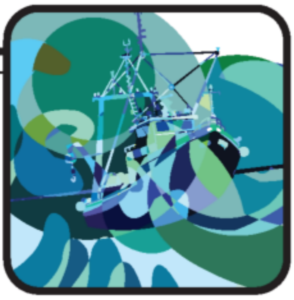


# CHAPTER 1: General Introduction, Objectives, Outline of the thesis

# CHAPTER 1. GENERAL INTRODUCTION, OBJECTIVES, OUTLINE OF THE THESIS

## 1.1 HEALTHY AND PRODUCTIVE SEAS AND OCEANS

### 1.1.1 INTEGRATED POLICIES AND ECOSYSTEM-BASED MANAGEMENT

The results of large scale assessments indicate that overexploitation of resources and changes in habitats are the main causes for the continued rates of loss of biological diversity (MEA 2005, EEA 2009), and that coastal and marine areas face particularly high impacts (OSPAR 2010). It is estimated that marine ecosystems provide two thirds of the value generated by ecosystems globally (Costanza et al. 1997). In terms of food production only, 128 million tonnes (t) of fish products are the primary source of protein for 17% of the world's population and nearly 25% in low-income or food-deficit countries (FAO 2012). The livelihoods of 12% of the world's population depend directly or indirectly on fisheries and aquaculture in marine waters and coastal zones. However, these ecosystems have traditionally been considered as infinite (Daly 1992) and for similar reasons, the concept of internalisation of environmental costs and the restoration and management of degraded ecosystems and resources have been scarcely applied in the marine environment.

By implementing the concept of ‘ecosystem-based management’, the European Commission (EC) sets healthy and productive marine ecosystems at the core of current and future developments in European marine waters. To comply with the objectives of marine policies, such as the EU Common Fisheries Policy (CFP), the Water Framework Directive (WFD 2000/60/EU) and the Marine Strategy Framework Directive (MSFD 2008/56/EU) as the environmental pillar of the Integrated Maritime Policy (IMP), Member States increasingly have to meet new requirements. This includes the obligation to assess the status of fish stocks and marine biological resources against the targets for sustainable management of marine resources and the protection of biological diversity in support of ‘Healthy and Productive Oceans’ (Ostend Declaration 2010). The objectives and targets of these policies also urge Member States to cooperate or extend existing cooperation in the management of marine ecosystems at the scale of regional seas, through cross-border cooperation and in agreement with third countries bordering Europe’s regional seas. Cross-border cooperation is particularly relevant for the conservation and management of habitats and species in marine waters, where physical borders cannot be implemented.

To achieve these objectives, Member States need to construct a common view and understanding of ‘healthy and productive’ conditions in marine ecosystems. In the context of the current policy frameworks these conditions are defined as a combination of quality elements or descriptors of ‘good environmental status’ (MSFD), as ‘favourable conservations status’ (Habitat directive 92/43/EEC), as ‘good ecological status’ and ‘good chemical status’ (WFD), and ‘above maximum sustainable yield’ in the case of commercially exploited fish stocks (CFP). While objectives and targets are set for separate policies, different policy targets must be translated into complementary operational objectives in the field. At the national and regional level, progress must be measured for the marine areas under the jurisdiction of Member States. These targets are often set against reference or baseline conditions, e.g. a target can be defined as ‘an increase in the area of key habitat to 50% of its reference conditions in pre-exploitation levels’. One of the issues that therefore needs to be addressed is to what extent and at what cost these reference conditions need to be restored and maintained and how these are translated as achievable targets of ‘Good Environmental Status’ or GES (Piha and Zampoukas 2001). Determining reference conditions and targets is of paramount importance for the future of the Seas and Oceans, and one that will affect society in many ways. Setting targets – for e.g. GES, Maximum Sustainable Yield MSY, and in other policies - requires a huge effort to integrate scientific knowledge, policy instruments and priority societal issues. Therefore, setting reference conditions and targets needs to be a transparent, objective and scientifically underpinned process. It must strive to integrate all available and relevant data and information for improved assessments and decision-making. There are different approaches, methods and sources to set reference conditions for current conservation and management targets. Although it may represent many challenges, incorporating historical data into conservation and management frameworks is one of the alternative methods (Pinnegar and Engelhard 2008, McClenachan et al. 2012, see also section 1.2.).

### 1.1.2 Data and Information in support of an ecosystem-based management

Science-based assessments in the context of integrated policies increasingly need access to quality controlled and integrated data. The importance of information and integrated databases cannot be underestimated, as stated by the EC Communication 'Green Paper on Marine Knowledge' (COM(2012)473). The EC estimated that existing users would save €300 million a year if the data were properly integrated and managed (EC 2010). The first specific objective of 'Marine Knowledge 2020' is to reduce costs for industry, public authorities and researchers, and major efforts have been put in place to achieve these objectives. Although important progress is made, further improvements can still be achieved in the field of data sharing and accessing data and information.

## 1.2 Marine environmental history and the use of historical data in current management

It is now widely accepted that human activity has been impacting marine ecosystems for millennia, and that the concept of 'pristine' ecosystems is merely a theoretical one (Myers and Worm 2003). Fishing is considered to be the human activity with major impact (Salomon 2009) and the activity mostly associated with overexploitation in the marine environment (Myers and Worm 2003). Concern about overexploitation is not a recent phenomenon: in the $18^{th}$ and $19^{th}$ centuries different authors expressed their views related to overfishing in the North Sea (Mann 1777, Du Bus and Van Beneden 1866, Olsen 1883 (Figure 1.1.), Garstang 1900) and measures to regulate fishing intensity and mitigate fishing impact on the exploited stocks in the Southern North Sea were established as early as 1289 (Roberts 2007).

The impact of fishing has become evident in the first place at the level of the exploited fish stocks: worldwide almost 30% of the formally assessed commercial fish stocks today are overexploited, about 57% are fully exploited (i.e. at or very close to their maximum sustainable production) while only about 13% are non-fully exploited. These resources are therefore under increasing pressure and threats generated by the fishing activity itself, by other human-induced impacts (e.g. introduction of invasive species) and by impacts of global change (FAO 2012).

Supported by research from different disciplines (i.e. historical, genetic, archaeological, modelling) increasing evidence is being built about prehistoric reference conditions and the need to develop multidisciplinary research to improve our knowledge on these early baselines. Furthermore, this interest is fuelled by the emphasis on the precautionary approach that is embedded in many of the current policies in support of sustainable development (section 1.1.). This evidence has also increased awareness on the limitations associated with the current scientific methods in determining appropriate reference conditions against which current targets for conservation and management are set (Pinnegar and Engelhard 2008). There is a wealth of recent studies illustrating how our perception of pristine conditions in the seas and oceans has shifted over generations, and many of these refer to fisheries (Pauly 1995, Saenz-Arroyo et al. 2005, McClenachan et al. 2012). The multi-disciplinary approach, much supported by the Open Access movement, has led to the development of datasets and methods to estimate (pre)historical baseline for marine species and has demonstrated how baselines used in management have changed when historical data are included, e.g., in the management of data-poor fisheries (Pinnegar and Engelhard 2008, McClenachan et al. 2012). Awareness on the shifts in perception of the status of stocks or the health of marine ecosystems has influenced current marine ecological research and its methods and assumptions.

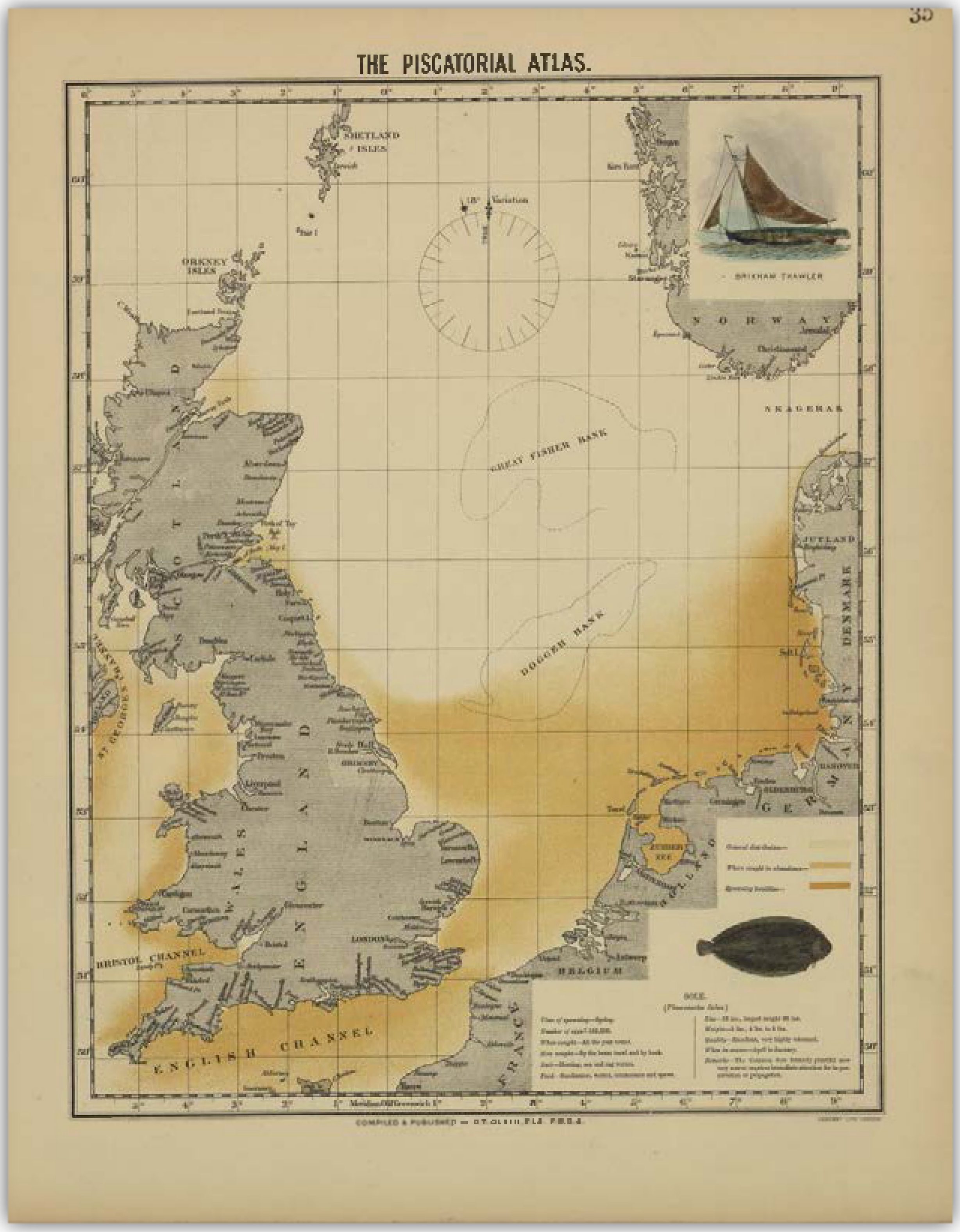



**Figure 1.1.:** Olsen (1883, map 35). Distribution map of sole (*Pleuronectes solea*, synonym of *Solea solea*) at the end of the 19th century. Source: Olsen, O.T. (1883). Note the text in the key to the map, as an illustration of the concept of 'shifting baselines': *"The Common Sole formerly plentiful now very scarce, requires immediate attention for its preservation or propagation".*

