Département d'évaluation
de la recherche

Research unit

Self-assessment document

EVALUATION CAMPAIGN 2018-2019
GROUP E

INFORMATIONS

Unit name:	**Unité Halieutique de Manche – Mer du Nord / Channel & North Sea Fisheries Research Unit**
Acronym:	**HMMN**
Hceres scientific domain and sub-domain:	**Sciences de la Vie et de l'Environnement (SVE) / Life and Environment Science (SVE)**
Director's name (current contract):	**Paul MARCHAL**
Director's name (future contract):	**Paul MARCHAL**

Application type:

Renewal (w/o important modifications) ☒ Restructuration □ *Ex nihilo* creation □

List of supervising institutions and bodies of the research unit:

Current contract:	Next contract:
- IFREMER	- IFREMER

Inter-disciplinary evaluation for the research unit (or for one or more internal team):

Yes ☐ No ☒

Number of teams / number of themes for the next contract:

3 themes

Requested label (UMR, EA etc.):

NA

SELF-ASSESSMENT DOCUMENT

1. THE IFREMER CHANNEL & NORTH SEA FISHERIES RESEARCH UNIT

1.1 Presentation of the unit

Introduction

The HMMN Research Unit, created in 2005, has belonged since 2011 to the *Ressources Biologiques et Environnement* (RBE) Department which is one of the four IFREMER scientific Departments, along with the *Océanographie et Dynamique des Ecoystèmes* (ODE), the *Recherches physiques et Ecosystèmes de fond de Mer* (REM) and the *Infrastructures de Recherche et Systèmes d'Information* (IRSI) Departments.

The HMMN Research Unit consists of two laboratories, one located in Boulogne s/mer (LRHBL) and another one in Port-en-Bessin (LRHPB). Both laboratories, like the other ODE and REM laboratories implemented in Boulogne s/mer and Port-en-Bessin (ODE: two *Laboratoires Environnement Ressources*, LERBL and LERN; REM: one *Laboratoire Comportement des Structures en Mer*, LCSM), are administratively attached to the IFREMER *Centre de Manche – Mer du Nord* (CMMN).

HMMN delivers research in fisheries science and marine ecology, with a focus on the English Channel and the Southern North Sea region, delving into data collection and advice-giving in support of the management of fisheries resources and marine ecosystems affected by commercial fishing and other sectors of activity (e.g., sand and aggregate extractions, renewable marine energy production), in a context of climate change.

Since 2013, HMMN activities have been structured in three inter-connected themes: Individuals, Populations and Ecological niches (Theme 1); Communities, Trophic networks and Biodiversity (Theme 2); Fleets, Exploitation and Management Scenarios (Theme 3). In terms of monitoring, HMMN contributes to fisheries and ecosystem data collection at sea, in harbour, and in laboratory. HMMN coordinates three large-scale sea surveys and hosts four technical facilities: a National Sclerochronology Center (PNS), a trophic ecology facility (PRT), and a Zooplankton Taxonomy and Ecology Center (PTEZOO), which is shared with the LERBL laboratory, and finally a national service for processing and standardizing data in response to fisheries data calls supporting stock assessments (CREDO).

The HMMN organizational chart is shown in Appendix 3.

Workforce and resources of the unit

HMMN permanent staff has varied without notable trends over 2013-2017 (32-34 in total, of which 10-12 research scientists and 21-23 ITA), but dropped to a record low in 2018 (29 in total, of which 9 research scientists and 20 ITA). This represents less than 2/3 of the 45 permanent staff members present at HMMN over 2013-2018, which illustrates the massive turnover experienced by HMMN over the evaluation period. It should also be mentioned that one HMMN research scientist specialized in life trait history investigations works part-time (50%) for the IFREMER Scientific Direction (as EAF referent) since 2016. The proportion of permanent research scientists relative to total permanent staff has been stable (31-36%) over the whole period 2013-2018 (Table 1.1).

The number of non-permanent research scientists employed more than 1 month per year at HMMN (19 in total, 7-9 annually), including PhD students (12 in total, 6-8 annually), has been stable over 2013-2017. The drop in the number of PhD students observed in 2018 (4) is explained by the evaluation period ending the 30/06 of that year, while 4 new students will commence their PhD in October–November 2018. The amount of "AP_aut" staff has been quite versatile over 2013-2018. This is because the occurrence of such temporary contracts is determined by projects or the absence of colleagues with a permanent position, which is rather variable.

Nombre de Staff	Staff category					Ratio
Year	Ch_tit	Ch_aut	AP_tit	AP_aut	Total	Ch_tit / (Ch_tit + AP_tit)
2013	11	9 (6)	23	11	54	32%
2014	12	9 (8)	21	13	55	36%
2015	10	7 (6)	22	16	55	31%
2016	11	7 (6)	21	17	56	34%
2017	11[1]	9 (6)	22	9	51	33%
2018 (until 30/06)	9	7 (4[2])	20[3]	14	49	31%
Total (2013-2018)	**15**	**19 (12)**	**30**	**62**	**126**	**33%**

Table 1.1. HMMN staff per year and per staff category. Ch_tit: permanent research scientists; AP_tit: permanent engineers and technicians; Ch_aut: non-permanent researchers (number of PhD students in brackets); AP_aut: non-permanent technicians, engineers and students under training.

The bulk of HMMN budget consists of salaries and overheads (84-96% altogether). HMMN total budget has varied between 3,500 and 4,000 k€ over the period 2013-2016, and it has increased above 4,500 k€ in 2017. This upwards trend reflects an increase in the 2017 IFREMER allocation to anticipate the CPER MARCO investments (480 k€) that will be subject to a later refund. External funding obtained by the HMMN team has represented on average 12% of the total budget (9-15%) over the period 2013-2017. External funding has exceeded IFREMER annual allocation in all years except in 2017, due to the lag between the anticipation by IFREMER of CPER MARCO investments and the actual cost recovery from the clients expected after 2018 (Figure 1.1). It should finally be mentioned that the HMMN team also participates in projects for which funding is received by other IFREMER units or by the RBE Department, and which do not appear in Figure 1.1. These include in particular data collection and international advice-giving activities which are cost-recovered by the EU Data Collection Framework and/or the French Marine Fisheries and Aquaculture Directorate.

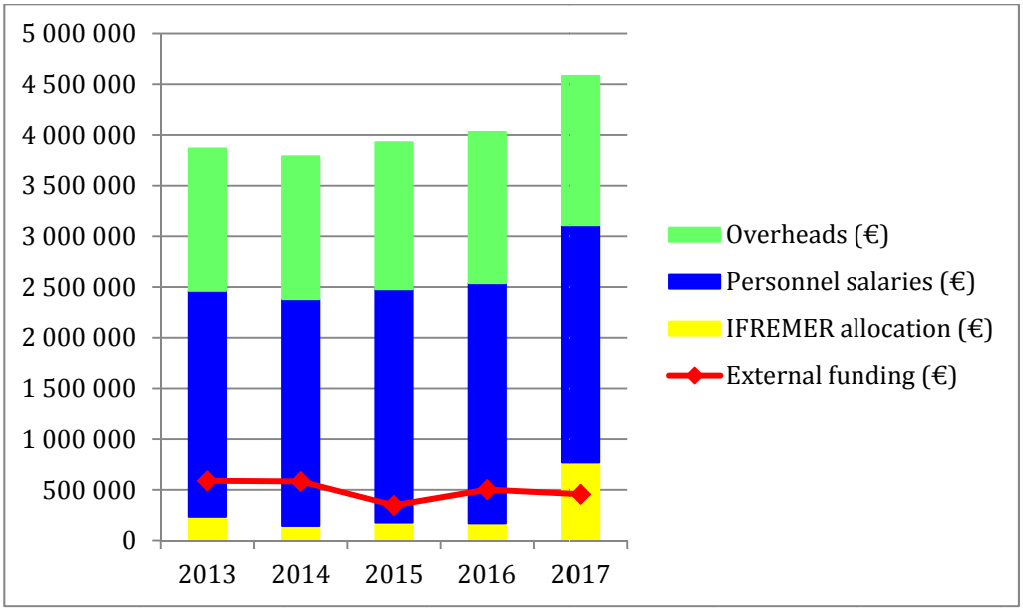


Figure 1.1. Inter-annual variations of HMMN total budget (€) split into salaries (blue chart), overheads (representing 63% of salaries, green chart) and a research allocation annually received from IFREMER central services (yellow chart). The red curve represents the total amount of external funding obtained by HMMN.

The amount and distribution of HMMN external funding across sources is shown in Figure 1.2. The details are provided in Appendix 4 (Section I.10) for a selection of key projects. The total amount of external funding obtained by HMMN has varied between 350 k€ and 590 k€ with peaks in 2013-2014, lows in 2015, and 2016-2017 values around average. The structure of HMMN external funding sources has also varied between 2013 and 2017. While EU sources (H2020; Interreg) were dominant (2/3) in 2013-2014, they only represented 20% of the total external funding received in 2015-2017. In contrast, funding from charities and foundations (e.g.,

[1] Including a research scientist working part-time (50%) for the IFREMER Scientific Direction
[2] The figure does not include 4 PhD students starting their PhD contract at HMMN in October-November 2018.
[3] The figure does not include 1 permanent technician recruited in September 2018.

France Filière Pêche) has drastically increased between 2013-2014 (7%) and 2015-2017 (46%). Regional funding has been stable over the period 2013-2016 (23%). The 2017 decrease is due to an administrative delay in receiving PhD grants. While CPER funding has been low over the period 2013-2017, this will develop from 2018 onwards with the full implementation of the MARCO project (Section 1.3, "Highlights"). The funding trends shown in Figure 1.2 are commented in Section 1.3 ("Quantitative data").

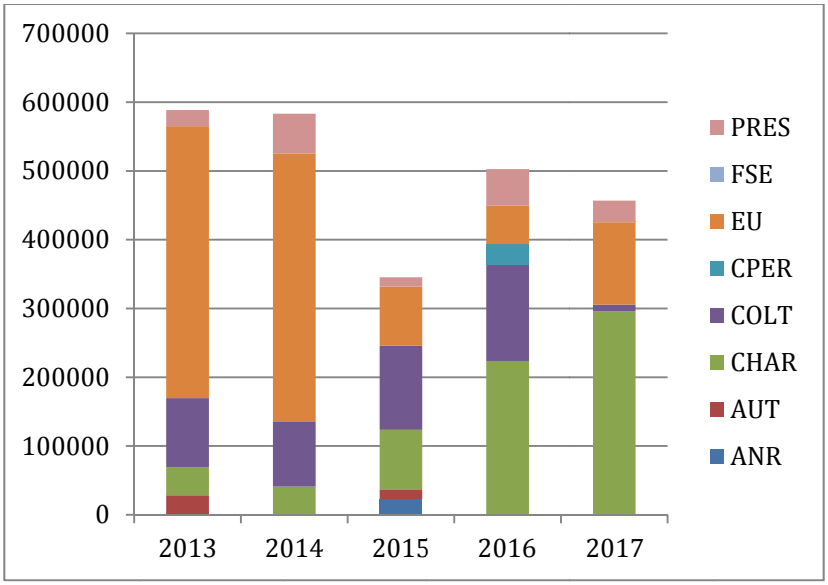


Figure 1.2. Amount (€) and distribution of HMMN external funding across sources (EU: European Union except structural funds, CHAR: charities and foundations, COLT: regional, CPER: Contrat Plan Etat Région, FSE: EU structural funds, PRES: sub-contracting for private/semi-private sources, AUT: other competitive public funding).

HMMN scientific objectives and strategy over 2013-2018; national and international positioning

Global change is exerting environmental pressure, which is threatening marine biodiversity and the sustainability of fisheries resources. Marine biodiversity in the North Atlantic has thus been considerably altered in the past century, which may be illustrated by the decline in the trophic level of fisheries catch over the period 1950-2000, as revealed by the 2005 Millenium Ecosystem Assessment. This is also illustrated by the most recent (2016) FAO - Food and Agricultural Organization[4] - fisheries assessment, which found that the proportion of the worldwide commercial fish being overexploited (i.e., with a fishing mortality exceeding the target/limit Maximum Sustainable Yield – MSY- level) has continuously increased from 10% in 1974 to 30% in 2013. Although the proportion of overexploited stocks in EU Northeast Atlantic waters has slightly decreased from 75% in 2003 to 60% in 2016[5], it remains at a much higher level compared to the worldwide average (FAO, 2016) and other comparable jurisdictions (e.g., Australia and New Zealand) where fisheries management is considered successful (ACL098), and it is still far away from the 2013 CFP objective of achieving MSY for all fish stocks, if possible by 2015, and at latest by 2020[6].

Understanding how marine biodiversity, ecosystem functioning and the dynamics of fisheries resources are modified in relation to human and climatic pressures, and their cumulated effects, has become a primary focus for managers, stakeholders and scientists. On the EU management side, this has in particular been reflected by a strengthening of policy actions and directives aiming at protecting marine biodiversity and harvested resources in EU waters (e.g.; Common Fisheries Policy, CFP; Marine Strategy Framework Directive, MSFD), with explicit objectives to be achieved at the horizon 2020 (e.g., achieving MSY for all fish stocks, banning fisheries discards, achieving Good Environmental Status).

Marine research institutes like IFREMER in France are strongly involved in the process of surveying, filling knowledge gaps and providing support to decision-makers in achieving the 2020 objectives relevant to the status of and pressures exerted on marine ecosystems and the fisheries resources they nurture.

HMMN is one of the five IFREMER Research Units delivering science in support of the ecosystem approach to fisheries (EAF), along with MARBEC (Marine Biodiversity, Exploitation and Conservation), STH (Sciences et

[4] FAO (2016). The State of World Fisheries and Aquaculture 2016. Contributing to food security and nutrition for all. Rome. 200 pp.
[5] Scientific, Technical and Economic Committee for Fisheries (STECF) –57th Plenary Meeting Report (PLEN-18-01), Publications Office of the European Union, Luxembourg, 2018, ISBN 978-92-79-85804-8, doi:10.2760/088784, JRC111800.
[6] EC (2013) Regulation (EU) No 1380/2013 of the European Parliament and of the Council of 11 December 2013 on the Common Fisheries Policy, amending Council Regulations (EC) No 2371/2002 and (EC) No 639/2004 and Council Decision 2004/585/EC.

Technologies pour l'Halieutique), EMH (Ecologie et Modèles pour l'Halieutique) and HGS (Halieutique de Gascogne Sud). The HMMN roadmap has been established in 2013, consistent with the project previously accepted by the AERES, which has resulted in a structuration in three research themes:

- THEME 1: Individuals, Populations and Ecological Niche
- THEME 2: Communities, Trophic Networks and Biodiversity
- THEME 3: Fleets, Exploitation and Management Scenarios

It is important to note that these three themes have no strict frontiers, and HMMN scientists commonly venture from one theme to another, and meet at their interfaces. Examples of such interfaces are provided here. The dynamics of fish life history traits (Th1) depend on their diet and on the functioning of the trophic network (Th2) and infer population dynamics parameters built in stock assessment and fisheries models (Th3). The development of ecosystem models builds on an analysis of ecosystem structure and functioning (Th2), and these are subsequently used to evaluate the effects of management scenarios on ecosystems in a global change context, and also for the purpose of multi-species stock assessments (Th3).

HMMN thematic classification allows, (i) making explicit the interactions between exploitation and the different biological scales, (ii) identifying the common vectors of change of the three thematic components and, (iii) distributing homogenously the research effort across themes. The multidisciplinary research activities of HMMN over the period 2013-2018 have clearly been planned to support the implementation of the EAF, with an extension to other human activities. Following this roadmap, HMMN has been mandated to, (i) gain knowledge on the ecology of fisheries resources, the functioning of the ecosystem in which they are embedded and the dynamics of the fishing fleets harvesting them, (ii) apply research evidence to forecast the effects of global change on ecosystem and fisheries futures and, (iii) evaluate the performances of management scenarios aimed at mitigating those effects. The research evidence obtained by HMMN and their applied products are of relevance to the broader scientific community (fisheries scientists, marine ecologists), policy-makers at all geographical scales (EU-wide: CFP, MSFD; national: DPMA, "code minier"; regional), and the industry (fishing, aggregate extractions, renewable marine energy production). HMMN science builds on several observation tools – at-sea and in-harbour surveys, and the four technical facilities: PNS, PRT, PTEZOO, CREDO.

HMMN objectives are also clearly enrooted within the "*Contrat d'Objectifs ETAT-IFREMER*" (COEI), initially covering the period 2014-2017, and recently extended to 2018. HMMN has more particularly contributed to three out of the seven COEI objectives:

- **O1 : Strengthening the position of French marine research in the EU and international context.** HMMN has co-chaired with the Canadian Department of Fisheries and Oceans an international French-Canadian Research Network (*Groupement de Recherche International,* GDRI RECHAGLO). HMMN has also been involved, as WP leader, in three FP7/H2020 research projects (VECTORS, SOCIOEC, DISCARDLESS) and two Interreg projects (PANACHE, SUMARIS), over the period 2013-2017. In 2017-2018, HMMN has also obtained funding for an international Belmont forum project (SOMBEE) and a bilateral German-French project (COCKTAIL), in collaboration with the Alfred Wegener Institute. HMMN PhD students have increasingly been requested to visit a foreign laboratory in relation to their subject for a period ranging from 1 to 12 months: DTU-Aqua (Denmark), IMARES (Netherlands), University of Washington (USA), Thünen Institute (Germany) and CSIRO (Australia) have thus been visited. On the other hand, several foreign PhD students and postdocs visited HMMN (Appendix 4, Sections I.11 & III.5). Finally, HMMN has been involved in a joint EU programming initiative relevant to the EAF, the ERANet COFASP (2013-2017) and, more recently, an extension of EU article 185 BONUS2, which will offer an opportunity for HMMN to develop its future research activities in the English Channel and Southern North Sea (EC-SNS), in an international context.
- **O2 : Fostering French marine science research within a regional strategy.** HMMN has strived to produce high level research to fill some knowledge gaps in the understanding and representation of the EC-SNS marine ecosystem dynamics and of its potential fisheries production (see Theme Sections 2-4), which has materialized by 139 papers produced over the evaluated period (Appendix 4, Section I.1). While the other EAF-oriented IFREMER Research Units have also contributed to this generic objective, HMMN has developed research specificities over the period 2013-2018, which will be illustrated further in this report. These include: (Theme 1) the exploration of key life history traits building on sclerochronology and specific condition indices, for both adult fish and larvae; (Theme 2) the investigation of biodiversity dynamics and functioning by coupling empirical (survey-based) and end-to-end ecosystem modelling approaches; (Theme 3) a contribution to stock assessment methods building on trophic interactions and/or applicable to data-limited fish species. Another HMMN specificity is that its scientific activities are by large focused on the EC-SNS region, which hosts one of the most intensively used marine ecosystem on earth. This regional positioning has fostered an increasing amount of collaborations with the other major academic partners from the Hauts-de-France (HDF) Region involved in marine science (e.g., UMR LOG, ANSES, LISIC). This regional collaboration has vested a new dimension with the acceptance and launching of the CPER MARCO project (2014-2020), and the submission to the HCERES in 2018 of an application for the creation *ex*

nihilo of a "*Fédération de Recherche*" involving most of the HDF academic partners, where HMMN is part of the project team.

- **O3 : Delivering sound science and support relevant to public policies.** HMMN is responsible for coordinating a number of marine statutory services including sea surveys monitoring and more generally collection and reporting on the fisheries data collection framework (DCF) and MSFD. In addition, HMMN is heavily involved in the collection of evidence for a wide range of statutory obligations relevant to the conservation of English Channel and North Sea ecosystems, including fisheries stock assessments and evaluating the effects of other sectors of activity (e.g., aggregate extractions, energy production) in a climate change context. HMMN expertise and advice-giving activities are perhaps best illustrated by an active participation to and/or chairing of several international ICES, NAFO and DCF Working Groups, in addition to the responses provided to the many requests generated by the national or local authorities (Appendix 4, Section II.4).

HMMN activity profile

Over the period 2013-2017, HMMN scientific activities (representing on average 52,000 working hours per annum, excluding administrative and management tasks) have been shared between basic research (42% of worked hours, on average), data collection (50%) and advice-giving (7%), with only little inter-annual changes (Figure 1.3). This is a reflection of HMMN staff composition, with a majority of engineers and technicians (2/3) and a relatively lower number of researchers (1/3), as shown in Table 1.1. Compared to the previously evaluated period (2008-2011), the proportion of time dedicated to research has been relatively stable (44% in 2008-2011 versus 42% in 2013-2017). However, the percentage of working hours dedicated to data collection has increased from 38% to 50% between 2008-2011 and 2013-2017, while a decrease from 18% to 7% in the proportion of time dedicated to advice-giving has been observed between both periods. These contrasted trends reflect, (1) an overall increase (+1) in the number of research technicians, (2) the recruitment of an engineer in charge of coordinating the CREDO fisheries data processing facility but also, (3) a strong reduction (-3) in the number of HMMN scientists contributing to institutional expertise and advice-giving.

