Utrecht University

The Common Fisheries Policy: how does the implementation in European waters compare to that in northwest African waters?

A comparative analysis of the North Sea herring fishery and the central Atlantic sardinella fishery.

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Glossary

CCLME – Canary Current Large Marine Ecosystem
CECAF – Fisheries Committee for the Eastern Central Atlantic
CFP – Common Fisheries Policy
DWF – Distant water fleet
EC – European Community
EEZ – Exclusive Economic Zone
FAO – Food and Agriculture Organization of the United Nations
FPA – Fisheries Partnership Agreement
GRT – Gross Register Tonnage
HAWG – Herring Assessment Working Group
ICES – International Council for the Exploration of the Sea
JSC – Joint Scientific Committee
MSY – Maximum Sustainable Yield
SES – Social-ecological system
SFPA – Sustainable Fisheries Partnership Agreement
SSB – Spawning Stock Biomass
STECF – Scientific, Technical, and Economic Committee for Fisheries
TAC – Total allowable catch
UNCLOS – United Nations Convention on the Law of the Sea Convention

Abstract

The EC adopted the Common Fisheries Policy (CFP) in 1983 to 1) conserve their marine resources, 2) regulate their fisheries, and 3) maintain the activity of their distant water fleets (DWFs) in the Exclusive Economic Zones (EEZs) of non-EC coastal states by establishing fisheries agreements. The CFP reformation in 2002 extended the first two objectives to marine resources included in fisheries agreements. This study compares the implementation of the CFP in EC waters and non-EC waters by using two case-studies: the North Sea herring fishery and the central Atlantic sardinella fishery. These two case-studies are analysed by applying the social-ecological systems (SES) framework. This research focussed on the operational rules of the two fisheries and how these are influenced by the ecological performance measures of the two fisheries in terms of fishing mortality and spawning stock biomass (SSB). For the North Sea herring (*Clupea harengus*) fishery, a management plan including fishing mortality and SSB management reference levels has been in force since the adoption of the CFP to avoid overfishing or an overfished stock state respectively. These reference levels have been revised over time in alignment with the CFP, towards the maximum sustainable yield (MSY) principle. The operational rules are adapted in order to reach the management objectives. The MSY management objectives have been reached since 1997. The operational rules for the EC DWF targeting sardinella are established in fisheries agreements negotiated with the northwest African states. These agreements have granted access to the round sardinella (*Sardinella aurita*) and the flat sardinella (*Sardinella maderensis*). No management targets in terms of fishing mortality or SSB have been set for this fishery. In addition, fishing by the EC DWF continued to be allowed and even increased when the sardinella stocks were subject to overfishing and/or were overfished. The operational rules are thus not adjusted to reach the CFP objectives accordingly. This study therefore illustrates an inconsistency of the implementation of the CFP on EC fisheries in EC waters and non-EC waters.

Keywords: Common Fisheries Policy, *Clupea harengus*, *Sardinella aurita*, *Sardinella maderensis*, social-ecological system framework.

Chapter 1. Introduction

The industrialization of the fishing fleet enabled European fishing fleets to expand their fishing grounds all over the globe (Pauly et al., 2002; Swartz et al., 2010). Some technological innovations that played a role in this industrialization are the replacement of sailing vessels with steam engine trawlers in the 1890s, diesel engines after the First World War, and freezer trawlers equipped with radar and acoustic fish locating devices after the Second World War (Engelhard, 2008). Mechanized stern-ramp rather than side trawl nets furthermore allowed the use of much larger nets (Engelhard, 2008). Due to the expansion of fishing fleets and the fishing effort (the combination of the fishing capacity of the fleets and the fishing activity) in the 1950s and 1960s, global catches increased rapidly (Bell et al., 2017; Srinivasan et al., 2012; Swartz et al., 2010). This increase in catch, however, caused local depletion of target species (Lear, 1998; Palomares et al., 2020). As a response, European fishing fleets moved further offshore beyond their national jurisdiction, in their quest to encounter rich fishing grounds (Belhabib et al., 2012; Kalaidjian, 2010; Pauly, 2011; Tickler et al., 2018). These fleets are called distant-water fleets (DWFs).

The continuous growth of the fishing industry, depletion of fish stocks and consequent declining landings urged the need for (inter)national fishing regulations (EC, 1983a; UNCLOS, 1982). Especially considering the decrease of fishing activities during the two World Wars had shown that fish stocks could recover from heavy fishing pressures if fishing got reduced (Churchill & Owen, 2010; Pauly et al., 2002). The United Nations Convention on the Law of the Sea (UNCLOS), which was adopted in 1982, stressed the need for the sustainable use and conservation of marine resources (UNCLOS, 1982). It furthermore extended the geographical area in which coastal states have sovereign rights to explore, exploit, conserve and manage natural resources in the so-called Exclusive Economic Zone (EEZ) (UNCLOS, 1982). The European Community (EC) implemented the UNCLOS by adopting the Common Fisheries Policy (CFP) in 1983 (Okafor-Yarwood & Belhabib, 2020). This policy made the EC responsible for the regulation of the EC fishing sector and the protection of European marine resources (EC, 1983a). Another objective of the CFP was to maintain the activity of EC DWFs in their fishing grounds which had become Exclusive Economic Zones (EEZs) of coastal states (EC, 1983a).

After the implementation of the CFP, the EC negotiated fisheries agreements with several northwest African states (Alder & Sumaila, 2004; Bonfil et al., 1998; EC, 1987a, 1987b,1995; Kaczynski & Fluharty, 2002). A fisheries agreement includes which species may be caught in the host country's EEZ, financial compensation for the catch and technical requirements of the fishing vessels. The content of the fisheries agreements became more extensive in 2002 when the scope of the CFP objectives got extended to waters beyond their national jurisdiction in which their fleets were active (EC, 2002). From that moment, fisheries agreements included amongst others financial support to the host country fisheries sector to improve fisheries management and the responsibility of the EC to contribute to scientific research on the target species.

So although northwest African states have sovereign rights to conserve the fish stocks in their EEZs, the EC plays a role in this as well as stated in the CFP and the fisheries agreements. The objectives of the CFP have been the same in European and northwest African waters since 2002. Nevertheless, the EC has faced the critique of shifting their overexploitation issues to the EEZs of northwest African coastal states (Alder & Sumaila, 2004; Okafor-Yarwood & Belhabib, 2020; Witbooi, 2008). This suggests that the implementation of the CFP is not the same in European and northwest African waters.

To examine if there is indeed a difference in implementation of the CFP in EC and northwest African waters, this study compares the implementation of the CFP by analysing two case-studies: the North Sea herring fishery and the central Atlantic sardinella fishery. These fisheries are selected because the herring and sardinella are both small pelagic species with similar life history traits such as a small size, maturity at young age, high fecundity and a short life span (Adams, 1980; AFNS/IDRC, 1991; Ba et al, 2016; Bjørndal, 1988; Samba et al., 2021).

The Social-Ecological System (SES) framework is used to analyse the implementation of the CFP in these two fisheries (Ostrom, 2009). A SES consists of four subsystems: the resource system (the geographic location of a fishery), resource units (here, herring and sardinella), resource users (fishing industry), and governance systems (here, the CFP). Interactions between these subsystems lead to outcomes at the SES level, and in their turn influence the four subsystems (Ostrom, 2009). This framework is used to explore similarities and differences of the implementation of the CFP on regional fleets fishing on herring and European DWFs targeting sardinella. The objective of this study is to compare the implementation of the CFP in these systems. Therefore, this study focusses on interactions between the resource user and the resource unit (catch levels of users), between the users and the governance system (the fisheries management rules the users have to comply with), and on information sharing (data collection for management advice). The outcomes of these interactions are compared with ecological performance measures such as the size of the spawning stock biomass (SSB) and the fishing mortality of the stock relative to their management targets. In the comparative analysis, the similarities and differences of the variables in these two systems are highlighted and it will be investigated how ecological performance measures influence interactions between governance and users.

Chapter 2. Methods

This research used a comparative, case-study based approach. To analyse the case-study outcomes and their causes, this study compares six subsystems within the herring and sardinella fishery. A combination of peer-reviewed articles and online databanks was used.

2.1 Online literature search

Peer-reviewed articles were accessed via the two search engines Google Scholar (scholar.google.com) and WorldCat for Utrecht University (utrechtuniversity.on.worldcat.org/discovery). The search functions included the fish species and the second-level variable (table 1). Characteristics of the resource system were found with the search term of the North Sea or Canary Current Large Marine Ecosystem and primary production. Searches were performed on titles and abstracts in English. In addition, a search for French articles for sardinella was conducted as French is the second language in the northwest African countries included in this research (table 1). These articles were accessed by selecting French as the output language in the advanced settings of Google Scholar. Citations and the bibliography of articles were furthermore consulted to find more relevant literature. Despite the efforts described, I am aware that this method may have excluded relevant sources. For instance, no search in Google Scholar or WorldCat is conducted in the first language of the northwest African states.

A quality assessment of all articles was conducted. I assessed whether the articles were peer-reviewed, the types of sources used and how the sources where cited. Information cited was always traced back to the original source. Multiple sources were used to backup each statement. When reports or articles did not cite their sources or cited them faulty, these articles were judged as unreliable and were subsequently discarded.

Table 1. Literature search functions.
The same search terms are used for *Sardinella maderensis* and *Sardinella aurita*, but the searches were performed independently.

North Sea herring (EN)	Sardinella maderensis/sardinella aurita (EN)	Sardinelle maderensis/sardinelle aurita (FR)
Size, growth rate, fecundity, life history, spatial distribution, Common Fisheries Policy, management, management plan, management target, stock status.	Size, growth rate, fecundity, life history, spatial distribution, Common Fisheries Policy, European Union, distant water fleet, fisheries agreement, fisheries partnership agreement, sustainable fisheries partnership agreement, fisheries management, stock status.	Common Fisheries Policy, politique commune de la pêche, accord de pêche, Union européenne, flotte européenne, état de stock.

2.2 Information on fisheries agreements

The CFP and the fisheries agreements with the northwest African host countries were gathered from EUR-Lex (eur-lex.europa.eu), the official database of the EC providing access to EC law documents. The northwest African countries included in this research are Morocco, Mauritania, Senegal, The Gambia and Guinea-Bissau. All five countries have negotiated fisheries agreements including small pelagic species with the EC in different time intervals between 1980-present.

2.3 Data on catch levels and ecological performance measures

Three databases were conducted for the herring catch levels: ICES (ices.dk), FAO (FishStatJ software) and Sea Around Us (seaaroundus.org). ICES is an intergovernmental marine science organization which collects catch data, conducts stock assessments and provides fisheries management advice to the EC concerning the North Sea herring fishery. The ICES database shows catch levels of the autumn-spawning herring in the North Sea ecoregion. The FAO database shows the combined herring catch of all herring sub-stocks from the northeast Atlantic from 1950-2020. The Sea Around Us project shows the combined herring catch performed in the North Sea, not specified for the different sub-stocks. For this study, it is important to distinguish the North Sea autumn spawning herring sub-stock that falls under EC fisheries management and the herring sub-stocks that do not. Therefore, the ICES database was chosen to retrieve the herring catch level. Ecological performance measures in terms of herring SSB and fishing mortality were also obtained from the ICES database.

Sardinella catch levels were retrieved from the Sea Around Us project (seaaroundus.org). This project is a research initiative of the University of British Columbia. The Sea Around us research project reconstructs catch data performed in EEZs that are, or could be, claimed by coastal states under the UNCLOS. The project follows a seven-step approach for reconstructing the catch (Pauly et al., 2020). First, reported catch data are collected by area, taxon, and year. This data is retrieved from ICES for EC countries, and the FAO of non-EC countries. Missing data components are then identified based on literature searches and consultations with local experts. In the third step, alternative information sources for the missing data components are sourced. This leads to the establishment of anchor points for the missing catch data per country. These anchor points are then interpolated for the time periods in between the anchor points. The sixth step sums up the official catch data with the estimated catch data. Uncertainty of the catch reconstruction is quantified in the final step.
The Sea Around Us database was chosen as it provides sardinella catch performed in northwest African EEZs from 1950-2018 specified by fishing entities. This allowed for the calculation of catch performed by EC fishing entities. EC fishing entities were included in this calculation from the year they entered the EC.

Sardinella ecological performance measures were retrieved from 1) reports of the FAO Working Group on Small Pelagic Fish off northwest Africa, 2) a stock assessment of the Sea Around Us project, and 3) reports of the Joint Scientific Committees (JSCs) between the northwest African host countries and the EC. The reports of these JSCs are accessible online from 2017 onwards (ec.europa.eu). The EC Department for Environment, Maritime affairs and Transport did not grant me access to the JSC reports prior this time. The Europe Direct Contact Centre did send me redacted JSC reports with Mauritania of 2004, 2007-2011 and 2013-2014. According to the Europe Direct Contact Centre, these were the only JSC reports they had on file.

A limitation of the stock assessments performed by FAO Working Group on Small Pelagic Fish and the JSCs is that these are based on registered catches. However, Illegal, Unregistered and Unreported (IUU) catches are of concern in the northwest African study area (Agnew et al., 2010; Gascuel et al., 2007; Liddick, 2014). Only taking registered catches into account undermines the reliability of the stock assessments, and thus the reliability of the ecological performance measures presented in this study. This is why an additional search in Google Scholar and WorldCat was performed for peer-reviewed articles that did take IUU catches into account when assessing the sardinella stock. Sardinella catch levels retrieved from the Sea Around Us database included an estimate of IUU catches.

2.4 Study approach

In this study, the CFP is first described with regards to its objectives and principles. Then, the complex SES framework from Ostrom, 2009 is used to analyse the implementation of the CFP to the North Sea herring fishery and central Atlantic sardinella fishery. Within the SES framework, six subsystems are identified: the resource system, the resource unit, the resource users, governance system, interactions and outcomes. Each subsystem is composed of multiple second-level variables, as described in Ostrom, 2009. I began by reviewing the second-level variables for relevance to the study objective. This process resulted in the exclusion of several second-level variables. The selection of variables included in this research is presented in table 2.

The variables of the resource unit are included to illustrate the similarities of the herring and the sardinella. The governance system within the SES analysis regard the operational rules the resource users must adhere to. The users are described by their nationality and history of use, focussed on EC fishing entities. Interactions of interest are between the users and resource unit (catch levels of EC fishing entities), and the data of the stocks that is collected for fisheries management. Relevant outcomes are the ecological performance measures, and of specific interest is how these outcomes influence the governance system.

Table 2. Second-level variables for an SES for analysing the implementation of the CFP. Modified from Ostrom, 2009.

Subsystem	Second-level variable
Resource system	Location
	Primary production
Resource unit	Life history traits (size, life span, growth rate, fecundity, maturity at age)
	Spatial distribution in EEZs
Users	Fishing entities
Governance system	Operational rules
Interactions	Catch levels of users (in tonnes per year)
	Biological and fisheries data collected to perform stock assessments
Outcomes	Ecological performance measures (spawning stock biomass, fishing mortality and their management reference levels)

Chapter 3. Results

3.1 Governance system: the Common Fisheries Policy

In 1983, the EC adopted the CFP to manage the exploitation of living marine resources within the national jurisdiction of EC member states (EC, 1983a). The objectives of this policy were to protect EC fishing grounds, to conserve marine resources and to ensure long-term economic and social benefits from marine resources (EC, 1983a,1992, 2002, 2013a). The CFP consequently established principles and rules of fisheries management to be implemented on a fish stock or group of fish stocks exploited by EC fishing vessels. Every ten years, the CFP is evaluated to which extent the objectives are reached (EC, 1983a). As a result, the CFP has undergone three reforms since its adoption. Since 2002, the objectives of the CFP have been extended to non-EC waters in which EC distant water fleets (DWF) conduct fishing activities (EC, 2002). This meant that the fisheries agreements established between the EC and northwest African host countries should also follow the CFP principles from then onwards.

The first principle stems from 1983 and states that fisheries management plans must follow the best available scientific information. Information used regards, for example, the spawning stock biomass (SSB) (the combined weight of all fish in the fish stock that have reached sexual maturity), the fishing mortality (fraction of the stock that is caught) it is subject to and projections of these variables under different management measures. For EC fish stocks, this information is collected by ICES, an intergovernmental marine science organization. Besides the collection of information, the organization also advices on management plan refinements.