### 1.2.1 THE SHIFTING BASELINE SYNDROME

Because ecological research is often based on limited spatial and temporal scales, and conducted mostly after the 1950s (Jackson et al. 2001) much of the 'forgotten' or inaccessible historical data are of value for current and future research. Historical data can contribute in explaining underlying cause-effect relations in changes in the ecosystems, but they can also potentially reveal information and knowledge from past conditions (Jackson et al. 2001) and help defining reference conditions and achievable targets for environmental management today. In other words, historical data can counter the 'shifting baseline syndrome'.

The concept of the shifting baseline syndrome was developed by Pauly (1995) in reference to fisheries management, describing how depleted fisheries were evaluated by using the state of the fishery at the start of the careers of the experts as a baseline or reference condition, rather than the fishery in its untouched state. Pauly signposted the risks associated with this shifting perception and the challenge this represents for the management of marine ecosystems. Illustrative of the concept of shifting baselines, Sàenz-Arroyo et al. (2005) collected information over generations of fishermen, long before statistics were collected, and documented this shift in perception related to trends in abundance of target species (Figure 1.2.).

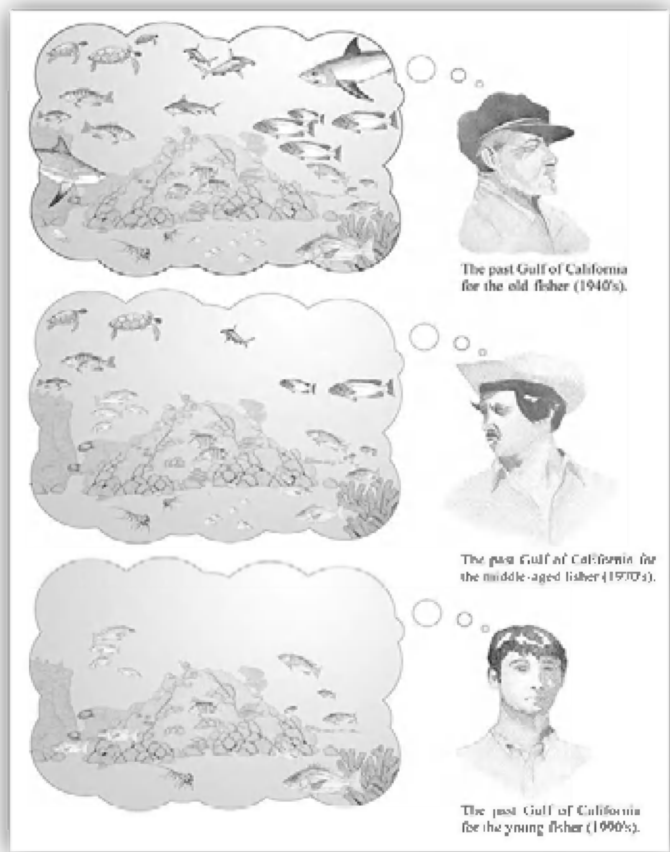



**Figure 1.2.:** 'Shifting baselines' translated in fisheries management (pictorial by Randall&Thiret *in* Sàenz-Arroyo et al. 2005)

In the absence of historical data, it is a widely accepted practice in ecological research to compare the impacted system with a supposedly un-impacted replica. However, with shifting baselines, much of this research is potentially based on erroneous starting points (Sheppard 1995).

Large-scale and/or long-term spatio-temporally explicit datasets collected decades ago therefore provide fundamental baselines of abundance, size structures and biodiversity patterns. These data can, among others:

- Contribute to time-series collections to feed e.g. ecosystem modeling or improved stock assessments (Cox et al. 2002)
- Support the establishment of indicators of biodiversity and geographic range
- Estimate historical population biomass and natural mortality rates of unexploited populations (Cushing 1984)
- Assist in countering the 'shifting baseline syndrome' (Pauly 1995)
- Provide early time period anchor points for meta analyses and modelling (Cardinale et al. 2009a)

Therefore, the exercise of data recovery, storage, integration and distribution is a valuable contribution to science as it allows a wider use and sharing of data by the scientific community and furthermore ensures long-term returns on funds invested by society in data gathering (Zeller et al. 2005).

### 1.2.2 Testing ecological hypotheses based on long term data series

Specifically related to the effects of harvesting in marine ecosystems and the shifting baseline syndrome, at least three types of hypotheses can be identified and tested by using historical data or long-term time-series:

1. Cases of temporal or permanent changes in abundance or distribution of exploited species that are caused and explained by sudden environmental changes (Corten 1999, Lindquist 2002, Poulsen et al. 2007, Eero et al. 2011). The challenge is to uncover cause-effect relationships that shape these changes and to obtain good environmental data over long-term periods or time-series on these environmental parameters, of sufficient quality to develop robust models and sound evidence.

2. Alterations in the physiological functioning of marine organisms that lead to shifts in the size structure, spatial distribution and temporal abundance of their populations, and are related to gradual or cyclic environmental changes. Examples are the gradual increase in ocean temperature (Bindoff et al. 2007) and acidity (Doney et al. 2009), rising atmospheric $CO_2$ and sea level rise (Hoegh-Guldberg and Bruno 2010) as well as the effects of habitat degradation, overexploitation and invasive species (Halpern et al. 2008). Examples of cyclic changes include the El Niño Southern Oscillation ENSO and North Atlantic Oscillation NAO, the cycles in solar radiation and solar energy.

3. Conditions in which the exploitation of one species has long-term effects on populations sizes and structures of other species. Examples include shifts in relative abundance of shorter-lived species lower in the food web and longer-lived species higher in the food web (e.g. Sherman et al. 1991, Steele and Schumacher 2000, Eero et al. 2011). Examination of historical and paleo-ecological data can be used as test cases to demonstrate changes in response to e.g. depletion of top predators.

Pinnegar and Engelhard (2008) and McClenachan et al. (2012) provide an overview of different types and sources of data and examples of how historical data have significantly contributed to an increased understanding of changing baselines. These may include fisheries data, fishermen logbooks, export and other economic statistics, statistics of fish consumption and transportation of fish, archaeological data, genetic studies, anecdotal information, local ecological knowledge and traditional knowledge. Even menu cards and price lists can provide a source of information for qualitative studies (Jones, *in* Starkey et al. 2000).

## 1.3 RECONSTRUCTING HISTORICAL DATA ON FISH AND FISHERIES

### 1.3.1 POLICY DRIVERS IN SUPPORT OF DATA COLLECTION

The United Nations declarations of Rio (1992) and Johannesburg (2002), the revised EU Common Fisheries Policy and the EU Marine Strategy are a few of the policy drivers that call for an integrated assessment of fishing impact. Fishing impact can be measured either as direct mortality of target and non-target species in fishing gear, or as indirect impact (Kelleher 2005). Publicly reported data and statistics on sea fisheries - which are used in conjunction with scientific surveys to produce fish stock assessments - have been typically restricted to commercial landings. However, commercial landings are only a part of the catch and hence of the total removals and impact. The difference between publicly reported versus total anthropogenic removals includes several components. Besides the unreported and misreported commercial landings (Zeller et al. 2006, Zeller et al. 2007) part of the catch is discarded at sea by fishers and dies after being thrown overboard alive (Kelleher 2005), suffers unaccounted underwater mortality e. g. in the towpath of bottom gear (Rahikainen et al. 2004, Kaiser et al. 2006, Depestele et al. 2008) or is removed by unreported recreational/artisanal fishing (Coleman et al. 2004, Zeller et al. 2008). This affects both commercial and non-commercial species such as brittle stars, seaweeds, diving birds and cetaceans. It is widely accepted that the discarding of fish at sea is unethical and represents a substantial waste of resources (Diamond and Beukers-Stewart 2011). In its resolution 57/142 of 2002 the UN have urged states and regional organizations to develop and implement techniques to reduce and eliminate bycatch and fish discards.
The impact on the sea floor can range from permanent destruction of biogenic structures (coral reefs, oyster beds) to temporary changes in sea floor cover (gravel, sediment composition) and local short-term disturbances in hydrology (suspended sediments) (Dayton et al. 1995, Turner et al. 1999, Jennings et al. 2001, Kaiser et al. 2006).