Figure 1.3. Proportion of hours worked for HMMN staff across activity types, over 2013-2017. Administrative tasks (~10% of the original total) have been excluded.

The research and knowledge transfer components of HMMN activities are inter-related. For instance, participation to international DCF, ICES or NAFO experts Working Groups facilitates the emergence of research priorities and the networking between scientists. Although the transfer of research evidence into applied outcomes is more long term, some of the results obtained by HMMN over the period 2013-2018 are expected to influence advice-giving and/or the organization of data collection. For instance, the Eastern English Channel (EEC) ecosystem model Atlantis developed by ACL055 is being used to evaluate the conservation performances of fisheries management scenarios (e.g., effort reductions, discard ban, Marine Protected Areas), and it will also be applied to identify the most critical functional groups of the EEC trophic network for which fish diet data have to be collected as a priority.

Finally, it is important to stress that all HMMN research, advice-giving and data collection activities are integrated within a national IFREMER quality framework (ISO9001), following a process approach described in Section 1.4 ("Scientific integrity").

Actions taken in response to the recommendations of the previous AERES visit committee (2013)

We summarize below how the recommendations provided by the 2013 AERES visit committee have been addressed over the period 2013-2018.

"The growth and development experienced by the unit during the past period should be consolidated. This has to include the anticipation of changes in personnel."

HMMN has experienced a dramatic turnover since the last AERES evaluation: 17 staff members have left and 15 have arrived. Most of departures have been replaced, and some research areas have even been strengthened (trophic ecology, ichthyoplankton ecology, sclerochronology). However, others have been weakened (individual processes investigations, ecosystem modelling, fisheries and stock assessment), despite the leading role played by HMMN in these fields of research in recent years.

"Caution should be taken relatively to the number and size of programs planned. It is recommended not to over-estimate the capacity and possibilities of implementation of programs in the unit."

Compared to the previous evaluation period, the capacity of all IFREMER research units, including HMMN, to carry out research projects is now entirely monitored before applications are submitted. This is a prerequisite of IFREMER ISO9001 certification (process P3: conducting research). Project slips (*Fiches Projets*) are completed with information on research objectives and human/financial resources, and are analyzed by the RBE Department Director (RBE/D), who is also informed by advice provided by the heads of other research units involved in the project and by IFREMER financial services. RBE/D decides whether the project may be submitted as it is, with changes, or not. The grand majority of HMMN projects initiated during 2013-2018 were submitted after clarification and/or adjustments in the amount of resources involved.

"It is recommended to consider the development of support to the team in terms of administrative support for further development of (European) projects, both in terms of capacity and expertise."

The financial support to the development and implementation of research projects has greatly improved, with finance officers being charged to follow up administrative matters right at the initiation stage.

"Scientific exploitation and dissemination of research results should be enhanced. Use of all available data including old data sets should be further explored."

The amount of peer-reviewed publications has more than doubled between the previous evaluation period (10 per year over 2007-2011) and he current one (25 per year over 2013-2018), while the number of research scientists has remained stable. A number of research papers have made use of old survey datasets, particularly to evidence regime shifts in fish communities in relation to climate change (ACL003, ACL004, ACL005).

"Finally it is recommended that, resources providing, the number of students, PhDs and post docs is increased."

The number of PhD students has also doubled between 2008-2011, where 4 students passed their viva, and 2013-2018, where 9 students graduated. It is important to note that HMMN has strongly encouraged the recruitment of PhD students by promoting PhD subjects, exploring grant opportunities, and by facilitating the insertion of recruitees (e.g., HMMN has a refund policy for university registration fees and covers the costs of French courses for foreign students). The number of postdocs has remained stable at a low level since 2017 (1 per year).

1.2 Unit's environment

The overall HMMN collaboration network, revealed by an analysis of the 139 WoS publications, is shown in Figure 1.4, and we comment below on how this has been structured at different geographical scales (international, EU-wide, national, regional).

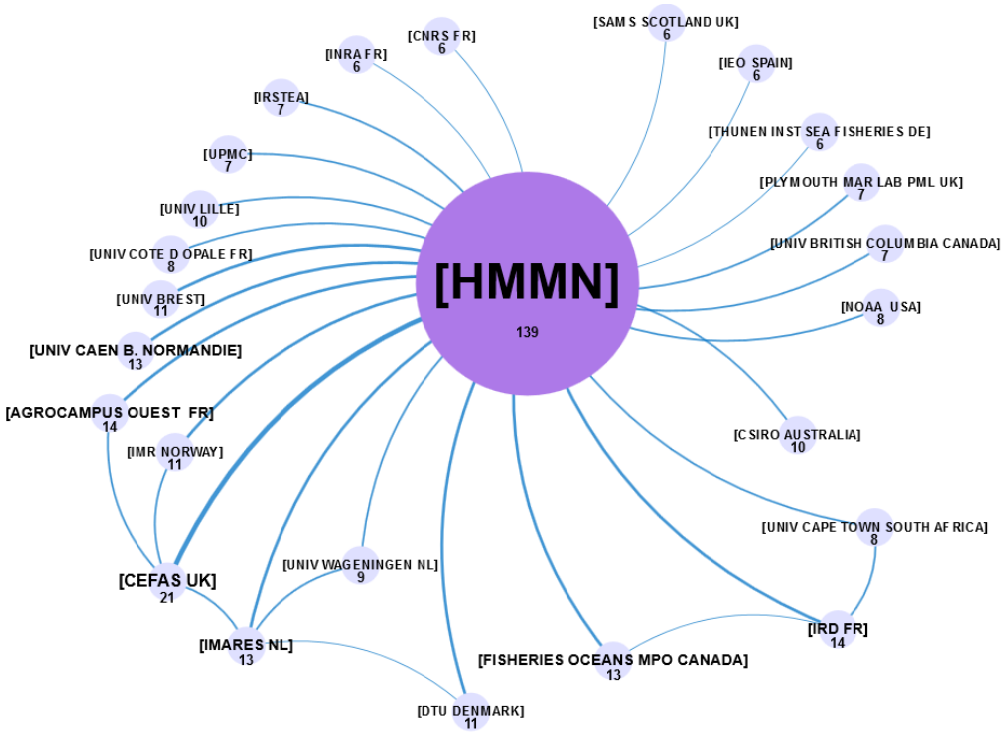


Figure 1.4. HMMN collaboration network revealed by an analysis of the 139 WoS articles (at least 6 publications in common) published from 2013 to June 2018.

International ecosystem

As revealed in Figure 1.4, the main HMMN international (non-EU) collaborator is the Canadian Department for Fisheries and Oceans), and it comes as no surprise that it is with this institute that an International Research Network (GDRI RECHAGLO) has been launched, where HMMN has acted as co-leader. Since its inception in 2015, the GDRI RECHAGLO has supported 7 bilateral scientific projects through the funding of roughly 20 visiting trips of one week each in a network of circa 50 scientists. Among other deliverables, the GDRI has already produced 9 peer-reviewed articles, has leveraged funding for 3 large scale projects, and has generated 10 oral contributions and posters at conferences.

Although not formalized, the collaborations with CSIRO (Australia), NOAA (USA) and the University of Cape Town (South Africa) evidenced in Figure 1.4 have facilitated the development of the two EEC ecosystem models (Atlantis, Osmose) over 2013-2018 and subsequently the international collaboration around complex models in which HMMN has played a major role. Like in 2008-2011, HMMN's EU partners are by large national institutes similar to IFREMER, and a few universities, mostly located in Northern Europe (Denmark, UK, Germany, The Netherlands, Norway). The collaboration has mainly materialized by common publications carried out under the auspices of several FP7/H2020 (VECTORS, SOCIOEC, DISCARDLESS) and Interreg (PANACHE, CRESH) projects, where HMMN has generally been involved, as WP leader. In 2017, HMMN has also obtained funding for an international Belmont forum project (SOMBEE) and a bilateral German-French project (COCKTAIL), in collaboration with the Alfred Wegener Institute. HMMN PhD students have increasingly been requested to visit a foreign laboratory in relation to their subject for a period ranging from 1 to 12 months: DTU-Aqua (Denmark), IMARES (Netherlands), University of Washington (USA), Thünen Institute (Germany) and CSIRO (Australia) have thus been visited. On the other hand, several foreign PhD students and postdocs visited HMMN. Finally, HMMN has been involved in a joint EU programming initiative relevant to the EAF, the ERANet COFASP (2013-2017) and, more recently, an extension of EU article 185 BONUS2, which will offer an opportunity for HMMN to develop its future research activities in the English Channel and Southern North Sea (EC-SNS), in an international context.

Data quality for research and expertise is also a strong activity of HMMN, which is underlined by its mandates as referent for the Fisheries Information System (SIH) on data collection and in coordinating the data processing and provision to end-users (CREDO). The international involvement in these activities comes through participation in the relevant working groups of the scientific, technical and economic committee of the European Commission (STECF) and in the European sampling coordination bodies (RCM/RCG). The international influence of the unit in the area of data quality can be measured by the chairmanship of several working groups on the collection of biological parameters, the organization of international working groups on both sites, the co-chairmanship of a STECF group dedicated to data quality (EWG-17-11), the upcoming chairmanship of the 2018 RCG synthesis group (Liaison Meeting) and the presidency of the ICES Data Planning

Group (PGDATA 2017-2019). Applied research projects have also been developed on this topic, such as projects funded by the European Commission on Strengthening Regional Sampling Coordination (WP leader on data quality in the fishPi and fishPi2 projects) and the project funded by the Scientific Direction of Ifremer on the objective qualification of collecting fish maturity (MATO project) together with the University of Caen.

HMMN international advice-giving has also to a large extent been structured by a regular participation to the ICES science process, where HMMN has, (1) actively contributed to Working Groups (WGs) in charge of assessing key EC-SNS stocks (e.g., sole, plaice, whiting, herring, scallops, pollack) and, (2) participated to other WGs with a more fundamental science orientation, yet supporting EAF-based stock assessments by exploring a variety of processes/approaches, e.g., eggs/larvae contribution to fish recruitment, fisheries-induced evolution, end-to-end modelling. HMMN has in particular (co-)chaired 20 ICES WGs (Appendix 4, Section I.12). Finally, Joël VIGNEAU is the referent for fisheries management advice in the EEZ of St-Pierre et Miquelon, where a bilateral agreement establishes the fishing rights and the necessary coordination of actions between France and Canada in the 3Ps area (St-Pierre bank). He also participated in the NAFO (Northwest Atlantic Fisheries Organization) advice-giving process (2013-2017) and chaired its scientific committee (2016-2017).

National ecosystem

The main national ecosystem of HMMN is obviously IFREMER and its RBE Department, and more particularly those research units with a clear Northeast Atlantic EAF research activity, e.g., EMH and STH around fleets and fisheries modelling, nurseries investigations, trophic ecology (51 publications in common over the period 2013-2018). The PNS team of HMMN has also collaborated with RBE Mediterranean and overseas research units to investigate the growth and/or stock identification of several fish and shellfish species worldwide. More recently, HMMN has tightened linkages with RBE units hosting the expertise and facilities to conduct controlled experiments: PFOM (*Physiologie Fonctionnelle des Organismes Marins*) and MARBEC. The different EAF-focused research units, including PFOM, BE (*Biogéochime et Ecotoxicologie*) and EM (*Economie Maritime*) meet every month under the auspices of a *Comité pour l'Approche Ecosystémique en Halieutique* (CAEH) to share relevant research activities and findings and make plans for future collaborations. The CAEH has thus produced an integrated mapping of all recent EAF-related activities by IFREMER research units. The Committee is now in the process of developing, in conjunction with RBE/D and the IFREMER Scientific Direction, a plan for the organization of future EAF-related activities within the different CAEH research units. This plan will be advanced in November 2018, when IFREMER organizes a prospective workshop involving external academic partners (IRD, Agrocampus-Ouest).

HMMN advice-giving activities abide by IFREMER ISO9001-certified requirements (process P9: delivering expertise and advice). These are monitored by a national coordinator, who ensures a liaison between the Ministries (particularly the *Direction des Pêches Maritimes et de l'Aquaculture* - DPMA) and IFREMER and defines priorities in terms of expertise requirements. Video-linked meetings are organized on a regular basis, where all IFREMER advice-givers (including EAF experts, but not only) and their heads of unit are invited to contribute. A specific role of HMMN in IFREMER advice-giving is the national coordination of MSFD Descriptor D3 for determining the Good Environment Status to be reached at the horizon 2020 (Populations of all commercially exploited fish and shellfish are within safe biological limits, exhibiting a population age and size distribution that is indicative of a healthy stock).

HMMN fisheries data collection and processing activities are centralized within the SIH (Fisheries Information System) program, with strong interactions with the EU Data Collection Framework (DCF). HMMN plays a central role in the SIH by coordinating, (1) the CREDO facility (see above), (2) data collection of biological parameters (through the PNS in particular), (3) several large-scale research surveys and, (4) the development of a national survey database.

HMMN national ecosystem also includes the ODE Department of IFREMER (the PTEZOO facility is co-coordinated by LERBL and HMMN), and external organisms with strong EAF and/or ecology research activities, more particularly Agrocampus-Ouest and IRD (14 publications in common with each), and also UBO, IRSTEA, UPMC, CNRS and INRA (6-11 publications in common with each).

Regional ecosystem

Hauts de France (HDF) Region. The collaboration between HMMN and regional research partners has mainly occurred with U. Lille and ULCO via the UMR LOG (8-10 publications in common with each, 1 Professor in secondment at HMMN in 2017-2018) and, more recently, the ANSES. This collaboration has been formalized in 2012 by the inception of the *Groupement d'Intérêt Scientifique* (GIS) « Campus de la Mer ». Although its remits have been relatively limited at the start, the GIS has stimulated the successful development of the highly federative CPER MARCO project (2015-2020), the scope of which is to comprehensively investigate the marine environment and resources, as well as the quality of aquatic products. The CPER MARCO has in particular allowed HMMN investing in up-to-date equipment in relation to trophic and ichthyoplankton ecology studies.

Following the progress made by the GIS and CPER MARCO, an application for a new Research Federation has been submitted in 2018 to the HCERES, as detailed in Section 1.6.

Normandy Region. A proposal for a framework agreement between IFREMER and the ComUE 'Normandie Université' is currently being drafted. A previous framework agreement was signed in June 2013 for a period of 4 years. The evaluation of actions carried out by HMMN with Normandie Université during this period has materialized by several theses in co-supervision, teaching within the IUT Biological Engineering, sharing of technical materials, collaborations in research projects and joint publications.

1.3 Research products and activities

Scientific outputs

An analysis of the main concepts investigated by HMMN over 2013-2018 is synthesized in Figure 1.5, based on an *Intellixir* analysis of the 139 HMMN WoS-referenced publications. The most salient key words reveal the strong anchoring of HMMN research activities within Theme 1 (Growth, Age, Distribution, Life History Trait, Otolith, Larval, Habitat), Theme 2 (Ecosystem, Trophic), Theme 3 (Fishery, Management, Stock), as well as cross-cutting aspects such as methods or objects of study (Fish, Model, English Channel). The synthesis and a few highlights of HMMN scientific achievements are presented in the thematic Sections 2 to 4.

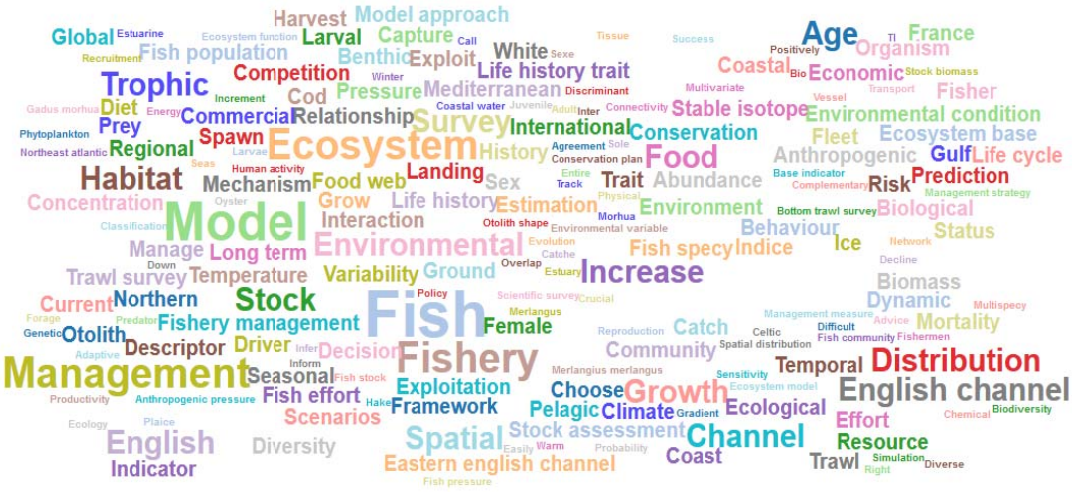


Figure 1.5. Main concepts investigated by HMMN over the period 01/2013-06/2018, based on an *Intellixir* analysis of titles and abstracts of the139 WoS-referenced HMMN publications.

Quantitative data

The HMMN team has published 139 WoS-referenced papers (gathering 961 citations) between the 01/01/2013 and the 30/06/2018, i.e., 25.3 (=139/5.5) papers and 174.7 (=961/5.5) citations per year without major trend, although a historically-high 31 WoS-referenced papers has been recorded in 2017 (Figure 1.6). This represents a substantial increase (X 2.4) compared to the 2008-2011 period evaluated in 2013 (42 papers and an annual average of 10.5), while the average amount of ETP (*Equivalent Temps Plein*) dedicated to research activities has only increased by 25% (X 1.25) between 2008-2011 (21,000 hours per annum) and 2013-2017 (26,000 hours per annum). The larger academic dissemination volume recorded in 2013-2018 is first a reflection of the increase in the number of PhD students, which has doubled between 2008-2011, where 4 students passed their viva, and 2013-2018, where 9 students graduated (19 out of the 139 WoS papers were thus first-authored by a PhD student supervised by HMMN scientists). It is also a reflection of an increasingly fruitful and complementary collaboration with regional (e.g., UMR LOG), national (e.g., other EAF-focused RBE research units, Agrocampus-Ouest) and international partners (e.g., CEFAS, CSIRO). Finally, it is perhaps also a corollary of the large staff turnover that has characterized HMMN over 2013-2018, and the recruitment of young scientists with a dominant work share dedicated to research activities.

The 139 papers produced from 2013 to 2018 were published in 70 journals, which represents again a substantial increase compared to the period 2008-2011, during which only 23 journals were targeted (2 of them, specialized in fisheries science, gathering 1/3 of the total HMMN production). Almost 50% of 2013-2018 HMMN papers (with a median IF of 2.33) were published in Q1-ranked papers (Figure 1.7). The number of publications with an IF > 5 has doubled between 2008-2011 (2 articles, representing 5% of the total 42) and 2013-2018 (14 articles, representing 10% of the total 139). These figures reflect a substantial diversification effort in the choice of publication outlets, including journals of higher quality and accessible to a broader audience of marine

ecologists than those fisheries research journals, which used to dominate HMMN scientific production in 2008-2011.

HMMN has contributed in 2013-2018 to 76 expert groups and advice-giving reports (Figure 1.6), of which 25% were requested by the French Fisheries & Aquaculture Directorate (DPMA), and 25% were produced under the auspices of ICES. It is difficult to compare the 2013-2017 trend with the 2008-2011 figures, due to a change in the criteria used to classify documents into experts groups/advice-giving reports between the two periods. However, Figure 1.6 suggests a decline over 2013-2017, which could be related to the overall reduction (-3) in the number of HMMN scientists contributing to institutional expertise and advice-giving between 2008-2011 and 2013-2017 (see Section 1.1, "HMMN activity profile").

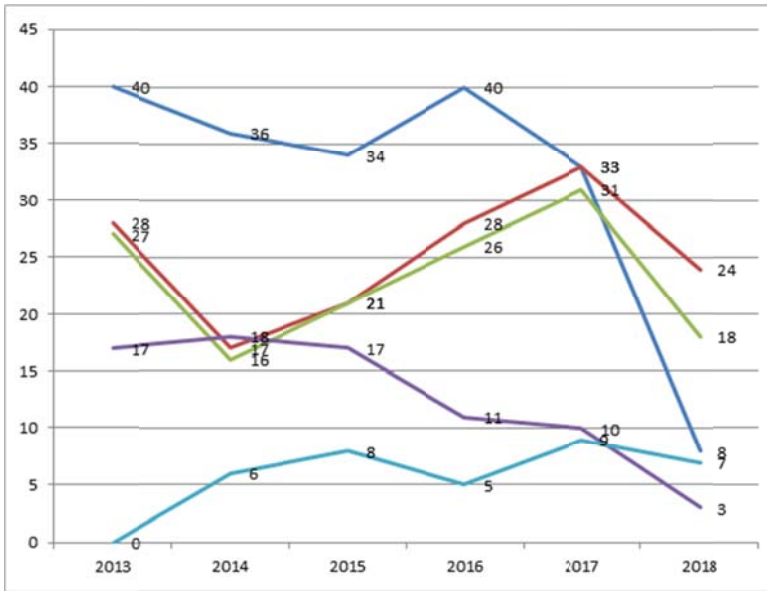


Figure 1.6. Annual trend in HMMN scientific production (green: WoS-referenced publications, red: all peer-reviewed publications, purple: experts/advice-giving reports, light blue: communications without proceedings, dark blue: all reports). Source : Archimer.