Under the 2002 reform, four additional principles for fisheries management plans were included in the CFP: 1) the multi-annual approach, 2) the target-driven management, 3) the ecosystem-based approach, and 4) the precautionary approach (EC, 2002). The first two principles entailed that management plans should work towards a target set over a specified number of years. These targets should be based on either the SSB, catches or fishing mortality. The third principle was introduced to change the fisheries management strategy from a single-species to an ecosystem-based approach, meaning that management plans should also conserve the functioning of the ecosystem from which the target species is caught by limiting the environmental impacts of the fisheries and reducing catches of non-target species. The precautionary approach urges management conservation plans to be implemented even when there is not sufficient scientific information regarding the size of the fish stock or the impact of fishing on a stock (EC, 2002).

To date, the last CFP reform took place in 2013 which presented the Maximum Sustainable Yield (MSY) principle (EC, 2013a). The MSY is the highest theoretic yield that can be sustained from a stock under average environmental conditions (Schaeffer, 1957). This model is based on the relationship between the biomass of the stock, the population growth rate, reproduction rate and natural mortality (Schaeffer, 1957). It assumes that the net growth of a stock can be caught by fisheries without depleting the stock. Net growth is highest at 50% of the maximum population size that can be sustained by the environment. This principle changed the target of management plans to keep or rebuild the SSB at the size at which MSY can be achieved (Bellido et al., 2020; EC, 2013a).

The management measures implemented to reach the CFP objectives are a combination of output and input control regulations (EC, 1983a,1992, 2002, 2013a). Since 1983, the corner stone of EC fish resource management has been an output control regulation: the total allowable catch (TAC) regime (Churchill & Owen, 2010; Da Rocha et al., 2010; Hegland, 2012). A TAC is an annually set stock-specific catch limit. A TAC will be increased when the SSB exceeds the target size or when the fishing mortality is below the target. In opposite situations, the TAC will be decreased. The TAC regime is essentially a single-species management approach and does not consider the effects of fishing on non-target species nor on the functioning of the ecosystem (Bellido et al., 2020; Möllmann et al., 2014; Reiss et al., 2010; Ulrich et al., 2012).

Bycatch regulations and the 2013 discard ban are examples of output control regulations that are in line with the ecosystem-based approach (Ono et al., 2018). The discard ban obliges fishers to land all catch if a catch limit applies to those species, instead of throwing it back in the water (Hatcher, 2014; Leitão & Baptista, 2017). This catch is then consequently deducted from the TAC of that species.

Input control regulations are furthermore in place to restrict fishing effort (the number of fishing vessels and their time spent at sea) and fishing efficiency (fishing gear, fishing zones and fishing seasons) (Bellido et al., 2020; EC, 1983a, 1992, 2002, 2013a; Kahlilian et al., 2010). These input control regulations can be designed to either benefit the target species or the ecosystem as a whole (Bellido et al., 2020; Ono et al., 2018; Reiss et al., 2010).

3.2 Case-studies: SES-descriptions

3.2.1 North Sea herring fishery

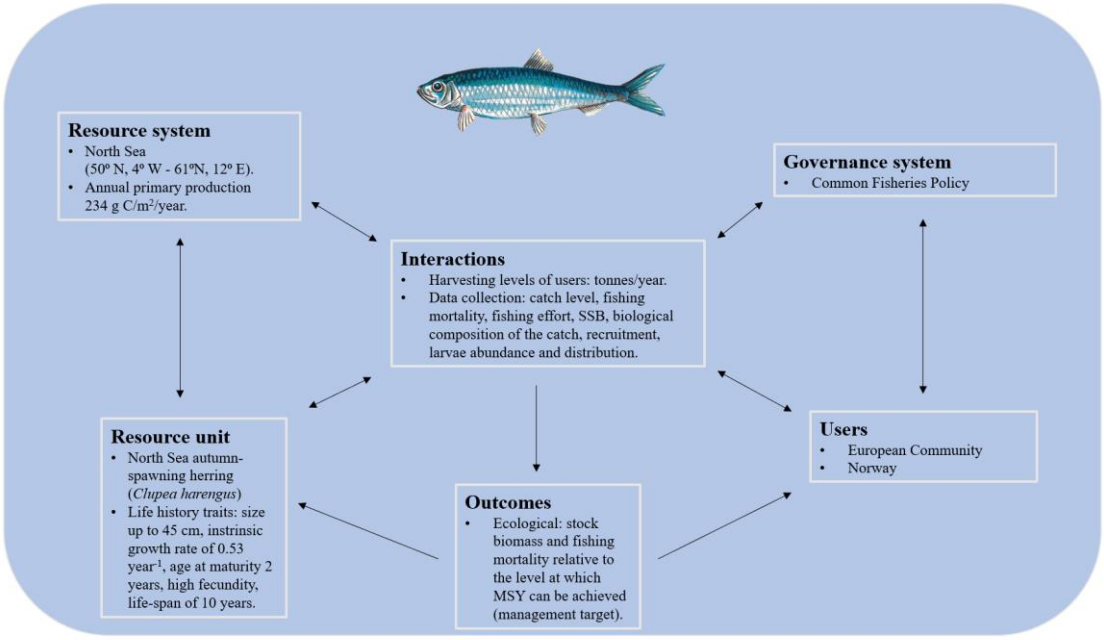

Figure 1. Ostrom's social-ecological systems framework operationalized for the North Sea herring fishery.

Resource system

The North Sea is located between 50º N, 4º W to 61ºN, 12º E. It borders the Netherlands, The United Kingdom, Belgium, France, Germany, Denmark and Norway (fig. 2) (Idon, 2004; Sündermann & Pohlmann, 2011). Annual primary production in this region is high, 234 g C/m^2/year, which supports a big variety of fisheries (Capuzzo et al., 2018). Overall primary production has however decreased since the 1980s due to 1) reduction of nitrogen and phosphorus load from river output, and 2) a warming sea surface temperature (Capuzzo et al., 2018; Desmit et al., 2020). Primary production is expected to further decline in the future due to global warming (Capuzzo et al., 2018; Desmit et al., 2020). This downward trend in primary production negatively affects the recruitment of herring (Capuzzo et al., 2018; Payne et al., 2009).

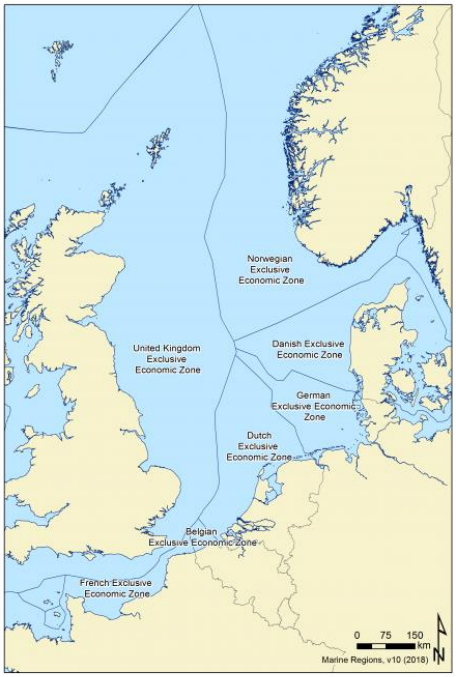

Figure 2. North Sea and the EEZ distribution of the coastal states therein.
Adapted with changes from Flanders Marine Institute (2022).

Resource unit

North Sea herring (*Clupea harengus*) is a pelagic fish species. It exhibits life history traits of an r-selected species: a small size (up to 45 cm), a high growth rate (0.53 year^{-1}), a low age at maturity (two years, with a length of 23.65 cm), a high but variable fecundity and a maximum age of 10 years (Adams, 1980; Berg et al., 2017; Bjørndal, 1988; Bjørndal & Lindroos, 2004). These life history characteristics contribute to a high reproductive potential which are selected on in environments where species are subject to unpredictable mortality factors (Adams, 1980;

Stearns, 1992). Due to these characteristics, herring can withstand relatively high natural and fishing mortality rates (Lowerre-Barbiere et al., 2015; Winemiller, 2005).

Three sub-stocks of North Sea autumn spawners are identified based on the location of their spawning grounds: the east of Scotland, the east of England and the English Channel (Bjørndal & Lindroos, 2004; Frässler et al., 2011). Outside the spawning period, these sub-stocks mix in the central and northern North Sea where fishing takes place (Bjørndal & Lindroos, 2004; Frässler et al., 2011). Herring migrates between the EEZs of the United Kingdom, France and Norway which makes it a transboundary fish resource (Bjørndal & Lindroos, 2004; Gullestad et al., 2020). The latter indicates that the EC and Norway are responsible for the co-management of the herring fishery under the UNCLOS.

Users

North Sea herring is caught by fleets from The United Kingdom, Norway, The Netherlands, Germany, Sweden, and Denmark. (ICES, 2018; Pauly et al., 2020). As herring is a schooling pelagic fish, the common fishing methods used for herrings are purse seines and mid-water trawlers (Bjørndal & Lindroos, 2004; Pauly et al., 2020). Both fishing techniques are active gears, meaning the gear is towed through the water to capture the fish. Purse seines deploy large nets that encircle a school of fish after which bottom side of the net is tightened and the net is pulled in (Tenningen et al., 2017). Sonars are used to detect and assess the characteristics of the herring school before a purse seine net is deployed (Tenningen et al., 2017). Mid-water trawls on the other hand are towed through the water column, and these fisheries use combinations of sonar and echo sounders to detect herring (Suuronen et al., 1997).

Governance system: operational rules

The first management regulation for the North Sea herring fishery was implemented in 1977 before the CFP was adopted: a closure of the herring fishing grounds after the fishery had collapsed (Dickey-Collas et al., 2010; Economic and Social Committee, 1978; ICES, 2018). The aim of this measure was to give the herring the opportunity to recover to a SSB of at least 800.000 tonnes in the North Sea (ICES, 1978). By maintaining the SSB at this level, it was believed that herring recruitment and stock growth were sufficient to allow fishing again. This target was reached in 1983, after which the herring fishery was opened again (ICES, 1984). At this time, the UNCLOS and CFP were adopted.

Acting in line with the UNCLOS and the CFP, the EC and Norway have cooperated in managing the transboundary North Sea herring stock (Dickey-Collas, 2016). The overall management aim has been to recover and maintain the herring SSB above 800.000 tonnes (ICES, 1984, 2018). In order to reach this goal, the main management measure has been to restrict the fishing mortality. Parameters that determine the allowed fishing mortality rate are the SSB estimation, past and projected recruitment, natural mortality and the size structure of the stock. A TAC follows from the fishing mortality target, which is consequently distributed amongst EC member states and Norway; the EC receives a 71% share and the rest goes to Norway (Arnason et al., 2018).

The fishing mortality and SSB management targets have been revised over time according to new management principle that were incorporated in the CFP. To deal with the uncertainty in the scientific data on which fisheries management is based, precautionary reference levels were introduced in the herring fisheries management plan in 1998 (González-Laxe, 2005; ICES, 2013). Precautionary levels try to avoid the potential risks of a fishery collapse that

could occur due to the uncertainty in estimations and future projections (González-Laxe, 2005). In 2013, the MSY framework was implemented (EC, 2013a). This changed the SSB and fishing mortality management targets to levels at which MSY can be achieved (ICES, 2013).

Several other measures have furthermore been in place. To protect juvenile herring, a minimum landing size of 20 cm is permitted to give juvenile herring the opportunity to grow and contribute to recruitment before being captured (EC, 1983b, 2019b). In addition, herring spawning grounds of the herring are seasonally closed for fishing (EC, 1984, 1997, 2019b). Lastly, a maximum number of vessels is allowed to fish simultaneously, to reduce fishing effort (EC, 2019b).

Interactions

1. Catch levels of users

Catches increased from the 1950s, with a sharp rise in 1962. This was driven by the increase of fishing efficiency due to the introduction of purse seine nets, echo sounders and sonar (Bell et al., 2017; Srinivasan et al., 2012; Swartz et al., 2010). From 1965, herring catches dropped rapidly (fig. 3).

From 1977 to 1983, a fishing moratorium restrained the activities of herring fishers. Herring fishing has been restricted by TACs since the fishing ban got lifted in all areas of the North Sea in 1983 (ICES, 1984; 2018). Since then, the trend in catches have therefore been caused by either TAC reductions or elevations.

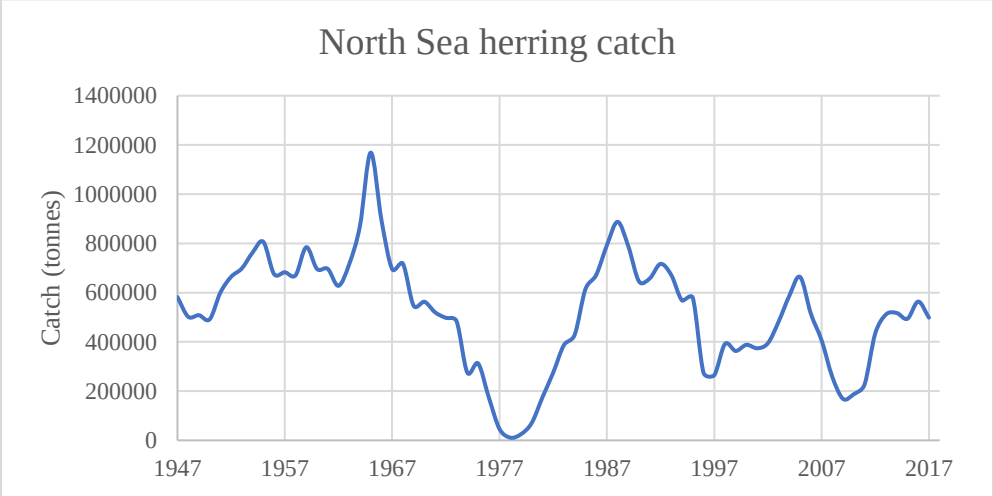

Figure 3. North Sea herring landings 1947-2017
Landings have been recorded since 1947. Introduction of industrialized fleets are visible in the steep increase of landings in 1962. The fishery closed from 1977 until 1983. Some illegal herring fishing occurred in the English Channel during this period and herring was also caught as bycatch of other fisheries in the North Sea. Data derived from ICES, 2018.

2. Data collection

National catch registration of the herring fishery started around the beginning of the 20th century (Simmonds, 2009). Since the 1960s, the North Sea herring has been assessed by the Herring Assessment Working Group (HAWG) for the Area South of 62ºN, an ICES working group (Dickey-Collas et al., 2010; ICES, 1969, 1971). Annual herring stock assessments have been performed by the HAWG since 1980.

Part of the data collected by the HAWG is fishery dependent and part is fishery independent. Fishery dependent information includes annual catches (wanted, unwanted and discards), fishing mortality, biological composition of the catch (size, age and weight), and changes in the fishery. Fishery independent information are retrieved with acoustic surveys (to determine mean weights-at-age, maturity-at-age and natural mortality), bottom trawl surveys (to determine recruitment and abundance of large herring larvae), and larvae surveys (to determine abundance and distribution of newly hatched herring larvae).

The stock assessments and the resulting fisheries management advice is shared with the Scientific, Technical and Economic Committee for Fisheries (STECF) of the EC (Borges, 2018; Churchill & Holden, 2010; Penas, 2007). The STECF assesses the socioeconomic consequences of the HAWG management advice. Both the HAWG and STECF provide management advice to the European Commission.

Outcomes

Until 1983, the North Sea herring was an open access resource. This meant that all users enjoyed free access to the North Sea herring beyond the territorial sea of the United Kingdom, France and Norway. The territorial sea extends 12 nautical miles from the shoreline. The open access regime enabled the rapid rising fishing mortality levels from the 1960s which led to the depletion of the stock as described in the "Tragedy of the commons" (Box 1). Fishers continued fishing for herring when their catches decreased in 1965, also because higher herring prices compensated the reduced catches rates, thereby enabling the herring fleet to survive a while longer (Dickey-Collas et al., 2010).

Box 1. A tragic relationship between user and resource unit in an open access regime

In open access regimes, no actor holds property rights over the marine resource. Hence, each fisher is allowed to conduct fishing activities freely. Such regime ultimately leads to the depletion of fish resources. The reason why fishers continue to maintain or increase their fishing pressure when catches decline, is due to "The tragedy of the commons", described by Garret Hardin (Hardin, 1968). Although Hardin originally described a tragedy for a common good, he actually describes a tragedy of an open access resource (Feeny et al., 1990; Frischmann et al., 2019; Ostrom, 2009).