In the pursuit of an ecosystem-based approach in the marine environment, Data Collection Regulations in support of the Common Fisheries Policy CFP (EU Council Regulation 1543/2000 and Commission Regulations 1639/2001, 1581/2004 and 199/2008) require EU Member States (MS) to collect data on technical, biological and economic aspects of their national fisheries, and their impact on the marine ecosystem. The Commission Regulation 136/2007 requests member states to collect data and report on discards. Besides these measures related to data collection and the scientific stock assessments that need to advise the Council of Fisheries each year on the definition of Total Allowable Catch (TAC) and MS quota, there is a large number of technical measures to reduce fishing effort and techniques and initiatives to support the development of sustainable fishing communities throughout Europe.
In many cases, there are considerable uncertainties in stock assessments as a consequence of low stock sizes, inaccuracies in catch data (total removals) and variability in survey indices. These uncertainties add to the challenges of setting targets for the recovery of stocks in a changing natural environment. Management issues are complex and spatio-temporally explicit information becomes increasingly important to strike a right balance for a sustainable use while staying within the carrying capacity of the marine environment (Kelleher 2005).

### 1.3.2 FISHERIES DATA TO RECONSTRUCT FROM PRESENT TO PAST

Currently fish stock assessments are based on the data and information generated in the context of the International Council for the Exploration of the Sea (ICES). ICES stock assessment working groups meet to review the status of the principal stocks. They use three types of data to do this. First, reported data from different countries on fish landings, fishing effort and commercial catch per unit effort are combined. Secondly, independent scientific data is sampled on the fish markets and at sea (data on age structure of the landings). Thirdly the relative abundance of stocks is measured by research surveys. With these data, the fishing mortality (F)-at-age and the population number-at-age are estimated. The population number-at-age is used to estimate recruitment (R), generally the number of fish at age one or zero. Finally the total biomass (summing up the products of number x weight by age class) and spawning stock (the number x weight of fish above age of first maturity) are estimated. This Virtual Population Analysis (VPA) method is based on the principle that fishing reduces the number of fish that survive from one year to the next. With assumptions on natural mortality and selectivity of fishing gear, the actual fishing mortality can be calculated by looking at the relative number of fish of different ages by year. Using the landings-at-age data scientists can back-calculate the likely number of fish-at-age that had to be in the sea to account for the observed landings. These calculations are tuned using the commercial catch per unit of effort and the research survey data (Ricker 1975, Quinn and Deriso 1999).

Combined with landings by fishing area, the European Commission Scientific, Technical and Economic Committee for Fisheries (STECF) - established by Council Regulation EC2371/2002- produce annual stock assessments by fish stock (e.g. sole in the North Sea). The STECF then generates advice to the EC Council of fisheries on harvesting levels for these formally assessed stocks, according to precautionary principles. For most species subject to quota, stock assessments are effectuated since the 1970s, in some cases since the 1950s. However, not all stocks are formally assessed, and not for all exploited stocks TAC are determined as yet. ICES has developed a classification of fish assessment approaches that can be applied according to the amount and/or types of data these models need, and the degree of age-structured population dynamics. In data-poor environments, assessment models may need to rely on catch-only or on catch and abundance time-series models, or biomass dynamics models if a relative abundance index is available. If data are available on body growth and natural mortality, ‘delay difference’ models can be used. For the age-structured production and the VPA-based assessments, more complex data are required to perform statistical catch-at-age and age-structured integrated analysis models (ICES 2012-SISAM).

Fisheries management with an ecosystem-based perspective requires moving from a single-species based management to multiple-species management. It includes measures to mitigate and reduce the bycatch, discards and mortality of non-target species, while optimizing catch of target species per unit of effort based on sustainable levels of exploitation. Therefore, there is increasing interest in the reconstruction of earlier states of marine ecosystems (including non-commercial fish stocks, benthic invertebrates and ecosystem-engineering species) to understand the ecological effect of fishing in the past and support the definition of sustainable management objectives (Pauly 1995, Christensen and Pauly 1998). A considerable number of tools and data are required to achieve this. Reliable data (historical, current and forward projections) including Illegal, Unreported and Unregulated (IUU) catches and landings and reliable estimates of fishing mortality and stock assessments are one piece of the puzzle. Each of these statistics, estimates and assessments contain levels of uncertainty.

The application of the ‘precautionary approach’ as a principle in fisheries management has been proved promising. This may require estimating the biomass of a fish stock before exploitation, or ‘virgin biomass’. According to Hilborn (2002) using recent recruitments to estimate virgin biomass in a stock that has been subject to recruitment overfishing will produce underestimations.

These assessments require datasets pre-dating exploitation, or at least before the onset of industrial or large-scale intensive fishing practices. However, historical time-series are scarce and available time-series or baselines for rebuilding depleted fish stocks typically refer to strongly exploited situations (Lescrauwaet et al. 2010a). Although highly valued, independent scientific surveys designed to estimate fish stock biomass, typically exist only for the 1970s or 1980s onwards, for some commercially important species from the 1950s. For a small number of stocks , assessments were conducted further back in time based on a variety of historical and other data sources available (Pope and Macer 1996, Rijnsdorp et al. 1996, Engelhard 2005, Cardinale et al. 2009a and 2009b).

### 1.3.3 FISHERIES DATA PRESERVED FROM PAST TO PRESENT

Humans have changed the marine environment and its resources ever since they started fishing. Zooarcheological evidence from the southern North Sea however, suggests that rapid changes in sea fisheries occurred around AD1000, involving large increases in catches of herring and cod (Barrett et al. 2004). The authors suggest that a rapidly increasing human population coincided with first signs of overfishing in river ecosystems due to urbanism, Christian fasting regulations, siltation and agriculture and water infrastructures (Barrett et al. 2004, Orton et al. 2011). They also suggest that commercial fishing in the marine environment was triggered by this increasing demand for fish and the declining availability of fish in nearby river and lake systems. Stable isotope analysis of archeological cod bones in England and Flanders indicates that marine catches between the 9th and the 12th centuries originated from the Southern North Sea. Later on - in the 13th and 14th centuries - the longer distance fisheries were to meet this increasing demand for fish products (Barrett et al. 2011). However, it is in particular with the implementation of fishing-enabling techniques developed during the industrial revolution that sea fisheries expanded to their current dimensions (Roberts 2007).

Fisheries in Europe have a long history and one of great economic importance. The powerful Hanseatic League in the 13th-17th centuries was built in part on the trade of herring and cod. Dutch commercial herring fisheries formed one of the best-organized and economically successful fishing ventures in the world throughout the 16th and 17th centuries (Poulsen 2008). In the 16th century, a number of towns formed the ‘College van de Grote Visserij’, which was granted jurisdiction over the herring industry in the Netherlands. It was operational until 1857. Poulsen (op. cit.) reconstructed time-series of catch per unit of effort of the Dutch herring fishery between 1600 and 1850, based on tax records in the Netherlands. It is the longest time-series on CPUE ever reconstructed. However, this is an exception and in spite of the strong administrative traditions of European countries, historical fish catch accounts from before the 20th century are not comprehensively available today.

Compared to other domains of human activities and in particular human activities on land such as agriculture and manufacturing, historical data on fisheries are limited and often take a narrow approach in temporal or spatial scope. Moreover, whereas historical ecological research requires a multidisciplinary approach by nature, it is still often driven by either environmental or historical research. Historical research may not take full account of the tools and theories that are instrumental to identify natural fluctuations in marine animal populations. On the other hand, fisheries ecology research questions tend to be focused on current fisheries management needs and based on the assumptions of steady state equilibria. Particular studies have incorporated climatological, oceanographic and paleontological information from historical archives to determine correlation between key environmental variables and marine animal populations (Southward and Boalch 1992, Alheit 1997) or reconstructed a historical state or evolutions in exploited marine ecosystems (Pauly 1998). In some cases, initiatives have been set up to collect and reconstruct historical reference conditions within a broader scope of developing a vision at regional sea or particular marine ecosystems, by bringing together historians, social scientists, biologists, oceanographers and fisheries managers (Holm and Starkey 1998).

Holm and Starkey (1998) distinguished three broad chronological categories of historical data and quantitative information on sea fisheries:

1. The ‘statistical period’: national fishery-specific records that were systematically collected by competent authorities mainly since 1900. Although much of this data - where available - may be kept and archived in printed form, quality control is needed and metadata to confirm or validate changes in data gathering procedures or changes in codes, standards, definitions, boundary classes etc. are scarce or lacking.

2. The ‘proto-statistical period’: often in ports and custom archives or in accountancy records of early entrepreneurship of the 18th and 19th century. Data are often quantitative but not systematically collected and hence provide a spatially and temporally restricted view on fisheries and fishing activities. The data can be used to extend the reconstruction based on statistical data from the 20th century back in

time to the mid-nineteenth century.

3. The ‘historical period’: mainly before 1850. Less extensive and mostly qualitative or anecdotal data. In some cases the data can be used to reconstruct ‘anchor points’ to extend from time-series from the proto-statistical and statistical periods.

The few available reconstructions of historical time-series are often based on indirect sources such as tax, transport and trade registers, legislation and technical fisheries measures, fishers logbooks, etc. In fact, most states in Europe did not develop a statistical approach to underpin policy development until during the first half of the 20th century (François and Bracke 2006) and standardizing fisheries statistics at the international level was certainly one of the important achievements by the ‘Statistical Committee’ of ICES.

For the present thesis, a thorough search was conducted in literature and archives, in search of quantitative information, as well as information that could prove crucial to interpret the quantitative data to be collected throughout the thesis. Chapter 2 of this thesis provides an overview of available data and time-series for the different historical periods for sea fisheries in Flanders and Belgium. Based on the findings from this extensive and in-depth - although not exhaustive - search in literature databases and archives, the existence of the three different chronological categories of data as identified by Holm and Starkey (1998) is confirmed for sea fisheries in Belgium. For particular periods, economic data was used and converted to biomass. Anecdotal information and results from studies of Local Ecological Knowledge LEK (Maes et al.  2012), proved to be valuable sources to validate outliers or support the quality control. Archaeological data and palaeo-ecological records, which use natural phenomena as ecological archives, are not the scope of the present study.

All publications, data and information sources were scanned, inventoried and described in the IMIS database (VLIZ). According to the ‘Open Access’ principles, all sources – except those for which author and other copyrights explicitly restrict access or dissemination – are made available from the Flanders Marine Institute website www.vliz.be and/or the webpages of the ‘wetenschatten’ project www.wetenschatten.be, hosted and developed by VLIZ with the support of the Province of West-Flanders.

