandinavian Fishing Year Book, Hedehusene, Denmark. 340 p.
EuropeanSprat	400	ICESFishMap
NorwayPout	980	ICESFishMap
EuropeanPlaice	265	ICESFishMap
CommonSole	800	ICESFishMap
Saithe	750	ICESFishMap
AtlanticCod	700	Yoneda, M. and P.J. Wright , 2004. Temporal and spatial variation in reproductive investment of Atlantic cod <i>Gadus morhua</i> in the northern North Sea and Scottish west coast. Mar. Ecol. Prog. Ser. 276:237-248
Haddock	500	ICESFishMap

BlueWhiting	600	Muus, B.J. and J.G. Nielsen, 1999. Sea fish. Scandinavian Fishing Year Book, Hedehusene, Denmark. 340 p.
Whiting	1700	ICESFishMap
CommonDab	482	Muus, B.J. and J.G. Nielsen, 1999. Sea fish. Scandinavian Fishing Year Book, Hedehusene, Denmark. 340 p.
GreyGurnard	255	Muus, B.J. and J.G. Nielsen, 1999. Sea fish. Scandinavian Fishing Year Book, Hedehusene, Denmark. 340 p.
Hake	426	Mehault, S., R. Dominguez-Petit, S. Cervino and F. Saborido-Rey, 2010. Variability in total egg production and implications for management of the southern stock of European hake. Fish. Res. 104(1-3):111-122.