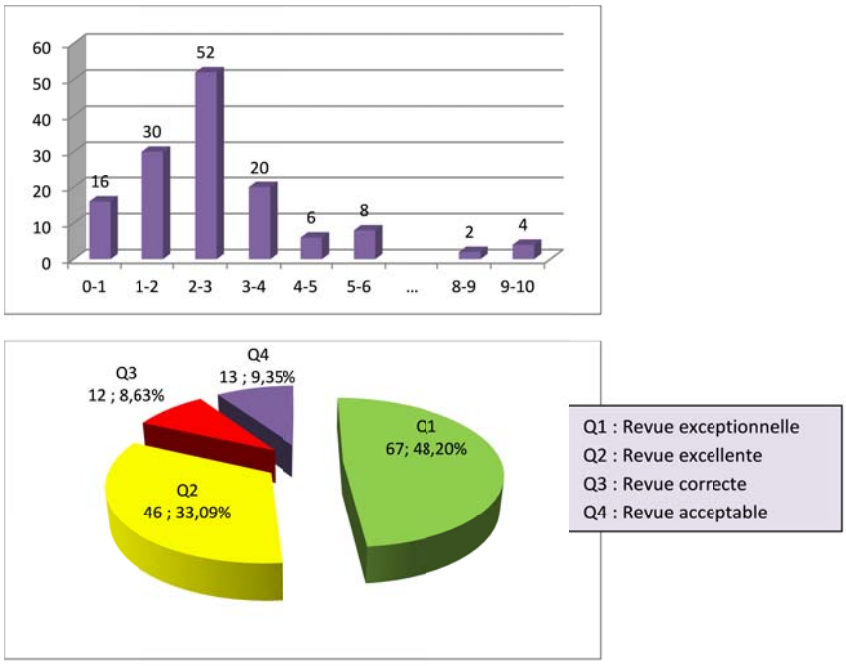


Figure 1.7. HMMN 2013-2018 (june) WoS-referenced publications – Distribution of the journals' IF and quartiles. Source: Archimer.

Most of the 139 WoS publications are related to Theme 1 (45%), followed by Theme 2 (30%) and then by Theme3 (25%). This is an illustration of the broadening of HMMN research activities towards an investigation of life history traits processes (Theme 1) and ecosystem functioning (Theme 2), beyond traditional fisheries

science (generally, although not always, associated with Theme 3). This is in contrast with the 76 experts group and advice-giving reports, of which 67% could be related to Theme 3, followed by Theme 1 (20%) and then by Theme 2 (13%). The dominance of Theme 3 in knowledge transfer reflects that half of the records stem from a demand by DPMA (25%) and ICES (25%), with requests generally focused on stock assessments and fisheries management plans evaluation.

HMMN has contributed in 2013-2018 to 14 EU-funded projects of which; (i) 3 large FP7/H2020 projects (25-37 partners), each time as WP leader; (ii) 7 Interreg projects, 2 as WP leader and; (iii) 2 DG-MARE projects. This represents a decrease, particularly for FP projects, compared to 2008-2011 where HMMN contributed to a total of 17 EU-funded projects, including 9 FP projects. The decrease in the amount of EU FP/H2020 funding, also shown in Figure 1.2, reflects that such projects have become increasingly large and selective with often more than 5 consortia competing for the same bid: HMMN contributed to the submission of 4 H2020 project proposals over 2013-2018 and was only successful in one (H2020 DISCARDLESS). It is also of note that HMMN has in 2017-2018 obtained funding for two research projects from a joint call between the competitive international Belmont forum and the ERA-Net BiodivERsA and from the bilateral AWI (German Alfred Wegener Institute – IFREMER) agreement. On the national side, HMMN has like in 2008-2011 contributed to 2 ANR (1 as coordinator) and 1 FRB projects. Five other attempts for ANR funding (either as coordinator or participant) were unsuccessful over 2013-2018. On the other hand, HMMN, has obtained valuable funding from *France Filière Pêche* – FFP (3 large-scale projects), FEAMP (4 projects) and EDF (2 projects). Although these funding sources mainly stem from an industry demand, the resulting projects have been a real opportunity to develop academic science in collaboration with the socio-economic sector (ACL025, ACL026, ACL027). On the regional side, HMMN has been successful in obtaining PhD grants from different origins: PMCO (4), Hauts de France (1), Haute Normandie (1), Basse Normandie (1). However, the successful bid and launch of the CPER MARCO project is perhaps the best illustration of the partnership between HMMN and its regional academic partners, as detailed in the "Highlights" Section below. The overall evolution and diversification of HMMN external funding sources is also illustrated by the trend in the financial benefits gained by the unit over the period 2013-2017 (Figure 1.2).

Selected production and research activities

A selection of HMMN scientific production is given in Appendix 4.

Highlights

A selection of research evidences obtained by the HMMN team over 2013-2018 is highlighted in the thematic Sections 2 to 4. In the current Section, we chose to highlight the MARCO project (Marine and Coastal Research on the Opal Coast), funded by the CPER - *Contrat de Plan Etat Région*, over the period 2014-2020. This is because MARCO comes across the three HMMN research themes, but also since this project has had, and will have, a structural effect on future HMMN activities and on their insertion within the HDF research network.

The MARCO project is coordinated by both UMR LOG and ANSES and it includes eight regional laboratories. MARCO has been and will mainly be funding the acquisition of up-to-date laboratory equipment for most of the partners including HMMN, which will receive 700 k€ over the whole project lifespan. MARCO will comprehensively investigate the marine environment and resources, as well as the quality of aquatic products. The project is structured into 6 research axes: (1) Observation and evaluation of the marine environment, (2) ecosystems structure, functioning and dynamics, (3) productivity and sustainability of fisheries and aquaculture resources, (4) quality and safety of aquatic resources, (5) vulnerability and utilization of marine and coastal eco-socio-systems and, (6) marine and coastal engineering. HMMN co-coordinates axes 2 and 3 along with UMR LOG, and it also participates to axis 4 in collaboration with ANSES. In axis 2, HMMN investigates the structure and dynamics of the EC-SNS trophic network by combining empirical studies with ecosystem modelling. In axis 3, HMMN will combine empirical studies and an experimental approach to enhance our understanding of the response mechanisms of exploited fish to their environment and anthropic pressures. The empirical investigations build on existing and newly acquired equipment for PRT and PTEZOO platforms. The experimental approach is expected to build on the development of a partnership with the NAUSICAA aquarium and a regionally-funded aquaculture experimentation structure, the PFI - *Plate-Forme d'Innovation Nouvelle Vague*. In axis 4, HMMN will contribute to the evaluation of the impact of chemical and biological contaminations on the English Channel trophic network.

In 2016-2017, the PRT could thus be equipped with three sets of working stations (binocular magnifier, camera and associated IT resources) dedicated to the analysis of fish stomach contents and morphometric parameters, while the PTEZOO could invest in a dehydration autonomous device, a iatroscan MK6 (Figure 1.8a), an histokinette and a microtome LEICA (Figure 1.8b) to investigate fish larvae conditions using histological and lipid indicators. Such equipment has already contributed to a recent publication (ACL053) and it has already been used by two PhD and four M2 students. MARCO has also strengthened an existing collaboration with UMR LOG, and it has facilitated the advent of a new collaboration with ANSES. Importantly

also, the emergence of the French-German COCKTAIL project, involving a collaboration with the Alfred Wegener Institute via the co-supervision of a PhD student, results to a large extent from MARCO's momentum.

However, MARCO is also expected to have more general long term and lasting effects on HMMN research activities. First, MARCO will be a unique opportunity for HMMN to combine for the first time empirical, experimental and modelling approaches to investigate processes shaping key relationships of the EC-SNS trophic web, including lower trophic levels. Second, MARCO has greatly inspired the emergence of the recently submitted SFR "Campus de la Mer" project, in which HMMN will be required to play a leading role in the future. These essential prospective aspects will be discussed in Section 1.6.

Figure 1.8a. Iatroscan MK6 used to analyze lipid classes

Figure 1.8b. Microtome LEICA used for histological analyses

1.4 Organisation and life of the research unit

Quantitative data

See table "Synth personnels unité ANG " in the Excel file "Données du contrat en cours".

Management, organisation and scientific animation

The three COEI objectives of relevance to HMMN (O1, O2, O3) and the extent to which these have been achieved are shown in Section 1.1, "*HMMN scientific objectives and strategy over 2013-2018; national and international positioning*".

As already indicated above, the HMMN is organized in two laboratories, located in Boulogne sur mer (LRHBL) and in Port-en-Bessin (LRHPB), and in three scientific themes, all supported by four technical facilities. The Direction team consists of Paul MARCHAL, HMMN manager (HMMN/D), who also runs LRHBL, and of Joël VIGNEAU, who leads LRHPB (LRHPB/D). Each scientific theme has a coordinator (Theme 1: Christophe LOOTS, Theme 2: Pierre CRESSON, Theme 3: Raphaël GIRARDIN), and each platform has referents (PNS: Kelig MAHE, PRT: Pierre CRESSON, PTEZOO: Elvire ANTAJAN (LERBL) and Christophe LOOTS (HMMN), CREDO: Joël VIGNEAU). All theme coordinators have changed once since 2013. One HMMN colleague, Bruno ERNANDE, is also part-time referent in EAF science for the IFREMER Scientific Direction. The organizational chart is given in Appendix 3.

The management of HMMN human and financial resources is coordinated nationally by dedicated IFREMER Functional Directions (the DRH and the DAFJ, respectively), with representatives in Boulogne. Until 2017, the management of HMMN financial resources was exclusively administered by the Boulogne DAFJ representative, Elodie DELPIERRE. Since 2017 and the reorganization of the DAFJ, HMMN financial affairs are managed by several DAFJ colleagues, possibly from the Brest site, although the financial management of HMMN research projects is still and by large assigned locally. We provide here some cues on HMMN human and financial resources management at HMMN, noting that the processes described here follow a national standard and hence are to a large extent applicable to other IFREMER research units.

On the human resources side, all HMMN staff is once a year subject to a formal and individual appraisal by his/her line manager in LRHBL and LRHPB. The primary purpose of the appraisal is to evaluate the extent to which the objectives assigned in the previous year have been achieved, and also to establish the new objectives for the coming year. Important outcomes of the individual appraisals include career advancement, promotion and training proposals, which are then submitted to HMMN/D (in the case of LRHPB) and RBE/D. 26 career advancements and 8 promotions (3 to research scientists, 2 to engineers, 3 to technicians) have been granted over the period 2013-2017. 210 training sessions have been organized over that period, of which 75 concerned directly science and technology, and 51 health and safety aspects. Job vacancies may also be identified within HMMN. These are typically presented and debated at the end of each year, along with job

vacancies identified in other RBE units, during a videoconference organized by RBE/D, to which all RBE research unit directors and a representative from the IFREMER Scientific Direction are convened. RBE/D then proceeds with a selection of those job vacancies, which will later on be advanced to the IFREMER *Direction Générale*, who makes the final decision. The overall approach to human resources management is embedded within IFREMER ISO9001 quality framework (process P12).

On the financial resources side, HMMN/D interacts closely with RBE/D, DAFJ representatives (Elodie DELPIERRE in Boulogne for all contractualized projects, Morgane KERLEGUER in Brest for HMMN central budget) and all project leaders to propose an initial budget request (BI – *Budget Initial*) in September each year. The proposal is submitted to RBE/D, who makes a decision on the budget allotted to HMMN in year n+1. The BI may be subject to amendments in the first semester of year n+1 (BR – *Budget Rectificatif*). The overall approach to financial resources management is embedded within IFREMER ISO9001 quality framework (process P13).

Decision-making within HMMN generally builds on a bottom-up approach, although the extent of staff consultation depends on the type of decision to be made. Strategic decisions regarding HMMN future (e.g., insertion of HMMN within the future RBE roadmap and regional partnership, identification of human and financial resources needs, preparation of the present HCERES auto-evaluation, reporting) primarily involve the HMMN direction team, theme and technical platform coordinators, the Scientific Direction referent and project leaders. Interviews for job vacancies involve HMMN/D, one HMMN scientist and 1-2 external experts (from another IFREMER Research Unit and/or research institute). When the vacancy concerns one of the technical platforms, HMMN technicians are invited to organize a visit of the laboratory facilities with all candidates, and then to reflect on their impressions to the recruitment committee. Operational decisions are also needed to organize activities and priorities within the technical platforms and to plan surveys, and these involve actively all staff categories, with little intervention from HMMN Direction. It is thus of note that while the scientific coordination of surveys is held by research scientists, several technicians and engineers have taken key survey responsibilities as operational coordinators and/or trip leaders. Finally, project leaders have considerable discretion in conducting and organizing their research, except when overspending, in which case a financial arrangement is sought (and generally found) with other HMMN and/or RBE project leaders, and when underspending, in which case alert messages are prompted by the HMMN/D and DAFJ representatives.

While both LRHBL and LRHPB teams work closely together and complementarily across the three HMMN themes, they differ in the proportion of activity they respectively dedicate to basic research, data collection/processing, and advice-giving. Thus, LRHBL activities were in 2013-2017 predominantly dedicated to basic research (50% of worked hours), closely followed by data collection/processing (47%), and then advice-giving (3%). In contrast, LRHPB activities were over the same period largely attributable to data collection/processing (57% of worked hours), followed by basic research (26%) and advice-giving (17%).

The internal communication within each of the two HMMN laboratories is formalized by "*flash*" meetings that are convened every Monday in LRHBL, once per quarter in LRHPB. The aim of these flash meetings, which rarely exceed 1h, is to give an opportunity for each participant to share his/her past and planned activities, and to get some feedback from other group members.

The 2013 AERES evaluation spotted that the distance between LRHBL and LRHPB (348 km) represented a management challenge, and a number of measures have been taken to address it to the extent possible. First, "*HMMN scientific days*" have been organized every year since 2013 over two days, in November, alternatively in Port-en-Bessin (2013, 2015, 2017) and Boulogne (2014, 2016). The primary purpose of those HMMN scientific days has been to allow all members of both laboratories learning to know each other better, by presenting and interacting directly on the science they developed within each of the three HMMN themes. HMMN scientific days have also represented an opportunity to discuss more transversal and strategic issues (e.g., insertion of HMMN within the RBE research, advice-giving and data collection prospective).

In addition, HMMN-wide video-conferences, "*HMMN plenary meetings*" have been organized once per quarter since 2016, in a similar fashion to within-laboratories *flash* meetings, but extended to the whole research unit staff and lasting ~2h. Ten HMMN plenary meetings have thus been organized since 2016, with HMMN/D alternatively being present in Boulogne or Port-en-Bessin.

Scientific seminars, involving both HMMN but also the other CMMN teams (LERBL, LERN, LCSM), and possibly external regional research-providers, are also organized. These include in particular student seminars, organized once a year in June, which provide an opportunity for PhD and Master students to present their progress and get some feedback from the audience. This has proved particularly useful for M2 students, for whom this seminar often represents an ultimate rehearsal before their viva.

Finally, HMMN has produced an annual activity report every year since 2014. This report has mainly been coordinated by the HMMN direction team and the three themes coordinators, with a contribution of all the scientific staff. All the information of relevance to the HMMN team (annual reports, seminar presentations,

meeting agendas, strategic documents) is shared on a common drive, while HMMN activities are populated on a dedicated website: https://wwz.ifremer.fr/manchemerdunord/Unite-Halieutique.

Technical facilities

We provide below a description of the four technical facilities hosted by HMMN (PNS, PRT, PTEZOO, CREDO). A list of the main PNS, PRT and PTEZOO equipment is given in Appendix 2. Note that some of the equipment is shared by the three facilities and that the full list of materials is collated in a common Access database.

National Sclerochronology Center (PNS). The PNS is located in Boulogne-sur-Mer and composed of 1 engineer (Kélig MAHE, referent), 1 assistant-engineer (Jean-Louis DUFOUR) and 4 technicians (Geoffrey BLED-DEFRUIT, Celina CHANTRE, Romain ELLEBOODE, Karine TRIBOUILLOY). This team is specialized in the estimation of marine fish and shellfish (cephalopods, mollusks…) age and growth based on the interpretation of their calcified structures (scales, otoliths, vertebrae, illicia, shell…) as well as on research topics revolving around the biomineralisation and the ontogeny of these structures. The PNS has all necessary equipment for the extraction, preparation and interpretation of calcified pieces including low speed saws, polishing machines and image acquisition devices in two and three dimensions. Since twenty years, Ifremer has developed software (TNPC) dedicated to the numerical processing of calcified structures. The PNS processes annually 35,000 calcified pieces received from all IFREMER fisheries laboratories to estimate the ageing histograms necessary for the assessment of commercial fish stocks. The estimation of fish age is principally obtained from calcified structure interpretation. To ensure consistency of interpretation among the various research institutes throughout Europe, the PNS organizes or participates in many international workshops to intercalibrate age estimation (co-chair of 7 WK over 2013-2018, see Appendix 4 Section I.12; participation to 9 WK). Moreover, the PNS is also involved in several ICES working groups, notably on the provision of biological parameters for stock assessment (WGBIOP) and on methods of stock identification (SIMWG). The PNS is also involved in several research topics covering fish nurseries or habitat quality, fish stock identification, the experimental study of otolith biomineralisation, life-history traits spatio-temporal variation and sclerochronology applied to archeological remains. During the 2013-2018 period, the PNS participated in 6 international (EU DG *MARE/2014/19; EU DG* MARE/2016/22; *EU* EASME/EMFF/2016/036; FEDER 2016 Micropolit; FEAMP Mesure 40 2017 Nourseine; INTERREG 2 SEAS Sumaris) and 4 national (DEFI NEEDS 2012 Uranium, Ministère de l'Outre-Mer 2013 Salmocodage; FFP 2014 Romeligo; FFP 2016 SMAC) research projects. The PNS has hosted 1 post-doc (App. 4, I.11), 3 PhD students, 2 master students (Appendix 4, Section III.3), and it has also contributed to the training of 11 PhD students within international programs (Appendix 4, Section III.5).

Trophic Ecology Facility (PRT). The PRT is located in Boulogne s/mer and it is composed of one research scientist (Pierre CRESSON, referent) and two technicians (Clémence COUVREUR, Margaux DENAMIEL). Several other HMMN colleagues, whose research fields are related to trophic problematics (e.g. fish larvae, trophic modelling or numerical ecology), have also contributed to the PRT research activities. The PRT has developed research activities on trophic interactions, at individual, population and community scales. PRT studies contribute mostly to Theme 2 (e.g., isotopic analyses to investigate the unique bentho-pelagic coupling in the English Channel). The PRT also benefits to Themes 1 and 3, as individuals' trophic traits may affect and/or explain their life-history traits (Theme 1) and some management models used by HMMN are based on multispecies trophic interactions (Theme 3). A summary of the major results over the period 2013-2018 is presented in Section 3.2. During the evaluated period, the PRT experienced massive changes in staff, facilities and equipment. Staff was almost totally renewed between 2013 and 2017 as three researchers and one technician moved to other Ifremer research units, while three researchers and two technicians were recruited. Staff changes were a challenge to melt individual practices into a coherent functioning but also an opportunity to develop new topics and include new methods in the platform's tool box. Massive building works also occurred in order to double the surface of the analytical facility. Consequently, the organization of the PRT was completely reconsidered, so as to increase working efficiency and quality. For example, each type of activity is now allocated to a dedicated area. A first area is dedicated to the processing of "field samples" collected during surveys (i.e. cleaning, measurement, photography and dissections), while a second one is dedicated to the processing of "lab samples" (*e.g.* grinding, chemical treatments or conditioning) and to the visual analyses of stomach contents. These modifications were needed to produce samples for chemical or isotopic analyses. More largely, it is included in the quality certification procedure fostered by Ifremer. Finally, several efficient devices were acquired during the period, such as a more efficient freeze-dryer, a larger -80°C freezer or fully-equipped stomach content analysis working stands. This equipment was mostly acquired through funding by the MARCO project. The PRT has hosted 1 Professor on secondment at HMMN (App. 4, I.11), 5 PhD students and 2 Master students (App. 4, III.3).