Open Access (OA, www.openarchives.org) is the practice of providing unrestricted access via the Internet to peer-reviewed scholarly journal articles, theses, scholarly monographs, book chapters, and citable datasets. OA to research results is promoted mainly on the basis that most of the research is paid for by taxpayers through government funding of research performing organizations. The OA concept is increasingly expanding from access to journals and journal articles, to sharing data and research findings. For the marine environment and marine research in Flanders and Belgium, the OA movement is strongly promoted by the Flanders Marine Institute VLIZ. The VLIZ Open Marine Archive OMA (www.vliz.be/oma) gives free access to the digital collection of the work of Flemish/Belgian marine researchers. It holds peer-reviewed articles, pre-prints, locally published articles, press releases, reports, symposium contributions and audio-visuals. Other examples of OA resources developed and managed by VLIZ are The World Register of Marine Species (marinespecies.org), an OA inventory of all marine species names, and Marine Regions (marineregions.org), an OA inventory of Exclusive Economic Zones EEZ and marine geographic places and names which are used throughout the present study as reference databases for species and locations.

The OA movement is much in line with the ‘Digital Agenda’ for Europe which sets out an ambitious ‘open data’ policy (2003/98/EC) covering the full range of information that public bodies across the European Union produce, collect or pay for. The European Commission established OA to peer-reviewed publications as the general principle in its next framework program Horizon 2020 and promotes the OA principles to research data (experimental results, observations and computer-generated information etc.).

## 1.4 STATE-OF-THE ART OF RESEARCH IN HISTORICAL ECOLOGY AND FISHERIES

As argued above, there is a growing scientific and public interest to make historical data accessible in electronic format. However, the challenges to achieve this do not only refer to the digitization process. Often time-series have data gaps, limitations in temporal-spatial coverage, changes in measurement units, and the analysis and interpretation are fraught with difficulties. Acknowledging these issues led to a call from the international scientific community for a tighter collaboration between 'classic' fishery scientists, historians, and ecologists (ICES 2008). The motivation is to gain better insight into the effects of climate change, fishing, and other anthropogenic drivers on marine organisms. Data used for this purpose can refer to tax records, commercial catch statistics, catch per unit of effort (CPUE), research survey information, length and/or age compositions, biodiversity and other diverse sources (e.g. menu cards from restaurants) that can throw light on marine organisms and the dynamics of the fleet(s) exploiting them before 1960 (SGHIST 2011).

A non-exhaustive overview of some of the integrated studies and analyses that have been conducted based on the recovery of historical data is included below. They provide a context of the current state-of-the-art in historical ecology and fisheries research, in which the current research is framed (see below). An important impetus to the historical work has been provided by the History of Marine Animal Populations (HMAP) project (2000–2010) that was funded under the Census of Marine Life. Within HMAP, some 100 researchers in 12 regional focus areas and 4 global/intercontinental projects analysed marine population data before and after human impacts on the ocean became significant with the goal of enhancing knowledge and understanding of how the diversity, distribution and abundance of marine life in the World's oceans changes over the long term. Other important initiatives in this field of research are the EU project, INCOFISH (2005–2008) (hull.ac.uk/incofish/index.htm), and the Canadian-led Sea Around Us project which has a historical component digitizing historical expeditions and surveys. The European network of excellence MarBEF (www.marbef.org) also studied historical aspects in fish and fisheries studies. All projects seek to develop large-scale databases of historical relationships between ocean life and human society, and HMAP as well as INCOFISH data is archived at the University of Hull (UK).

In 2008, ICES hosted the workshop on historical data on fisheries and fish (WKHIST) in an attempt to provide links between the marine environmental history community and the marine science community. WKHIST compiled an inventory of the historical information that has been identified in locations such as national and city-archives, libraries of marine science organizations and zoological museums. The inventory is available from ICES WKHIST 2008 (www.ices.dk/workinggroups/ViewWorkingGroup.aspx?ID=629).

A few examples and case-studies from this inventory exercise are included and briefly commented below in three main categories ranging from 1) efforts to describe and make available (meta)data to large-scale digitization projects; 2) studies on spatio-temporal changes in distribution and abundance of species, fishing effort and CPUE; and 3) studies linking changes in climate with changes in population dynamics:

### 1.4.1 EFFORTS TO DESCRIBE AND MAKE AVAILABLE (META)DATA AND LARGE-SCALE DIGITIZATION PROJECTS

a) **Sound Toll registers project.** One of the greatest data mining exercises within history in recent years is a Dutch-Danish collaborative effort to digitize the so-called Sound Toll Registers (www.soundtoll.nl) (www.soundtoll.nl). For more than 350 years (1497–1857), the Danish king levied a toll on all ships sailing in and out of The Sound – the then main entrance point for trade between the countries around the Baltic Sea and the wider world. The preserved records from the toll, which are now being digitized, total some 1.8 million ships passages (Gøbel 2010). For future research the project will provide a unique measurement for taking stock of more than 350 years of World trade. A sizeable portion of the records relates to trade in marine resources. Common commercially caught fish include herring and cod, while dozens of other species show up in the database, such as shellfish, oysters, whale bones or sardines. While the project is running, its data become available for download online through the principles of Open Access.

b) “One-hundred Years of Change in Fish and Fisheries” (CEFAS-UK): The UK Department for Environment, Food and Rural Affairs (DEFRA), and its agency the Centre for Environment, Fisheries and Aquaculture Science (CEFAS), hold unique historical fisheries data which are highly relevant to understanding the long-term effects of fisheries, pollution, and other human impacts on marine living resources. The 100 Years of Change project collated and digitized fish and fisheries data, collected over the past 100 years by DEFRA, CEFAS, and predecessors. DEFRA commercial fisheries ‘Statistical Charts’ (1913–1981) provide spatially detailed (by statistical rectangle) data on catches, effort, and CPUE by fish species and fishing fleet. The historical research survey data, covering the 1890s-1970s, were conducted in the North Sea but also in the Irish Sea, north and west of Scotland, and in the Barents Sea. Based on the datasets, changes in biological characteristics in fish populations and species compositions in relation to climate and fishing were examined. The commercial data are used to examine changes in distribution of commercially important fish populations throughout the 20th and early 21st Centuries, in relation to climate change and fishing pressure. The scientific survey data serve to investigate long-term changes in stock structure, age and size compositions of key fish populations (Engelhard 2008).

c) **Online fish stomach database (1894–1915, DAPSTOM).** CEFAS scientists have collected almost 100 years worth of fish stomach content data, from the seas around the UK (North Sea, Irish Sea, and Celtic Sea). Much of these data is now available in electronic form, through the DAPSTOM data portal (www.cefas.co.uk/dapstom). The DAPSTOM project was initially financed through the ’data rescue’ fund of the EU Network of Excellence EUROCEANS. The online database contains information (103927 records) on 82 predator species (most of those occurring in northern European groundfish surveys) and can be searched by predator name or by prey name for given sea areas and years (Pinnegar and Platts 2011).

d) **Fishery catch data (ICES catches from 1892 – present): reconstructing a time-series of international landings for the North Sea**. ICES collates fisheries catch data for all nations fishing in the North Sea (DK, UK, NO, NE, GE, FR, BE, SW), and makes this information available in electronic format through ‘Fishstat’ (1973–2005). Prior to ‘Fishstat’ (1903–1972) these data were available in paper format, as the annually produced publication *Bulletin Statistique*. Effort is underway (within ICES) to digitize this information and to produce a ‘standard’ time-series of fisheries catches for the ICES region. The data contained in *Bulletin Statistique* (Hoek and Kyle 1905) provided international fisheries data for the period 1892–1902, but only for certain key species (plaice, sole, turbot, brill, herring, haddock, cod).

### 1.4.2 Spatio-temporal changes in distribution and abundance of species; dynamics of fishing fleets and fishing power

a) **Northwest Atlantic: 1850s Cod Biomass Estimate on the Scotian Shelf**. This project estimated the adult cod biomass on the Scotian Shelf in 1852 by extracting daily catch records from the logbooks of 236 American fishing vessels. The total removals of cod for the Scotian Shelf were approximately 200,000 t per year or altogether 1.6 million t over 8 years (1852–1859). The Chapman-Delury method was used with the total removals and the Catch Per Unit Effort (CPUE) to derive an adult cod biomass estimate of 1.26 million t which is in stark contrast to the average annual biomass estimate of 50 000 t in the 1990s (Rosenberg et al. 2005).

b) **Changes in the North Sea cod stock.** Trends in landings, fishing mortality (F), recruitment (R), and spawning-stock biomass (SSB) were derived from analytical assessment undertaken annually by ICES extending back to 1963, as well as from earlier estimates of F and SSB back-calculated to 1920 by Pope and Macer (1996). Based on these reconstructions, relations between landings and fishing mortality, spawning stock biomass, and recruitment are analysed (Bannister 2001).

c) **Fishing and jellyfish eradicate herring…180 years ago (DTU Aqua, Univ. Aarhus, Univ Roskilde, Univ. Copenhagen-DK).** Herring has been commercially exploited for at least 400 years in the Limfjord, Denmark but its abundance has never been estimated for either historical or contemporary periods. The study developed two new estimates of herring spawner biomass for the Limfjord for a historical period of stable fisheries (ca. 1660 - 1800) following two different methods. The two independent methods produce estimates which do not differ significantly. Given these abundance estimates, the maximum carrying capacity under no-exploitation conditions (maximum spawner biomass) was calculated to be 23,000–34,000 t. These new estimates, and in particular the area-based approach, contributed to the development of reference fishing and biomass levels as well as sustainable fisheries and ecosystem management policies in situations where no other biomass estimates are available for areas such as the Limfjord, Celtic Sea and Irish Sea (MacKenzie and Poulsen 2010).