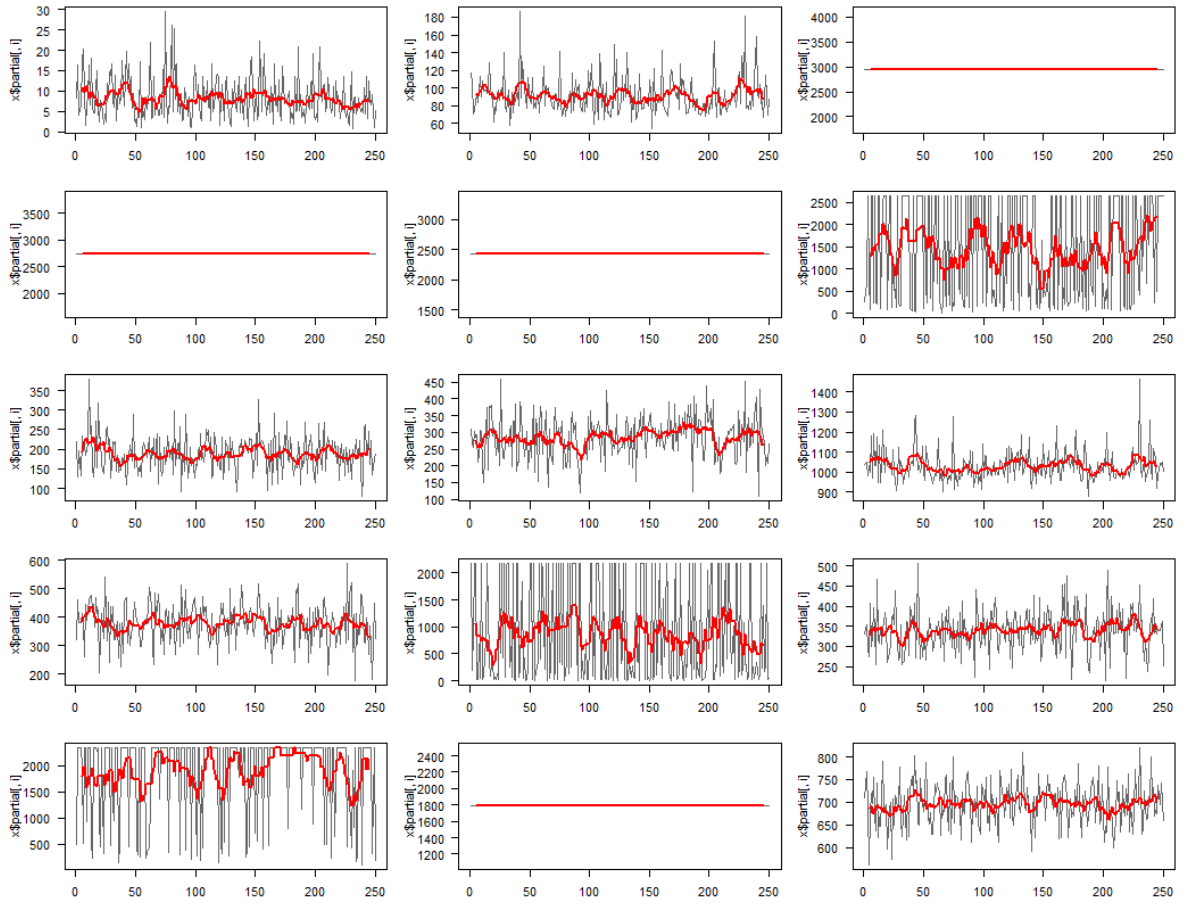
species	lifespan	ref
names	Amax	
AtlanticHerring	8	Brunel, T. and M. Dickey-Collas, 2010. Effects of temperature and population density on von Bertalanffy growth parameters in Atlantic herring: a macro-ecological analysis. Mar. Ecol. Prog. Ser. 405: 15-28
AtlanticMackere l	17	Anderson, E.D. and A.J. Paciorkowski, 1980. A review of the Northwest Atlantic mackerel fishery. Rapp. P.-V. Reun. CIEM. 177:175-211.
Sandeel	10	Muus, B.J. and J.G. Nielsen , 1999. Sea fish. Scandinavian Fishing Year Book, Hedehusene, Denmark. 340 p
EuropeanSprat	6	Beverton, R.J.H. , 1963. Maturation, growth and mortality of clupeid and engraulid stocks in relation to fishing. Cons. Perm. Int. Explor. Mer, Rapp. p.-v. Réun. 154:44-67
NorwayPout	5	Cohen, D.M., T. Inada, T. Iwamoto and N. Scialabba , 1990. FAO species catalogue. Vol. 10. Gadiform fishes of the world (Order Gadiformes). An annotated and illustrated catalogue of cods, hakes, grenadiers and other gadiform fishes known to date. FAO Fish. Synop. 125(10). Rome: FAO. 442 p
EuropeanPlaice	25	Beverton, R.J.H. , 1992. Patterns of reproductive strategy parameters in some marine teleost fishes. J. Fish Biol. 41(Suppl. B):137-160
CommonSole	26	Deniel, C. , 1990. Comparative study of growth of flatfishes on the west coast of Brittany. J. Fish Biol. 37(1):149-166
Saithe	25	Cohen, D.M., T. Inada, T. Iwamoto and N. Scialabba , 1990. FAO species catalogue. Vol. 10. Gadiform fishes of the world (Order Gadiformes). An annotated and illustrated catalogue of cods, hakes, grenadiers and other gadiform fishes known to date. FAO Fish. Synop. 125(10). Rome: FAO. 442 p
AtlanticCod	25	Muus, B.J. and P. Dahlström , 1974. Collins guide to the sea fishes of Britain and North-Western Europe. Collins, London, UK. 244 p.

Haddock	20	Muus, B. and P. Dahlström , 1978. Meeresfische der Ostsee, der Nordsee, des Atlantiks. BLV Verlagsgesellschaft, München. 244 p.
BlueWhiting	8	Tsikliras, A.C. and K.I. Stergiou , 2015. Age at maturity of Mediterranean marine fishes. <i>Medit. Mar. Sci.</i> 16(1):5-20
Whiting	20	Muus, B.J. and J.G. Nielsen , 1999. Sea fish. Scandinavian Fishing Year Book, Hedehusene, Denmark. 340 p.
CommonDab	12	Rijnsdorp, A.D., A.D. Vethaak and P.I. Van Leeuwen , 1992. Population biology of dab <i>Limanda limanda</i> in the southeastern North Sea. <i>Mar. Ecol. Prog. Ser.</i> 91:19-35
GreyGurnard	21	Clarke, M.W., C.J. Kelly, P.L. Conolly and J.P. Molloy , 2003. A life history approach to the assessment and management of deepwater fisheries in the Northeast Atlantic. <i>J. Northwest Atl. Fish. Sci.</i> 31:401-411
Hake	20	Muus, B.J. and J.G. Nielsen , 1999. Sea fish. Scandinavian Fishing Year Book, Hedehusene, Denmark. 340 p.