The Tragedy of the Commons consists of multiple consecutive stages, starting when the exploitation of a fish stock starts and then appears to be successful. Revenues of the fishers in this stage will be high which makes the fishers expand their activities, and attract more fishers. Environmental side effects of the increased fishing activity will start to become visible in the next stage, such as changed life histories of the fish species or a decline in average age or size of the caught fish. Users will, however, continue fishing as the positive utility of catching an extra fish increases their individual revenue whereas the negative side effects are shared between all users.

As the positive utility of overfishing exceeds the shared negative utility, users will use their maximum potential in pursuit of a maximum revenue. This short-term self-interested fish harvesting threatens long-term harvesting of a finite resource (Gifford & Wells, 1991). This ultimately leads to the collapse of a fishery, leaving the fishers with no revenue at all.

This tragedy and the outcomes of the herring management that followed from 1977 can be assessed by comparing the fishing mortality and SSB relative to their reference levels (Box 2). Here, the two parameters are compared to their level at which MSY can be produced. This allows to determine whether the management targets are reached, or if the herring stock continues to be overfished or subject to overfishing.

Box 2. The difference between 'overfishing' and 'overfished'

Fish stock assessments give an estimate of the fishing mortality and stock abundance. Comparing these with the corresponding management targets, the ecological performance measures of the fishery can be determined (Hilborn, 2020; Zhou et al., 2012). The estimation of fishing mortality gives an insight whether the stock is sustainably harvested or overfished, yet the size of the stock is used to judge whether a stock is in a healthy or overfished state (Collie & Gislason, 2001; Costello et al., 2016).

Overfishing is a process and takes place when the fishing mortality exceeds its management reference level (Costello et al., 2016; Hilborn, 2020). Until the introduction of the MSY principle, the management target was a set mortality rate by ICES. The MSY principle altered the definition of overfishing to a fishing mortality higher than the fishing mortality at which MSY can be achieved (F_{MSY}) (Hilborn, 2020; Mace, 2001).

An overfished stock can be the consequence of overfishing. A fish stock is considered to be overfished when the SSB is below the level at which recruitment of a stock is likely to be impaired and is below the level at which MSY can be achieved (Guillen et al., 2016).

Although these concepts are related, they do not have to co-occur. A fish stock can for instance be subject to overfishing albeit still being in a healthy state (Froese et al., 2018; Methot et al., 2014).

Indeed, the herring stock was subject to overfishing from the 1960s (fig. 4). This got followed by a rapid decline in SSB which reached the overfished state in 1967 (fig. 4). The fishing moratorium allowed the herring SSB to reach the recovery target (B_{lim}) in 1983. Catch limits were implemented when the fishing moratorium was lifted. Agreed TACs by the European Council exceeded the HAWG advice on average with 7% between 1987-1995, up to 26% and 27% in 1994 and 1995 respectively (ICES, 2019). Due to the increasing fishing pressure in the 1990s in combination with a low recruitment in the 1990s, the SSB dropped below the level at which MSY could be achieved again (Frässler et al., 2011; Nash et al., 2005; Payne et al., 2009). Stringent catch restrictions were imposed in 1995 as a response. Since 1997, the herring stock is likely not overfished nor subject to overfishing (fig. 4). Even though the TAC set in 2018 and 2019 exceeded the HAWG advice with 16% and 24% respectively (ICES, 2019).

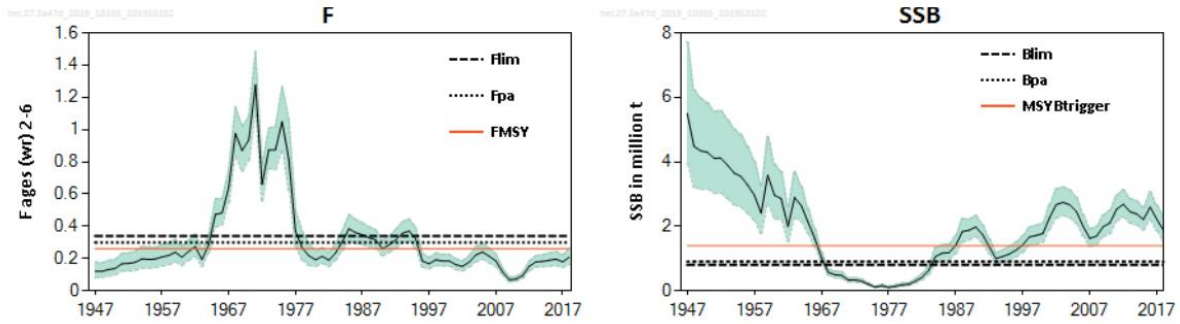

Figure 4. Stock assessment of the North Sea autumn-spawning herring between 1947-2017.
This figure shows the fishing mortality (left) and spawning stock biomass (SSB) (right) and their reference levels of the North Sea autumn spawning herring. The shaded green areas represent the 95% confidence interval of the fishing mortality and SSB estimates. The fishing mortality and SSB reference levels are set in 2019.
Adapted with changes from ICES, 2019.

3.2.2 Central Atlantic sardinella fishery

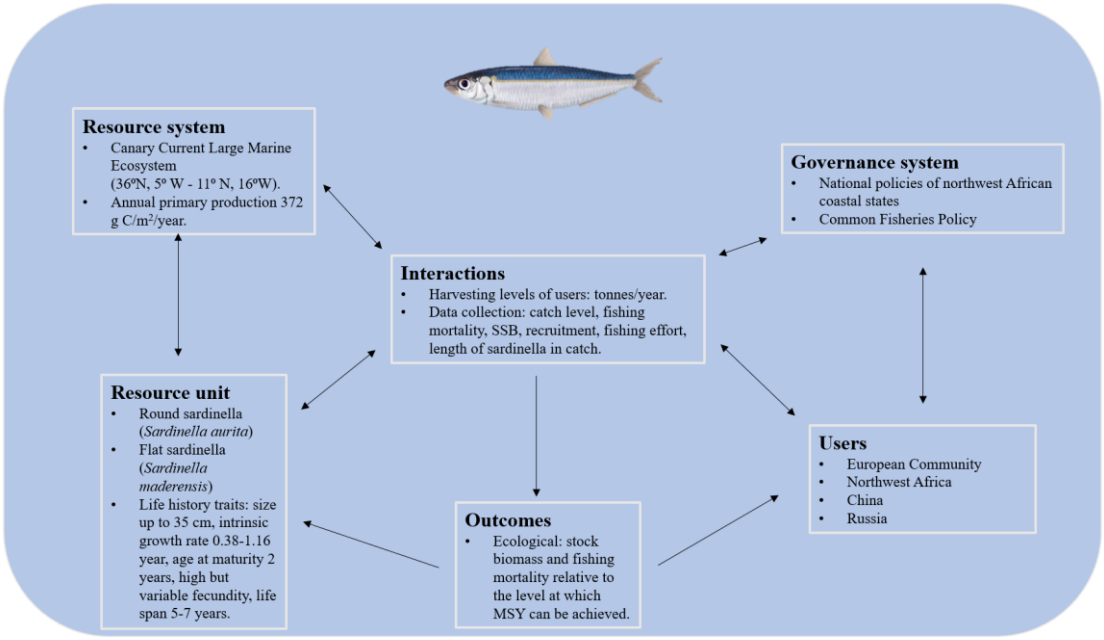

Figure 5. Ostrom's social-ecological systems framework operationalized for the central Atlantic sardinella fishery.

Resource system

The Canary Current Large Marine Ecosystem (CCLME) is an eastern boundary upwelling system named after the eastern branch of the subtropical gyre in the North Atlantic: the Canary Current (Bakun, 1990; Grecian et al., 2016; Halpern, 1977; Kämpf & Chapman, 2016). It extends from around 36ºN, 5º W to 11º N, 16ºW, along the coasts of Morocco to Guinea-Bissau and westwards to the Canary Islands (fig. 6). This ecosystem is one of the most productive areas in the ocean with a production of 372 g C/m^2/year due to strong year-round coastal upwelling (Arístegui & Montero, 2005; Chavez & Messié, 2009; Sambe et al., 2016). A wide variety of species is therefore supported in the waters along the coast (Anabalón et al., 2014; Braham & Corten, 2005; Grecian et al., 2016). The primary production of the CCLME has been decreasing over the past four decades due to rising sea surface temperatures (Sambe et al., 2016).

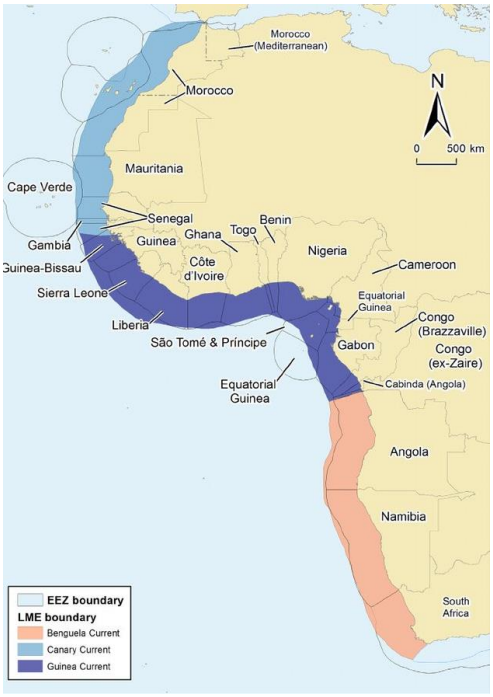

Figure 6. West African Large Marine Ecosystems and the Exclusive Economic Zone distribution of the coastal states therein. Adapted with changes from Belhabib et al., 2016.

The ecology of the CCLME exhibits a wasp-waist trophic structure, a common characteristic of eastern boundary current systems (Curry et al., 2000; Kämpf & Chapman, 2016; Madigan et al., 2012). Small pelagic fish are the dominant species in this food web, and they are responsible for the population control of species in lower and higher trophic levels (Braham & Corten, 2015; Curry et al., 2000).

Resource unit

Two sardinella species inhabit the central Atlantic Ocean: the round sardinella (*Sardinella aurita*) and the flat sardinella (*Sardinella maderensis*) (Ba et al., 2016; Samba et al., 2021).

Sardinellas are pelagic fish, with a high but variable intrinsic growth rate (0.38-1.16 $year^{-1}$), a small maximum size (up to 35 cm), a high fecundity with year to year variations depending on the weight and size of the females, a short life-span (5-7 years) and a young age at maturity (2 years with a length of 18.5-22.5 cm) (Baldé et al., 2019; Boëly et al., 1982; Palomares et al., 2020; Samba et al., 2021). These life history traits indicate that the sardinellas are r-selected species, at least potentially able to withstand high natural mortality rates and fishing pressure (Adams, 1980).

The distribution of sardinella is dependent on the seasonal upwelling and resulting zooplankton abundance (Ter Hofstede et al., 2007; Zeeberg et al., 2008). Round sardinella migrates northward from the Senegalese to the Moroccan EEZ between May-August (Brochier et al., 2018; Ter Hofstede et al., 2007). In December, the species moves southwards again. The migration pattern of the flat sardinella is less pronounced (AFNS/IDRC, 1991; Ba et al., 2016). Fisheries follow the migration routes of the sardinella, and mainly target round sardinella due to its higher commercial value (Braham & Corten, 2015; Corten et al., 2017).

Users

Sardinella is caught by both northwest African fleets and DWFs (Alder & Sumaila, 2004; Belhabib et al., 2019; Corten, 2017). Northwest Africa's artisanal sector uses canoes (pirogues), drift gillnets, encircling gillnets and beach sine nets (Ba et al., 2017; Trouillet et al., 2011). The artisanal sector is labour intensive and operates close to shore although this sector has become motorized. In addition, northwest African industrial fishing fleet has gained importance since the mid-1960s (Pauly et al., 2020).

Industrial DWFs predominantly fly the flag of a variety of EC member states, Russia, and more recently China (Alder & Sumaila, 2004; Mallory, 2013; Pauly et al., 2020). These fleets deploy freezer trawlers, non-freezer trawlers and purse seiners. In addition, a part of the industrial fishing fleet flying the flag of northwest African countries are in fact reflagged European or Chinese vessels (Alder & Sumaila, 2004; Belhabib et al., 2013; Belhabib et al., 2015, Intchama et al., 2020). Reflagging of European vessels occurs when their allocated fishing quotas have been used (Guggisberg, 2019; Intchama et al., 2020). As operators are not allowed to establish private agreements with the northwest African host countries, reflagging allows for these vessels to continue their fishing practices (Espósito et al., 2016; Mulazzani & Malorgio, 2014; Salomon et al., 2014 Watson et al., 2014).

Governance system: operational rules

Fisheries agreements between the EC and northwest African coastal states are the implementation of the UNCLOS and CFP. These agreements grant EC fishing vessels access to fish stocks in the EEZ of the host countries with whom the fisheries agreements are established. The content of the fisheries agreements has become more extensive over time in line with the CFP reformations (EC, 1987a, 1995, 2001, 2006, 2008, 2015, 2019a).

The first fisheries agreement including small pelagic fish such as sardinella was established with Senegal in 1980, followed by Mauritania and Gambia in 1987 and Morocco in 1995 (fig. 7) (EC, 1980, 1987a, 1987b, 1995). In these agreements, allowed fishing zones and fishing gear for small pelagic fisheries was arranged. Access of fishing vessels to small pelagic fish was limited based on the vessel's Gross Registered Tonnage (GRT), a measure of the cubic capacity of a vessel (Peng et al., 2011). This measure is not an indicator for a vessel's fishing capacity. Instead, fishing capacity is related to a vessel's engine power, net size and time spent fishing (Aranda et al., 2012; Stilwell et al., 2010). Financial contribution was also

agreed based on a vessel's GRT (Kaczynski & Fluharty, 2002; Witbooi, 2008; EC, 1987a, 1995, 2002, 2006, 2008). This therefore meant that under these fisheries agreements, EC fishing vessels could catch an unlimited amount of small pelagic fish for a fixed price.

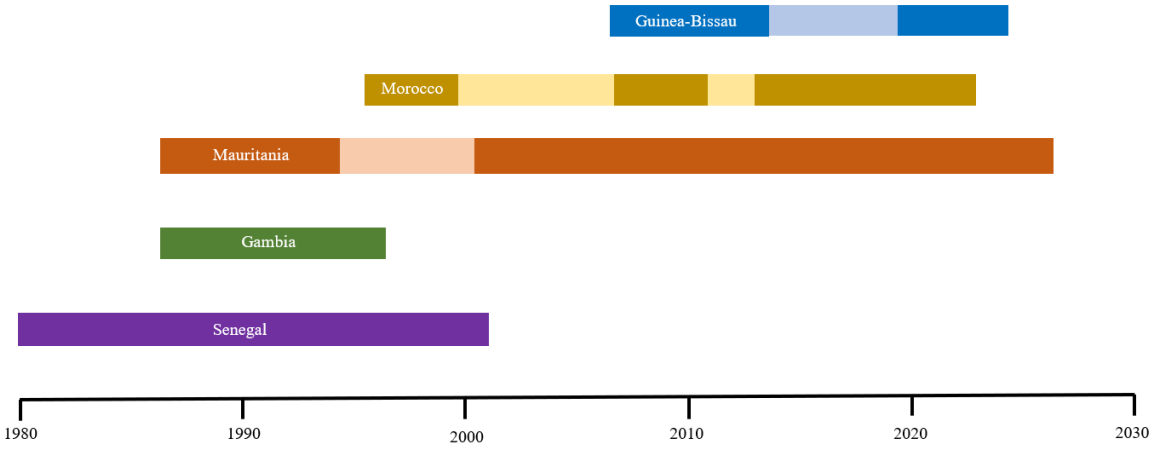

Figure 7. Timeline of fisheries agreements with northwest African coastal states including small pelagic fish. The dark colours indicate fisheries agreement including small pelagic fish were in force between the EC and the corresponding northwest African coastal state. The light colour indicates periods of absence of fisheries agreements including small pelagic fish.

After the CFP's objectives got extended to external waters in 2002, the EC established so-called Fisheries Partnership Agreements (FPAs) with northwest African host countries. New in these agreements were financial contributions for research to improve information on fishery resources, financial support for northwest African fisheries and sectoral support to the fisheries surveillance performed by the host countries (EC, 2001, 2006, 2007, 2008). FPAs furthermore added the responsibility of the EC to promote responsible fishing by setting up a Joint Scientific Committee (JSC) with the host country. This committee received the responsibility to publish an annual scientific report on the fisheries covered in the fisheries agreement in order to 1) improve the understanding of the state of the fisheries resources, and 2) adopt measures where necessary to ensure sustainable management of the fisheries resources. New in the 2006 FPA with Mauritania was a combined small pelagic fish catch limit in tonnes for pelagic freezer trawlers (EC, 2006). Non-freezer trawlers in Mauritanian waters were still only limited by their GRT.