d) **Drivers of change in European Herring Fisheries, c. 1350 - present.** The European herring fisheries are one the world's biggest fisheries of the last millennium. This study analyzed how different factors played a dynamic role in how the fisheries developed over a multi-centennial scale. The focus is on i) consumer demands, ii) fishing technology, iii) environmental changes. Until the early 15th century all fisheries were land-locked in the sense that they had to return to shore with their catches for processing. Flemish fishers started to fish offshore using long driftnets deployed from converted cargo vessels, implementing an early format of 'factory vessel'. Until then, the size of catches was entirely limited by the nearshore abundance of herring. When this limitation was overcome, the output of herring was able to flourish until the ceiling of total carrying capacity seemingly was hit from the 1920s onwards (Poulsen 2008). This study evidences the need of a multidisciplinary approach in marine environmental history looking at different drivers of change (political, technological, economic, socio-cultural).

e) **Drivers influencing dominance and subsequent decline of English North Sea demersal fisheries.** Landing trends in commercial fisheries are not only influenced by natural fluctuations or fishing pressure, but also by changing drivers affecting the fishing industry. Hence, for accurate interpretation of fisheries data and revealing trends in fisheries, the historical contexts of influencing drivers have to be understood. In this study, long-term datasets covering over 100 years of international North Sea demersal fisheries were compiled, focusing on England, and relating commercial landings to historical events and political, technological and economical drivers that influenced this fishery. In the 19th and first half of the 20th century Great Britain, and in particular England, had unchallenged dominance in North Sea demersal fisheries in Europe, but lost this lead in the second half of the 20th century. For England, favourable terms of political, technological and economical drivers brought about this vast rise, but as well influenced the decline (Kerby et al. 2012).

f) **Cod moves in mysterious ways: shifting distribution in the North Sea during the last century.** The distribution of cod within the North Sea has shown major shifts over the course of the last century (Engelhard et al. 2011b). This has become evident from an analysis of almost one-hundred years of British commercial fisheries data, digitized from CEFAS archives. Combined with contemporary fisheries data, these span the period 1913-2010 (excepting both World Wars), at the spatially detailed level of ICES rectangle (0.5° Latitude, 1° Longitude). New analysis of old data reveals that from the 1920s to the 1980s cod were especially distributed in the central-west and north-western North Sea, but in the 1990s a 'hollowing out' of cod from their previous stronghold east of Scotland and Northeast England occurred, leading to an eastward shift. In the 2000s, a strong decline of cod in the south-eastern North Sea implied that cod now mostly occur in the North and Northeast North Sea. As a result, the current distribution of cod in the North Sea is almost the opposite of that during most of the 20th century (Engelhard et al. 2011b).

g) **North Sea herring: differences in fishing power between North Sea herring fishing vessels from the 16th – 20th century**. The analysis is based on a time-series from Dutch fishing vessels catching herring with driftnets in the North Sea from 1604–1966. Until 1875 the Dutch herring fisheries were still operating a fleet of hoeker type vessels using driftnets made of hemp. The hoeker was very similar to a Dutch 15th century fishing vessel. From 1866 the hoeker was gradually replaced by the faster logger whereas cotton became the preferred fabric for driftnets. Sailing luggers were in use until 1929, followed by steam from 1892 and motor propulsion from 1901. The analysis suggests that the fishing power increased more than twenty-fold over the period. However, the relative CPUE in hoeker-units suggests that the relative stock abundance of herring was ten times higher in the 1600s than in the 1950s, and that by the 1800s it had already dropped to 50–60% of the level of the 1600s (Poulsen 2008).

h) **Standardization of Catch rate and Catch per unit of effort.** In fisheries, it is a common practice to use commercial catch rate as an index of relative abundance, particularly in fisheries where no regular surveys have been conducted. The use of catch per unit of effort CPUE as an index of abundance is based on the assumption that catch, effort and abundance are related, provided catchability is constant over time. However, catchability is unlikely to remain constant over the entire exploitation history. The efficiency of the fleet, the targeted species, the environment, and dynamics of the population or fishing fleet are some of the factors that affect catchability. Therefore, CPUE data are standardized for changes or variations in catchability. However, standardization can be problematic, and results are not always proportional to abundance, in particular when methods used do not account for spatial and temporal complexity in fishing effort, or changes in fleet composition and effort creep within vessels. Methods were developed to standardize CPUE for long-term spatio-temporal analysis of population dynamics, where differing levels of technological creep need to be accounted for (Maunder and Punt 2004, ICES 2008, Engelhard 2008, Cardinale et al. 2009a, Thurstan et al. 2010)

### 1.4.3 Research linking environmental changes and dynamics of fish populations from historical data

a) **Nine decades of North Sea sole and plaice distributions** (CEFAS-UK and IMARES-NL). Recent studies based mainly on research survey data suggested that within the North Sea, sole (*Solea solea)* and plaice (*Pleuronectes platessa)* have shown distribution shifts in recent decades - on average southward in the case of sole, and to deeper waters in the case of plaice. Conversely, landings data tentatively suggest a northward range expansion in sole. Various hypotheses may account for such shifts, including climate change effects and more intensive fishing effort in more southerly or shallower waters, but the relatively short time spans of datasets analyzed so far (~3 decades) have complicated the disentangling of these two effects. Extensive sole and plaice catch and effort data from the British North Sea trawlers were catalogued and digitized. These data cover nine decades and are spatially detailed by ICES rectangle (0.5° Latitude, by 1° Longitude) and allow quantifying long-term distribution changes of North Sea sole and plaice over a period of almost a century. The main conclusion from this study is that sole and plaice have shown major distribution shifts over the past 90 years and that these shifts are not the result of climate change per se, but likely also of (indirect) fishing effects and eutrophication. It would not have been evident to draw these conclusions from data coming from the last 3 decades alone (Engelhard et al. 2011a).

b) **Recreating 114 years in the North Sea using Ecopath and Ecosim**. Ecopath is a foodweb model, and includes all system fluxes from detritus and bacteria up to seals and whales. Ecosim is a time-dynamic version of Ecopath and can be used to simulate the wider ecosystem impacts of different fishing practices and to search for optimal management strategies (from an ecological or economic perspective). Ecosim can be 'tuned' to fit long-term time-series data or 'forced' using assumptions about climatic conditions and this methodology has come to be known as the 'Back to the Future' approach, whereby a model is constructed to represent a period in the past, then projected forward in time using time-series data to try to explain how events may have unfolded, prior to the current situation. Mackinson (2001) attempted to explore what the structure of the North Sea ecosystem may have looked like prior to the development of industrialized fisheries. He constructed a model for the period immediately prior to the arrival of the first British steam trawlers, Zodiac and Aries in 1881 (Mackinson 2001).

c) **Multidecadal responses of the eastern Baltic cod to human-induced trophic changes, fishing, and climate (DTU Aqua-DK).** The work builds on recent reconstructions of cod spawner biomass back to the early 1920s based on commercial CPUE, extended VPA and historical survey data (Eero et al. 2007a, Eero et al. 2007b, Eero et al. 2008, Eero et al. 2011). Combining long-term ecological datasets transcending the historical development of key human impacts, the study investigates how the onset of those impacts affected the population dynamics and productivity of cod (Eero et al. 2011). Simulations of population dynamics were conducted, 'turning off' the positive effect of one variable at a time, i.e. i) favourable climate, ii) increased nutrients, iii) reduced fishing.

d) **Shifts in spawning seasonality of sole.** This study reveals that over the past 4 decades a shift in the timing of spawning of sole has taken place, in relation to climate change. The work was carried out as an MSc project at CEFAS (Fincham et al. 2013).

e) **Historical spatio-temporal dynamics of eastern North Sea cod**. Recent analyses of historical data of fish abundance and distribution have shown promising potentialities, but pose numerous difficulties such as fragmentation and heterogeneities in the amount of available information in space and time. Using mixed-effects models in a multi-scale analysis, the appropriate spatio-temporal scale of investigation of a high-quality spatially explicit historical dataset was identified, and the long-term spatial dynamics of cod in the Kattegat-Skagerrak reconstructed along the 20th century. At the broad scale of the study area, a northern and southern main aggregation of adult cod were identified and characterized by largely independent spatial dynamics, however both suffering from a common extensive loss of coastal aggregations during the last decades. Population size widely fluctuated through the century, with a possible peak during the decade after the war. From the 1960s, a progressive contraction of the population was observed, up to the historical minimum in the 2000s when only 30% of the estimated early century cod biomass was left. The reconstruction showed that the collapse of the cod population in the area matched the peak in landings, while it anticipated the warming trend of at least two decades, supporting the major role played by the post-war development of the industrial fisheries in the decrease of local abundances and disappearance of local adult cod aggregations (Bartolino et al. 2012).

f) **Fisheries-induced evolution in fish populations**. Fishing and other anthropogenic influences can affect a species' resilience to harvesting. Fishing is thought to induce a genetic change in the populations, affecting age and length of maturity. Systematic extraction of the larger specimens of fish from a population leads to a shift in maturation to younger and smaller specimens. A decrease in the number of mature adults and recruiting individuals may lead to genetic changes in life-history traits that can be irreversible. Some studies have reconstructed parameters of somatic growth and parameters of sexual maturation. The evolution of genetic diversity and effective population size is studied based on the analysis of historical DNA from historical collections of otoliths, modeling techniques (Rijnsdorp et al. 1993, Mollet et al. 2007, Cuveliers et al. 2011, Garcia et al. 2012).

A special category of research refers to the collection of **local ecological knowledge** through which fisheries - and ecosystem related data and information is collected from oral information gathered through interviews with fishermen. The 'Yesterday's Sea' and 'LECOFISH' projects are examples of this type of research for Belgian sea fisheries covering the last 80 to 50 years. Although the research method is challenging and requires a truly multidisciplinary approach, the results show that fishermen are able to particularly recall marking events and outliers (e.g. great or unusual catches, extreme weather conditions) which can be of important value to confirm or challenge scientific knowledge and information (Maes et al. 2012).