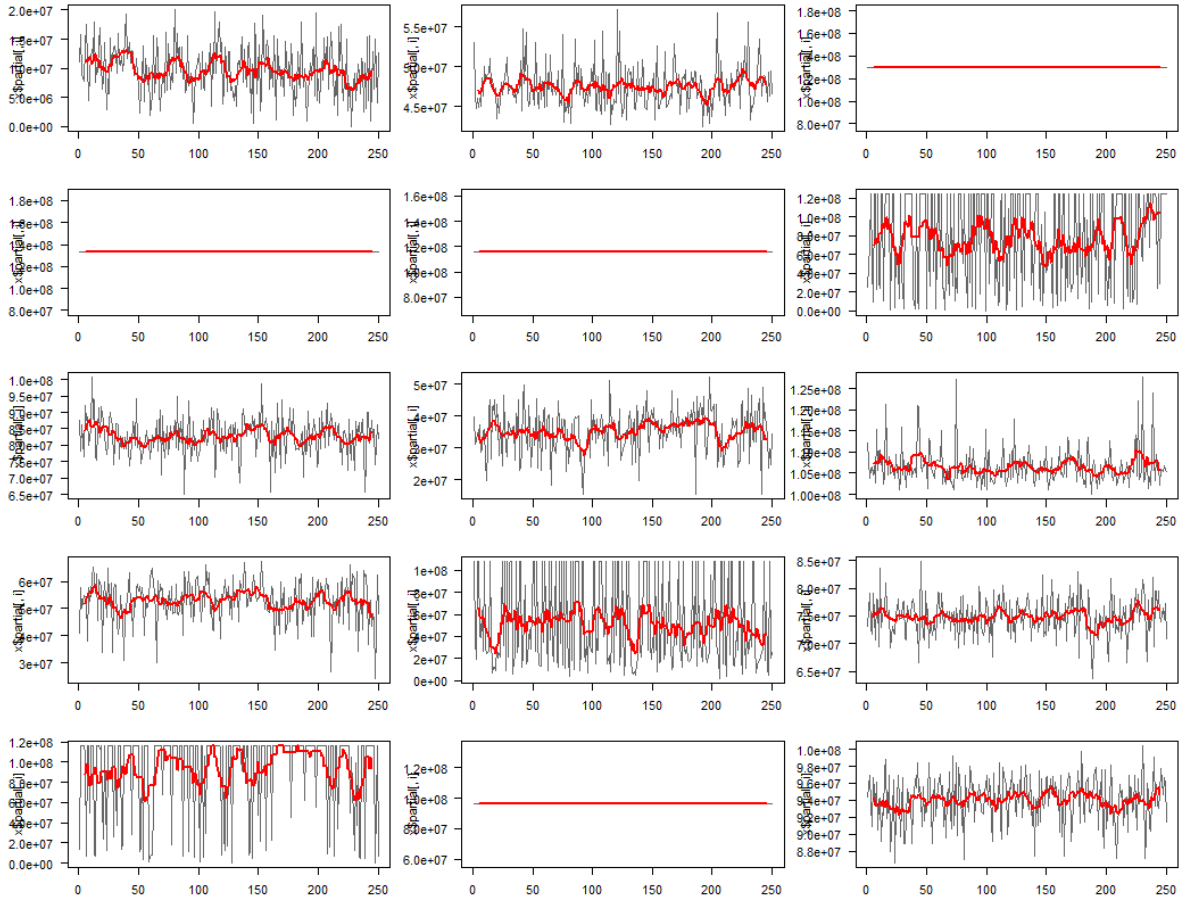
Appendix D: details of the first attempt of calibration (partial fitness)