The third CFP reform in 2012 resulted in a further expansion of the fisheries agreements, which were from then on called Sustainable Fisheries Partnership Agreements (SFPAs). Newly added was sectoral support to assist host countries in implementing sustainable fisheries policies and improving fisheries management, monitoring, control and surveillance (EC, 2013b, 2015, 2019a, 2019b). SFPAs with Morocco and Mauritania furthermore included catch restrictions in tonnes of small pelagic fish per year, but still not specific to sardinella (EC, 2013b, 2015). The 2019 SFPA with Guinea-Bissau on the other hand still includes a GRT limit on small pelagic fish for the first two years (EC, 2019a). A small pelagic catch restriction in tonnes of fish is agreed from 2021 onwards. A minimum landing size of sardinella of 18 cm was agreed with Mauritania only in 2019.

Interactions

1. Catch levels of users

Total sardinella catch has fluctuated, but shows an overall increasing trend since 1950 (fig. 8). Catch increased steadily from 1950-1970, after which the catch fluctuated periodically. European fleets commenced sardinella fisheries in the mid-1960s, but the catches took off more seriously in 1995 when a fisheries agreement with Morocco was established (fig. 8) (EC, 1995). The dominance of the EC DWF catches increased from 19% in 1995 to 39% in only two years. A drop in EC DWF sardinella catches occurred when the fisheries agreement with Senegal ended in 2002.

Since 2008, the total sardinella catch shows an increasing trend (fig. 8). This is mainly due to the development of a fishmeal industry in Mauritania, and the arrival of Chinese distant water vessels (Cherif, 2009; Corten et al., 2017; Pauly et al., 2020). The dominance of the EC fleet of the sardinella catch decreased in 2012 when Mauritania restricted access to DWFs in their coastal zone (EC, 2012). Several EC DWFs consequently left (CSC, 2014). The influence of Mauritania's access restriction to DWFs in their waters is not visible in the sardinella catch of non-EC DWFs, as their catch in this fishing region continues to show an increasing trend (fig. 8).

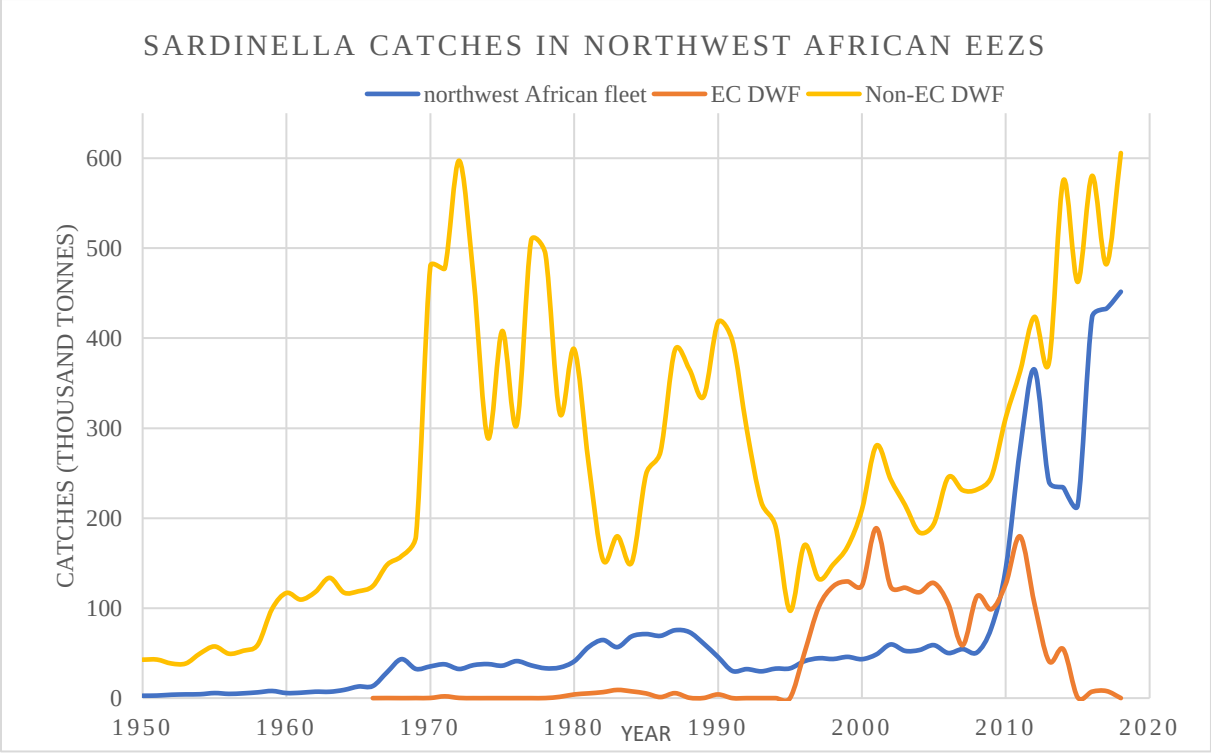

Figure 8. Sardinella catches in northwest African EEZs from 1950-2018.
This figure shows the catches of the round and flat sardinella in the EEZs of Morocco, Mauritania, Senegal, Guinea-Bissau and Gambia. These EEZs include the waters that countries have claimed under the UNCLOS, and the corresponding area is used for the years prior the EEZ declaration. The blue line represents the catches performed by fleets of the former five northwest African states. Catches of EC member states (orange) include the following fishing entities from the year these joined the EC: France (1958), Germany (1958), the Netherlands (1958), Italy (1958), Ireland (1973), the United Kingdom (1973), Portugal (1986), Spain (1986), Estonia (2004), Latvia (2004), Lithuania (2004), Poland (2004), Romania (2007). The non-EC DWF (yellow) includes catches from distant water fishing vessels that do not fly the flag of an EC member state.

2. Data collection

The northwest African coastal states are responsible for conducting scientific research on their fish resources, and to set measures based on this information. These states are united in a Fisheries Committee for the Eastern Central Atlantic (CECAF), established by the Food and Agriculture Organization of the United Nations (FAO). The CECAF is among others responsible to review the state of the fish resources, to establish the scientific basis for fisheries management measures and to recommend the northwest African states in the implementation of management measures. Within the CECAF, the Working Group on the Assessment of Small Pelagic Fish off Northwest Africa, further referred to as the FAO Working Group, has been responsible for the assessment of the sardinella and consequent management recommendations since 2002 (FAO, 2002). For this working group to review the state of the sardinella, the five northwest African states must submit catch data, data on fishing effort, acoustic surveys, and length sampling of the sardinella in the catch. However, the information submitted is often inadequate or incomplete which hinders the ability to assess the state of the stock and to make fisheries management recommendations (Corten, 2014; Trouillet et al., 2011; Lakhnigue et al., 2019).

After the 2002 CFP reform, the EC established JSCs with the northwest African host countries to collect scientific data on the sardinella species, to assess the state of the target fish species and to give fisheries management recommendations (EC, 2001, 2002, 2006, 2007, 2008).

Outcomes

The outcomes of the central Atlantic sardinella fishery are based on the fishing mortality estimates and biomass estimates relative to the level at which MSY can be achieved. Three sources have been conducted, which show different results.

1. FAO Working Group

This working group has been conducting stock assessments on the sardinella stocks in the waters from Morocco to Senegal since 2002 (FAO, 2002). The first stock assessments concluded there were no signs of overfishing on both the round and flat sardinella (FAO, 2002, 2003, 2004). Three years later, it showed both species were subject to overfishing (FAO, 2006a). The round sardinella was even judged to be overfished in 2005, and the flat sardinella was fished at the level at which MSY could be achieved (FAO, 2006a). Overfishing continued in the following years, and the flat sardinella has been assessed to be overfished since 2009 (FAO, 2011, 2020).

Since 2013, no reliable results on the stock size and fishing mortality have been obtained (FAO, 2015a, 2016, 2018). No reference points for the fishing mortality and biomass size could consequently be established by the working group. This is due to incomplete catch statistics in Mauritania, interruption of acoustic surveys in the entire sub-region since 2009, a lack of quantitative data of the fishing effort of non-EU vessels, insufficient data provided by the northwest African coastal states, and incomplete sampling of the catch (FAO, 2015a, 2016; 2018). Nevertheless, the FAO Working Group assessed the sardinella stocks to be overfished and consequently recommended a reduction in fishing effort of 50% (FAO, 2013). In 2018, the FAO Working Group concluded that the biomasses of the round and flat sardinella has been lowest in history and that the fishing pressure on both stocks is still higher than at which MSY can be achieved (FAO, 2018, 2020).

2. Joint Scientific Committees

The JSC of the EC and Morocco, Mauritania and Guinea-Bissau publish reports on the fisheries included in the fisheries agreements, and the stock status of the species exploited. The JSC with Morocco and Mauritania perform stock assessments for the round and flat sardinella stock in the coastal waters from Morocco to Senegal, corresponding to the research area of the FAO Working Group (CSC, 2004, 2017b). On the other hand, the JSC with Guinea-Bissau, performs a combined stock assessment of the round and flat sardinella in their EEZ only (CCC, 2017).

Since 2004, the JSC with Mauritania reports that the catches of the round sardinella should not increase (CSC, 2004, 2008, 2009, 2010, 2011, 2013, 2014, 2017a, 2018, 2021). Both sardinella stocks were considered fully exploited. In 2008, the round sardinella was considered to be overfished whereas the flat sardinella was considered underfished (CSC, 2008). Two years later, in 2010, the JSC concluded that both sardinella stocks were subject to overfishing and that the state of these stocks was overfished (CSC, 2010). It furthermore concluded that although the stocks had been subject to overfishing for some years already, no effective management plan had been established between the northwest African states which share the resources (CSC, 2010). In fact, fishing effort by the EC DWF on the sardinella stocks, and their catches, continued to increase (fig. 9). The report of 2014 urged the need of northwest African coastal states to establish catch restrictions and to divide these correspondingly (CSC, 2014). Then, Mauritania would be able to set a catch limit for the EC fleet.

In 2014, the JSC with Mauritania could not perform a stock assessment due to a lack of data. This was again the case in 2017 for the JSC with Mauritania and Morocco (CSC, 2014, 2017a, 2017b). In 2020 and 2021 the JSC with Morocco and Mauritania assessed both species to be overexploited, respectively (CSC, 2020, 2021).

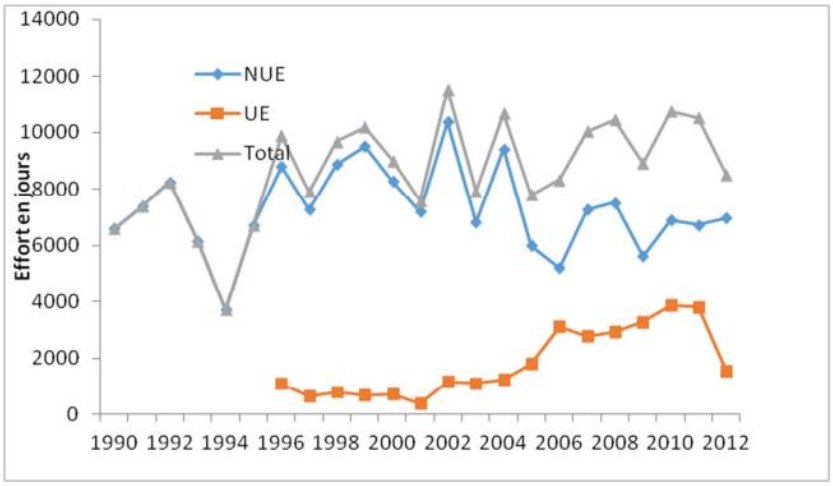

Figure 9. Fishing effort on small pelagic fish in northwest Africa.
This figure shows the fishing effort in hours of the fishing fleet targeting small pelagic fish in northwest African the waters of Morocco to Senegal. The orange line (UE) represents the fishing effort of the EC fleet. The blue line (NUE) represents the non-EC fishing fleet, consisting of DWFs and northwest African fishing fleets. The grey line (total) is the combined total of fishing effort.
Adapted with changes from CSC, 2013.

The outcomes of the JSC with Guinea-Bissau look quite differently, as these show that the sardinella SSBs have exceeded the biomass at which MSY can be achieved since 2002 (fig. 10). It furthermore shows that overfishing occurred between 2008-2012 and again since 2014.

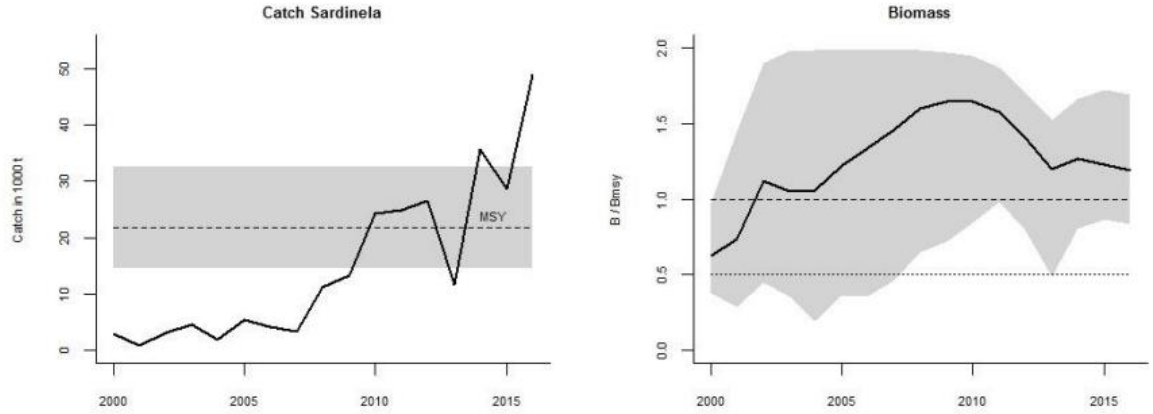

Figure 10. Combined stock assessment of round and flat sardinella in the EEZ of Guinea-Bissau
This figure shows the estimates of the catch (left) and SSB (right) on the round and flat sardinella in the EEZ of Guinea-Bissau between 2000-2017. The MSY is indicated with the dotted line in the left graph. The SSB at which MSY can be achieved is indicated with the top dotted line in the right graph. The bottom dotted line in the right graph indicates half the SSB size at which MSY can be achieved. The shaded grey area shows the 95% confidence interval.
Adapted with changes from CCC, 2017.

3. Sea Around Us

The stock assessments performed by the Sea Around Us project, although based on the same stock surveys, show different outcomes (Palomares et al., 2020). Here, it has been assessed that the biomass of the round sardinella has been below the biomass at which MSY can be achieved since 1989 (fig. 11). The flat sardinella on the other hand was overfished between 1988-2000, 2001-2012. Since then, the biomass exceeds the MSY reference point.

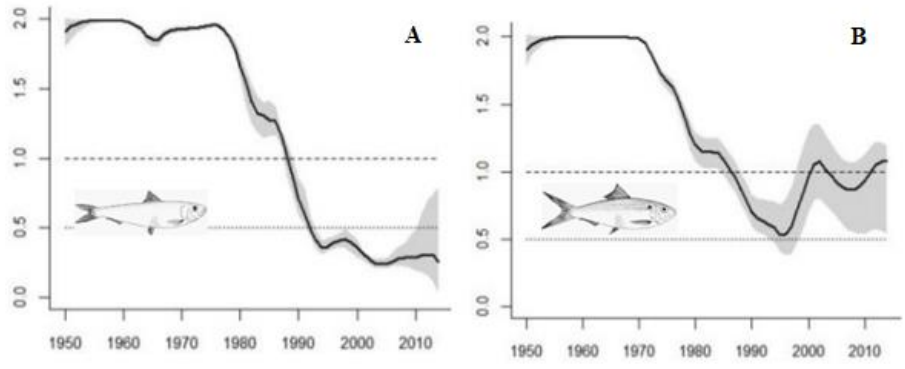

Figure 11. Stock assessment of the round and flat sardinella in the Gulf of Guinea West.
This figure shows the SSB relative to the SSB at which MSY can be achieved for the round sardinella (A) and the flat sardinella (B) between 1950-2014. The top dotted line indicates that the SSB of the stocks is at the level at which MSY can be achieved. The bottom dotted line indicates that the SSB of the stock is at half the size at which MSY can be achieved. Adapted with changes from Palomares et al., 2020.