PTEZOO. The PTEZOO platform is located in Boulogne sur Mer and it is shared between HMMN and the LERBL laboratory. The platform is co-coordinated by Elvire ANTAJAN (LERBL, scientifically attached to HMNN) a specialist of mesozooplankton, and Christophe LOOTS (HMNN) an expert in fish larval ecology. Two research

scientists (Christophe LOOTS and Carolina GIRALDO) and two technicians (Valérie LEFEBVRE and Josselin CABOCHE) are in charge of the ichthyoplanktonic (fish eggs and larvae) part of the platform. The two research scientists are also involved in several ICES working groups (WGEGGS2, HAWG, WGALES) dealing with ichthyoplankton. Christophe LOOTS has also chaired WGEGGS2. The platform is set up with basic equipment for collecting (plankton nets, niskin bottle, CTD…), fixing and identifying (four binoculars equipped with cameras and polarization system, one microscope, two zooscans) zooplankton samples. Since 2016, specific equipment dedicated to histology (spin tissue processor, microtome, cold plate) and lipids classification (iatroscan with an automatic sampler) has been acquired to perform larval condition analyses. The main research topic on ichthyoplankton is related to the study of essential fish habitats, in particular spawning grounds and larval concentration areas. More specifically, the main objectives are 1) to identify key processes influencing spatio-temporal variations in ichthyoplanktonic assemblages, 2) to characterize the trophic role of fish larvae within the planktonic ecosystem and 3) to evaluate individual larval parameters including nutrition, growth and condition in relation to fish recruitment. Within these three main objectives, past and present status of ichthyoplankton is analyzed to understand and forecast its response to global change. Within the 2013-2018 period, PTEZOO activities have been supported by different projects (FFP SMAC 2016-2019, CPER MARCO 2014-2020, EDF-funding) and used samples and observation data coming from recurrent (IBTS, CGFS, IGA) or punctual (REIVE, MSFD) sampling surveys in the eastern English Channel and North Sea. Nine non-permanent positions (7 master students, 2 PhD and 1 technician, Appendix 4) have been hosted by the PTEZOO to work on the different aspects of ichthyoplankton ecology.

CREDO. The Data Call Response Unit (CREDO) was created by the steering committee of the IFREMER Fisheries Information System (November 2012), based on a proposal drafted by HMMN. The purpose of CREDO is to organize the IFREMER expertise in the field of statistical processing of data collected in the framework of the European DCF Regulation. The objectives are to better meet the data needs of regional fisheries management organizations and international scientific bodies, in accordance with international obligations. The aim was also to free up time for stock assessment experts to prepare analyzes and develop models prior to their participation in international expert meetings. The CREDO unit is coordinated by HMMN (1 executive at 20% of his time and a full-time engineer), capitalizing on the experience gained in the development of tools dedicated to the processing of data (COST libraries). In 2017, the CREDO network, assisted by experts in all IFREMER fisheries laboratories, was able to process 80 data calls within the timing demanded by the applicants. This work corresponded to the sending of data and estimates of catch volumes and demographic structures in user-requested formats for more than 100 stocks. Figure 1.9 shows the continuous increase in data calls and the typology of end-users at the international and national levels. Part of the work in coordinating and engineering the CREDO unit relies on the participation and chairing of technical ICES meetings, such as PGDATA (chair 2017-2020), WGCATCH, BIOPTIM, WKPICS, and also STECF meetings dealing with the quality of data used for stock assessments.

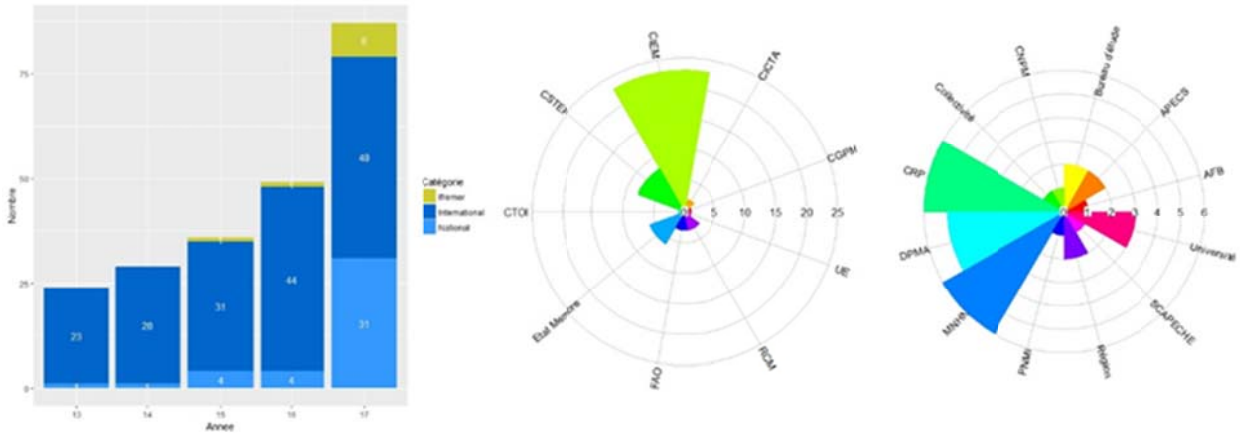


Figure 1.9. Evolution of the number of data calls operated by the CREDO unit (left) et typology of international (middle) and national (right) end-users.

Parity

The HMMN overall gender ratio (F / H + F) was of 39% over the period 2013-2018, with variations across staff categories: permanent research scientists (25%), permanent ITAs (41%), non-permanent research scientists (42%, 36% considering only PhD students) and non-permanent ITAs (45%). The stronger imbalance is then for permanent researchers, which was particularly true in 2018, where only one female scientist out of nine was part of HMMN staff. This imbalance reflects the massive turnover experienced by HMMN over 2013-2018: four of the five research scientists who left HMMN were thus female scientists. It is then unsurprising that in 2018, management and coordination responsibilities (unit and laboratory direction, theme coordination) are held

by male research scientists. However, it should also be stressed that key responsibilities were held by female scientists over the period 2013-2017, before they left HMMN: coordination of HMMN Theme 2 (Morgane TRAVERS-TROLET, 2013-2017), chair of ICES WGIPEM (Morgane TRAVERS-TROLET, 2015-2017), WP coordination of the H2020 DiscardLess project (Marie SAVINA-ROLLAND, 2014-2017), referent of the HMMN PRT facility (Ching VILLANUEVA, 2013-2014). Gender ratio imbalance is less pronounced for the other staff categories, and even decreased compared to the 2008-2011 period. For instance, six out of the nine ITAs being recruited at HMMN over the period 2013-2018 were female ITAs. Also, the gender ratio of PhD students will be balanced by the end of 2018 with the arrival of three female students. Overall, and although a particular attention will be paid to it, it should be stressed that the future evolution of gender ratio at HMMN is rather difficult to leverage, due the volatility of staff movements across gender and staff categories.

Scientific integrity

IFREMER has a clear purpose as a research provider and as the government's foremost source of evidence, applied science and impartial expert advice for marine environments. The activities of all IFREMER directions and research units, including HMMN, are embedded within a process-based quality framework ISO9001. HMMN is mainly concerned by three processes: P3 (conducting research), P7 (collecting and archiving reliable data on the coastal environment, biological and fisheries resources) and P9 (delivering expertise and advice).

Process P3 standardizes all key steps leading to research projects' management and implementation: proposal, validation, contracting, definition of workload, deliverables, publications, ending. A key element of the project proposal is the online submission by the leader of a FP - *Fiche Projet* (Project Slip), which includes all scientific, personnel and financial elements allowing RBE/D to decide on whether the project could be advanced or not. FPs have since 2015 been submitted systematically by HMMN staff. Except in rare occasions, FPs have been allowed to proceed after a few iterations with RBE/D. Most of the data produced by HMMN research work are stored on repositories managed at local, national or international level and data can be accessed freely or easily upon request. Following the current trend in scientific publication, HMMN researchers have also begun to submit datasets or R codes along with papers (e.g EDB1, EDB2, ACL068) guaranteeing long-term preservation and accessibility of the data and allowing third parties to replicate the analyses. The repeatability of the analyses is also supported by the online publication of methodological guidelines. P3 performance is rated by the number and quality of publications, which have been provided in this report. P3 does not make provision for standard rules concerning (co-)authorship or plagiarism monitoring, which are currently left to the research units' appreciation. HMMN (co-)authorship generally follows common academic practices, which are well accepted by the team. The first author is the one who provides innovative ideas, performs the bulk of the analysis, and writes the first paper draft. In the case of PhD papers, the student appears first and his/her main supervisor last. Other co-authors may have contributed in very different ways to publications: discussions on concepts and/or methods, results interpretation, manuscript through-reading. Although HMMN does not have a formal policy to monitor plagiarism, all research scientists are well aware of its deontological undesirability. Also, it may be fair to state that the inflation of electronic text-tracking means and of their utilization by journal editors has generated increasing disincentives for manuscript authors to venture in the troubled waters of plagiarism.

Process P9 aims at organizing/formalizing the treatment given to expertise or advice-giving requests in support of public policies. The following sequential steps are described and standardized: demand and capacity reviews, peer through-reading and validation, and the submission of a satisfaction questionnaire to the "clients". P9 aims at rendering the responses to public policy requests increasingly rational and traceable. HMMN is well informed of P9 requirements and applies its standards to the expertise and advice it delivers. This may in particular be illustrated by the comprehensive archiving of all documentation related to advice-giving requests on a privately-shared (*Alfresco*) drive, while the final report is publicly available on the IFREMER *Archimer* database. The same applies to process P7, which HMMN follows closely by coordinating the CREDO data-processing facility, large-scale surveys, and via in-laboratory empirical studies. All produced data are recorded (on the public IFREMER SIH URL in the case of surveys) and sometimes published via SEANOE (Sea Scientific Open Data Edition), and the protocols produced to describe laboratory best practices (e.g., fish dissections, otolith interpretations, taxonomic identifications) are archived on *Archimer*.

Since 2015, HMMN has been subject to two AFNOR external and three internal audits in relation to processes P3, P7 and P9, which have had positive effects on HMMN practices, particularly in terms of developing more realistic project proposals, regulating an inflating public (and private) demand for expertise and advice-giving, and archiving relevant documentations.

Health and safety

IFREMER has a structure dedicated to Health and Safety issues, the *Comité d'Hygiène, de Sécurité et des Conditions de Travail* (CHSCT): one central and one by IFREMER Centre, of which the *Centre Manche Mer du Nord* (CMMN), which hosts the HMMN Unit administratively. The CMMN has an Health and Safety engineer in Boulogne s/mer. No work accidents were recorded among the HMMN team over the period 2013-2018. The

risks the team may potentially be exposed to are identified and analyzed in a unique risk evaluation document (DU). The DU, which is regularly updated, identifies potential dangers inherent to each activity, analyzes the risks and how to prevent them. The risks related to the use of chemical products are evaluated by means of SEIRICH software provided by CARSAT. Some activities require specific habilitation and training (first-aid, electrical-clearance, fire-fighting, scuba-diving). The Head of each laboratory fills a working condition slip for each new collaborator, which makes a census of the potential risks he/she may be exposed to (drudgery, physical, chemical and biological nuisances). These slips are then transmitted to and recorded by the CMMN Health and Safety engineer. The main aspects identified for HMMN staff were working at sea, travelling abroad, driving, frequent screen exposures, using chemical products within the technical facilities. It is of note that specific risk evaluation slips have been made for the PNS and the PRT facilities. In addition to the works prompted by IFREMER to address the comments raised by the CHSCT and safety control authorities, the institute has also taken precautionary measures to alleviate risks: hoods, lighting, individual safety equipment.

1.5 SWOT analysis

Strengths	Weaknesses
✓2013-2018 vs. 2008-2011, increase in publications (X2.4), and PhD students (X2); ✓Multidisciplinarity from basic to applied research; ✓Coupling research-advice-monitoring: ensuring the liaison between science and public service; ✓Geographical situation : active collaborating research network, locally (<5 km: UMR LOG, ANSES, ULCO), within 1-day travelling distance in France (U. Caen, U. Rouen, U. Le Havre, U. Lille, U. Sorbonne, MNHN), Belgium (ILVO, U. Louvain, U. Leuven), and further away with EU labs focusing their research on the English Channel and North Sea ecosystem (PML, SAHFOS, CEFAS, U. Wageningen, U. Hamburg, A. Wegener Institute, Thünen Institute, DTU-Aqua); ✓A National Centre for Sclerochronology Science, with good national and international visibility; ✓Two well-structured and regularly updated facilities dedicated to the analysis of trophic networks and zoo-ichtyoplankton ecology/taxonomy, funded via CPER MARCO; ✓A National coordination structure dedicated to the provision of fisheries data to stock assessments and research groups (cellule CREDO); ✓Two calibrated ecosystem models for the eastern English Channel (Atlantis, OSMOSE); ✓Coordination of national surveys in the English Channel and the Southern North Sea;	✓ The HMMN Unit has lost expertise in ecosystem modelling, stock assessment and a capacity to interface with experimentall sciences; ✓ The CMMN Centre has limited infrastructures to host laboratory facilities (dimension, electric conditioning) ✓ The zoo-ichtyoplankton laboratory has reached full-capacity in Boulogne/mer: problem for hosting students, postdocs & visitors; ✓ The zoo-ichtyoplankton laboratory is shared between two Ifremer Departments, which is a source of complexity; ✓ Low number of HDRs: 2 in 2013, 1 in 2018; ✓The number of H2020/ANR project coordinations/participations has declined;
Opportunities	**Risks**
✓ Important turn-over in HMMN staff : an opportunity to adapt to emergent research priorities, if job openings balance departures in numbers; ✓ HMMN domain of activity fits the 2030 Ifremer strategic plan well; ✓ Emergent partnerships: – International: NOAA (USA) and CSIRO (Australia), around ecosystem modelling; DFO (Canada) through GDRI RECHAGLO; – EU-wide: with Danish, German, Dutch and UK research partners involved in the BONUS2	✓ Important turn-over in HMMN staff : a risk, if job openings do not balance departures in numbers; ✓ 4 departures planned over 2019-2022 ; ✓ The future of HMMN will depend on decisions made regarding the national organization of EAF science at Ifremer; ✓ HMMN will increasingly need expertise from other Ifremer units having their own research priorities (e.g., hydrodynamics and biogeochemical modeling, larvae drift modelling, acoustics); ✓ The distance between the Boulogne and Port-en-

research programme; – Regional: Creation in 2018 of a research federation involving all marine research laboratories of the Hauts-de-France Region; ✓ Possibility to implement ecosystem science combining empirical studies (building on surveys), controlled experiments and modelling; ✓ Possibility to access local NAUSICAA and PFI (Plateforme Nouvelles Vagues) experimental facilities and staff via CPER MARCO; ✓ Public policies at all scales (international, EU, national) promote an ecosystem approach to ocean human activities; ✓ The English Channel is an appropriate case to investigate cumulated impacts (e.g., Baie de Seine, Baie de Somme, Dover Strait); ✓ Observation tools: New scientific surveys in the Western Channel and in coastal nurseries;	Bessin laboratories (348 km); ✓ The production of marine renewable energies in the English Channel is high in the political agenda, but the involvement of HMMN to investigate their ecosystem effects is not entirely deep-rooted; ✓ The fate of the COMOR scallops survey is uncertain after the RV *Thalia* has decommissioned ✓ Impact of Brexit on the development of EU projects involving UK partners

1.6 Scientific strategy and projects (2018-2023)

Context

The 2018-2023 HMMN project will be embedded within the new COEI that will be established for the period 2019-2023, and likely released in December 2018. Importantly, the terms and conditions of the new COEI will be linked to the strategic agenda of Ifremer at the horizon 2030 "Ifremer 2030", which has recently been finalized building on the outcomes of an internal think tank (in which two HMMN research scientists contributed). The "Ifremer 2030" report has in particular identified three excellence areas (knowledge and characterization of marine life; biodiversity and ecosystem functioning and services; evaluation of anthropic pressures and their socio-economic stakes), six emergent priorities (coastal ecosystems, evaluation of cumulated impacts, ecosystems' resilience and shifts, evolution and adaptation of living organisms, novel marine bio-resources, adaptive ecosystem management) and two challenges (experimentations, integrated and predictive modelling), which are of direct relevance to HMMN future research activities. In addition to the overall COEI framework, it is also important to note that the HMMN project will be influenced by the future RBE roadmap for the organization of science in the different EAF research units, which was under development at the time of writing.

The 2018-2023 HMMN project will also be informed by research priorities emerging from the broader scientific community. The European Fisheries and Aquaculture Research Organisations (EFARO), an association composed of the Directors of the main European Research Institutes involved in Fisheries and Aquaculture research, has during its 2018 General Assembly identified research gaps and future research needs for fisheries and aquaculture after H2020. Of particular interest to HMMN research activities, a high priority was given to the following topics: integrated impact assessment, MSY & management plans, biological processes, lifecycles and distributions; while a high/medium priority was given to multispecies & fleet assessment models, end to end ecosystem models; discards, avoidance, landing obligation & utilization. New marine living resources and data collection were given a medium priority.

We provide below ("Science" sub-section) and in the three theme-specific projects (Sections 3.3, 4.3, 5.3) a selection of projects recently submitted and/or accepted by HMMN that will address some of the EAF scientific priorities and challenges presented above.

Science

HMMN activities will still follow the three research themes already defined for the 2013-2018 period. However, the structure of the three themes will be somehow restructured, to better reflect upcoming scientific priorities and also the renewal of HMMN domain of expertise. In short, Theme 1 will explore spatio-temporal variations in ecological processes affecting fish recruitment and life-history traits, and it will also investigate biological markers of fish populations (mainly calcified pieces, but also parasites), their variations, and the extent to

which they may be used to inform populations' spatial structure. Theme 2 will investigate mechanisms of trophic niche variations, the structure and functioning of exploited trophic networks and spatio-temporal dynamics of fish communities. Finally, Theme 3 will focus on tools and methods for the evaluation of fisheries resource, with a focus on data-limited stocks, and on the evaluation of fisheries management strategies in a global change context. While HMMN project will follow up recent achievements, the team will also promote emerging and innovative topics, of which many have already been built in recently submitted and/or accepted project proposals. These include in particular:

- Assessing the role of fish larvae as sentinel species to track environmental changes by combining in situ and experimental approaches;
- Disentangling the effects of environmental and genetic drivers on the growth and the biomineralisation mechanisms of otoliths;
- Combining calcified pieces with other biological markers (e.g., parasites) to enhance our understanding of fish populations' spatial structure;
- Developing a conceptual framework to predict isotopic incorporation from metabolic activity, and improving our understanding of stable isotopes as trophic tracers;
- Exploring the capacity of fatty acids and lipids class composition to trace trophic levels in combination with stable isotopes;
- Exploring the mechanisms maintaining functional rarity and ecological outliers in fish communities;
- Exploring sustainable and utilization opportunities of exploiting zooplankton as a novel bioresource;
- Developing stock assessment adapted to skates and rays, building on an improved understanding of their life-history traits;
- Estimating uncertainty around ecosystemic Maximum Sustainable Yield reference points building on sensitivity analyses and optimization methods adapted to complex ecosystem models;

To balance the advent of these emerging topics, several of the research subjects investigated in 2013-2018 will receive only limited attention in 2019-2023:

- Spatial modelling of marine habitats;
- Identification of appropriate conservation areas;
- Larvae drifts modelling;
- Fleet dynamics analyses;

The reason why these topics will receive a low priority in 2019-2023 is partly due to the turnover in HMMN staff and expertise field, as evoked in several occasions in this report, but it is also the result of the progress made in some research areas. Consider fleet dynamics analyses. Key results have been achieved by HMMN in terms of identifying key drivers of fishers' behavior, modelling fleet dynamics and evidencing the value-added of explicitly including the human component of fishing in fisheries and ecosystem models (ACL007, ACL008, ACL050, ACL056, ACL057, ACL099, ACL100, ACL101, ACL113, ACL132, BOP2, BOP6). We now believe that further developments beyond that point would require a stronger expertise in economic and social sciences, which should be sought in other research units (e.g., UMR AMURE in France).

A detailed description of specific scientific developments planned by HMMN over the period 2019-2023 is provided for each Theme in Sections 2.3, 3.3 and 4.3.

HMMN will also address, in tight collaboration with adequate partners, a key methodological challenge that will come across its three research themes. That challenge will consist of reproducing, using experimental conditions and ecosystem modelling, the *in situ* dynamics of EC-SNS marine populations (fish adults, ichthyo- and zoo-plankton), their effects on the ecosystem functioning, and how these may be impacted by the exploitation and/or pressure exerted by human activities, in a climate change context. While HMMN has conducted studies applying empirical analyses of survey data, controlled experiments or ecosystem modelling, the investigation of ecological functions building on the three approaches simultaneously is fairly innovative. The complementary expertise and facilities needed to pursue this tryptic combination will be found in existing collaborations in France (e.g., UMRs LOG, LEMAR, MARBEC), or abroad (e.g., Alfred Wegener Institute in Germany).

A recent example has been the submission to the ANR of the ZOOFISH project. By combining a suite of empirical, experimental and modelling approaches, ZOOFISH aims at, (1) investigating processes shaping key relationships of the EC-SNS trophic web, (2) deciphering bottom-up and top-down control mechanisms affecting trophodynamics, ecological functions (biomass production, element cycling) and services (food supply, water quality) and, (3) forecasting ecosystem futures subject to zooplankton exploitation, climate

change and evaluating the conservation performances of dedicated management plans, using the ATLANTIS model.