Landings partial fitness



Threshold partial fitness



	Diplôme : Master Spécialité : SML-Biologie Parcours : Sciences halieutiques et aquacoles (REA) Enseignant référent : Didier Gascuel
Auteur(s) : Marine Ballutaud Date de naissance* : 07/01/1994	Organisme d'accueil : IFREMER Adresse : Rue de l'Île-d'Yeu B.P. 21105
Nb pages : 56 Annexe(s) : 4	44311 Nantes Cedex 03
Année de soutenance : 2018	Maître de stage : Morgane Travers-Trolet
Titre français : Tentative de modélisation End-to-end en Mer du Nord pour évaluer l'interaction de la pêche et autres usages sous changement climatique. Titre anglais : End-to-end modelling attempt in the North Sea to assess interactions of fishing and other human uses under climate change.	
Résumé (1600 caractères maximum) : La mer du nord est un écosystème soumis au changement climatique et aux pressions anthropiques, telles que la pêche et les structures éoliennes. Ces composantes impactent l'environnement marin. L'objectif est donc de comprendre et évaluer ces interactions entre les différents impacts sur les organismes marins, sous changement climatique. Pour répondre aux questions : quels sont les effets combinés de la pêche et du climat, et quels sont les effets de la compétition spatiale entre les usages ? L'application du modèle OSMOSE en Mer du Nord est développée. OSMOSE est un modèle trophodynamique spatialisé, pour lequel 15 espèces ont été sélectionnées ainsi qu'une période et zone de modélisation. Durant la phase de paramétrisation, les paramètres biologiques et les choix de modélisation sont définis d'après la littérature et l'analyse de données (comme les captures, l'effort de pêche). La variabilité climatique est forcée par le modèle ERSEM qui fournit les biomasses des bas niveaux trophiques. La nouvelle version d'OSMOSE implémente la pêche par pêcherie via l'effort de pêche et la capturabilité. La calibration n'ayant pas abouti, les résultats présentent quelques indicateurs issus de simulations de modèle non calibré. La calibration permet (via des scénarios) de mettre en évidence la sensibilité des paramètres dans OSMOSE ainsi que la nécessité d'une phase de validation des paramètres. Une version test de calibration pourrait permettre aussi de vérifier l'algorithme de calibration. Enfin, il serait intéressant de pouvoir construire des scénarios de gestion reflétant les stratégies de gestion mises en place et celles à venir. Afin d'évaluer les interactions entre les impacts de la pêche, des éoliennes et du climat.	
Abstract (1600 caractères maximum) : The North Sea is an ecosystem subject to climate change and anthropogenic pressures, such as fishing and wind farms. These components impact marine environment. The aim is to understand and evaluate these interactions between the different impacts on marine organisms under climate change. To answer questions: what are the combined effects of fishing and climate, and what are the effects of space competition between uses? The application of the OSMOSE model in the North Sea is developed. OSMOSE is a spatial trophodynamic model, for which 15 species have been selected and modelled period and area. During the parameterization step, biological parameters and modelling choices are defined derived from literature and data analysis (such as catch, fishing effort). Climate variability is forcing by the ERSEM model which provides biomasses of low trophic levels. The new version of OSMOSE implements fishing by fisheries with fishing effort and catchability. Since calibration was unsuccessful, the results present some indicators from uncalibrated model simulations. The calibration allows (via scenarios) to highlight the sensitivity of the parameters in OSMOSE as well as the need for a parameter validation phase. A calibration test version could also be used to check the calibration algorithm. Finally, it would be interesting to be able to construct management scenarios reflecting the management strategies implemented and those to come. To assess the interactions between the impacts of fishing, wind turbines and climate.	
Mots-clés : modèle OSMOSE – écosystème Mer du Nord – calibration – champs d'éolienne – changement climatique – pêcheries Key Words: OSMOSE model – North Sea ecosystem – calibration – offshore wind farms – climate change - fisheries	

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