3.2.3 Comparative analysis

The findings in the former sections indicate that there are both similarities and differences in the two observed SESs. These, and their implications for fisheries management, will be briefly discussed here (table 3). However, in order to compare the implementation of the CFP in both systems, this section will primarily focus on the operational rules the users must adhere to with regards to the fisheries management approaches introduced in the CFP, and how the SES outcomes influence the these rules.

Table 3. SES analysis of the North Sea herring and central Atlantic sardinella.

	North Sea herring	Central Atlantic sardinella
Resource system		
Location	50º N, 4º W - 61ºN, 12º E.	36ºN, 5º W - 11º N, 16ºW.
Resource unit		
Species	Herring (*Clupea harengus*).	Round sardinella (*Sardinella aurita*) and flat sardinella (*Sadinella maderensis*).
Life history traits	Small size (up to 45 cm), high growth rate (0.53 $year^{-1}$), low age at maturity (2 years), high but variable fecundity, life-span up to 10 years.	Small size (up to 35 cm), high growth rate (0.38-1.16 $year^{-1}$), low age at maturity (2 years), high but annually variable fecundity, life-span 5-7 years.
Spatial distribution in EEZs	France, Norway, United Kingdom.	Gambia, Guina-Bissau, Mauritania, Morocco, Senegal.
Users		
Fishing entities	EC member states and Norway	NW African states, EC member states, Russia, China, Turkey
Governance system		
Governance body	CFP since 1983.	CFP since 2002.
Operational rules	Fishing moratorium 1977-1983. TAC regime, minimum landing size, minimum mesh size, fishing grounds and maximum amount of vessels since 1983.	Minimum mesh size, fishing grounds, maximum amount of vessels and GRT vessel limit since 1980. Combined small pelagic fish catch limit for freezer trawlers in Mauritanian waters since 2006. Combined small pelagic fish catch limit for all vessels in Morocco and Mauritania since 2012, in Guinea-Bissau since 2021.
Interactions		
Harvesting levels	Increasing trend 1950-1965. Fishery collapse followed by a fishery closure from 1977-1983. Decrease in mid-1990s and 2005-2011. Relatively stable since 2014.	Increasing tred since the 1950s. EC DWF started exploitation in mid-1960s. Sharp increase of EC catches in mid-1990s. Decrease in EC catches since 2012.
Data collection	Stock assessments since 1960s.	Stock assessments since 2001.
Outcomes		
Ecological performance measures	Overfishing between 1960-1977 and 1983-1997. Overfished between 1967-1983 and 1990-1997.	Overfishing round and flat sardinella since 2005. Round sardinella overfished since 2005. Flat sardinella overfished since 2009.

Resource system

The resource systems in which the herring and sardinella fishery take place are both located in productive waters. As the CCLME is more productive than the North Sea, it supports a bigger variety of fisheries (Capuzzo et al., 2018; Sambe et al., 2016). The decline in primary production in the North Sea will urge the need for adaptive fisheries management when it negatively affects herring recruitment (Payne et al., 2009).

Resource unit

Herring and sardinella are both small pelagic fish and represent an important role in their ecosystem by performing top-down and bottom-up control of other species (Boëly et al., 1982; Curry et al., 2000; Samba et al., 2021). Both species furthermore share the same life history traits and are selected to endure a high natural mortality (Adams, 1980). They combine a small size, with high fecundity, low age at maturity and a high growth rate (Baldé et al., 2019; Berg et al., 2017; Bjørndal, 1988; Bjørndal & Lindroos, 2004; Boëly et al., 1982; Samba et al., 2021). The intrinsic growth rate of the sardinella is higher than herring, hence sardinella is more resilient to high fishing pressures. Although the life history traits of herring and sardinella make these species relatively resilient to fishing, they are still vulnerable. Indeed, both the herring and sardinella stocks have been overfished due to overfishing (Belhabib et al., 2019; Dickey-Collas et al., 2010; FAO, 2018; Palomares et al., 2020; Simmonds, 2009).

As the species migrate between the EEZs of multiple states, the management responsibility of both fish stocks is shared between the corresponding coastal states (Baldé et al., 2019; Bjørndal & Lindroos, 2004; Boëly et al., 1982; Gullestad et al., 2020; UNCLOS, 1982). Six countries are responsible for the management of sardinella, compared to the two actors for the North Sea herring. This could make negotiating management decisions more problematic for the sardinella fishery (Sumaila et al., 2016; Trondsen, 2006).

Users

Herring has been caught by industrial purse seiners and mid-water trawlers since the 1950s by fleets from EC member states and Norway (ICES, 2018; Pauly et al., 2020). The fleet targeting sardinella is more diverse, consisting of both artisanal and industrial fleets from northwest African states and industrial DWFs. The latter have dominated sardinella catches at least since the 1950s, of which the EC played a significant part since the mid-1990s until 2012 (Pauly et al., 2020). DWFs can make fisheries management more challenging for a shared resource such as the sardinella, as it needs cooperation between the coastal states for dividing and distributing catch opportunities between the coastal states and distant water fishing nations (Kaczynski, 1989; Munro, 1994).

Governance system

The herring fishery has been subject to fisheries management following the CFP since its adoption in 1983. The key management measure to keep the herring stock within the target levels is the setting of a TAC (Arnason et al., 2018; Dickey-Collas, 2016; EC, 1984; Simmonds, 2009). The biological reference levels were adjusted in line with the precautionary approach in 1998, and the MSY approach in 2013 (González-Laxe, 2005; ICES, 2013). The TAC regime is a single-species approach, and does not correspond with the ecosystem-based approach introduced in the CFP in 2002 (Bellido et al., 2020; EC, 2002; Möllmann et al., 2014; Reiss et al., 2010; Ulrich et al., 2012). Additional measures such as the establishment of fishing grounds and minimum mesh sizes are taken are to protect spawning and juveniles (EC, 1998; ICES, 2018). The number and size of fishing vessels are regulated to restrict fishing effort.

The northwest African states are responsible for the management of the sardinella stocks, but the objectives of the CFP have applied to the sardinella fishery since 2002 (EC, 2002; UNCLOS, 1982). Since then, fisheries agreements have provided financial contribution to fisheries research (EC, 2006, 2007, 2008). In addition, JSCs are set up with the northwest African host countries. The FAO Working Group, of which the EC is also a member, has set

biological reference levels for fishing mortality and the sardinella SSB at which MSY can be achieved (FAO, 2002). These activities correspond with the first principle of the CFP that management must be based on the best available information. Nevertheless, no management plan is in place for sardinella, and the catch performed by EC DWF is not restricted by catch limit as is the case for the herring fishery. Technical restrictions negotiated in the fisheries agreements are the number of fishing vessels allowed fishing simultaneously and a minimum mesh size. Similar technical regulations are in place in the herring management plan.

Interactions

1. Catch levels of users

Catches of herring and sardinella rose rapidly in the 1950s, and the increasing catches led to a collapse of both species in different periods of times (ICES, 2018; Pauly et al., 2020). Similarities can be drawn in the causes of overfishing for the herring and sardinella.

The collapse of the herring fishery in the mid-1970s can be attributed to the tragedy of the commons, as herring was still an open access resource in that time (Box 1). Fishers acted in their self-interest and caught as much herring possible, and management measures were implemented too late as the scientific data was not deemed to be trustworthy (Dickey-Collas et al., 2010; Simmonds, 2009). The open access regime lasted until the coastal states bordering the North Sea claimed their EEZs in 1977 and initiated a fishing mortarium (Coull et al., 1991; ICES, 1978; Song, 1995). After the five year closure of the herring fishery, the catch got restricted by the implementation of TACs (ICES, 1984).

Sardinella too was an open access resource until the adoption of the UNCLOS when northwest African countries claimed their EEZs (Kaczynski & Fluharty, 2002). The EC fleet could continue its fishing activities on the sardinella stocks after the negotiation of fisheries agreements (Corten, 2017; EC, 1983a). Even though the sardinella was not an open access resource anymore when the EC started increasing their sardinella catch, some key elements of the Tragedy of the commons can however be recognized. First, the fisheries agreements established with northwest African states only limited EC fishing vessels by their GRT, which is no indicator for a vessel's fishing capacity (EC, 1980; EC, 1995; EC, 2001; Peng et al., 2011). EC vessels were therefore allowed to catch sardinella unlimitedly. This causes the fishers to maximize their catch as the positive utility of an extra fish outweighs the negative shared utility (Box 1). The catch restrictions that did get added in some fisheries agreements after 2006 were not specific to sardinella (EC, 2006, 2013b, 2015, 2019a). Second, the lack of coordination in managing the shared sardinella resource by the northwest African coastal states leads to a race for fish (Ba et al., 2017; Gordon, 1954; Hardin, 1968; McWhinnie, 2009). The northwest African host countries all wish to maximize their benefit from the EC; the more fish access granted to the EC DWF, the higher the derived income (Kaczynski & Fluharty, 2002; Le Manach et al., 2013 Thorpe et al., 2005). This also prevents long-term sustainable exploitation.

2. Data collection

Biological sciences play an important role in the development of fisheries management measures (EC, 1983a; Galland et al., 2018). It generates knowledge about the fish stock and the fishing activities, after which policymakers can make decision regarding catch levels, effort controls, fishing areas and gear restrictions (Hare, 2020; Ramirez-Monsalve et al., 2016). This has been recognized in the CFP which states that fisheries management should be based on the best available scientific information (EC, 1983a, 1992, 2002, 2013a).

Herring catch data has been registered since the beginning of the 20th century, and the management measures taken since the implementation of the CFP are based on the data collected by the ICES such as the SSB and fishing mortality reference levels, fishing effort and recruitment (ICES, 1984, 2018; Simmonds, 2009).

For the sardinella, acoustic surveys to estimate the biomass size of the stocks are performed sporadically by the northwest African host countries (FAO, 2002, 2020). EC fisheries agreements include financial contribution to research, yet the data collected is inadequate according to the FAO Working Group and the Joint Scientific Committee with Mauritania. Since 2013, no updated reliable biological reference levels and stock assessments could be established by the FAO Working Group because of a lack of data (FAO, 2015a, 2018). This makes it troublesome to draft management measures, and calls for the coordination of the coastal states and the EC to conduct additional fisheries research. It furthermore indicates the need of applying the precautionary approach in fisheries management (EC, 2002).

Outcomes

Both herring and sardinella suffered from overfishing and got overfished as a consequence. The herring stock was being overfished in the 1960s and between 1983-1992, and the SSB was in an overfished state until 1983 (ICES, 2019). Periods of overfishing and overfished stock states are less defined for the sardinella stocks. However, signs of overfishing and overfished stock states have been seen since 2005 for the round sardinella and since 2009 for the flat sardinella by the FAO working group, and since 2009 by the JSC with Mauritania (FAO, 2006a, 2011; CSC, 2009).

The ecological performance measures of the herring fishery led to management actions. First, a fishing moratorium was implemented from 1977-1982. Second, a TAC regime has been in force since 1983. Third, when the herring was overfished again in the beginning of the 1990s, the TAC was severely restricted. Since 1997, the herring stock has not been subject to overfishing and the SSB has exceeded the level at which MSY can be achieved.

For the sardinella fishery on the other hand, the ecological performance measures do not seem to influence management action in like manner. For instance, it has been advised by both the JSC with Mauritania and the FAO working group that the catches and fishing effort should be limited since 2005 (CSC, 2004; FAO, 2006a). Instead, the fishing effort of the EC DWF on small pelagic fish increased and the sardinella catch did too. In addition, the lack of data has not led to more research projects conducted by the EC.

Chapter 4. Discussion

This study reviewed the implementation of the CFP in two SESs; one in EC waters and one beyond EC waters in northwest Africa. It is shown, that although the policy's objectives in these two waters since its reform in 2002 have been the same, the CFP has not been implemented in a similar way. The results are relevant as the two investigated species are similar and it shows that the management plan for the herring turned out to be successful in terms of ecological performance measures. Thus, the EC was fully aware of the consequences of high fishing pressures in combination with a lack of a management regime when its fleet started exploiting sardinella, and how effective management could turn the tables.

4.1 Limitations

The herring and sardinella fishery are no perfect analogy. The herring stock distributes within the EEZs of EC member states, hence the EC exerts the sovereign rights to conserve it according to the UNCLOS and implemented with the CFP (UNCLOS, 1982; CFP, 1983a). And although the EC extended the CFP objectives to the waters beyond their jurisdiction, the northwest African coastal states remain the sovereign rights to conserve the sardinella stocks which disperse in their EEZs. In other words, the northwest African coastal states are responsible for the distribution of access to fish resources to DWFs. It should therefore be stressed that this study does not in any way intend to lay the blame of the outcomes of the central Atlantic sardinella resource system on a specific actor. This research merely examines whether the sardinella fishing activities conducted by the EC DWF, and the operational rules the fleet has to adhere to, align with the CFP objectives and their implementation in EC waters.

This study relied on the results of the FAO Working Group and JSC reports for the ecological performance measures. Although no reliable stock assessments could be performed since 2013, this research assumes that the round and flat sardinella continued to be subject to overfishing and to be in an overfished state as a consequence (FAO, 2015a). This assumption was made because 1) the last acoustic survey performed in 2018 indicated that the biomass of the sardinella stocks were the lowest in history and 2) the FAO working group continued to report that their management recommendations were not followed and fishing effort and sardinella catches increased rather than decreased after 2013 (CSC, 2013; FAO, 2015b, 2016, 2018, 2020).

4.2 Implementation of the CFP on the North Sea herring fishery

The herring fishery in an example of an EC fish stock that suffered from 1) being an open access resource, 2) technological innovations of the fishing fleet, and 3) a rapid increase of fishing effort in the 1950s. These three factors led to the collapse of the herring fishery in the late 1970s.

The CFP was adopted in 1983 to protect and conserve EC fish stocks whilst maintaining food production and employment for fishers at the same time (EC, 1983a). For the herring stock, reference levels for the SSB and fishing mortality established by ICES have been revised over the years in response to new available research and additional management principles introduced to the CFP during decadal reforms (ICES, 2020). For instance, precautionary reference levels were added to the herring management plan in 1998 and the MSY was implemented in 2013. The establishment of refence levels and assessments of how the fishery

performed relative to these levels is a prerequisite for effective fisheries management (Beddington et al., 2007).

Several management measures have been implemented on the herring fishery to reach the management objectives. The main regulatory tool for the herring fishery is, as for most North Atlantic fisheries under the CFP, the TAC regime (Cardinale et al., 2017; ICES, 2020). This regime is based on stock surveys conducted by ICES and catch advice given by this organisation. The interactions between the outcomes and the government institution, and the interaction between the research institute and governance system both follow the CFP principle that management decisions should be based on the best available scientific information (EC, 1983a, 1992, 2002, EC, 2013a). Nevertheless, herring TACs have been persistently set above scientific advice, which corresponds with the critique that the EC TAC setting is biased towards short-term socioeconomic benefits rather than on long-term sustainability goals (Borges, 2018; ICES, 2019; Kahlilian et al., 2010; Villasante et al., 2011). To illustrate, the TAC overshoot caused rapid herring stock declines in the mid-1990s and early 2000s (Dickey-Collas et al., 2010; Simmonds, 2009).

A critique of this output control is that it exhibits a single-species perspective rather than a multispecies or an ecosystem-based approach that were incorporated in the CFP in its second decadal reform (EC, 2002; Mackinson et al., 2018). According to the last two principles, the impact of herring fishing on the ecosystem should be incorporated in the management plan. The ecosystem impact of fishing is mostly related to fishing effort, and TACs only weakly relate to fishing effort (Lynam & Mackinson, 2015; Reiss et al., 2010). In addition, all catch limits established in North Sea fisheries are based on stock-specific MSYs. However, the MSY cannot be obtained in all fisheries in the North Sea simultaneously (Guillen et al., 2013; Mackinson et al., 2018; Reiss et al., 2010; Thorpe, 2019; Voss et al., 2014; Worm et al., 2009). A trade-off between the MSY of all North Sea fisheries is necessary for implementing the ecosystem-based approach.