The implementation of HMMN scientific project will require a strong partnership combined with reinforced internal human resources, as detailed below.

Partnership

IFREMER. HMMN will collaborate around ecosystem and fisheries modelling, zooplankton ecology, connectivity and trophic interactions with the other RBE research units dedicating their work to EAF science in the Northeast Atlantic (EMH, STH), and it will provide expertise in sclerochronology (e.g., age-reading, otoliths shape analyses) on a project basis to all RBE units, including those with a focus on the Mediterranean and overseas. HMMN will also strengthen more recent interactions with IFREMER research units hosting expertise and infrastructures dedicated to experimental studies (PFOM, MARBEC), to investigate the dynamics and condition of harvested population and ecosystems via, e.g., the on-going COCKTAIL, TOOLBAR and MARCO projects, in combination with HMMN expertise in ecosystem modelling and statistical analysis (see "Science" sub-section). Although this is not engaged via formal projects yet, a collaboration will be sought with the BE unit, specialized in ecotoxicology, to investigate, (1) the cumulated effects of fishing and contaminants on the EC-SNS ecosystem, particularly focusing on the Baie de Seine commercial fish nurseries and, (2) possibilities of using contaminants as trophic tracers. Finally, a stronger collaboration with ODE units (DYNECO, ULITTORAL) will be needed to investigate the EC-SNS ecosystem dynamics comprehensively, and more particularly explore the coupling between benthic and pelagic compartments, with HMMN focusing on upper trophic levels (commercial fish in particular) and ODE on lower trophic levels (pelagos, benthos and biogeochemical cycles).

Regional partnership. In the Hauts-de-France region, HMMN/D has been part of the team in charge of building *ex nihilo* the « Structure Fédérative de Recherche (SFR) Campus de la Mer », which will be launched in the beginning of 2019. The SFR will group 11 laboratories associated with ULCO, University of Lille, CNRS, Ifremer, Anses (UMR LOG, EA LISIC, LMPA, TVES, ICV, HLLI, LARJ, Ifremer research units HMMN, LER, LCSM). The SFR will follow up the GIS Campus de la Mer and existing collaborations between the different partners (particularly UMR LOG and ANSES in the case of HMMN). The SFR will investigate marine socio-ecosystems, combining oceanography, ecology, mathematics, engineering and social sciences. The SFR President, Professor Sébastien Lefebvre, has been on secondment at HMMN over the period 2017-2018. HMMN will thus bond on the SFR momentum to seek new collaborations and carry out novel investigations: (1) signal processing in relation to the analysis of otoliths' shape and daily increments (LISIC: *Laboratoire d'Informatique Signal et Image de la Côte d'Opale* – EA 4491), (2) trait-based approaches in the analysis of ecosystem functioning (LOG: *Laboratoire d'Océanologie et de Géosciences* – UMR 8187), (3) development of genetic algorithms to optimize the calibration of the ATLANTIS ecosystem model (LISIC and LMPA: *Laboratoire de Mathématiques Pures et Appliquées* – EA 2597), (4) integration of chemicals, parasites and bacteria as trophic tracers and drivers of food web functioning (ANSES LSA-PPA: *Laboratoire de Sécurité des Aliments, des Produits de la Pêche et de l'Aquaculture*) and, (5) understanding the onshore-offshore trophic continuum in the English Channel (LOG). The interactions have already materialized by PhD co-directions that will be initiated or continued over the project period (LOG). In addition, a joint request has been submitted to allow Dr Mélanie GAY, a senior scientist from ANSES LSA-PPA to work on secondment at HMMN over the period 2019-2023, and that is currently being processed by IFREMER and ANSES central services. Mélanie GAY would contribute to the utilization of parasites as biomarkers of both fish life-history traits (Theme 1, Axis 3) and trophic levels (Theme 2, Axis 2). In the Normandy region, a scientific roadmap is being drafted between the ComUE and Ifremer to serve as a basis for the future collaboration between HMMN unit and the Normandy Universities. HMMN will use this opportunity to consolidate collaborations with the University of Caen (e.g., exploration of the benefits of histological analyses in the determination of fish maturity). Beyond the academic partnership presented above, HMMN will continue to work in partnership with fishers and producers organizations, particularly via FFP- and/or FEAMP-funded research projects (building on the positive dynamics of on-going industry-participative projects, e.g., SMAC, VARITROPH, SUMARIS).

National partnership. HMMN has been contacted by CNRS to join in two GDRs (*Groupement De Recherche*): PlastPhen and GRET. GDR PlastPhen will associate French researchers investigating phenotypic plasticity. It will be co-coordinated by Vincent DEBAT (MNHN, Paris) and Luis-Miguel CHEVIN (CNRS, CEFE, Montpellier). HMMN is expected to contribute to 3 of the 5 PlastPhen axes: temporal and trans-generational aspects, natural populations and ecology, evolutionary implications. The application has been submitted to CNRS and it is currently under review. The Groupe de Recherche en Ecologie Trophique (GDR 3716 GRET, http://gdr-

gret.univ-bpclermont.fr/) focuses on trophic ecology issues, and the HMMN team will bring its expertise and insights in the functioning of marine ecosystems. Finally, HMMN will collaborate with Sorbonne University (Professor Philippe KOUBBI) and IRD (Dr Yunne SHIN) through PhD theses co-directions. A joint request has also been submitted to allow Pr KOUBBI to work on secondment at HMMN over the period 2019-2023, and that is currently being processed by IFREMER and Sorbonne University central services. Philippe KOUBI would investigate spatio-temporal variations in ecological processes affecting early life-stages of fish (Theme 1, Axis 1).

International partnership. A clear objective of HMMN will be to increase collaborations with EU institutional partners, and more particularly those from Northern Europe with an interest in English Channel and North Sea ecosystems. The setting of common research projects is expected to benefit from the successful application of the EU article 185 BONUS2 research programming initiative, to which HMMN has brought its contribution. BONUS2 will thus offer an opportunity for HMMN to promote and develop its future EAF research activities in the English Channel and Southern North Sea (EC-SNS), in an international context. HMMN will also remain engaged in projects resulting from the forthcoming EU FP9 program. Specific bilateral collaborations will also develop building on recently accepted/started projects, i.e., SUMARIS (ILVO, Belgium), COCKTAIL (Alfred Wegener Institute, Germany), SOMBEE (University of Kiel, Germany). Although the fate of GDRI RECHAGLO was still uncertain at the time of writing, HMMN and Canadian DFO will collaborate around the assessment of cod in Newfoundland, and more generally of those straddling stocks which occur in both the EEZs of France (St Pierre et Miquelon) and Canada.

Workforce

At 01/07/2018, the permanent staff of HMMN is composed of 9 research scientists (including 1 expert in life-history traits now working part-time for the IFREMER Scientific Direction), 8 engineers and 12 technicians. The staff also includes 3 PhD students (plus 1 permanent scientist under PhD training), 1 post-doc and 5 non-permanent technicians. Towards the end of 2018, HMMN will also recruit 1 permanent technician, 4 non-permanent technicians, 4 new PhD students and 1 postdoc. In addition, Kélig MAHE is currently completing a PhD project, while Romain ELLEBOODE is pursuing a L3 degree. Both should be graduated by the end of 2019. HMMN has only one HDR, which is partly explained by the departure of several research scientists who had, or who were in a position to pass, a HDR in 2013-2018. 4 HMMN research scientists will be in a position and strongly encouraged to pass their HDR over the period 2019-2023.

HMMN has experienced a huge turnover over the period 2013-2018. Although many of the departures (16, plus 1 research scientist working part-time for the IFREMER Scientific Direction) have been balanced by recruitments (14 in total), some key positions are still vacant, including an ecosystem modeler and a researcher specialized in life-history traits and individual-level processes investigations. In addition, three HMMN engineers and one technician are expected to retire or depart over the period 2019-2022 (Marie-Laure COCHARD and Yves VERIN, two fisheries engineers; Jean-Louis DUFOUR, a sclerochronology expert; Nicolas GOASCOZ, a fisheries research technician). The implementation of the HMMN project will necessitate to strengthen several fields of expertise, to address the core and emergent research questioning identified in Sections 2.3, 3.3, 4.3, and also to balance staff losses (experienced during 2013-2018 and planned over 2018-2023). This challenge will be met by increasing interactions with regional and national partners, including visiting senior scientists on secondment and students co-directions (see Partnership sub-section above), and also by promoting/supporting job vacancies in HMMN and in other Ifremer research units, as shown below. HMMN will thus encourage job vacancies promoted by other IFREMER research units, which are supportive of its 2018-2023 project. Particular support will be provided by HMMN for job vacancies in acoustic ecology (EMH) and larvae drift modelling (ODE) in relation to ichthyoplankton ecology investigations, and for the recruitment of zoo-technicians to implement fish condition experimental tests (PFOM, MARBEC).

Several recruitments will also be needed within HMMN to support the 2018-2023 project. Six job vacancies have thus already been identified for the period 2019-2020, which will be further analyzed and prioritized by IFREMER Directions, and these are shown below.

Research scientist specialized in the modelling of exploited marine ecosystems. The overarching objective attached to this job vacancy will be to strengthen, building on existing models already developed by HMMN (ATLANTIS, OSMOSE) and others (EwE) in the EC-SNS, the conceptualization of marine ecosystem functioning through a multi-model approach. The model(s) being developed will be applied to better understand and quantify the role of different trophic compartments (including poorly informed zooplankton and fish species), but also to predict the effects of external environmental and anthropic factors, on the EC-SNS ecosystem functioning. He/She will validate model results using the outputs of empirical work carried out within the PRT

and the PTEZOO technical platforms. Modelling results will at the same time be used to identify those functional groups or species for which diet information should be collected in priority. Finally, he/she will contribute to HMMN advice-giving activities (ICES) by promoting stock assessment approaches in a multi-species context. This job vacancy will mainly contribute to HMMN Themes 2 and 3 and, in the short term, the CPER MARCO project (WP2).

Research scientist specialized on processes determining the biomineralisation of fish otoliths. The prime objective attached to this job vacancy will be to enhance our understanding of the life-history traits of adults and juvenile fish, e.g., birth place, movements and migrations, growth, metabolism, trophic regime, stress, and also to validate age-reading methods, by exploring the mechanisms of otoliths bio-mineralisation and morphogenesis and how these may be affected by environmental and anthropic pressures. A variety of tools (e.g., chemical markers) and approaches (empirical, experimental) will be considered to that purpose. This job vacancy will mainly contribute to HMMN Theme 1 and, in the short term, the CPER MARCO project (WP3).

Research scientist specialized in fisheries science. The objective attached to this job vacancy will be to strengthen the research and advice-giving capacity of HMMN in the modelling and assessment of data-limited species, e.g., rays, pollack, whelk, cuttlefish (DLS). He/she will work in close collaboration with the teams working on life-history traits variability (growth, sexual maturity) and trophic ecology to augment the credence of DLS stock assessment methods and diagnostics, which will be promoted through ICES working groups. This job vacancy will mainly contribute to HMMN Theme 3 and, in the short term, the SUMARIS project (WP1).

Research technician specialized in fisheries data collection. He/She will support research and investigations carried out within the SIH and other HMMN-lead projects by collecting biological data (e.g., calcified pieces, gonads, stomach contents) in harbor and at sea. He/She will in particular participate in sea cruises onboard scientific and commercial fisheries vessels in the EC-SNS region. This job vacancy will contribute to HMMN Themes 1, 2 and 3.

Research technician specialized in sclerochronology. He/She will support research and investigations carried out within the PNS technical platform: preparation of otoliths, scales and other calcified pieces, numerical analyses using TNPC software, participation to EU age-reading working groups. This job vacancy will mainly contribute to HMMN Theme 1.

Recruitments may also be required for the longer-term period 2020-2023, in relation to the emergent subjects that have been identified in Sections 2.3, 3.3, and 4.3. These will depend to a large extent on the organization plan of future EAF-related activities within the different CAEH research units, which was still under discussion at the time of writing. Still, the need for one research position could already be identified,, and it is shown below.

Research scientist specialized in metabolic ecology of planktonic systems. The main objective of this research position will be to investigate changes in the nutritional quality (stoichiometry, biochemical ratios, energetic values of lipids and proteins) of the lower trophic levels and their impact on early-life stages of fish. This position will thus clearly be supported by both the PTEZOO and the PRT facilities.

Governance

No major changes are expected in the organization of HMMN governance over the period 2019-2023: HMMN will still consist of two laboratories (LRHBL in Boulogne s/mer, LRHPB in Port-en-Bessin), its activities will be structured along the three 2013-2018 themes (although the content of these themes will be adapted to emergent research questioning and to current HMMN expertise; see Sections 2.3, 3.3, 4.3) and these will build on the PNS, PTR, PTEZOO and CREDO technical facilities. It should yet be mentioned that the (second) mandates of Paul MARCHAL (HMMN/D, LRHBL/D) and Joël VIGNEAU (LRHPB/D) will be completed in the beginning of 2021.

2. THEME 1 : INDIVIDUALS, POPULATIONS ET ECOLOGICAL NICHE

2.1. Presentation

Theme 1 - "Individuals, populations and ecological niche" covers the ecological processes occurring at the individual and population scales with a special focus on spatio-temporal dynamics linked to the ecological niche at different developmental stages and on population structure. It is structured in four axes, ordered by increasing scale of biological organization: 1) individual-level processes through the estimation and identification of the ecological phenomenon generating spatio-temporal variations in life-history traits, 2) population dynamics, in particular spatio-temporal patterns of distribution including demographical aspects, 3) the ecological niche of species and its geographical projection as a habitat for the different life stages, some of which are essential, and 4) spatial organization of populations in terms of ontogenetic or metapopulation structure and the connectivity between the different components.

Since 2013, more effort was devoted to axes 1, 3 and 4, relatively to axis 2, as a result of HMMN staff turnover and evolving domain of expertise. More specifically, life-history traits were thoroughly investigated, with otolith-based sclerochronology as a prominent in-house analytical tool, while essential fish habitats (spawning grounds, larval concentration areas), population structure and connectivity were explored.

18 permanent staff members, 6 research scientists, 3 engineers and 9 technicians contributed to Theme 1 during the last five years. Scientific results obtained within Theme 1 are linked with the other themes. Processes occurring at the individual scale, such as life-history trait variation and fish larval feeding, studied within Theme 1, are used to explain observed phenomenon at higher levels of organization (community, trophic network) in Theme 2. Also, the evaluation of biological parameters (growth, age, weight, maturity, larval condition) and stock structure for numerous fisheries resources are used for stock assessment purpose and to improve ecosystem models (e.g., Atlantis, OSMOSE) developed in Theme 2 and applied in Theme 3.

2.2. Research products and activities

In axis 1, methods to estimate life-history traits were developed based on the combination of individual growth curves back-calculation from otolith reading and bioenergetic modelling (ACL017, ACL109). Beside methodological developments, several life-history traits of (non-) fisheries resources were estimated and potential factors influencing their observed variability were identified for different species and/or developmental stages. The use of calcified pieces such as otoliths, but also scales and statoliths, allowed determining age-size relationship and growth rate for numerous (including fossil) species (fish, molluscs) living in different (temperate, tropical and polar) areas (ACL092, ACL089). The impact of some environmental (temperature, turbidity…) and anthropic (pollution, fishing) factors on the phenotypic plasticity and the evolution of marine fish life-history traits was also assessed (ACL102, ACL103, ACL025, ACL065, ACL107, ACL109). The potential consequences for fish stock productivity and management of evolutionary changes in life-history traits were also considered (ACL062, ACL080).

In axis 2, the spatio-temporal variability of the distribution and survival of several fisheries resources such as red mullet, cuttlefish and lobster was described at different geographical scales in the English Channel and the North Sea. For the first time, data from scientific surveys and from fisheries were combined in a statistical modelling approach in order to specify the seasonal and annual spatial distribution of key commercial species (ACL014). The interannual variability in the spatial distribution of fish larval assemblages in the eastern English Channel and the North Sea was described in spring and winter and the relation of species' larvae with some environmental factors was highlighted (ACL036, ACL037).

In axis 3, the habitat, i.e. the geographical projection of the ecological niche, of saithe (*Pollachius virens*) and of a new invasive ctenophore (*Mnemiopsis leidyi*) in the North Sea were described and mapped. A habitat modelling approach including a large set of controlling factors (environment, space, interspecfic relationships…) was developed to study the seasonal variability of saithe habitat and its spatial interactions with hake (*Merluccius merluccius*), a newly abundant species in the North Sea (ACL027). For the ctenophore species, a statistical habitat model was also built and coupled with an individual-based model in order to define environmental preferences and suitable areas for this species (ACL034).

In axis 4, population structure and connectivity of several marine organisms including fish (e.g. red mullet, blue whiting, common sole, swordfish) and molluscs (e.g. scallops, cuttlefish, mussel) were investigated. Various approaches, including mark-recapture methodology, otoliths shape analyses, growth curve variability and population and larval drifting models were used to identify different stocks of the same species from micro- to meso-scale (ACL067; ACL006; ACL093, ACL123; ACL111; ACL059).

Some of the most salient results obtained in Theme 1 are highlighted below.

Diet is correlated with otolith shape in marine fish (Axes 1 and 4)

Previous studies have shown that the amount of food influences fish otolith structure, opacity and shape and that diet composition has an effect on otolith chemical composition. This study investigated the potential correlation between diet and otolith shape in 5 wild marine fish species (Figure 2.1) by addressing 4 complementary questions (ACL107). First, is there a global relationship between diet and otolith shape? Second, which prey categories are involved in this relationship? Third, what are the respective contributions of food quantity and relative composition to diet–otolith shape co-variation? Fourth, is diet energetic composition related to otolith shape? For each species, we investigated how otolith shape varies with diet. These questions were tackled by describing diet in the analysis in 4 different ways, while also including individual-state variables to remove potential confounding effects. First, besides the strong effect of individual-state, a global relationship between diet and otolith shape was detected for 4 out of the 5 fish species. Second, both main and secondary prey categories were related to variability in otolith shape, and otolith outline reconstructions revealed that both otolith global shape and its finer details co-varied with these prey categories. Third, the contribution of relative diet composition to diet–otolith shape co-variation was much higher than that of ingested food quantity. Fourth, the energetic composition of diet was related to otolith shape for only 1 species. These results suggest that diet in marine fish species may influence the quantity and composition of saccular endolymph proteins which play an important role in otolith biomineralization and their resulting 3D structure.

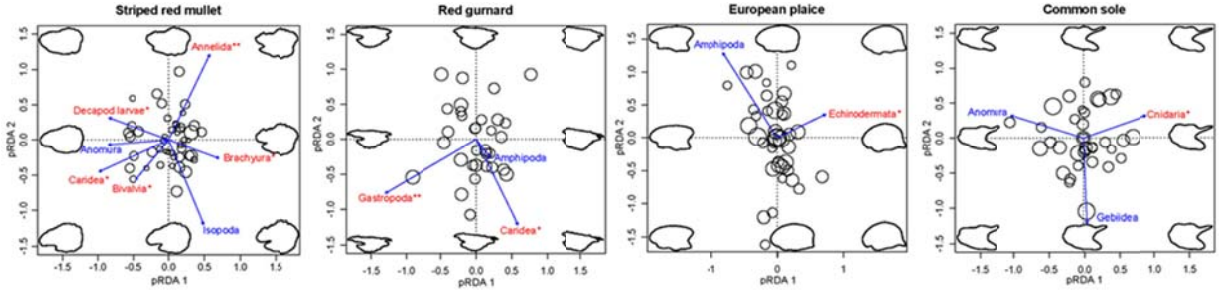


Figure 2.1. Variability in otolith shape according to diet for the four species. pRDA biplot of otolith shape constrained by selected taxonomic prey categories and conditioned by selected individual variables according to species.

There might be a second critical period during the larval phase of fish (Axis 1)

Evaluating fish larval condition in terms of nutrition and growth is essential as it will influence their development and survival capacity. The larval condition of Downs herring (*Clupea harengus* L.) was investigated during winter in the eastern English Channel and Southern Bight of the North Sea (ACL036). Four condition indices including ingestion rate based on gut fluorescence, instantaneous growth based on RNA/DNA, DNA/C ratios, and otolith microstructure were combined at an individual scale on herring larvae collected during the 2015 International Bottom Trawl Survey—MIK sampling. The four indices demonstrated a clear shift in the larval condition occurring at a larval size of 13 mm (Figure 2.2). While smaller larvae were shown to feed and grow, larger larvae exhibited a slower growth rate though actively feeding. This suggests that 13 mm could be a critical size for Downs herring larvae and it is concluded that the shift from an omnivorous to a carnivorous diet constitutes an additional critical step to the shift from endogenous to exogenous nutrition.