### 1.4.4 The role of ICES in advancing the understanding of long-term dynamics of fish populations and fisheries

Following a recommendation from the 2008 Workshop on Historical Data on Fisheries and Fish (WKHIST), it was concluded that ICES should have a role as coordinator of the historical work on marine systems. The Study Group on the History of Fish and Fisheries (SGHIST) was created in 2009, bringing together fisheries scientists, historians and marine biologists working on multi-decadal to centennial changes in the marine environment, aiming at improving the understanding of the long term dynamics of fish populations, fishing fleets, and fishing technologies. SGHIST aims to bring together scientists working on these topics to facilitate and coordinate data recovery and digitization processes, to exchange ideas, and harmonize methodologies on spatio-temporal analysis, and to discuss methods for the analysis of technological creep and the interpretation of historical time-series of fishing power and CPUE. The results are used for setting baselines for management, restoration and conservation of marine resources and ecosystems. Several fisheries research institutes in Europe have started to make inventories of available historical information (see above).

## 1.5 Why we bother: the added value of integrated databases

### 1.5.1 Data management and integrated databases

Often marine biological data are the result of projects with a limited temporal and spatial cover (Jackson 2001). Taken in isolation, datasets resulting from these projects are only of limited use in the interpretation of large-scale phenomena. More specifically they fail to be informative on a scale commensurate with the problems of global change that humankind is confronted with (Costello and Vandenberghe 2006, Vandenberghe et al. 2009).
Databases have evolved since the 1960s with the purpose to manage increasing and complex information systems. Data integration is particularly interesting and increasingly needed in the Life Sciences: large-scale questions in science, such as global warming, invasive species spread, resource depletion, require the collection of disparate data sets for meta-analysis. This type of integration is especially challenging for ecological and environmental data because a common language of standard definitions and codes (usually referred to as metadata and standards) are not agreed upon and there are many different types produced in these fields. Such data have never been of greater importance considering the recent observation of major shifts of marine species due to global change.

There is no specific definition of the term *Integrated database*, but basically it allows to combine data that reside in different sources so as to provide the user with a unified view of these data. The advantages of creating integrated databases are many:

- Sharing of data: single files are generally owned by single users whereas a database is often owned or managed by a supporting organization.

- Control of redundancy: different users may have the same data whereas a database contains only one occurrence of the same data (version control).
- Data consistency: eliminates redundancy. In databases, the data need to be updated only once at one place, whereas in a single file system, files are distributed and data need to be updated in all of the files.
- Improved data standards: the database manager or managing authority defines organization-wide standards on how to represent data in a database (format, conventions).
- Improved data Security: single-file systems are not secure. Databases can give security to the very basic level.
- Improved data Integrity: databases give the database authority the power to define integrity constraints. e.g. question type1 cannot access information that answers question type 2.
- Faster development of new applications: a well-designed DB is modular, when a new application is purposed, the database can respond.
- Improved access to data: a query language support allows any user to get data required anytime, and there is no need for a programmer to extract the data.
- Economy of scale: cost and resources can be pooled, so a lower cost is involved per user.
- More control of concurrency: simultaneous access is possible.
- Better backup and recovery procedures: simple backup is the procedure for databases, whereas backing up the single files of all contributors is needed in a single-file-system.

The disadvantages are mainly related to the high costs of a database management system and the potential overall loss of data in case of database failure.

The global database on fisheries catches is maintained by the United Nations Food and Agriculture Organization FAO and relies on annual reports and contributions from each member country. Global data are only as good as their underlying national data. However, as described above, most national data collections are incomplete, as they focus predominantly on commercial fisheries landings and under-estimate or even ignore non-commercial (e.g., recreational) and small-scale catches (subsistence and artisanal), as well as discards. ICES is currently developing a regionally coordinated database platform for regional fisheries assessments. The database (DB) covers fisheries in the North Atlantic Ocean, the North Sea and the Baltic Sea, and addresses fishery management needs related to the European Union Common Fisheries Policy (CFP). The DB will facilitate a transparent and regional approach to the collection and processing of catch and landings data and ensure a standardized and regional approach to fisheries assessments. The database will also make it easier for countries to share data and results, and provide information to decision makers in a streamlined way.

### 1.5.2 Historical Fisheries data: HiFiDatabase in Belgium

The efforts of reconstructing and integrating the fragmented and dispersed data sources for the period (1830)-1929-2010, led to a thematic database for Historical sea Fisheries Data or HiFiDatabase in Belgium (see Chapter 2 of this thesis). It is the most complete and integrated database for historical time-series on sea fisheries for Belgium, and contains the most detailed spatial, temporal and taxonomic data and information. It also contains unique economic information and integrated catch (landings) with effort data and with the value of catch (landings).

## 1.6 BELGIAN SEA FISHERIES: OVERVIEW OF A DYNAMIC SECTOR

### 1.6.1 BELGIAN SEA FISHERIES: THE HISTORICAL, POLITICAL AND SOCIO-ECONOMIC CONTEXT

Belgium covers a land area of 30,528 km2 and has a population of approximately 10.7 million. Historically, the area known as Belgium, the Netherlands and Luxemburg was called the ‘Low Countries’. From the 16th century until the Belgian revolution (1830), the area of Belgium was occupied and ruled by Spain (1549-1713) as the ‘Spanish Netherlands’, by Austria (1713-1794) as the ‘Austrian Netherlands’, and annexed by the French First Republic (1794-1815). The ‘Low Countries’ were brought together as the ‘United Kingdom of the Netherlands’ in 1815 and ruled by the House of Orange. After the Belgian revolution of 1830 it became the independent state and Kingdom of Belgium. In this thesis, the fisheries before 1830 is therefore referred to as ‘Flemish or Flanders’ fisheries, whereas ‘Belgian sea fisheries’ is used as a correct term from 1830 onwards.

Belgium has three regions: Flanders (Dutch-speaking) in the north, Wallonia (French-speaking) in the south, and the Capital region of Brussels (officially bilingual, Figure 1.3.). A slight majority of the population (59%) lives in Flanders.

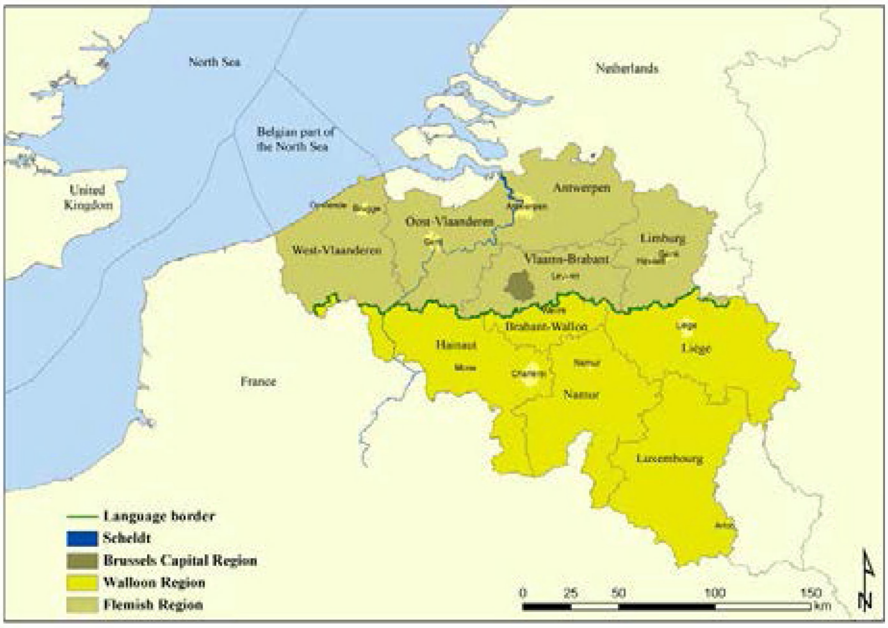



**Figure 1.3.:** Map of the geography and administrative structure of Belgium, and the Exclusive Economic Zone in the southern North Sea. Map by Flanders Marine Institute (VLIZ).

The Belgian coast is 67 km long and is entirely bordering the province of West-Flanders (region of Flanders, Belgium). The Belgian part of the North Sea is 3,457 km$^2$ (0.5% of the North Sea area), of which more than 1/3 or 1,430 km$^2$ are territorial sea within 12 nautical miles distance of the coastline. Belgium currently has four coastal ports (Nieuwpoort, Oostende, Zeebrugge and Blankenberge), and besides the fish auctions located in Oostende, Zeebrugge and Nieuwpoort (Figure. 1.4.) where fish is sold according to legal procedures, there are no other dispersed landing points. Although historically the port and auction of Oostende was by far the most important, today the auctions of Zeebrugge (53%) and Oostende (45%) receive the largest share of the landings of Belgian fisheries in Belgian ports.

### 1.6.2 BELGIAN SEA FISHERIES: AN OVERVIEW OF THE SECTOR ANNO 2012

Belgium has a minor role in the European fisheries context with 0.35% of the total EU production of fish. In 2012, the Belgian commercial sea fishing fleet counted 86 ships, with a total engine capacity of 49,135 kW and gross tonnage of 15,326 GT (Roegiers et al. 2013). 45 vessels are part of the Small Fleet Segment (max 221 kW engine power) of which 2 use passive gear. The remaining 41 vessels belong to the Large Fleet Segment and have an engine power between 221 kW and a maximum of 1,200 kW. This fleet segment represents approximately 80% of the engine power capacity and 77% of the GT of the fleet. While a smaller number use trammel nets (passive gear) and otter trawl, the largest share of the Large Fleet Segment are beam trawl vessels (≥662 kW). The Belgian fleet is highly specialized: more than 68% of the effort (days at sea) and 77% of total landings are achieved by beam trawlers (2010) focusing primarily on flatfish species such as plaice (*Pleuronectes platessa*) and sole (*Solea solea*). The results of the reconstruction of the Belgian fleet dynamics since 1830 are presented and analyzed in Chapter 5.