The success of the management of the herring fishery has varied over time. Until 1997, the stock remained the subject of overfishing (ICES, 2019). Although fishing mortality targets were set, the TAC was not restrained accordingly. By judging the management action following the herring fishery ecological performance measures, it seems that the EC has learned from their past mistakes. The SSB decline in the beginning of the 2000s led to a sharp decrease of catch opportunities for the fishing fleet to prevent the SSB to drop below the level at which MSY could be achieved. Since 1997, the herring stock has not been subject to overfishing and has not been in an overfished state. Both management targets have thus been reached. This makes the herring fishery an example of an effectively managed fishery from 1997 onwards.

4.3 Implementation of the CFP in the central Atlantic sardinella fishery

The objective of the external pillar of the CFP was to maintain the fishing grounds of the EC DWF after the establishment of EEZs by coastal states in the late 1970s. This objective has been reached by the negotiation of among others fisheries agreements including small pelagic fish like sardinella with several northwest African states since 1980.

It was not until 2002 when the CFP objectives also applied to the sardinella stocks, as these were targeted by the EC DWF (EC, 2002). The first steps taken by the EC to comply with the CFP objectives was the provision of additional funds to scientific research and the foundation

of JSCs (EC, 2001, 2006, 2007, 2008). Both actions are in line with the science-based management approach. However, although SSB and fishing mortality reference levels at which MSY can be achieved were established for the round and flat sardinella stock in 2002, and stock assessments have been performed since 2005, no output control has been negotiated for the EC fleet. In fact, it could be argued that the sardinella has remained an open access resource to the EC DWF. This is because the catch limit was first based on the vessels' GRT which is not an indicator of its catch capacity (Kaczynski & Fluharty, 2002; Peng et al., 2011). A catch limit in tonnes only got established in 2006 for pelagic freezer trawlers in Mauritanian waters, and for all vessels in Moroccan and Mauritanian waters in 2012 (EC, 2006, 2013b, 2015). In Guinea-Bissau on the other hand, the open access regime for sardinella lasted until 2021 (EC, 2019a). In addition, the catch restrictions in all fisheries agreements is a combined catch limit for small pelagic fish and is not specific to sardinella.

Although there was uncertainty regarding the state of the sardinella stocks before 2002 and the fishing pressure these stocks were subject to, and again since 2010, that should not be used as an excuse to postpone management measures according to the precautionary principle adopted in the CFP in 2002. The lack of management measures implemented on the sardinella gives the impression that EC policy makers did use the uncertainty to their advantage. However, even negative ecological performance outcomes (overfishing and overfished) did not lead to management action by the EC. Fishing on the sardinella continued without more stringent restrictions. This rather suggests EC policymakers to be reluctant to comply with the CFP in non-EC waters. Although the sardinella catch performed by the EC fleet dropped in 2012 and have remained low since, this is however due to the access restriction imposed by Mauritania in their coastal waters rather than due to the EC's conservation efforts.

Input regulations in force regard technical measures of the fishing vessels such as vessel length and minimum mesh sizes. The allowed mesh sizes correspond to the length of the sardinella caught to ≥ 18 cm (Baldé et al., 2019). Size limits are imposed to prevent catches of juvenile sardinellas which have not yet had the chance to reproduce before capture as a size limit is based on the length at which the fish is able to reproduce. Although a minimum landing sizes have been established in EC waters since the CFP got adopted, it has been established in Mauritanian waters only in 2019 (EC, 1983b, 2019b). In addition, the allowed mesh sizes, and the established size limit may not allow the sardinella stocks to reproduce properly as the length at which sardinella matures ranges between 18.5-22.6 cm (Baali et al., 2017; Baldé et al., 2019; Boëly et al., 1982; Samba et al., 2021; Ter Hofstede & Dickey-Collas, 2006).

Overall, the fisheries agreements negotiated with the northwest African coastal states including sardinella do not align with the CFP principles. Although the EC contributed to scientific research on these species, the negative ecological performance measures did not lead to catch restrictions. Both the round and flat sardinella have not met the two ecological performance measures which are aimed for in the CFP since 2005 and 2009 respectively, yet fishing continued to be allowed without species specific catch restrictions. Sardinella is still included in the fisheries agreements with Mauritania, Morocco and Guinea-Bissau. Yet the fishing activity of the EC fleet on the sardinella stocks has been minor since 2014 (Pauly et al., 2020).

4.4 Implications and recommendations

The SES framework worked well to compare the implementation of the CFP in EC waters and northwest African waters and to analyse its outcomes. It allowed for a focus on the relevant similarities and differences between the two fisheries in terms of the governance system, operational rules and the interactions between the outcomes and operational rules. The catch levels of the users showed that the catch of the North Sea herring increased during the time of industrialization of the EC fishing fleet. It also shows that these high catches led to overfishing and depletion of the herring stock as examined with the ecological performance measures. The operational rules that followed for the herring fishery were not the same on the sardinella fishery in terms of output regulations. In addition, fisheries research plays a different role in the herring than in the sardinella fishery. To illustrate, the outcomes of the herring fishery lead to management action whereas this is not true for the sardinella fishery.

The findings of this study are important, as it illustrates the duplicity of CFP actions in EC and non-EC waters although the ambitions of the EC for both waters have been the same on paper since 2002. The herring case study depicts that, although the management plan implemented on North Sea herring has not complied with all management principles included in the CFP, the fishery has been relatively well-managed over time. The sardinella case study shows that, despite the EC's rhetoric of promoting and extending sustainable management on fish resources in non-EC waters, the resulting fisheries agreements are opposite to this. The study outcomes should be integrated in future negotiated SFPAs between the EC and northwest African coastal states for the EC to actually contribute to sustainable fisheries in northwest Africa.

For a holistic approach of the effects of fisheries agreements in northwest Africa, the social outcomes of these agreements should be also be investigated in future research. This research focussed on the biological outcomes of the fisheries agreements negotiated with northwest African states for sardinella. However, fisheries agreements also contain socio-economic objectives such as generating employment opportunities and social empowerment in the states it negotiates the agreements with (EC, 2013a). Questions relevant to be answered in the socioeconomic outcomes of the fisheries agreements are for example how the benefits of the fish resources shared between the EC and the northwest African host countries, how much employment opportunities are created relative to the loss of employment opportunities due to overfishing, and whether the financial contribution of the EC to research and sectoral support are efficient enough to reach their objectives. For instance, although the EC has contributed to fisheries research, no reliable stock assessments could be performed on the sardinella stocks since 2013 (FAO, 2018). This could either mean that the sectoral support is not used for its purpose, that the requirements of this contribution are not strict enough or not enforced, or that the contribution is simply not sufficient enough.

Chapter 5. Conclusion

This study used the SES framework to compare the implementation of the CFP on the North Sea herring fishery and the central Atlantic sardinella fishery. The management plan of the North Sea herring fishery relies on the best available scientific information available since the adoption of the CFP. It has furthermore complied with the multi-annual, precautionary and MSY principle since these have been included in the CFP. The main management tool has been the TAC regime in order to maintain the North Sea herring within SSB and fishing mortality management reference levels. Although the TAC is persistently set higher than advised, both the fishing mortality and SSB management targets have been reached 1997. Since the sardinella fishery falls under the CFP, the fisheries agreements aim to comply with the policy's science-based principle by setting up JSCs and by providing financial contribution to research. The corresponding operational rules for the EC DWF, however, do not comply with the science-based, precautionary, multi-annual, ecosystem-based nor MSY principle. These findings show 1) the duality of the implementation of the CFP by the EC in the North Sea and in the northwest African EEZs, and 2) that the fisheries agreements negotiated with northwest African coastal states do not contribute to sustainable fisheries.

References

Adams, P. B. (1980). Life history patterns in marine fishes and their consequences for fisheries management. *Fishery bulletin*, *78*(1), 1-12.

AFNS/IDRC (1991). *Sardinella fishery off the coast of West Africa: the case of a common property resource.* Retrieved from: https://idl-bnc-idrc.dspacedirect.org/bitstream/handle/10625/10232/89469.pdf?sequence=1

Agnew, D. J., Pearce, J., Pramod, G., Peatman, T., Watson, R., Beddington, J. R., & Pitcher, T. J. (2009). Estimating the worldwide extent of illegal fishing. *PloS one*, *4*(2), e4570.

Alder, J., & Sumaila, U. R. (2004). Western Africa: a fish basket of Europe past and present. *The Journal of Environment & Development*, *13*(2), 156-178.

Anabalón, V., Arístegui, J., Morales, C. E., Andrade, I., Benavides, M., Correa-Ramírez, M. A., ... & Orbi, A. (2014). The structure of planktonic communities under variable coastal upwelling conditions off Cape Ghir (31 N) in the Canary Current System (NW Africa). *Progress in Oceanography*, *120*(2014), 320-339.

Aranda, M., Murua, H., & De Bruyn, P. (2012). Managing fishing capacity in tuna regional fisheries management organisations (RFMOs): Development and state of the art. *Marine Policy*, *36*(5), 985-992.

Arístegui, J., & Montero, M. F. (2005). Temporal and spatial changes in plankton respiration and biomass in the Canary Islands region: the effect of mesoscale variability. *Journal of Marine Systems*, *54*(1-4), 65-82.

Arnason, R., Bjørndal, T., Gordon, D. V., & Bezabih, M. (2018). Measuring potential rents in the North Sea herring fishery. *American Journal of Agricultural Economics*, *100*(3), 889-905.

Ba, A., Schmidt, J., Dème, M., Lancker, K., Chaboud, C., Cury, P., ... & Brehmer, P. (2017). Profitability and economic drivers of small pelagic fisheries in West Africa: A twenty year perspective. *Marine Policy*, *76*(2017), 152-158.

Ba, K., Thiaw, M., Lazar, N., Sarr, A., Brochier, T., Ndiaye, I., ... & Brehmer, P. (2016). Resilience of key biological parameters of the Senegalese flat sardinella to overfishing and climate change. *Plos one*, *11*(6), e0156143.

Baali, A., Bourassi, H., Falah, S., Abderrazik, W., Manchih, K., Amenzoui, K., & Yahyaoui, A. (2017). Reproductive Biology of Sardinella sp.(Sardinella aurita and Sardinella maderensis) in the South of Morocco. *Pakistan Journal of Biological Sciences*, *20*(4), 165-178.

Bakun, A. (1990). Global climate change and intensification of coastal ocean upwelling. *Science*, *247*(4939), 198-201.

Baldé, B. S., Fall, M., Kantoussan, J., Sow, F. N., Diouf, M., & Brehmer, P. (2019). Fish-length based indicators for improved management of the sardinella fisheries in Senegal. *Regional Studies in Marine Science*, *31*(2019), 100801-100810.

Bailey, R. S., & Simmonds, E. J. (1990). The use of acoustic surveys in the assessment of the North Sea herring stock and a comparison with other methods. *Rapports et Procés-Verbaux des Réunions Conseil International pour l'Éxploration de la Mer*, *189*(1990), 9-17.

Beddington, J. R., Agnew, D. J., & Clark, C. W. (2007). Current problems in the management of marine fisheries. *Science*, *316*(5832), 1713-1716.

Belhabib, D., Mendy, A., Subah, Y., Broh, N. T., Jueseah, A. S., Nipey, N., ... & Pauly, D. (2016). Fisheries catch under-reporting in The Gambia, Liberia and Namibia and the three large marine ecosystems which they represent. *Environmental Development*, *17*(Suppl. 1), 157-174.

Belhabib, D., Sumaila, U. R., & Le Billon, P. (2019). The fisheries of Africa: Exploitation, policy, and maritime security trends. *Marine Policy*, *101*(2019), 80-92.

Belhabib, D., Sumaila, U. R., & Pauly, D. (2015). Feeding the poor: contribution of West African fisheries to employment and food security. *Ocean & Coastal Management*, *111*(2015), 72-81.

Belhabib, D., Zeller, D., Harper, S., Harper, S., & Pauly, D. (2012) Marine fisheries catches in West Africa, 1950-2010: Part 1. *Faculty Research and Publications. R, University of British Columbia. Fisheries Centre.* Retrieved June 20, 2021, from https://open.library.ubc.ca/collections/facultyresearchandpublications/52383/items/1.0354243

Bell, J. D., Watson, R. A., & Ye, Y. (2017). Global fishing capacity and fishing effort from 1950 to 2012. *Fish and Fisheries*, *18*(3), 489-505.

Bellido, J. M., Sumaila, U. R., Sánchez-Lizaso, J. L., Palomares, M. L., & Pauly, D. (2020). Input versus output controls as instruments for fisheries management with a focus on Mediterranean fisheries. *Marine Policy*, *118*(2020), 103786-103789.

Berg, F., Slotte, A., Johannessen, A., Kvamme, C., Clausen, L. W., & Nash, R. D. (2017). Comparative biology and population mixing among local, coastal and offshore Atlantic herring (Clupea harengus) in the North Sea, Skagerrak, Kattegat and western Baltic. *PLoS One*, *12*(10), e0187374.

Bjørndal, T. (1988). The optimal management of North Sea herring. *Journal of Environmental Economics and Management*, *15*(1), 9-29.

Boëly, T., Fréon, P., Stéquert, B. (1982). La croissance de Sardinella aurita au Sénégal. *Océanographie Tropicale*, *17*(2), 103-119.

Bonfil, R., Munro, G., Valtysson, H. T., Wright, M., Preikshot, D., Haggan, N., ... & Pitcher, T. J. (1998). Distant water fleets: An ecological, economic and social assessment. *Faculty Research and Publications. R, Fisheries Centre. University of British Columbia.* Retrieved 23 June 2022, from https://open.library.ubc.ca/collections/facultyresearchandpublications/52383/items/1.0074783

Braham, CB, & Corten, A. (2015). Pelagic fish stocks and their response to fisheries and environmental variation in the Canary Current Large Marine Ecosystem. In Valdés, L. & Déniz-González, I. (Ed.), *Oceanographic and biological features in the Canary Current Large Marine Ecosystem* (pp. 197-213). Paris: IOC-UNESCO.

Brochier, T., Auger, P. A., Pecquerie, L., Machu, E., Capet, X., Thiaw, M., ... & Brehmer, P. (2018). Complex small pelagic fish population patterns arising from individual behavioral responses to their environment. *Progress in Oceanography*, *164*(2018), 12-27.

Capuzzo, E., Lynam, C. P., Barry, J., Stephens, D., Forster, R. M., Greenwood, N., ... & Engelhard, G. H. (2018). A decline in primary production in the North Sea over 25 years, associated with reductions in zooplankton abundance and fish stock recruitment. *Global change biology*, *24*(1), e352-e364.

Cardinale, M., Osio, G. C., & Scarcella, G. (2017). Mediterranean Sea: a failure of the European fisheries management system. *Frontiers in Marine Science*, *4*(2017), 72-85.

Carpenter, G., Kleinjans, R., Villasante, S., & O'Leary, B. C. (2016). Landing the blame: The influence of EU Member States on quota setting. *Marine Policy*, *64*(2016), 9-15.

CCC (2017). *Relatório da reunião anual do Comité Científico Conjunto sobre o acordo de pesca entre a República da Guiné-Bissau e a União Europeia.* Retrieved from: https://oceans-and-fisheries.ec.europa.eu/publications/report-seventh-meeting-joint-scientific-committee-eu-guinea-bissau-fisheries-partnership-agreement_en

Charles, A. T., Mazany, R. L., & Cross, M. L. (1999). The economics of illegal fishing: a behavioral model. *Marine Resource Economics*, *14*(2), 95-110.

Chavez, F. P., & Messié, M. (2009). A comparison of eastern boundary upwelling ecosystems. *Progress in Oceanography*, *83*(1-4), 80-96.

Cherif, A. M. (2009). The bilateral agreements between the European Union and Mauritania on fisheries. *Studia Diplomatica*, *62*(4), 127-149.

Churchill, R., & Owen, D. (2010). *The EC common fisheries policy*. Oxford, New York: Oxford University Press.

Corten, A. (2014). EU–Mauritania fisheries partnership in need of more transparency. *Marine Policy*, *49*(2014), 1-11.

Corten, A., Braham, C. B., & Sadegh, A. S. (2017). The development of a fishmeal industry in Mauritania and its impact on the regional stocks of sardinella and other small pelagics in Northwest Africa. *Fisheries research*, *186*(2017), 328-336.

CSC (2004). *Duexieme reunion du groupe de travail scientifique RIM/UE.* Retrieved 17 June 2022, from personal communication.