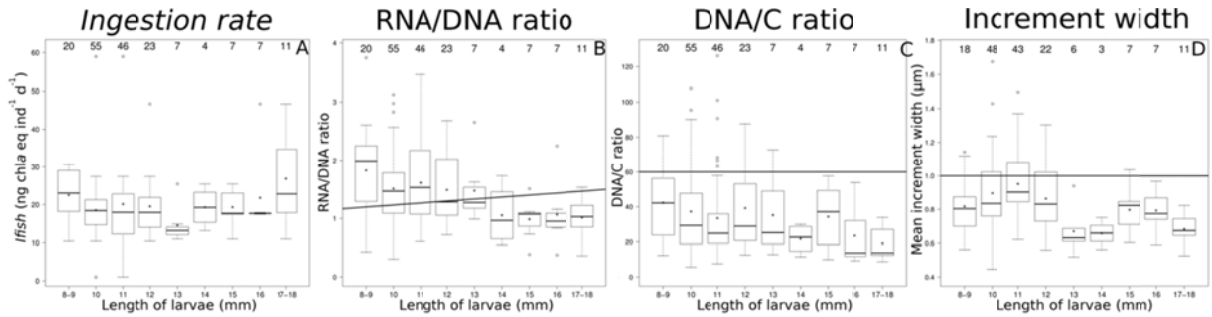


Figure 2.2. Larval condition analysis of Downs herring larvae. Boxplots of the four condition indices according to the larval size.

The use of commercial catches improves the estimation of the spatial distribution of several fish species (Axis 2)

The objective of this study (ACL014) was to analyse at fine scale the annual, seasonal and spatial distributions of several species in the eastern English Channel (EEC). On the one hand, data obtained from scientific surveys are not available all year through, but are considered to provide consistent yearly and spatially resolved abundance indices. On the other hand, on-board commercial data do cover the whole year, but generally provide a biased perception of stock abundance. The combination of scientific and commercial catches per unit of effort (CPUEs), standardized using a delta-generalized linear model, allowed to infer spatial and monthly dynamics of fish distributions in the EEC, which could be compared with previous knowledge on their life cycles. Considering the scientific survey as a repository, the degree of reliability of commercial CPUEs was assessed with survey-based distribution using the Local Index of Collocation. Large scale information was in agreement with literature, especially for cuttlefish (Figure 2.3). Fine scale consistency between survey and commercial data was significant for half of the 19 tested species (e.g. whiting, cod). For the other species (e.g. plaice, thornback ray), the results were inconclusive, mainly owing to poor commercial data coverage and/or to particular aspects of the species biology.

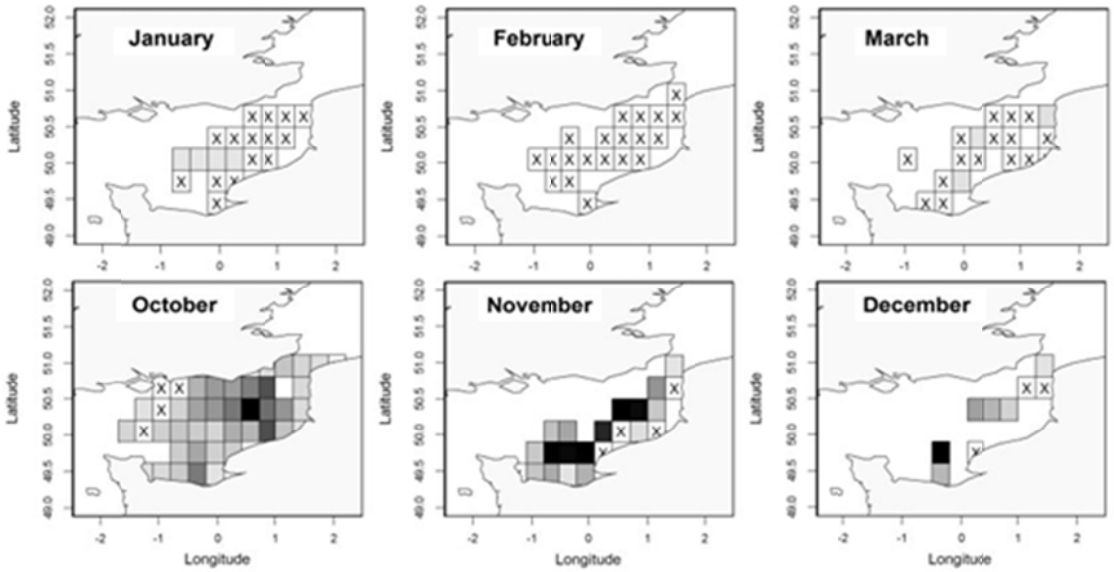


Figure 2.3. Monthly spatial abundance distribution estimated from OBSMER (commercial CPUEs) and CGFS survey (scientific CPUEs) for cuttlefish. 'X' represents areas where no cuttlefish was ever fished during a month.

A new invasive ctenophore in the North Sea (Axis 3)

The invasive ctenophore *Mnemiopsis leidyi* has been reported in various coastal locations in the southern North Sea in the past years. Since 2009, International Bottom Trawl Surveys have recorded this species each winter in open waters. As this species, well-known for its dramatic disturbance of ecosystems, was expected not to be able to overwinter offshore it is crucial to understand its distribution dynamics. Two modelling methods, a quantile regression and a particle tracking model, were used (1) to identify habitats where *M. leidyi* could survive the North Sea cold winters and (2) to investigate the dispersal of individuals between these different habitats, emphasizing favorable areas where sustainable populations could have been established (ACL034). Temperature was found to be the crucial factor controlling the winter distribution of *M. leidyi* in the North Sea. High predicted probabilities of presence in winter were associated with low values of temperature, which characterize southeastern coastal areas and estuaries influenced by riverine runoff (Figure 2.4). A retention-based *M. leidyi* population was indicated along the northern Dutch coast and German Bight and a transport-based population offshore from the western Danish coast. Individuals found in the open waters were transported from southern coasts of the North Sea, thus the open water population densities depend on the flux of offspring from these areas. Based on the agreement of habitat and dispersal model results, the conclusion was that *M. leidyi* has become established along the southeastern coasts of the North Sea where the environmental conditions allow overwintering and where it can be retained for later blooms.

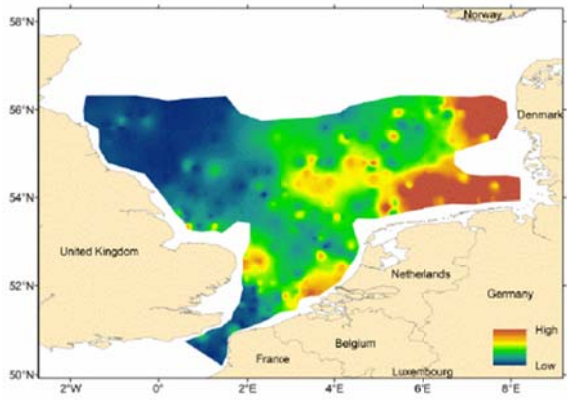


Figure 2.4. Predicted probabilities of *M. leidyi* abundance in winter conditions resulting from the habitat model

2.3. Research project (2018-2023)

Introduction

During the next five years, Theme 1 will still focus on ecological processes occurring at individual and population scales. The strong turnover experienced by HMMN led to the reduction of some research subjects, but also resulted in the advent of several timely topics. Theme 1 was thus reorganized to better reflect those topics that will be strengthened or newly developed by the team. Three main axes have been identified for the next five years. The first axis will be dedicated to the early life-stages of fish, i.e. ichthyoplankton (eggs and larvae). The second axis will focus on the study of life-history traits of fish in a spatio-temporal context. The third axis will investigate the sources of variation of otolith shape and of other biomarkers (e.g., parasites) as relevant tools for fish stock identification and management. These axes are coherent with the excellence areas, emergent priorities and challenges of the "Ifremer 2030" plan, regarding coastal ecosystems, evolution and adaptation of living organisms and experimental approaches. They are also fully in accordance with the gaps and future research needs, identified with a high priority by EFARO, especially on biological processes, life cycles and distributions.

Axis 1: Spatio-temporal variations in ecological processes affecting early life-stages of fish

Axis 1 will focus on the ecology of early-life stages (eggs and larvae), mainly of relevant commercial fish species in the English Channel and North Sea. Within the fish life cycle, the ecology of the larval phase is poorly known compared to that of the juvenile and adult phase, although it is considered as a particularly critical period for fish survival. Indeed, its strong dependency upon the environmental conditions linked to its planktonic character leads to high variability in the mortality rate experienced by individuals, which in turn affects fish population dynamics. It then appears essential to identify key processes influencing fish eggs and larvae if one wants to better understand and predict fish population renewal through the recruitment process. In particular the ecological niche/habitat, the trophic niche and the suitable niche of the ichthyoplanktonic ecophase will be investigated. The ecological niche/habitat will be assessed based on the spatio-temporal variability of spawning grounds and larval concentration areas in relation to the physical environment. Observation data (presence-absence, abundance), available from existing regular surveys (IBTS, CGFS) of the DCF or newly planktonic dedicated surveys within the MSFD, will be used for this purpose. The trophic niche at the individual and species levels will be characterized from larval nutrition and prey-predator relationships among the first trophic levels (phytoplankton, mesozooplankton, ichtyoplankton) of the planktonic ecosystem. Results from Theme 2 will then feed in Theme 1. The concept of suitable niche/habitat during the larval phase, i.e., the environmental conditions suitable for fish larvae to develop, grow and survive will be deepened. The suitability measured through larval condition determined from several indices (histology, molecular, biochemical) will be used to map and identify suitable areas. The seasonal and inter-annual variability of these areas will also be addressed. Moreover, since the nutritional condition can be used as a proxy of larval mortality (according to the growth-mortality hypothesis), it will be monitored yearly for key species (e.g., herring, plaice) used as sentinel species for tracking environmental change. While most of these aspects will be tackled from in-situ observations, experimental studies will be conducted in parallel to calibrate larval condition indices and to test the effect of several scenarios of climate change (temperature and pH increase, food-web modification) on larval fish condition. Results will be expected to clarify factors influencing fish recruitment, which is one of the main ecological drivers in long-term fluctuations of fish populations.

Axis 2: Estimation and spatio-temporal variation of fish life-history traits

In axis 2, HMMN will continue developing methods for estimating life-history traits (LHTs), mainly growth, age and size at maturation, and reproductive effort. These will be mainly based on sclerochronology, notably on the back-calculation of individual growth curves from otolith reading. Building on the in-house developed image processing software for sclerochronology TNPC, individual growth curve back-calculation will be (partly) automated and combined with mixed effect statistical models to account for individual variability in growth and LHTs in general. More precisely, LHTs will be estimated by fitting bioenergetic models to individual back-calculated growth curves. Beyond their estimation, HMMN will study LHT spatio-temporal variation and its sources. Spatial variation will be investigated at the inter- and intra-population scale. Regarding the former, variation as the result of local adaptation along latitudinal or environmental gradients will be studied and the consequences in terms of fish stock boundaries will be considered. Intra-population LHT spatial variation will be analyzed in relation to fish spatial distribution and local environmental conditions and its potential as an indicator of population structure will be explored. Regarding temporal variation, HMMN will pursue its work on the evolutionary response of LHTs to fishing by estimating fisheries-induced selective pressures for a series of fish stocks throughout the North Atlantic in collaboration with the ICES Working Group on Fisheries-induced Evolution (WGEVO). The correlation between such selective pressures and observed temporal changes in LHTs will allow assessing the likelihood of these changes being evolutionary. The phenotypically plastic and evolutionary responses of LHTs to the combined pressures of fishing and climate change will also be investigated in a multi-species context through the development of an evolutionary ecosystem model based on the model OSMOSE already in use in the HMMN Unit. The resulting modifications in intra- (genetic and traits) and inter-specific (traits and taxonomy) diversity under scenarios of fishing and climate change and the consequences on provisioning ecosystem services will be projected. Finally, HMMN will develop the mechanistic understanding of processes generating variation in LHT in collaboration with internal (PFOM, MARBEC) and external (Nausicaa, PFI Nouvelles Vagues) partners having experimental facilities. Notably, the impact and mode of action of various natural and anthropic factors, such as temperature, food abundance, parasites and persistent organic pollutants, on LHTs, but also on the biomineralisation of otoliths (as these are precisely used to estimate LHTs), will be experimentally investigated.

Axis 3 : Biological markers of fish populations: sources of variation and their applications

Stock identification and information on populations' spatial structure provide a basis to understand population dynamics and to improve fisheries management. Several methods based on different types of markers can be used for stock identification, including physical tags for mark-recapture, electronic (archival) positioning tags, genetic markers, morphological traits, life-history traits, parasites, and contaminant or trace element concentrations. In axis 3, HMMN will develop the use of two types of biological markers: an intrinsic one, otolith shape, and an extrinsic one, parasites. The application of such biological markers necessitates the identification of their sources of variation as well as the understanding of the mechanisms generating such variation. Otolith shape has proven efficient for stock identification because it is under both genetic and environmental influence. As a result, its inter-individual variations reflect genetic heterogeneity between individuals and variability in the environmental conditions they experience, thus possibly indicating population structure. Likewise, the parasitic fauna hosted by individual fish can be a good marker of environmental conditions encountered by individuals and thus of population structure. Some *in situ* studies will be carried out on different species (*Solea solea*, *Engraulis encrasicolus*, *Boops boops*, *Micromesistius poutassou*…) collected on board fishing vessels and from fish markets to investigate stock structure at large geographical scale and to explore the impact of environmental effects on otolith shape. Moreover, the influence of otolith directional asymmetry on otolith-shape based stock identification will be investigated. *In situ* studies in lakes and experimental studies in common garden will be carried out on wild and aquaculture specimens, respectively, to separate genetic and environmental effects on otolith shape. These experiments in controlled environment could also be carried out to disentangle the effects of environmental drivers (i.e. temperature, food, salinity…) on the growth and the biomineralisation mechanisms of otoliths. Notably, climate change generates modifications of a number of ecosystem characteristics such as global warming, a decrease in oxygen saturation, ocean acidification and a reduction in dietary polyunsaturated fatty acids concentration that will be experienced by fish. The potential effects of these future changes on otolith biomineralisation and morphogenesis will be tested in experimental studies. In parallel, the application of parasites as a tool for stock identification will be developed. As this line of research will be new in HMMN Unit, the first steps will be to document the parasitic fauna found in exploited fish species, to established standardized protocols for sampling and parasite identification, and to tailor specific statistical analyses. One particular question to tackle is whether the entire parasitic fauna will be necessary for stock identification or whether some specific family will be sufficient. These investigations will first be developed for exploited fish species from the English Channel and the North Sea. These two different methods based on alternative biological markers will also be combined in a multidisciplinary approach to improve the efficiency of populations' spatial structure analysis.

3. THEME 2 : COMMUNITIES, FOOD WEB AND BIODIVERSITY

3.1. Presentation

Food webs have become a central object in ecology, explicitly mentioned by or underlying most current questions in this field. Since trophic interactions result from a large set of physiological, behavioral and environmental mechanisms, trophic descriptors (*e.g.*, trophic level or trophic guilds) are powerful and synthetic functional traits. They can be efficiently used in combination with other descriptors, such as thermal preferences or fecundity, to explain past response of biodiversity to environmental changes and predict the future of marine systems. Trophic interactions also structure the functioning of communities and ecosystems. Food web approach thus provides a convenient tool to address problematics at these levels of organization, justifying the inclusion of the studies focused on these questions within Theme 2. Functional traits are notably powerful to address the relationship between biodiversity and functioning. Finally, trophic interactions are classically perceived as a strong stabilizing factor in marine systems, notably when trophic interactions connect remote ecosystems or when a time-lag occurs between organic matter production and consumption. In the global and local context of pressures on marine ecosystems, an accurate assessment of trophic pathways is thus crucial.

During the 2013-2018 period, research developed within HMMN Theme 2 has addressed these problematics. They were grouped within the three working axes defined in the previous AERES project. Studies in Axis 1 have investigated the structure of fish communities and how it was altered by environmental and anthropogenic pressures. Axis 2 has focused on empirical and theoretical studies about trophic interactions, and their influence on community structure and organisms' niche. Finally, Axis 3 has used these empirical data as inputs in models describing communities' dynamics and responses to multiple pressures. The second and third axes received most of the working effort, notably as a result of staff turnover, and as research pursued by newly-recruited staff was mostly dedicated to studies at ecosystem levels.

These works were based on (*i*) an empirical approach, i.e., laboratory work made within the PRT using samples collected during fisheries surveys led by HMMN, (*ii*) numerical analyses of functional traits and/or time series of fish biomass/abundance collected during surveys, and (*iii*) implementation and calibration of ecosystem models, that allow describing community functioning, identifying key mechanisms and forecasting community changes under multiple and combined impacts. Knowledge acquired in Theme 2 allowed some researchers to contribute to French MSFD evaluation and to be part of or to chair national and international expert groups on the ecosystem effects of marine renewable energy, aggregate extraction or integrated modeling. Research about trophic interactions may also be implemented in operational multispecies stock assessment models. The team involved in Theme 2 is now composed of 4 permanent researchers (1 full time handling the daily activity of the PRT, two spending half of their time and one ¼ of his time) and two technicians. Four PhD students have been doing their research within Theme 2.

3.2. Products and research activities

The effects of global changes on fish communities in the Eastern English Channel (EEC) and the North Sea were largely assessed within Axis 1. Researches have depicted first the taxonomic changes of the community and then have used functional traits to explain these changes accurately. Time series of fish abundance allowed the identification of a shift in the EEC fish community between 1997 and 1998 [ACL004]. The initial taxonomic approach identified which species were mostly affected by the shift, in which direction, *i.e.*, either positively or negatively, and explained these alterations by a switch of the AMO from a negative to a positive phase of its cycle. Further work implemented a functional approach to explain the community alteration in more details, notably by including several functional traits in the analysis (Figure 3.1) and calculating species-specific thermal tolerance or trophic levels (DB2). Tropicalization of the community was thus demonstrated, as species with warmer thermal tolerance increased in abundance in the EEC. The same pattern occurred in the Bay of Somme, where the average thermal optimum of the community increased by 0.16°C/decade (ACL003), a trend consistent with values measured in most marine ecosystems worldwide. The increased abundance of "cold" species in the south of the North Sea testified their northward movement, but not as fast as water warming, resulting in a thermal debt in fish communities. A method called the Principal Response Curve, often applied in ecotoxicology, was also adapted to estimate the effect of the temperature increase on the spatio-temporal dynamics of communities, and to assess the relative contribution of each species to the general change at community level (ACL005). The EEC was included as one of the 12 marine ecosystems worldwide included in the INDISEAS project that developed and benchmarked several indicators of fisheries and climatic pressures on marine ecosystems, based on model outputs, fisheries statistics or survey-derived data. Despite some discrepancies, indicators exhibited similar responses to fisheries or climatic drivers, ensuring their future use for ecosystemic management of fisheries (ACL024, ACL074, ACL124).

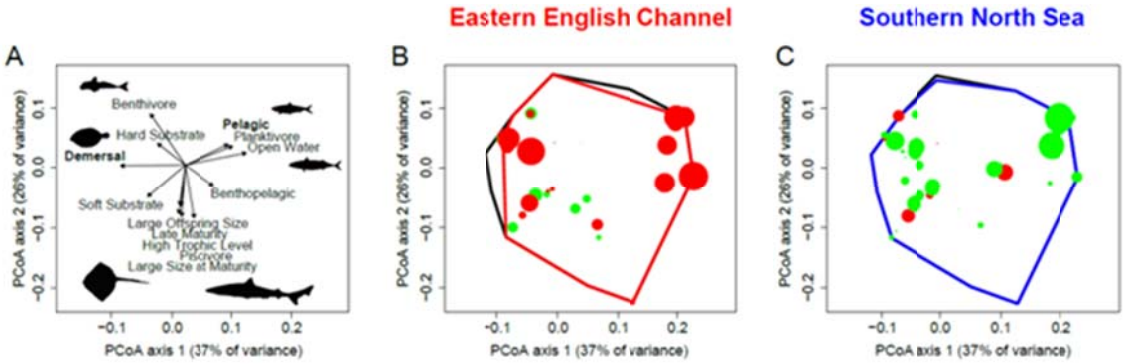


Figure 3.1. Functional state of fish communities in the EEC and Southern North Sea. B/C: distribution of species in the functional space and abundance variation. Red dots represent species with decreasing abundance, green dots for species with increasing abundance, and dot size is proportional to the relative amplitude of the change for each species.

Assessing the trophic functioning of the EEC has been the core of the work developed in Axis 2, more specifically on food webs. Empirical measurements of fish stable isotope ratio of carbon and nitrogen and stomach content analyses were used to estimate food webs topology and fluxes intensity with statistical analyses and models. The EEC emerged as a unique trophic system and as an appropriate case study for investigating how environmental heterogeneity, and more specifically environmental gradients, drives spatial variation of trophic interactions. Benthic production appeared as an important dietary source for all fish species, certainly because the EEC is a shallow epicontinental sea, compared to most marine ecosystems worldwide (except those sharing EEC characteristics). More importantly, some spatial variation of food web structure was explained by a decreasing intensity of the pelagic-benthic coupling with increasing depth (ACL076). The effect of depth on pelagic-benthic coupling through fish diet was then more precisely studied by using stomach contents to determine the general topology of the food webs and carbon and nitrogen stable isotopes to estimate the contribution of different food sources to fish functionall groups. Including depth in the analysis, it was shown that, in shallow waters, fish species benefited from both pelagic and benthic prey whereas, in deeper waters, they fed predominantly on either benthic or pelagic sources depending on their habitat preferences (ACL053; Figure 3.2). This highlights a stronger benthic-pelagic coupling in shallow waters, notably through fish diet. To some extent, the trophic functioning of the EEC fish communities seems more related to lakes than to other marine ecosystems.