The number of days at sea per vessel is fixed at a maximum of 265 per year and in 2011 the entire fleet realized a fishing effort of 15,855 days at sea. In 2011, the Belgian fleet landed a total of 20,138t, of which 16,905t were landed in Belgian ports. Plaice is the most important species in terms of landed weight. Eighty-eight percent of the 3233 t landed in foreign ports is sold in The Netherlands (plaice and brown shrimp). They mostly represent the catch of Dutch crews and shippers that sail under Belgian flag and are assigned Belgian fishing quota.
The landings of 2011 represented a value of €76.3 million, 14% of which was marketed in foreign ports. Sole generates 47% of the current total value of fisheries in Belgium. The Belgian sea fisheries represent 0.04% of the national Gross Domestic Product (Anon. 2008). The main fishing grounds in terms of volume of landings in 2010 were in descending order: North Sea South (IVc), Eastern English Channel (VIId), North Sea Central (IVb), Southeast Ireland/Celtic Sea (VIIg) Bristol Channel (VIIf) and Irish Sea (VIIa) (Fig. 1.5.).

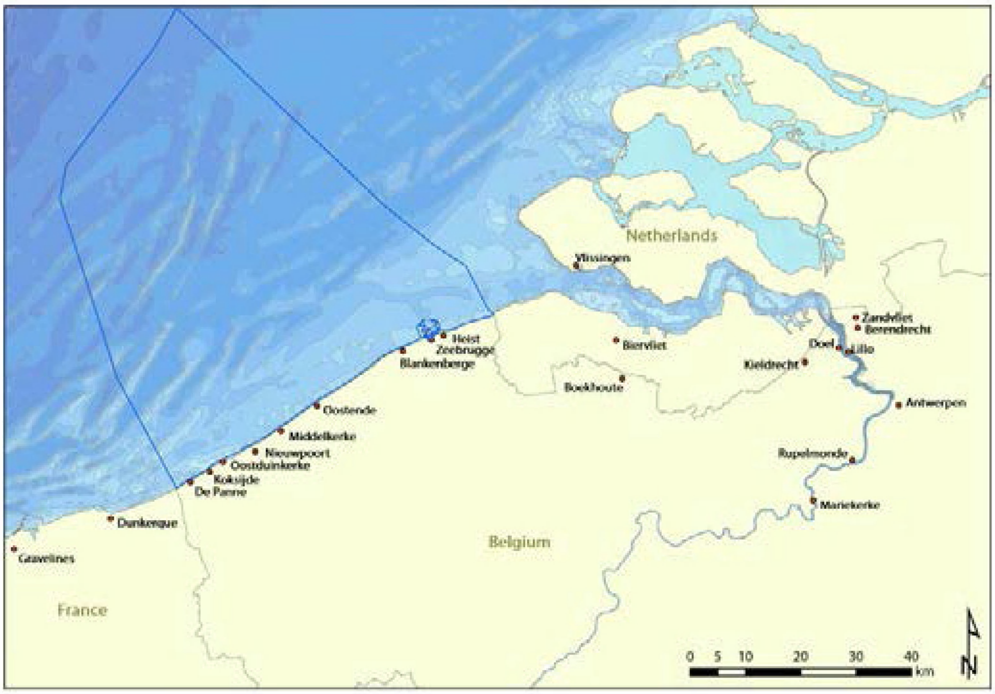
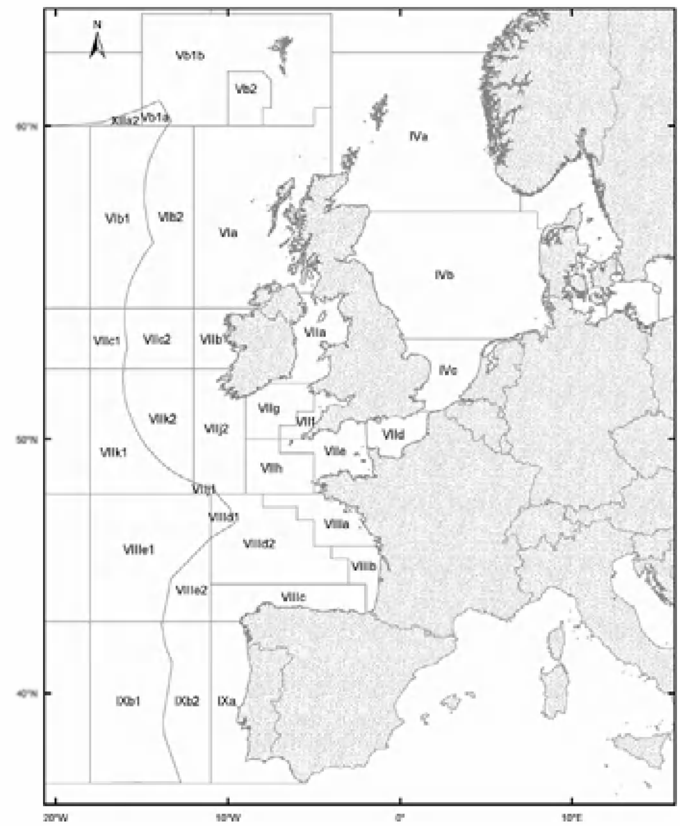



**Figure 1.4.:** Map of the Belgian coast with the historical coastal and estuarine fishing ports and historical fishing communities in Flanders, and the ports of Gravelines and Dunkerque in France. The blue line indicates the EEZ boundaries of the Belgian part of the North Sea. *Map by Flanders Marine Institute (VLIZ)*

In terms of direct employment, 439 fishers are registered of which approximately 350 are of Belgian nationality. Direct employment in fisheries represent approximately 0.5% of the total employment in the Belgian coastal zone. Another 1040 persons work in the fish processing industry and another 5000 persons in associated trade and services (Roegiers et al. 2013).

The Belgian fleet operates in the Belgian part of the North (BNS), in the marine waters of the European Union and in marine areas of third countries. The boundaries of the territorial sea and the BNS have been established by bilateral agreements and formalised in Belgian and international legislation. The Belgian fleet fishes in the BNS, in the southern North Sea (IVc), the central North Sea and the Western waters. The fleet is also active in the Bay of Biscay during a limited number of weeks, to fish for sole. In the framework of the EC Council Regulation (EC) No 2371/2002 of 20 December 2002 on the conservation and sustainable exploitation of fisheries resources under the CFP, the Belgian fleet also gained access to the coastal waters of other member states. Belgian fishers also legally operate in geographically demarcated areas of the coastal waters of the United Kingdom, Ireland, Denmark and France, between 6 and 12 nautical miles (nm). Furthermore, the entire coastline of the Netherlands is also accessible for the Belgian fleet in the zone between 3 and 6 nm, and the area between 0 and 3 nm according to the Benelux-agreement. Vessels that operate in the territorial sea need to observe the requirements in terms of access, fishing gear and maximum engine power, as well as minimum mesh sizes. The territorial sea is fished by coastal fishers and by a few 'eurocutters' (*eurokotters*) which are small vessels with approximately 221kW engine power being the maximum allowed power for beam trawlers within the 12nm zone. Dutch and French vessels also have access to the territorial sea of Belgium (Chapter 6).

The fishing areas to which the Belgian fleet has access in terms of assigned fishing effort and quota, include (Fig. 1.5.):




- North Sea, in area IIa (Norwegian Sea)
- North Sea areas IVa, IVb and IVc,
- Faroër in Vb
- Skagerrak in IIIa,
- West of Scotland in VIa,
- Irish Sea in VIIa,
- Western part of the English Channel VIIe,
- Eastern part of the English Channel VIId,
- Celtic Sea in VIIf,g,h,j,k
- Bay of Biscay in VIII.

**Figure 1.5.:** Map of the ICES Fishing areas. International Council for the Exploration of the Sea ICES (http://geo.ices.dk/viewer.php?add_layers=ices_ref:ices_areas)

Belgium is assigned fishing quota in areas considered as ‘traditional fishing areas’. These assignations refer to ‘historical use’ and are based on the spatial dynamics of the Belgian fleet after the transition to beam-trawling had taken place. The assigned quota for a number of fishing areas (I, II, IIIa, Vb (Faröer), XII, and XIV) are generally not utilized today and they are exchanged with other EU countries, for other species or fishing areas. In non-EU waters, Belgian vessels dispose of limited quota in Norwegian waters based on bilateral agreements.

### 1.6.3 BELGIAN SEA FISHERIES: CURRENT ADMINISTRATION AND MANAGEMENT

Since the creation of the Kingdom of Belgium in 1830, the responsibility for marine fisheries has changed between ministries such as the ‘Ministry of Mobility and Infrastructure’ created in 1884, the ‘Ministry of Mobility, Post, Telegraphy and Telephones’, the ‘Ministry of Labour and Industry’, and the Ministries responsible for Agriculture in the Belgian government. With the regionalization of Belgium, the Flemish government was created in 1980 by the Special Act of 8 August 1980. The *Lambermont agreements*, signed in 2002, finally transferred sea fisheries from the federal level to the domain of agriculture of the Flemish government. The federal government of Belgium is responsible for the environment, mobility, energy, nature conservation, heritage and spatial planning at sea.

Access to Fisheries in Flanders is managed through a collective system, by a Quota Commission which consist of representatives of the different segments of the fleet and is coordinated by the (only) producers organisation. The Quota commission also advices the Flemish government in terms of regulating the fishing effort, seasonal and spatial access to the resources, and the exchange of quota with other EU MS.

Recreational fisheries on the Belgian part of the North Sea mainly use small beam trawls (<3m wide) for flatfish and shrimp, while sea angling for cod and European sea bass are quite popular. The dimension of recreational fishing is unknown since it is not subject to licensing or reporting.

In Belgium, the Fisheries Authority (department of Agriculture and Fisheries, Flemish government) together with the producers' organization, the Fisheries Research Institute ILVO and environmental NGO have taken first steps towards a more sustainable future for fisheries through a formal Agreement and a Strategy for Sustainable Fisheries (2011), which is carried forward by its Task Force. One of the main objectives and ambitions pursued by this Task Force is to promote the transition towards more sustainable fishing by means of a general prohibition of illegal, unreported and unregulated fish and fisheries (IUU), the use of fishing gear and fishing techniques (e.g. the sumwing, eco-beam trawl, hovercran-electric pulse system) with less impact on the sea floor and benthic species and habitats, exploring passive fishing techniques, and improving the quality of the fish products. By setting these aims and objectives, Belgian fisheries are closely aligning to the EU Common Fisheries Policy.