CSC (2007). *Rapport de la première réunion du Comité Scientifique Conjoint RIM-UE.* Retrieved 17 June 2022, from personal communication.

CSC (2008). *Rapport de la seconde reunion du Comité Scientifique Conjoint RIM-UE.* Retrieved 17 June 2022, from personal communication.

CSC (2009). *Rapport de la troisième réunion du Comité Scientifique Conjoint RIM-UE.* Retrieved 17 June 2022, from personal communication.

CSC (2010). *Rapport de la quatrième reunion du Comité Scientifique Conjoint RIM-UE.* Retrieved 17 June 2022, from personal communication.

CSC (2011). *Rapport de la cinquième réunion du Comité Scientifique Conjoint RIM-UE.* Retrieved 16 June 2022, from personal communication.

CSC (2013). *Rapport de la sixième réunion du Comité Scientifique Conjoint RIM-UE.* Retrieved 16 June 2022, from personal communication.

CSC (2014). *Rapport de la* septi*ème réunion du Comité Scientifique Conjoint RIM-UE.* Retrieved 17 June 2022, from personal communication.

CSC (2017a). *Rapport de la Réunion annuelle du Comité Scientifique Conjoint relative à l'Accord de pêche signé entre la République islamique de Mauritanie et l'Union européenne.* Retrieved from: https://oceans-and-fisheries.ec.europa.eu/publications/report-2017-meeting-joint-scientific-committee-eu-mauritania-fisheries-partnership-agreement_en

CSC (2017b). *Rapport de la Réunion Scientifique Conjointe extraordinaire relative à l'Accord de pêche signé entre le Royaume du Maroc et l'Union européenne.* Retrieved from: https://oceans-and-fisheries.ec.europa.eu/publications/report-2017-meeting-joint-scientific-committee-eu-morocco-fisheries-partnership-agreement_hr

CSC (2018). *Rapport de la Réunion annuelle du Comité Scientifique Conjoint relative à l'Accord de pêche signé entre la République islamique de Mauritanie et l'Union européenne*. Retrieved from: https://oceans-and-fisheries.ec.europa.eu/publications/report-2018-meeting-joint-scientific-committee-eu-mauritania-fisheries-partnership-agreement_nl

CSC (2020). *Rapport de la Réunion Scientifique Conjointe extraordinaire relative à l'Accord de pêche signé entre le Royaume du Maroc et l'Union européenne.* Retrieved from: https://oceans-and-fisheries.ec.europa.eu/publications/report-2020-meeting-joint-scientific-committee-eu-morocco-fisheries-partnership-agreement_nl

CSC (2021). *Rapport de la Réunion extraordinaire du Comité Scientifique Conjoint relatif à l'Accord de pêche signé entre la République islamique de Mauritanie et l'Union européenne*. Retrieved from: https://oceans-and-fisheries.ec.europa.eu/publications/report-2021-meeting-joint-scientific-committee-eu-mauritania-fisheries-partnership-agreement_pl

Cury, P., Bakun, A., Crawford, R. J., Jarre, A., Quinones, R. A., Shannon, L. J., & Verheye, H. M. (2000). Small pelagics in upwelling systems: patterns of interaction and structural changes in "wasp-waist" ecosystems. *ICES Journal of Marine Science*, *57*(3), 603-618.

Da Rocha, J. M., Cerviño, S., & Villasante, S. (2012). The common fisheries policy: an enforcement problem. *Marine Policy*, *36*(6), 1309-1314.

Desmit, X., Nohe, A., Borges, A. V., Prins, T., De Cauwer, K., Lagring, R., ... & Sabbe, K. (2020). Changes in chlorophyll concentration and phenology in the North Sea in relation to de-eutrophication and sea surface warming. *Limnology and Oceanography*, *65*(4), 828-847.

Dickey-Collas, M. (2016). North Sea herring: longer term perspective on management science behind the boom, collapse and recovery of the North Sea herring fishery. In *Management Science in Fisheries* (pp. 415-428). Abingdon: Routledge.

Dickey-Collas, M., Nash, R. D., Brunel, T., Van Damme, C. J., Marshall, C. T., Payne, M. R., ... & Simmonds, E. J. (2010). Lessons learned from stock collapse and recovery of North Sea herring: a review. *ICES Journal of Marine Science*, *67*(9), 1875-1886.

EC (1970). Council Regulation No. 2141/70. Laying down a common structural policy for the fishing industry. In *Official Journal of the European Communities*, *L236*. Retrieved from: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A31970R2141&qid=1656438152084

EC (1983a). Council Regulation No. 170/83. Establishing a Community system for the conservation and management of fishery resources. In *Official Journal of the European Communities, L24*. Retrieved from: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A31983R0170&qid=1656437763334

EC (1983b). Council Regulation (EEC) No. 2931/83 of 4 October 1983 amending Regulation (EEC) No 171/83 laying down certain technical measures for the conservation of fishery resources. In

Official Journal of the European Communities, L 288. Retrieved from: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A31983R2931&qid=1656602377394

EC (1985). Council Regulation No. 1/85. Fixing, for certain fish stocks and groups of fish stocks, provisional total allowable catches for 1985 and certain conditions under which they may be fished. In *Official Journal of the European Communities, L1*. Retrieved from: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A31985R0001&qid=1656438387031

EC (1987a). Agreement between the European Economic Community and the Islamic Republic of Mauritania on fishing off the coast of Mauritania – protocol setting out fishing opportunities and financial compensation for the period of 1 July 1987 to 30 June 1990. *In Official Journal of the European Communities, L302*. Retrieved from: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:21987A1024(02)&qid=1648393410009

EC (1987b). Agreement between the European Economic Community and the Government of the Republic of the Gambia on fishing off the Gambia. In *Official Journal of the European Communities, L146.* Retrieved from: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A21987A0606%2801%29&qid=1656439500278

EC (1992). Council Regulation No. 3760/92. Establishing a Community system for fisheries and aquaculture. In *Official Journal of the European Communities, L389.* Retrieved from: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A31992R3760&qid=1656440053176

EC (1995). Agreement on Cooperation in the sea fisheries sector between the European Community and the Kingdom of Morocco - Protocol setting out fishing opportunities and the financial compensation and financial contributions. In *Official Journal of the European Communities, L306*. Retrieved from: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A21995A1219%2802%29&qid=1648633864248

EC (1997). Council Regulation No. 894/97. Laying down certain technical measures for the conservation of fishery resources In *Official Journal of the European Communities*, L132. Retrieved from: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A31997R0894&qid=1656602874684

EC (2001). Protocol setting out the fishing opportunities and financial compensation provided for in the Agreement on cooperation in the sea fisheries sector between the European Community and the Islamic Republic of Mauritania for the period of 1 August 2001 to 31 July 2006. In *Official Journal of the European Communities, L341*. Retrieved from: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A22001A1222%2802%29&qid=1656440751886

EC (2002). Council Regulation No. 2371/2002. Conservation and sustainable exploitation of fisheries under the Common Fisheries Policy. In *Official Journal of the European Communities, L358.* Retrieved from: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32002R2371&qid=1656438291408

EC (2006). Council Regulation No. 1801/2006. Protocol setting out the fishing opportunities and financial compensation provided for in the Agreement on cooperation in the sea fisheries sector between the European Community and the Islamic Republic of Mauritania for the period of 1 August 2001 to 31 July 2006. In *Official Journal of the European Union, L343*. Retrieved from: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32006R1801&qid=1648648454175

EC (2007). Fisheries Partnership Agreement between the European Community and the Republic of Guinea-Bissau for the period of 16 June 2007 to 15 June 2011. In *Official Journal of the European Union, L342*. Retrieved from: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:22007A1227(02)&qid=1656438526920&from=EN

EC (2008). Protocol setting out the fishing opportunities and financial contribution provided for in the Fisheries Partnership Agreement between the European Community and the Islamic Republic of Mauritania for the period 1 August 2008 to 31 July 2012. In *Official Journal of the European Union, L203*. Retrieved from: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:22008A0731(01)&from=EN

EC (2012). Council Decision No. 2012/827/EU. Protocol setting out the fishing opportunities and financial contribution provided for in the Fisheries Partnership Agreement between the European Union and the Islamic Republic of Mauritania for a period of two years. In *Official Journal of the European Union, L361*. Retrieved from: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32012D0827&qid=1656438039870

EC (2013a). Council Regulation No. 1380/2013. Common Fisheries Policy, amending Council Regulations (EC) No 1954/2003 and (EC) No 1224/2009 and repealing Council Regulations (EC) No 2371/2002 and (EC) No 639/2004 and Council Decision 2004/585/EC. In *Official Journal of the European Union, L354*. Retrieved from: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32013R1380&qid=1656439820406

EC (2013b). Protocol between the European Union and the Kingdom of Morocco setting out the fishing opportunities and financial contribution provided for in the Fisheries Partnership Agreement between the European Union and the Kingdom of Morocco. In *Official Journal of the European Union, L328*. Retrieved from: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A22013A1207%2801%29&qid=1656441798059

EC (2015). Protocol setting out the fishing opportunities and financial contribution provided for in the Fisheries Partnership Agreement between the European Community and the Islamic Republic of Mauritania for a period of four years. In *Official Journal of the European Union, L315*. Retrieved from: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A22015A1201%2801%29&qid=1656441438879

EC (2019a). Protocol on the implementation of the Fisheries Partnership Agreement between the European Community and the Republic of Guinea-Bissau (2019-2024). In *Official Journal of the European Union, L173*. Retrieved from: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A22019A0627%2801%29&qid=1656441935836

EC (2019b). EC Regulation No. 2019/1241. Conservation of fisheries resources and the protection of marine ecosystems through technical measures, amending Council Regulations (EC) No 1967/2006, (EC) No 1224/2009 and Regulations (EU) No 1380/2013, (EU) 2016/1139, (EU) 2018/973, (EU) 2019/472 and (EU) 2019/1022 of the European Parliament and of the Council, and repealing Council Regulations (EC) No 850/98, (EC) No 2549/2000, (EC) No 254/2002, (EC) No 812/2004 and (EC) No 2187/2005 L198/105. In *Official Journal of the European Union, L198*. Retrieved from: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32019R1241&qid=1656442130164

Economic and Social Committee (1978). Opinion of the Economic and Social Committee on the proposals for: a Council Regulation defining for 1978 measures for conservation and management of fishery resources by the establishment of quotas, a Council regulation laying down technical measures for the conservation of fishery resources, a Council Regulation laying down certain measures of control for fishing activities, a Council Decision on financial participation by the Community in respect of the inspection and surveillance operations in the maritime waters of Denmark and Ireland, a Council Regulation laying down special aid measures herring fisheries in the North Sea and the Celtic Sea. In *Official Journal of the European Communities, C181*. Retrieved from: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A51978AC0424&qid=1656440978254

Eigaard, O. R., Marchal, P., Gislason, H., & Rijnsdorp, A. D. (2014). Technological development and fisheries management. *Reviews in Fisheries Science & Aquaculture*, *22*(2), 156-174.

Engelhard, G.H. One hundred and twenty years of change in fishing power of English North Sea trawlers. (2008). In Cotter, J., Potter, T., & Payne, A. I. (Eds.). *Advances in fisheries science: 50 years on from Beverton and Holt (pp. 1-25)*. Oxford: Wiley-Blackwell.

Espósito, C., Kraska, J., Scheiber, H.N., & Kwon, M.S. (2016) West Africa & the new European Common Fisheries Policy: impacts and implications. In *Ocean Law and Policy* (pp. 68-100). Leiden: Brill Nijhof.

FAO (2002). *Report of the FAO Working Group on the Assessment of Small Pelagic Fish off Northwest Africa. Banjul, Republic of Gambia, 5-12 April 2002*. FAO Fisheries Report No. 686. Rome: FAO. Retrieved from: https://www.fao.org/3/y4427b/y4427b01.htm

FAO (2003). *Report of the FAO Working Group on the Assessment of Small Pelagic Fish off Northwest Africa. Agadir, Morocco, 31 March-10 April 2003.* FAO Fisheries Report No. 723. Rome: FAO. Retrieved from: https://www.fao.org/3/y5081b/y5081b00.htm

FAO (2004). *Report of the FAO Working Group on the Assessment of Small Pelagic Fish off Northwest Africa. Saly, Senegal, 17-27 March 2004.* FAO Fisheries Report No. 762. Rome: FAO. Retrieved from: https://www.fao.org/publications/card/en/c/9ccbffa2-7809-57e0-9e1e-e7702ac5d83a

FAO (2006a). *Report of the FAO Working Group on the Assessment of Small Pelagic Fish off Northwest Africa. Nouadhibou, Mauritania, 26 April-5 May 2005.* FAO Fisheries Report No. 785. Rome: FAO. Retrieved from: https://www.fao.org/publications/card/en/c/2e7719a0-fd46-5657-a152-478fa2f7d22c

FAO (2006b). *Report of the FAO Working Group on the Assessment of Small Pelagic Fish off Northwest Africa. Banjul, Gambia, 2-11 May 2006.* FAO Fisheries Report No. 811. Rome: FAO. Retrieved from: https://www.fao.org/publications/card/en/c/b1a83c8f-a92f-521f-8f22-7533430c547c

FAO (2011). *Report of the FAO Working Group on the Assessment of Small Pelagic Fish off Northwest Africa. Nouakchott, Mauritania, 21-30 April 2009.* FAO Fisheries and Aquaculture Report No. 965. Rome: FAO. Retrieved from: https://www.fao.org/publications/card/en/c/a06c9b6b-7f5a-5e6f-b3e3-0e40ab2fdc96

FAO (2013). *Report of the FAO Working Group on the Assessment of Small Pelagic Fish off Northwest Africa. Dakar, Senegal, 21-25 May 2012.* FAO Fisheries Report No. 1036. Rome: FAO. Retrieved from: https://www.fao.org/fishery/en/publications/74273

FAO (2015). *Report of the FAO Working Group on the Assessment of Small Pelagic Fish off Northwest Africa. Nouadhibou, Mauritania, 10-15 June 2013*. FAO Fisheries and Aquaculture Report No. 1115. Rome: FAO. Retrieved from: https://www.fao.org/3/i5145b/i5145b.pdf

FAO (2015). *Report of the FAO Working Group on the Assessment of Small Pelagic Fish off Northwest Africa. Banjul, the Gambia, 19-24 May 2014.* FAO Fisheries and Aquaculture Report No. 1116. Rome: FAO. Retrieved from: https://www.fao.org/fishery/en/publications/29325

FAO (2016). *Report of the FAO Working Group on the Assessment of Small Pelagic Fish off Northwest Africa. Casablanca, Morocco, 20-25 July 2015.* FAO Fisheries and Aquaculture Report No. R1122. Rome: FAO. Retrieved from: https://www.fao.org/publications/card/en/c/f2c917ae-7ab6-499a-805d-466045025f68

FAO (2018). *Report of the FAO Working Group on the Assessment of Small Pelagic Fish off Northwest Africa. Dakar, Senegal 23-28 May 2016.* FAO Fisheries Report No. R1220. Retrieved from: https://www.fao.org/publications/card/en/c/I9852B

FAO (2020). *Report of the FAO Working Group on the Assessment of Small Pelagic Fish off Northwest Africa. Casablanca, Morocco, 8-13 July 2019.* FAO Fisheries Report No. 1309. Retrieved from: https://www.fao.org/fishery/en/publications/267841

Fässler, S. M., Payne, M. R., Brunel, T., & Dickey-Collas, M. (2011). Does larval mortality influence population dynamics? An analysis of North Sea herring (Clupea harengus) time series. *Fisheries Oceanography*, *20*(6), 530-543.

Feeny, D., Berkes, F., McCay, B. J., & Acheson, J. M. (1990). The tragedy of the commons: twenty-two years later. *Human Ecology*, *18*(1), 1-19.

Flanders Marine Institute. (2022). Exclusive Economic Zones in the North Sea. Retrieved 20 June 2022, from https://www.marineregions.org/maps.php?album=3747&pic=129395.

Frischmann, B. M., Marciano, A., & Ramello, G. B. (2019). Retrospectives: Tragedy of the commons after 50 years. *Journal of Economic Perspectives*, *33*(4), 211-28.

Froese, R., Winker, H., Coro, G., Demirel, N., Tsikliras, A. C., Dimarchopoulou, D., ... & Matz-Lück, N. (2018). Status and rebuilding of European fisheries. *Marine Policy*, *93*(2018), 159-170.