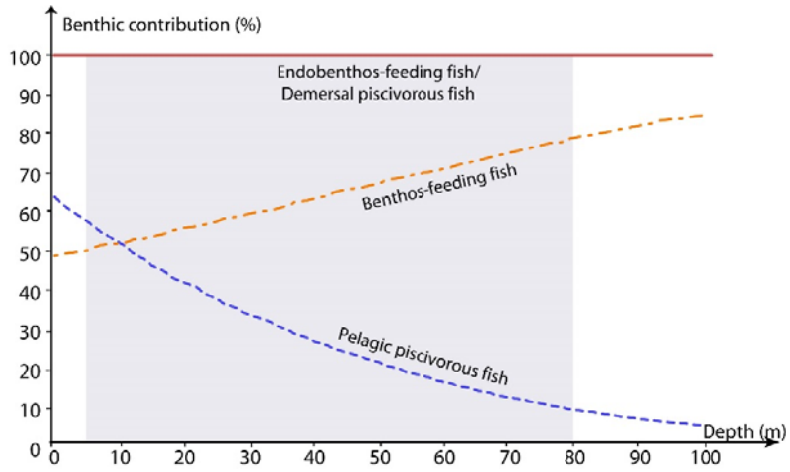


Figure 3.2. Depth-driven changes of benthic organic matter contribution to the diet of 4 fish functional groups in the EEC (full red line: endobenthos-feeding and demersal piscivorous fish; orange dotted line: benthos-feeding fish; blue dotted line: pelagic piscivorous species).

Axis 2 was also marked by numerous collaborations. At national and internationall levels, Axis 2 tools and approaches were applied to address other scientific questions in various geographical contexts, such as Antarctic food web functioning (ACL054), trophic behavior of contaminants in marine food webs of all French subareas (ACL028, ACL029), or trophic connectivity between remote marine ecosystems (ACL010). Within HMMN, strong exchanges occurred with Theme 1, as individuals traits (e.g., growth rate, fish condition) depend on individuals' trophic ecology. The stomach content database mentioned above was also used within Theme 1 to demonstrate the role of diet on otolith shape (ACL107). Similarly, using life-history traits (growth rate or maturity status for instance) measured on individual fish sampled during surveys in the

ecosystem of interest, rather than data from other ecosystems or aggregated at the population/species-level, can increase the precision of functional analyses.

Some more fundamental investigations were also undertaken in Axis 2. First, stomach contents were used to test the sources of between-individual diet variation and notably its link with specific trophic niche width within the EEC fish community. The Niche Variation Hypothesis (NVH) states that, due to ultimate causes, a wide species trophic niche could allow conspecifics to diverge in terms of diet. Complementarily, Optimal Foraging Theory (OFT) states that proximate causes such as variability of individuals' habitat and/or state (size, sex, etc.) may also generate individual diet variation. Predictions of OFT were confirmed, as individual diet variation increased with variability of individuals' state and resources heterogeneity. In contrast, the main prediction of the NVH was not verified. However, the overlap between species niche increased less than expected with species niche width and individual diet variation. These results suggest that interspecific competition within the community may limit the diversity of resources actually available to individuals of a species because of partial resource partitioning (ACL018). Secondly, the ability of metrics calculated with stable isotopes to describe trophic patterns was investigated. These indices are increasingly being used as proxies of functional diversity, but without actual calibration and verification of their robustness. Based on a realist simulation framework, this work highlighted the ability of isotopic-derived metrics to describe general trophic patterns. In contrast, indices are somewhat less effective to describe fine patterns and in complex food webs, *i.e.*, with large vertical diversity, low connectance and high omnivory. The resulting paper (ACL068) called for a cautious use of isotopic indices alone and recommended a coupling with other data (*e.g.* stomach content, DNA metabarcoding or feeding choices trials) when a finer understanding of food web structure is required.

Modeling is recognized as a powerful tool to describe community functioning, infer system properties and forecast future community functioning under different scenarios, notably when models and intrinsic trophic tracers are used in combination. Works developed by HMMN in Axis 3 have thus benefited from the collection of trophic data to set up, parameterize and calibrate two end-to-end models (Atlantis and OSMOSE) in the EEC. Several steps of calibration were needed for the Atlantis model, notably (*i*) to ensure fluxes conservation, (*ii*) to produce time series of biomass for trophic groups consistent with measured data, and (*iii*) to implement mortality by fisheries. This model was then used to identify dynamics and processes structuring the EEC ecosystem, with a special focus on flatfish species (common sole *Solea solea* and plaice *Pleuronectes platessa*). Similarly, an OSMOSE model was calibrated by adjusting larval mortality, plankton accessibility and fishing mortality to actually measured values, and then validated by comparing trophic levels calculated by the model to empirical values measured with stable isotopes. Interestingly, model outputs are consistent with the trends derived from independent empirical data. They confirm the importance of benthic invertebrates in the EEC and also the major role played by bentho-demersal predators, such as whiting *Merlangius merlangus* or cod *Gadus morhua* (ACL055, Figure 3.3). Models revealed a strong positive relationship between length and trophic level for pelagic species, as could be expected from the literature. That relationship, however, appeared to be blurred for benthic species. Both models were finally applied to evaluate management strategies in Theme 3, *e.g.*, implementation of landing obligations (discards as usual *vs.* complete landing obligation scenarios), and decrease of fishing effort or spatial closures and also to forecast the effect of global change and anthropogenic pressure on local and worldwide marine ecosystems.

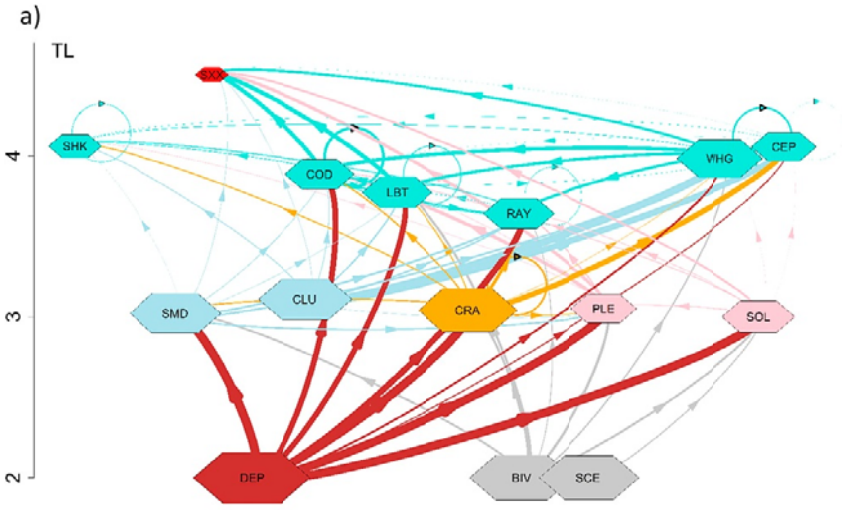


Figure 3.3. Trophic network produced by the EEC-Atlantis model centered on sole (SOL) and plaice (PLE). Size of the arrows is proportional to the proportion of the preys in the diet of predators. Species or groups are vertically sorted based on their trophic levels.

3.3. Research project (2018-2023)

Introduction

For 2019-2023, Theme 2 will pursue the work engaged between 2014 and 2018, focusing on the natural and anthropogenic factors driving the structure and functioning of marine ecosystems. Most research will thus remain based on a combination of empirical measurements, statistical analyses, and mechanistic modelling. As a novelty, the implementation of experiments in controlled mesocosms with simple systems (*e.g.*, phytoplankton - zooplankton - fish larvae) will allow validation of the expected influence of some natural factors (*e.g.*, diversity and abundance of food) and anthropic stressors (*e.g.*, climate change or ocean acidification) on trophic mechanisms. The inclusion of new tracers, whether of natural (lipids/fatty acids or parasites) or anthropic origin (chemicals) will complement the scope of the previously used tracers.

The boundary between Themes 1 and 2 was somehow blurred during the 2014-2018 period, notably regarding the individual variability in the diet of some life stages. As a result, all work dealing with factors driving the variation of trophic niche will be now included in Theme 2. Theme 2 will consist of three axes that follow the classical continuum of biological organization levels, from individual and populations in the first axis to communities and ecosystem in axes 2 and 3.

Axis 1: Mechanism of trophic niche variation

Trophic niche has been a fundamental object in ecology for the last decades, notably to understand the drivers of niche width at population or species level. Trophic niches are the results of several biological traits such as feeding strategy (*i.e.* separating generalists, specialists and opportunist predators), habitat used (*e.g.*, benthic *vs.* pelagic) and feeding modes (*i.e.*, filter feeders, scavengers or active predators) but are also under the constraint of environmental drivers (*e.g.* food availability). Axis 1 will mainly pursue the work about the influence of these drivers. Due to the large number or individuals (and consequently the amount of work) needed, Axis 1 will necessarily focus on some species identified *a priori* for their economic and/or ecological importance. Studies may for example compare benthic, pelagic or demersal species, as resources availability and trophic strategies differ between habitats. Here are some examples of scientific avenues that will be explored within this axis.

Exploring individual variations within a population is a promising research avenue that has been overlooked so far. In other words, is a population niche wide because all individuals have a similar but wide niche or because individuals have narrow but different niches? Assessing individual diet variability is a complex exercise for wild fish individuals, as diet assessment is classically based on lethal methods and/or sampling the same individual several times is impossible. The measurement of trophic tracers in tissues with different metabolic turnover rates could nevertheless represent an innovative proxy of temporal changes in diet. Intrinsic trophic tracers will reflect assimilated diet during a period depending on the metabolism of the tissue. Active tissues (*e.g.* liver) with quick turnover reflect recent diet, while tissues with longer turnovers (muscle or hard tissues) reflect average diets over the past months. Differences in tracer values and tracers-derived indicators between tissues of the same individual could then be used as proxies of individual specialization and frequent dietary changes, while similarities would suggest a generalist diet. A similar approach can be expanded at population level, for example by the calculation of metrics of niche width derived from empirical tracers (*e.g.* with dedicated tools like nicheRover or SIBER R packages already available). In an initial approach, this work will be mostly based on stable isotope ($\delta^{13}C$, $\delta^{15}N$) analysis but may be complemented by other biomarkers such as lipids and fatty acids. Furthermore, theoretical models predicting isotopic ratios from physiological or behavioral rules can be developed and results compared with empirical measurements of individuals collected during surveys or reared in controlled conditions. The development of a model predicting isotopic incorporation from metabolic activity, within an international consortium led by LOG, should provide a conceptual framework that can be helpful to better understand the results observed, by comparing model outputs with empirical data. Comparison of patterns observed for individuals of the same species but of different life stages and/or collected in different environments will allow exploring if all individuals respond similarly to environmental variability and/or competition, and to detect the influence of metabolic activity and nutritional demands. Sampling will largely benefit from surveys led by HMMN in coastal nurseries (*e.g.*, NOURSEINE, NOURCANCHE) and in offshore larval and adult habitat (IBTS and CGFS). In addition, the standardized protocol adopted by all Ifremer surveys targeting fisheries resources could allow extending the geographical scope of the analysis to include a larger range of environmental conditions.

Axis 2 : Structure and functioning of exploited food webs

At the community level, results obtained during the past period have unraveled some effects of environmental gradients and anthropogenic stressors on EEC marine food webs, but they have also highlighted some knowledge gaps to be filled. In addition, the importance of human activities in this zone requires good descriptive and predictive tools to estimate the effects of pressures, with the necessity of assessing the

cumulated effect of different stressors, like contaminants, fisheries, and Renewable Marine Energy deployment.

Understanding organic matter fluxes, trophic structure and dynamics of groups at the base of the food web remains a question to be addressed before fully depicting food webs dynamics in the EEC. Zooplankton, in particular, is a "trophic black box" in the EEC (as in most marine ecosystems), despite the assumed trophic complexity of this group, and its pivotal role in pelagic food webs, linking primary producers and high trophic level species. Facing the rarefaction of traditional fisheries resources, zooplankton has been considered as a potential new resource, but its sustainable exploitation requires a considerably improved understanding of its pivotal role in the ecosystem functioning, which also needs to be reflected in ecosystem models. Similarly, little is known about the trophic functioning of benthic invertebrate communities, even though they represent an important food source for fish species. The study of these two specific compartments and their contribution to marine food webs sustaining fisheries resources will still be based on the coupling between intrinsic trophic biomarkers (stable isotopes and stomach contents), statistical analyses and modelling approaches, but with some novelties. New trophic tracers, such as fatty acid content and lipid class composition, will thus be included in Theme 2's toolbox as they can efficiently complement stable isotopes. Future projects will build upon collaborations with other Ifremer units/laboratories with knowledge on zooplankton and benthos taxonomy (mainly DYNECO, LERBL, LERBN, STH and EMH). Regarding models, a local collaboration with a computer-science lab (LISIC) will allow the development of new tools to calibrate models more efficiently and explore processes uncertainty. Combining and comparing the outputs of the three ecosystemic models developed in the EEC (EwE, OSMOSE, Atlantis) will provide a powerful approach to describe ecosystem functioning through the comparison of ecosystems indicators and to identify key groups or pathways.

Axis 3 : Spatio-temporal dynamics of fish communities

Marine ecosystems are increasingly impacted by overfishing and climate change. Understanding how these drivers affect community stability will be critical for predicting biological responses and thus planning conservation and management efforts. In the previous decades, studies on this topic were largely based on a taxonomic approach, *i.e.*, describing how the taxonomic component of biodiversity is responding to environmental and anthropic pressures. Alternatively, the functional approach emerged recently as a more efficient tool to further describe, understand and predict how communities' functioning is altered by environmental changes. The EEC-SNS is a convenient system to investigate the combined effects of these stressors, as it has been largely affected by anthropic perturbations and as it lies between tropical and boreal systems.

The application of the functional approach was initiated at the end of the period 2013-2018 and gave promising preliminary results. It will thus be continued during the 2018-2023 period. This work will be based on the use of the biomass and abundance time series collected during fisheries surveys operated by Ifremer since ~1980 and on functional traits mostly collected in the literature for fish species. It will also benefit from empirical data actually collected in the EEC and SNS within Theme 1 (growth rate, maturity, fecundity etc.) and axis 2 and 3 of Theme 2 (trophic descriptors, whether they are empirical or derived from models). One of the expected results is the identification of "winning" and "loosing" traits, *i.e.* traits that increased or decreased in response to anthropic or environmental perturbations.

The functional approach is commonly limited by the accuracy of the data, since biomass or abundance are hard to collect along with functional traits, so that functional traits are usually retrieved from external repositories. Fisheries surveys coordinated by HMMN thus offer a unique opportunity to gather both data types together. Axis 3 will also benefit from the development of new inferential statistical methods by HMMN research scientists, from the implementation of innovative concepts (*e.g.* functional rarity), and also from an increased integration of spatial and temporal variability in the analyses, in order to better identify the causes and the consequences of community changes and the mechanisms by which those changes occur.

4. THEME 3 : FLEETS, EXPLOITATION AND MANAGEMENT SCENARIOS

4.1. Presentation

Theme 3 aims at a better understanding of the impacts of marine resources exploitation on the ecosystem and to help supporting the ecosystem approach to fisheries management. Through the integration of knowledge gathered in Themes 1 and 2 (ACL014, ACL027, ACL102, and ACL103), the study of fishers behavior (ACL056, ACL099, and ACL100) and the close relationship with expert assessment, Theme 3 participates to the development of tools and methods (ACL001, ACL014, ACL026, ACL086, BOP2, and BOP6) to evaluate fish resources and fishery management strategies (ACL098). These studies nurtured several international collaborations and contributed to the four main axes of Theme 3: 1) the development of stock assessment methods and the evaluation of stocks status, integrating ecosystem consideration and including data limited stocks (DLS), 2) the investigation of spatio-temporal fleet dynamics and of how fishers behave in regards to resources distribution, other human activities and management constraints, 3) the evaluation of conventional management strategies such as effort, catches and discards limitations, and 4) spatial management and the evaluation of marine protected areas (MPA).

Most of the research planned in the last HMMN AERES evaluation project was investigated. HMMN has participated, through collaborations in international projects, in the development of new tools to evaluate the properties of reference points, improve stock assessment methods, standardize data acquisition for stock assessment (CREDO) and account for trophic interaction and fishers' behaviour in the evaluation of fishery management scenarios. Nonetheless, less effort has been invested into vessel trajectory analyses, and spatial management planning, mainly due to staff turnover.

Currently, 6 permanent researchers and 3 technicians are involved in Theme 3. 3 PhD students and 7 undergraduate students have also contributed to Theme 3.

4.2. Products and research activities

In Axis 1, HMMN contributed to the assessment of several data-limited species (DLS), such as red mullet (*Mullus surmuletus*), whelk (*Buccinum undatum*), cuttlefish (*Sepia officinalis*), and pollack (*Pollachius pollachius*) using data from Theme 1 and a set of assessment models such as depletion correct average catch, and models from FLR library or the US stock synthesis plateform (ACL001). By combining results from the three themes, new estimates of maximum sustainable yield were produced for several species. Two approaches were carried out. First, bottom-up trophic relationships were added to an existing multi-species stock assessment model that already accounted for top-down trophic interactions (i.e., predation), the Stochastic MultiSpecies model (SMS, ACL026). Second, technical interactions, reflecting the competition among fleets for exploiting common fish assemblages, were included into the OSMOSE model developed in Theme 2.

In Axis 2, a spatio-temporal bio-economic model including fishing fleet dynamics processes was developed (ACL099). In addition, the deterministic drivers of fisher's behavior (i.e., process of deciding where, what and how to fish) were investigated using discrete-choice modeling approaches. It was showed that past effort allocation (a proxy for habits), the spatial distribution of target species and the expected revenue determine most of the spatial allocation choices made by fishers in the EEC mixed fisheries (ACL057) as well as in most worldwide fleets investigated with discrete-choice models (ACL056). The interaction between fleet dynamics and other uses of maritime space such as other fishing fleets, maritime traffic and aggregate extraction were also explored. In the case of aggregate extraction, most fisheries fishing near impacted area were not deterred (ACL100). The importance of accounting for fleets dynamics in fishery management was also highlighted by combining complex ecosystem models developed in Theme 2, such as OSMOSE and Atlantis-EEC, with fleet dynamics (BOP2, BOP6).

In Axis 3, the performances of fisheries management strategies of several countries around the world were compared to those of the EU (ACL098). The impact of the landing obligation (LO) implemented in the 2013 Common Fishery Policy (CFP) was assessed. A complete review of discard practices was carried out in collaboration with the project partners. The relationship between species targeting and discard of co-occurring species was explored. Three complex models (ISIS-Fish, OSMOSE (BOP2), and Atlantis-EEC (ACL055)) were proposed to evaluate the impact of the LO on ecosystem and fleet dynamics (BOP2). The preliminary results showed that applying only a strict landing obligation (stop discarding practices without change in fisher behaviour or selectivity of gear) has generally little influence on the marine food webs, with rare exceptions. When coupling ecosystem models with fleet dynamics, the new management policy would have short-term negative effect but medium benefit on fishers' revenue, assuming a full compliance (BOP2).

In Axis 4, spatial and conventional management measures were compared. The capacity of the existing MPA network to protect abundance of target species, benthic and pelagic habitats was tested using Marxan Zone

coupled with a fleet dynamics model ISIS-Fish (MPR4). Two kinds of protections zones were tested: (i) no-take zone, and (ii) no ground-towed gears, however only few minor differences were noticed in term of landings and abundance of the target species. Using Atlantis-EEC, the combined effect of total no-take area (based on current MPA distribution) and conventional effort restriction on the EEC ecosystem and the netters fleet dynamics was forecast and compared to the status-quo scenario (no change in management) (BOP6). The most beneficial scenario was the use of both MPA and effort restriction resulting in an increase of commercial species biomass and fishers outcome (based on constant fish prices and with no cost accounted for).

Some of the most salient results obtained in Theme 3 are highlighted below.