## 1.7 OBJECTIVES OF THE PHD STUDY

The present PhD study focuses on the commercial sea fisheries of Belgium, both in Belgian and in foreign waters. It covers the historical evolution in terms of species composition and economic value of landings, spatial dynamics, fleet dynamics, and aspects of impact of the fisheries. In order to develop this analysis, a major effort was invested in collecting and managing data and literature sources.

The core **research questions** that are addressed in the present PhD study are two-fold:

- What are the trends in the Belgian Sea Fisheries, based on standardized quantitative parameters in terms of input (fleet, effort) and output (landings, economic value), and compared to a historic baseline of one century ago?
- What are the quantitative impacts or indications of impact of the Belgian Sea Fisheries both on the targeted commercial fish stocks and on other marine living resources (e.g. bycatch), as reconstructed from these long-term data series?

To answer these questions, the following research **objectives** were set forward:

- To identify, rescue, describe, quality control, permanently store and safeguard historical data of the Belgian sea fisheries as far back in time as achievable, and to integrate these data into a standardized Historical Fisheries database HiFiDatabase. The HiFiDatabase is a product of the present PhD study.

- To reconstruct the overall history of Belgian Sea Fisheries based on the parameters related to:
  - volume and value of landings by species, by port of landing (kg, Belgian francs, Euro)
  - spatial dynamics (by fishing area)
  - temporal information (months, seasons, years)
  - fleet (number of vessels, vessel class, tonnage, type of engine, engine power)
  - fishing effort by fishing area, by fishery (days at sea, hours at sea, fishing days, fishing hours)
- To conduct an analysis of reconstructed time-series and of the relationships between these parameters: spatio-temporal trends in landings, value of landings, diversity of landings, fleet size and power, fishing effort.
- To reconstruct indicators of impact: historical total removals (including unreported catches and discards) by the Belgian Sea Fisheries, historical catch per unit of effort, historical catch compositions
- To document cases of ‘shifting baselines’ in Belgian Sea fisheries for important fishing métiers: the spent herring fisheries (1930-1960), the cod fisheries in Iceland (1947-1996), a reconstruction of total versus reported catches (1929-2010), others.

The scope of this research was on the production of the Belgian fleet: officially recorded and geographically explicit reported landings by the Belgian fleet, in the fish auctions in the Belgian ports and in foreign ports. Landings from foreign fleets in the Belgian ports are not covered in the present analysis.

## 1.8 OUTLINE OF THE THESIS

*This thesis is a compilation of research articles (published, under review or in preparation) , which are included as chapters. These articles are set in a broader research and policy context in the first introductory chapter, and the results are tied together in a general discussion in the last chapter. Although each chapter can be read on its own, there may clearly be some overlap in the introduction and description of material and methods. The cited literature is compiled as one list of references at the end of the thesis.*

The general context and rationale for setting up an initiative for the collection, quality control, standardization and integration of historical data with regard to sea fisheries in Flanders/Belgium is drawn in the first introductory part. It provides the rationale for the present PhD thesis. The objectives of the study are set in context of the current situation of sea fisheries in Belgium and the framework of European and international existing and upcoming legislation. It introduces some of the important concepts that are referred to throughout the thesis. The introductory chapter also draws a state-of-the-art of similar research efforts in marine environmental history and history of fish and fisheries, in Europe and elsewhere, as a context for the present PhD study.

A study that contains an important component of data management, from inventorying to digitization, standardization, integration and quality control, requires a detailed description of how this process was conducted. The second chapter therefore gives an overview of literature sources and screened databases, the process and methodology of data inventory, metadata, quality control, graphical analysis, and other aspects of data management and issues related to the reliability of the datasets. This chapter is adapted from the published paper with reference: *Lescrauwaet, A.-K.; Debergh, H.; Vincx, M.; Mees, J. 2010b. Historical marine fisheries data for Belgium: Data sources, data management and data integration related to the reconstruction of historical time-series of marine fisheries landings for Belgium. Fisheries Centre Working Paper Series, 2010-08. University of British Columbia: Vancouver. 69 pp.*

The third chapter draws on the first and broad findings of the data-integration process: it provides overall trends and findings related to the landing statistics by species or groups of species, by fishing area, by volume and value of landings, for the period 1929-2010. It also demonstrates some of the potential applications of the database to further reconstruct the historical trends for specific species or métiers. An example of reconstructed time-series of landings for cod (*Gadus morhua*) from 1835-2010 is included. *Published as: Lescrauwaet AK, Debergh H, Vincx M, Mees J .2010a. Fishing in the past: Historical data on sea fisheries landings in Belgium Mar. Policy 34(6): 1279-1289*

The spatial dynamics of sea fisheries in Belgium are described and documented in Chapter 4. Time-series of the fishing effort and landings for the 5 most important fishing areas are complemented with an analysis of species diversity of the landings. Annual trends and seasonal variability are presented and discussed for the most important fishing areas and species (plaice, sole, cod, shrimp,..). Special attention is dedicated throughout this thesis to the 'Coastal waters', considering their relative importance for sea fisheries in Belgium in terms of the value and volume of landings obtained from this nearby fishing area. The 'Coastal waters' were historically defined as the marine waters at 20-30 nautical miles distance from the coast, stretching from northern France into the Dutch territorial sea. In practice however, in the present thesis work it was found to provide a good proxy for the fisheries on the Belgian part of the North Sea (BNS).

Trends in landings can not possibly be interpreted in the absence of data on fleet dynamics. Chapter 5 brings a detailed reconstruction of time-series related to the sea fishing fleet in Flanders/Belgium: number, average and overall tonnage, average and total installed engine capacity, and parameters related to fishing effort (days at sea and fishing days). However, an analysis of trends in abundance and biomass of fish stocks requires data of landings and fleet dynamics at the scale of specific fishing metiers and fishing areas. *Published as: Lescrauwaet, A.-K.; Fockedey, N.; Debergh, H.; Vincx, M.; Mees, J. (2012). Hundred and eighty years of fleet dynamics in the Belgian sea fisheries Rev. Fish Biol. Fish. Online first: 15 pp*

Chapters 6, 7 and 8 take a closer look at the impact of sea fisheries, both on the targeted commercial stocks and on other marine resources. In Chapter 6, a quantitative approach is taken to reconstruct total removals by Belgian sea fisheries by including the unreported and misreported landings of commercial and recreational fishing, as well as an estimation of discards. This reconstruction covers 6 fisheries with historical or current importance for Belgium. Special attention is given to the Belgian part of the North Sea (BNS) and its fishing areas, estimating unreported removals and discards for these nearby waters. An indication of data and information gaps and challenges for future work is provided. The methodology applied in this reconstruction can serve as a blueprint for similar reconstructions in other countries. The results are useful to inform current policy issues and societal challenges. *Chapter 6 accepted for publication as: Lescrauwaet, A.-K., Torreele,' E., Vincx,' M., Polet, H. and Mees, J. accepted. Invisible Catch: A Century of bycatch and unreported removals in Sea Fisheries, Belgium 1929-2010. Fisheries Research. 2013. 10.1016/j.fishres.2013.05.007.*

Special attention is given in Chapter 7, to the exceptional situation of sea fisheries in Belgium during the Second World War WWII (1939-1945) when unusually high landings of herring (*Clupea harengus*) were achieved under restricted fishing conditions. Plausible arguments to explain these historical trends are explored and validated through additional historical data and information from population parameters. *Chapter 7 included as revised manuscript currently under review: Lescrauwaet, A.-K., De Raedemaecker, F., Vincx, M., and Mees, J. revised manuscript currently under review. Flooded by herring: Downs herring fisheries in the Southern North Sea during World War II. ICES Journal of Marine Science.*

Chapter 8 focuses on the otter trawl fishery in Icelandic waters targeting cod. Iceland's fishing resources have played a major role in the economy of fishing nations around the North Sea in the 20th century and before. The 'Iceland fishery' was of great economic importance in Belgium but decreased with the 'Cod Wars' (1958, 1972 and 1975) coming finally to a complete end in 1996. While the decline in total landings from Icelandic waters started after Iceland declared exclusive access to its territorial sea in 1958, the fishing effort of the Belgian fleet continued to increase until a peak was reached in 1963. Historical data on Belgian commercial fisheries landings and fishing effort include information on vessel type and fishing rectangle. The results document the Belgian gadoid fisheries in Icelandic waters from 1929-1995 and argue that the decline in the Iceland cod stock was visible at different levels, even before the Cod Wars. *Chapter 8 is included as manuscript currently under review. Lescrauwaet, A.-K., Vincx,' M., Vanaverbeke, J. and Mees, J. manuscript currently under review. In Cod we trust: Trends in Cod and gadoid Fisheries in Iceland 1929-1996. Canadian Journal of Fisheries and Aquatic Sciences.*

The conclusions in chapter 9 are oriented to the different topics addressed by this thesis including data management, research applications and potential future research, policy issues.

All data presented in this thesis are publicly made available on-line according to the Open Access principles and following a work plan that was set out at the beginning of the study. By setting up the HiFiDatabase the purposes and multiple advantages of databases over single-file-systems are achieved. Examples of how the HiFiDatabase has contributed - both in the context of the current PhD thesis and outside- to research and applications in fisheries management, are described in Chapter 7 and listed in the Appendices. The HiFiDatabase is an illustration of the Open Access and Open Data movement.

Furthermore, as data and information are consolidated and validated, different types of outreach and communication products are developed such as factsheets, timelines, photo-gallery, search options and summary articles for the wider public. A list of these publications and products is available from the annex list of publications by the PhD candidate.

By addressing the above objectives, this PhD thesis will have hopefully achieved its aim, of describing trends in Belgian Sea Fisheries over at least Ten Decades, with shifts in relative importance of each of the Seven Seas where the fleet has been operational historically, targeting a variety of at least Forty different Species as reported in the landings; **Belgian Sea Fisheries: Ten Decades, Seven Seas, Forty Species.**