Evaluation of the potential impact of trophic interactions between hake, saithe and Norway pout on saithe fisheries productivity (ACL026)

The northern European hake stock has increased in abundance and its spatial distribution has expanded in the North Sea in correlation with temperature. Saithe (*Pollachius virens*) spatial overlap with hake has increased while saithe spawning-stock biomass has decreased recently despite sustainable exploitation. A multispecies assessment of North Sea saithe, using the SMS model, was performed to assess potential trophic interactions between hake and saithe and their effects on the sustainable levels of fishing mortality (F_{MSY}) for saithe. Bottom-up processes relating Norway pout (*Trisopterus esmarkii*) abundance and saithe weight-at-age were implemented in SMS. The effects of combining different hake abundance trends scenarios with the bottom-up processes were simulated and the saithe F_{MSY} estimated (Figure 4.1). A negative impact of hake emergence on saithe biomass was observed, resulting from an increase of predation pressure on Norway pout. These results also confirmed the hypothesis of trophic competition between saithe and hake in the North Sea.

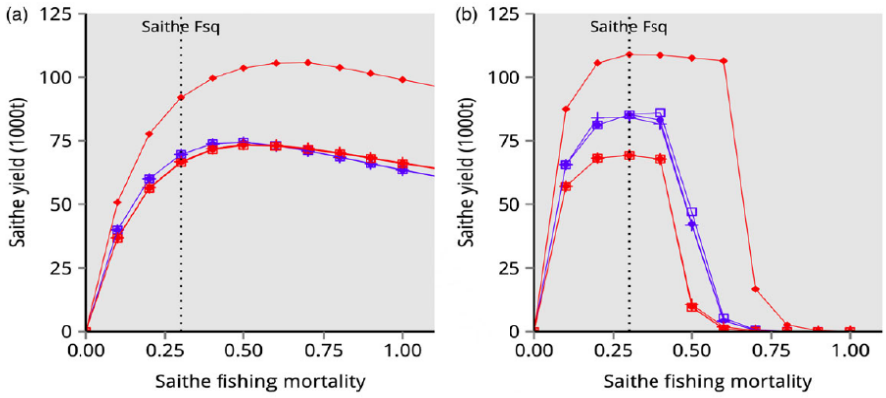


Figure 4.1. Saithe yield as a function of saithe fishing mortality depending on the species interaction scenarios and Norway pout fishing mortality. (a) Short-term yield estimated by averaging yield from 2014 to 2018 included. (b) Long-term yield estimated at final year of the forecast period value (2065). Blue: Norway pout status-quo fishing mortality. Red: Norway pout precautionary approach fishing mortality. Diamond: baseline scenario where hake abundance is constant and no bottom-up processes are included. Plus: constant hake abundance and bottom-up processes. Dot: moderate hake abundance and bottom-up processes. Square: high hake abundance and bottom-up processes.

Thirty years of fleet dynamics modeling using discrete-choice models: what have we learned? (ACL056)

Random utility models (RUMs) have attracted considerable attention in the past three decades to understand fishers' behavior. RUM results focusing on fishing effort spatial allocation from different studies around the globe were standardized and compared. Six types of fisher behavior drivers were considered: other fishing vessels density, tradition, expected revenue, species targeting, costs, and risk-taking. Linear modelling approaches were used to assess the extent to which these different drivers impacted fisher behavior in three fleet types: demersal fleets using active gears, demersal fleets using passive gears and pelagic fleets. Fishers are attracted by higher expected revenue, tradition, species targeting and presence of others, but avoid choices involving large costs. Results also suggest that fishers fishing for demersal species using active gears are generally more influenced by past seasonal (long-term) patterns than by the most recent (short-term) information. Finally, the comparison of expected revenue with other fisher behavior drivers highlights that demersal fishing vessels are risk-averse and that tradition and species targeting influence fisher decisions more than expected revenue (Figure 4.2).

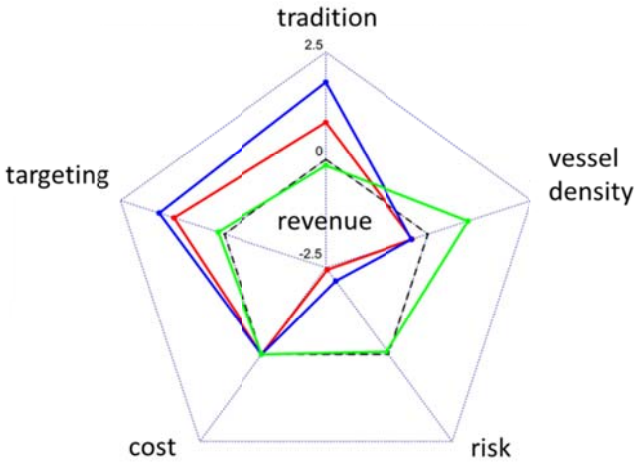


Figure 4.2. Comparison across fleets of the importance of different (non-revenue) fishers' behavior drivers relative to expected revenue. Each axis represents estimates of the effect of one driver compared to that of revenue. Point inside the black dotted pentagon line indicates a fleet's preference for a driver group relative to expected revenue. Active demersal fleets are shown in red, passive demersal fleets in blue and pelagic fleets in green. Significant values with P < 0.05 are represented; others are set to zero.

A comparative review of fisheries management experiences (ACL098)

This study compares the details and performance of fisheries management in the EU and in a selection of other countries worldwide, Iceland, New Zealand and Australia, which are considered amongst the most advanced ones in this respect. In terms of conservation and economic efficiency, the management of domestic fisheries ressources performed better in Australia and New Zealand than in the EU. The proportion of fish stocks with a biomass (B) over B_{lim} (Biomass under which the stock has a significant risk of collapsing) and the proportion of stocks with fishing mortality (F) under F_{lim} (Fishing mortality limit over which the stock has high probability to collapse) was higher in Australia and New Zealand. However it should be highlighted that fleets over-capacity (relative to available fisheries resources) was more of an issue in Europe than in Australia or New Zealand when restrictive management measures came into force. Still, the situation of EU fisheries has improved over the period 2004-2013 in the northeast Atlantic (Figure 4.3).

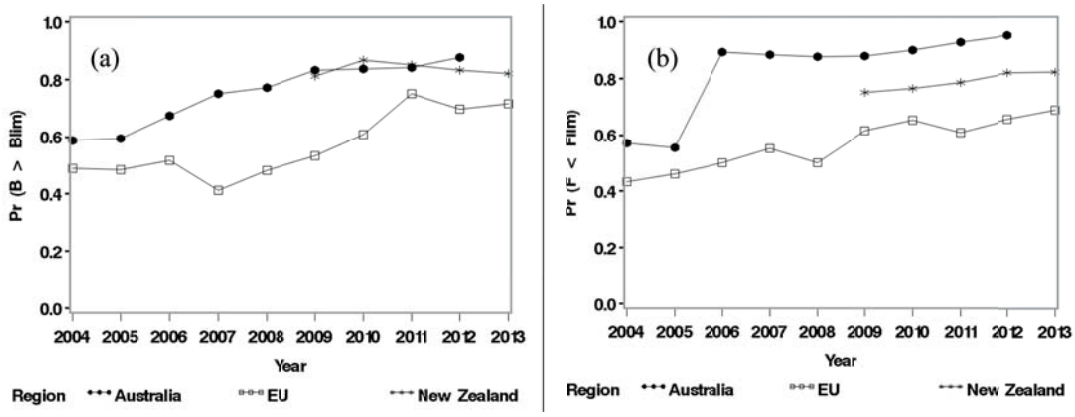


Figure 4.3. Annual variations in the proportion of stocks managed in the EU (empty squares), New Zealand (stars), and Australia (black dots), for which (a) biomass B > B_{lim} and (b) fishing mortality F < F_{lim}.

4.3. Research project (2018-2023)

Introduction

While Theme 3 research will build on evidence achieved over the period 2013-2018, it will also be restructured to better reflect the scientific priorities emerging from both the Ifremer 2030 plan, the broader scientific community (Section 1.6), and also the renewed expertise domain of the HMMN team that has resulted from the staff turnover we have experienced since 2013. Particular attention will then be given, over the period 2018-2023, to the evaluation of cumulated impacts, sustainable harvesting of novel bio-resources, MSY reference points, adaptive ecosystem management, in a changing environment context (e.g., climate

change, diversification of human activities in the EEC-SNS maritime domain, enforcement of a landing obligation). These priorities will be addressed by broadening the scope of two of the four axes previously investigated between 2013 and 2018, 1) developing methods to evaluate the status of fisheries resources, including data-limited species, in an ecosystem context and, 2) evaluating management strategies to mitigate the impact of natural and anthropogenic pressures on the marine ecosystem. Both axes 1) and 2) will be using the outcomes of Themes 1 and 2. Thus, the development of stock assessment methods applicable to data-limited species will benefit from knowledge gained on key life traits processes under Theme 1 (e.g., growth, maturity). In addition, Theme 2 advances on ecosystem functioning and modeling will be gathered to evaluate the feasibility of exploiting new marine resources (e.g., zooplankton assemblages) and to promote management strategies that aim at mitigating their impacts on the whole ecosystem in a global change context.
At the same time, the HMMN team will give less attention to the other axes investigated over the period 2013-2018: (i) spatio-temporal fleet dynamics and, (ii) spatial management. HMMN team will build on the results already achieved on these topics over the period 2013-2018 and on collaborations to integrate the most relevant processes into the research carried out in axes 1) and 2). Making further progress would require getting better insights into fine-scale economics and/or theoretical behavioral ecology which are beyond the remits of the HMMN team. HMMN will still collaborate on this subject with other Ifremer units working on vessel trajectories (EMH, STH) or economics (UMR AMURE), and with our European colleagues (CEFAS, DTU-aqua, University of Wageningen) to improve the integration of fleet dynamics into the ATLANTIS and OSMOSE ecosystem models developed during the previous period. In the same way, the evaluation of spatial management measures will not be given a particular focus, but rather included in the management strategies toolbox investigated under Axis 2.

Axis 1: Tools and methods for the evaluation of fisheries resources

The diversification of fishing activities in the EEC-SNS over the last few years (e.g., emergence of Danish seine métiers) and the increased management concerns that have aroused on the sustainability of highly valuable yet poorly informed fisheries resources (e.g., skates, seabass, cephalopods, red mullet, scallops) has stimulated the development of alternative assessment methods to evaluate these data-limited stock (DLS). HMMN will bond on the promising results obtained during the past period in developing specific DLS evaluation methods (ACL001, ACL059). Within the Interreg SUMARIS project, HMMN will thus investigate assessment approaches adapted to skates and rays, building on growth processes unraveled by the Theme 1 team within the same project. These scientific advances will fuel the ICES stock assessment and advice-giving process. HMMN will also develop methods in collaboration with Canadian DFO colleagues to improve the cod 3P assessment and the NAFO basis for advice.

The overall decrease in fishing pressure and mortality observed in EU fisheries since the mid-2000s has required re-considering some of the traditional key assumptions underlying most stock assessment models. For instance, top-down (e.g., predation mortality) and bottom-up (e.g., prey-dependent growth) processes and their inter-annual variations have generally been considered negligible compared to fishing mortality. While this assumption was reasonable at high fishing mortality (F) levels, it has been shown to be at fault with currently lower F values, with adverse consequences for the precision of stock assessments and the estimation of MSY reference points, as evidenced by the HMMN team during the previous period (ACL026, ACL055). HMMN will use the EEC ecosystem models developed and results from Themes 1 and 2 to evaluate the behavior and properties of multispecies reference points. Building on three ecosystem models (EwE, OSMOSE, and Atlantis, ACL055), a multi-model approach will be considered to analyze the response of reference points to changes in natural and anthropic stressors affecting the EEC ecosystem. The development of sensitivity analyses and optimization methods on complex ecosystem model in Theme 2 could be implemented to estimate the uncertainty around those reference points. Results from Themes 1 and 2 projects relative to zooplankton and benthic functional groups dynamics could also be used to analyze the response of multispecies reference points to climate change, new bio-resources exploitation and emerging marine activities.

Axis 2 : Evaluation of fisheries management strategies in a global change context

The persistent diversification and intensification of human activities in the maritime domain pose regular, and sometimes new, challenges to marine scientists in their ability to anticipate long-term ecosystem responses to global change and to promote and evaluate integrated management strategies to mitigate their effects. The EEC-SNS is no exception to the global change experienced worldwide, with the recent emergence of new fisheries (Danish seining, pulse fishing) and other human activities (several windfarms will become operational on the French side of the EEC over the period 2018-2023), in a context where sea temperatures have increased with consequences on the distribution of fish communities (ACL003, ACL004). On the EU fisheries and ecosystem management side, stricter (CFP- and MSFD-driven) regulations are gradually coming into force, with several conservation and utilization targets set at the horizon 2020. These include, the full implementation of a landing obligation (banning discards for most commercial fisheries), the reduction of fisheries harvesting

below MSY for all stocks, and the achievement of a good environmental status, which are of particular relevance to Theme 3 research.

Based on the results obtained and the models developed during the previous period, HMMN will explore the conservation and utilization effects of fishing activities and the performance of management strategies. Using a multi-models approach (including end-to-end models OSMOSE and Atlantis), HMMN is currently investigating within the ongoing H2020 DiscardLess project the combined effects of a discard ban combined with catch quotas and/or Marine Protected areas on the EEC ecosystem and fisheries, with final results expected by 2020. A similar modelling approach could be pursued to investigate the cumulated effects of different human activities (fishing, but also wind energy production, aggregates extraction, pollutions) subject to climate change, and of uncertainty around those management and climate scenarios being investigated.

The approach presented above is focusing on commercial fisheries targeting adult fish belonging to upper trophic levels. However, despite stricter management measures coming into force, the growth potential of such fisheries is considered limited. Because of the growing demand for fish feed in the worldwide aquaculture sector, zooplankton has been considered as an alternative marine bioresource. Even if some copepod species have long been harvested by dedicated Norwegian fisheries, zooplankton remains an untapped resource in EU waters. Zooplankton organisms contribute to the functional biodiversity of marine ecosystems but their spatio-temporal dynamics and their relation with the trophic network remain poorly known. It is therefore crucial to balance the economic opportunity that zooplankton exploitation could create with the conservation threats it could induce for ecosystems.

The novel project (ZOOFISH) under preparation will study the feasibility of sustainably exploiting zooplankton assemblages in the EEC-SNS. ZOOFISH will provide innovative tools to evaluate the abundance of key zooplankton species (including both potential bioresources and undesired by-catch with a strong influence on ecosystem functioning), the level of exploitation they could sustainably support, the trophic cascade effects resulting from their harvesting, and at the same time evaluate the nutritional potential these bioresources could provide for the aquaculture sector. ZOOFISH will also identify new species of interest, which could be sustainably exploited considering their biological traits, and their influence on the functioning of the trophic web. Results from Theme 1 (life traits processes) and 2 (top-down and bottom-up role played by zooplankton in the ecosystem functioning) will be integrated into ecosystem models (e.g., ATLANTIS) to evaluate the performances of a combination of management and climate scenarios. Three types of scenario will then be investigated to mimic: (i) different exploitation levels of zooplankton with or without fish larvae bycatch, (ii) different changes in ecosystem productivity in relation to climate change and finally, (iii) different management plans building in core HCRs (Harvest Control Rules) and spatial-seasonal closures to regulate zooplankton fisheries. In addition, HMMN will take advantage of the EU BONUS2 program to promote the zooplankton exploitation research topic within a broader EU partnership.

APPENDICES

Appendix 1: Contractual mission statement

Ifremer

décision PDG

n°	2013 - 076
date	11 mars 2013

Le Président-Directeur Général,

Vu le décret n° 84-428 du 5 juin 1984 relatif à la création, à l'organisation et au fonctionnement de l'Institut français de recherche pour l'exploitation de la mer, modifié par les décrets n° 98-90 du 18 février 1998, n° 2002-380 du 14 mars 2002, n° 2005-436 du 9 mai 2005 et n° 2010-879 du 26 juillet 2010.

Vu le décret du 3 juin 2010 portant nomination du Président du Conseil d'Administration de l'Ifremer,

Vu la décision PDG 2011-260 du 1er mars 2011, relative à l'Organisation Générale de l'Ifremer à compter du 1er mars 2011,

décide

Paul MARCHAL est nommé Responsable de l'unité Halieutique Manche Mer du Nord du département Ressources Biologiques et Environnement à compter du 18 mars 2013 et pour une durée de 4 ans.

Il reçoit délégation de signature dans les conditions définies par l'instruction PDG n° 2011-01 du 1er mars 2011.

Il bénéficie d'une prime de fonction fixée par l'instruction PDG n°2007-736 du 19 décembre 2007 pendant la durée de sa nomination.

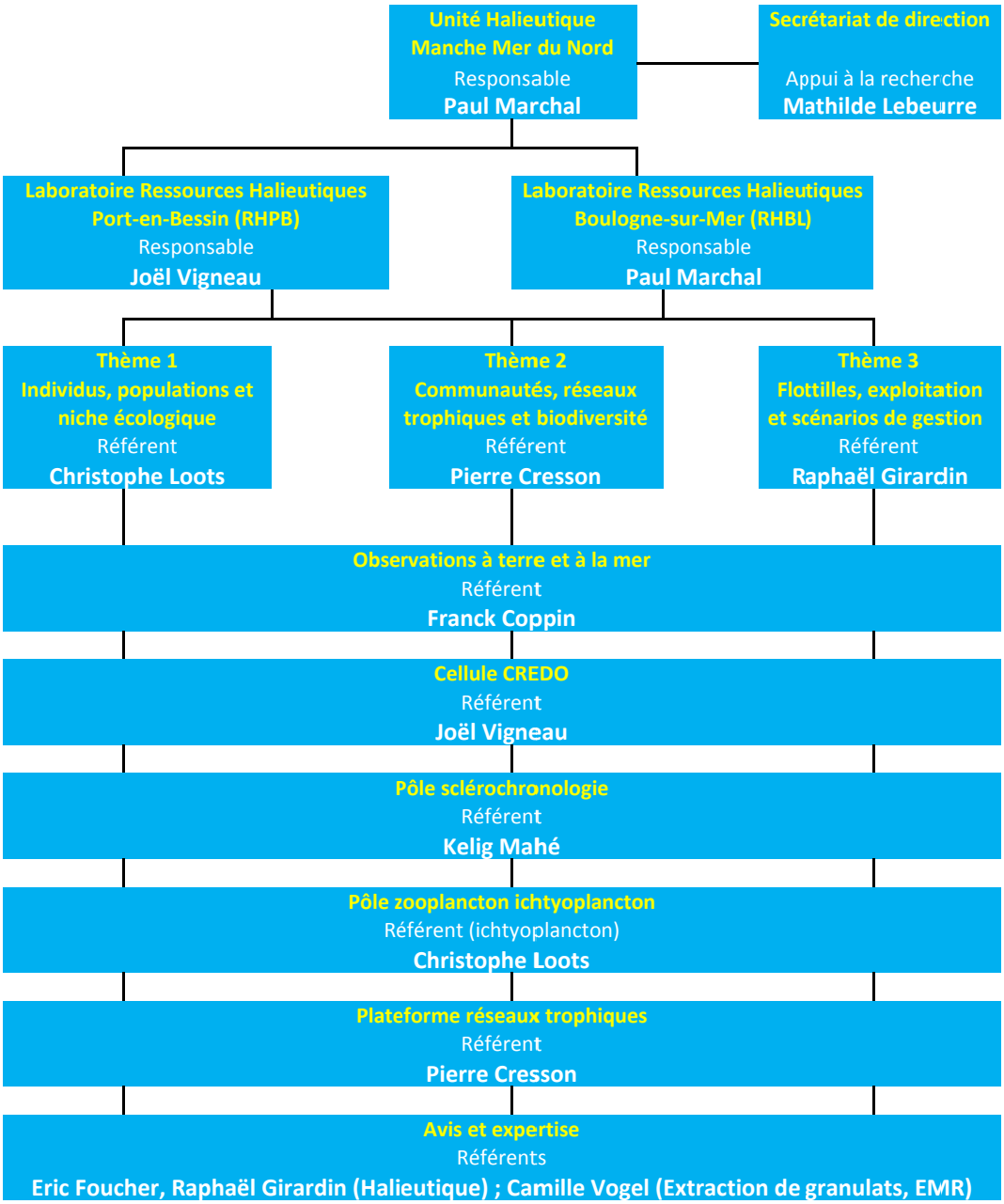
Jean-Yves PERROT
Président-Directeur Général

Diffusion générale

Appendix 2: Equipment, platforms

National Sclerochronology Centre (PNS)	Trophic Ecology Facility (PRT)	Zooplankton Taxonomy and Ecology Center (PTEZOO)
6 binocular microscopes		
6 image analysis systems consisting of binocular microscopes coupled with numerical cameras and computers equipped with image analysis software		
3 precision cutting machines for calcified structures	-20°C and -80°C freezers	
4 automated binocular microscopes	Freeze dryer	
1 scanner 3D	Computer-coupled standardized digital photography system	2 Zooscan systems dedicated to digital imaging of zooplankton (shared with LERBL)
2 high-resolution scanners 2D		Histology Equipment Leica Brand (tissue processor TP 1020, microtome RM 2255, Stand-alone cold plate Histocore Arcadia C)
2 polishing machines for calcified structures		Iatroscan with an automatic sampler

Appendix 3: Organisational chart of HMMN (30/06/2018)



Appendix 4: Selected scientific production and activities

See attachment.