Galland, G. R., Nickson, A. E., Hopkins, R., & Miller, S. K. (2018). On the importance of clarity in scientific advice for fisheries management. *Marine Policy*, *87*(2018), 250-254.

Gascuel, D., Zeller, D., Taleb Sidi, M. O., & Pauly, D. (2007). Reconstructed catches in the Mauritanian EEZ. *Reconstruction of marine fisheries catches for key countries and regions (1950–2005). Vancouver (Canada): Fisheries Centre, University of British Columbia*, 105-119.

González-Laxe, F. (2005). The precautionary principle in fisheries management. *Marine Policy*, *29*(6), 495-505.

Gordon, H. S. (1954). The economic theory of a common-property resource: the fishery. In *Classic papers in natural resource economics* (pp. 178-203). London: Palgrave Macmillan.

Grecian, W. J., Witt, M. J., Attrill, M. J., Bearhop, S., Becker, P. H., Egevang, C., ... & Votier, S. C. (2016). Seabird diversity hotspot linked to ocean productivity in the Canary Current Large Marine Ecosystem. *Biology Letters*, *12*(8), 20160024.

Guggisberg, S. (2019). The EU's Regulation on the Sustainable Management of External Fishing Fleets: International and European Law Perspectives. *The International Journal of Marine and Coastal Law*, *34*(2), 291-324.

Guillen, J., Macher, C., Merzéréaud, M., Bertignac, M., Fifas, S., & Guyader, O. (2013). Estimating MSY and MEY in multi-species and multi-fleet fisheries, consequences and limits: an application to the Bay of Biscay mixed fishery. *Marine Policy*, *40*(2013), 64-74.

Guillen, J., Santos, A. C., Carpenter, G., Casey, J., Lleonart, J., Maynou, F., ... & Carvalho, N. (2016). Sustainability now or later? Estimating the benefits of pathways to maximum sustainable yield for EU Northeast Atlantic fisheries. *Marine Policy*, 72 (2016), 40-47.

Gullestad, P., Sundby, S., & Kjesbu, O. S. (2020). Management of transboundary and straddling fish stocks in the Northeast Atlantic in view of climate-induced shifts in spatial distribution. *Fish and Fisheries*, *21*(5), 1008-1026.

Halpern, D. (1977). Description of wind and of upper ocean current and temperature variations on the continental shelf off northwest Africa during March and April 1974. *Journal of Physical Oceanography*, *7*(3), 422-430.

Hare, J. A. (2020). Ten lessons from the frontlines of science in support of fisheries management. *ICES Journal of Marine Science*, *77*(3), 870-877.

Hardin, G. (1968). The tragedy of the commons: the population problem has no technical solution; it requires a fundamental extension in morality. *Science*, *162*(3859), 1243-1248.

Hatcher, A. (2014). Implications of a discard ban in multispecies quota fisheries. *Environmental and Resource Economics*, *58*(3), 463-472.

Hegland, T. J. (2012). *Fishing for change in EU governance: excursions into the evolution of the Common Fisheries Policy*. (Doctoral dissertation, Aalborg University, Denmark). Retrieved from https://vbn.aau.dk/ws/files/316469814/PhD_Thesis_Hegland.pdf

Hilborn, R. (2020). Measuring fisheries management performance. *ICES Journal of Marine Science*, *77*(7-8), 2432-2438.

ICES (1969). *Report on the North Sea Young Herring Working Group*. Retrieved from: https://ices-library.figshare.com/articles/report/Report_of_the_North_Sea_Young_Herring_Working_Group/18626495

ICES (1971). *Report of the North Sea Herring Assessment Working Group.* Retrieved from: https://ices-library.figshare.com/articles/report/Report_of_the_North_Sea_Herring_Assessment_Working_Group/18626285

ICES (1978). *Reports of the Herring Assessment Working Group for the Area South of 62 N (HAWG).* Retrieved from: https://ices-library.figshare.com/articles/report/Reports_of_the_Herring_Assessment_Working_Group_for_the_Area_South_of_62_N_1978/18625013

ICES (1984). *Report on the international young fish survey in the North Sea, Skagerrak and Kattegat in 1984: herring*. Retrieved from: https://www.ices.dk/sites/pub/CM%20Doccuments/1984/H/1984_H31.pdf

ICES (2013). *Report of the Herring Assessment Working Group for the Area South of 62 N (HAWG).* Retrieved from: https://ices-library.figshare.com/articles/report/Report_of_the_Herring_Assessment_Working_Group_for_the_Area_South_of_62_N_HAWG_/19281764

ICES (2018). *Report of the Herring Assessment Working Group for the Area South of 62 N.* Retrieved from: https://ices-library.figshare.com/articles/report/HAWG_Report_2018/19255418

ICES (2019). *ICES Advice on fishing opportunities, catch and effort. Herring (Clupea harengus) in subarea 4 and divisions 3.a and 7.d, autumn spawners (North Sea, Skagerak and Kattegat, eastern English Channel).* Retrieved from: https://ices-library.figshare.com/articles/report/Herring_Clupea_harengus_in_Subarea_4_and_divisions_3_a_and_7_d_autumn_spawners_North_Sea_Skagerrak_and_Kattegat_eastern_English_Channel_/18634133

Iheduru, O. C. (1995). The political economy of Euro-African fishing agreements. *The Journal of Developing Areas*, *30*(1), 63-90.

Intchama, J. F., Belhabib, D., & Tomás Jumpe, R. J. (2018). Assessing Guinea Bissau's legal and illegal unreported and unregulated fisheries and the surveillance efforts to tackle them. *Frontiers in Marine Science*, *5*(2018), 79-89.

Kaczynski, V. M. (1989). Foreign fishing fleets in the subSaharan West African EEZ: the coastal state perspective. *Marine Policy*, *13*(1), 2-15.

Kaczynski, V. M., & Fluharty, D. L. (2002). European policies in West Africa: who benefits from fisheries agreements?. *Marine Policy*, *26*(2), 75-93.

Kalaidjian, W. (2010). Fishing for Solutions: The European Union's Fisheries Partnership Agreements with West African Coastal State in an Exploited Ocean. *Emory International Law Review*, *24*(2010), 389-431.

Karagiannakos, A. (1996). Total Allowable Catch (TAC) and quota management system in the European Union. *Marine Policy*, *20*(3), 235-248.

Kämpf, J., & Chapman, P. (2016) The Canary/Iberia Current Upwelling System. In *Upwelling systems of the world* (pp. 31-42). Cham: Springer International Publishing Switzerland.

Khalilian, S., Froese, R., Proelss, A., & Requate, T. (2010). Designed for failure: a critique of the Common Fisheries Policy of the European Union. *Marine Policy*, *34*(6), 1178-1182.

Lakhnigue, A., Tandstad, M., Fuller, J., Sambe, B., & Caramelo, A. M. (2019). More than fifteen years of collaboration on the assessment of small pelagic fish off Northwest Africa: Lessons learned and future perspectives. *Deep Sea Research Part II: Topical Studies in Oceanography*, *159*(2019), 92-102.

Le Manach, F., Andriamahefazafy, M., Harper, S., Harris, A., Hosch, G., Lange, G. M., ... & Sumaila, U. R. (2013). Who gets what? Developing a more equitable framework for EU fishing agreements. *Marine Policy*, *38*(2013), 257-266.

Lear, W. H. (1998). History of fisheries in the Northwest Atlantic: the 500-year perspective. *Journal of Northwest Atlantic Fishery Science*, *23,* 41-73.

Leitão, F., & Baptista, V. (2017). The discard ban policy, economic trends and opportunities for the Portuguese fisheries sector. *Marine Policy*, *75*(2017), 75-83.

Liddick, D. (2014). The dimensions of a transnational crime problem: the case of IUU fishing. *Trends in Organized Crime*, *17*(4), 290-312.

Lowerre-Barbieri, S., Crabtree, L., Switzer, T., Burnsed, S. W., & Guenther, C. (2015). Assessing reproductive resilience: an example with South Atlantic red snapper Lutjanus campechanus. *Marine Ecology Progress Series*, *526*(2015), 125-141.

Lynam, C. P., & Mackinson, S. (2015). How will fisheries management measures contribute towards the attainment of Good Environmental Status for the North Sea ecosystem?. *Global Ecology and Conservation*, *4*(2015), 160-175.

Madigan, D. J., Carlisle, A. B., Dewar, H., Snodgrass, O. E., Litvin, S. Y., Micheli, F., & Block, B. A. (2012). Stable isotope analysis challenges wasp-waist food web assumptions in an upwelling pelagic ecosystem. *Scientific reports*, *2*(1), 1-10.

Mace, P. M. (2001). A new role for MSY in single-species and ecosystem approaches to fisheries stock assessment and management. *Fish and fisheries*, *2*(1), 2-32.

Mackinson, S., Platts, M., Garcia, C., & Lynam, C. (2018). Evaluating the fishery and ecological consequences of the proposed North Sea multi-annual plan. *PLoS One*, *13*(1), e0190015.

Mallory, T. G. (2013). China's distant water fishing industry: Evolving policies and implications. *Marine Policy*, *38*(2013), 99-108.

McWhinnie, S. F. (2009). The tragedy of the commons in international fisheries: An empirical examination. *Journal of Environmental Economics and Management*, *57*(3), 321-333.

Methot Jr, R. D., Tromble, G. R., Lambert, D. M., & Greene, K. E. (2014). Implementing a science-based system for preventing overfishing and guiding sustainable fisheries in the United States. *ICES Journal of Marine Science*, *71*(2), 183-194.

Möllmann, C., Lindegren, M., Blenckner, T., Bergström, L., Casini, M., Diekmann, R., ... & Gårdmark, A. (2014). Implementing ecosystem-based fisheries management: from single-species to integrated ecosystem assessment and advice for Baltic Sea fish stocks. *ICES Journal of Marine Science*, *71*(5), 1187-1197.

Mulazzani, L., & Malorgio, G. (2014). The external and commercial dimensions of the EU fisheries policy: An institutional approach applied to the whitefish case. *Marine Policy*, *46*(2014), 123-131.

Munro, G. R. (1994). Coastal states and distant water fleets under extended jurisdiction: the search for optimal incentive schemes. In *Advances in Dynamic Games and Applications* (pp. 301-317). Boston, MA: Birkhäuser.

Nash, R. D. M., & Dickey-Collas, M. (2005). The influence of life history dynamics and environment on the determination of year class strength in North Sea herring (Clupea harengus L.). *Fisheries Oceanography*, *14*(4), 279-291.

Okafor-Yarwood, I., & Belhabib, D. (2020). The duplicity of the European Union Common Fisheries Policy in third countries: Evidence from the Gulf of Guinea. *Ocean & Coastal Management*, *184*(2020), 104953-104963.

Ono, K., Haynie, A. C., Hollowed, A. B., Ianelli, J. N., McGilliard, C. R., & Punt, A. E. (2018). Management strategy analysis for multispecies fisheries, including technical interactions and human behavior in modelling management decisions and fishing. *Canadian Journal of Fisheries and Aquatic Sciences*, *75*(8), 1185-1202.

Ostrom, E. (2009). A general framework for analyzing sustainability of social-ecological systems. *Science*, *325*(5939), 419-422.

Palomares, M. L. D., Froese, R., Derrick, B., Meeuwig, J. J., Nöel, S. L., Tsui, G., ... & Pauly, D. (2020). Fishery biomass trends of exploited fish populations in marine ecoregions, climatic zones and ocean basins. *Estuarine, Coastal and Shelf Science*, *243*(2020), 106896-106905.

Palomares, M. L. D., Khalfallah, M., Woroniak, J., Pauly, D., & Us, S. A. (2020). Assessment of 14 species of small pelagic fish caught along the coast of Northwest African countries. *Fisheries Centre Research Reports*, *28*(4), 69-96.

Pauly, D. (2011). Beyond duplicity and ignorance in global fisheries. *Pacific Ecologist*, (20), 32-37.

Pauly, D., Christensen, V., Guénette, S., Pitcher, T. J., Sumaila, U. R., Walters, C. J., ... & Zeller, D. (2002). Towards sustainability in world fisheries. *Nature*, *418*(6898), 689-695.

Pauly, D., Zeller, D., & Palomares, M.L.D. (2020). Sea Around Us Concepts, Design and Data. *Sea Around Us*. Retrieved 7 April 2021, from: https://seaaroundus.org

Payne, M. R., Hatfield, E. M., Dickey-Collas, M., Falkenhaug, T., Gallego, A., Gröger, J., ... & Nash, R. D. (2009). Recruitment in a changing environment: the 2000s North Sea herring recruitment failure. *ICES Journal of Marine Science*, *66*(2), 272-277.

Penas, E. (2007). The fishery conservation policy of the European Union after 2002: towards long-term sustainability. *ICES Journal of Marine Science*, *64*(4), 588-595.

Peng, X., Lei, H., & Zhong, W. (2011). Research on Estimation Method of Gross Registered Tonnage of Ships in Grand Canal. In *Modeling Risk Management for Resources and Environment in China* (pp. 101-108). Berlin: Springer Heidelberg.

Polidoro, B. A., Ralph, G. M., Strongin, K., Harvey, M., Carpenter, K. E., Arnold, R., ... & Williams, A. (2017). The status of marine biodiversity in the Eastern Central Atlantic (West and Central Africa). *Aquatic Conservation: Marine and Freshwater Ecosystems*, *27*(5), 1021-1034.

Ramirez-Monsalve, P., Raakjær, J., Nielsen, K. N., Santiago, J. L., Ballesteros, M., Laksá, U., & Degnbol, P. (2016). Ecosystem Approach to Fisheries Management (EAFM) in the EU–Current science–policy–society interfaces and emerging requirements. *Marine Policy*, *66*(2016), 83-92.

Reiss, H., Greenstreet, S. P., Robinson, L., Ehrich, S., Jørgensen, L. L., Piet, G. J., & Wolff, W. J. (2010). Unsuitability of TAC management within an ecosystem approach to fisheries: an ecological perspective. *Journal of Sea Research*, *63*(2), 85-92.

Idon (2004). *Noordzee-atlas deel 1*. Retrieved from: https://www.noordzeeloket.nl/beheer/noordzeeatlas/

Salomon, M., Markus, T., & Dross, M. (2014). Masterstroke or paper tiger–The reform of the EU′ s Common Fisheries Policy. *Marine Policy*, *47*(2014), 76-84.

Samba, O., Diouf, K., Fall, M., Ndiaye, P., & Panfili, J. (2021). Long term changes in life history traits and catches of the round sardinella, Sardinella aurita (Clupeidae), along the Senegal coast, West Africa. *Regional Studies in Marine Science*, *42*(2021), 101621-101631.

Sambe, B., Tandstad, M., Caramelo, A. M., & Brown, B. E. (2016). Variations in productivity of the Canary Current Large Marine Ecosystem and their effects on small pelagic fish stocks. *Environmental Development*, *17*(2016), 105-117.

Schaefer, M. B. (1957). Some considerations of population dynamics and economics in relation to the management of the commercial marine fisheries. *Journal of the Fisheries Board of Canada*, *14*(5), 669-681.

Simmonds, E. J. (2009). Evaluation of the quality of the North Sea herring assessment. *ICES Journal of Marine Science*, *66*(8), 1814-1822.

Song, Y. H. (1995). The EC's common fisheries policy in the 1990s. *Ocean Development & International Law*, *26*(1), 31-55.

Srinivasan, U. T., Watson, R., & Sumaila, U. R. (2012). Global fisheries losses at the exclusive economic zone level, 1950 to present. *Marine Policy*, *36*(2), 544-549.

Stearns, S. C. (1992). *The evolution of life histories*. Oxford: Oxford University Press.

Stilwell, J., Samba, A., Failler, P., & Laloë, F. (2010). Sustainable development consequences of European Union participation in Senegal's Marine Fishery. *Marine Policy*, *34*(3), 616-623.

Sumaila, U. R., Bellmann, C., & Tipping, A. (2016). Fishing for the future: An overview of challenges and opportunities. *Marine Policy*, *69*(2016), 173-180.

Sumaila, U. R., Zeller, D., Hood, L., Palomares, M. L. D., Li, Y., & Pauly, D. (2020). Illicit trade in marine fish catch and its effects on ecosystems and people worldwide. *Science Advances*, *6*(9), eaaz3801.

Sündermann, J., & Pohlmann, T. (2011). A brief analysis of North Sea physics. *Oceanologia*, *53*(3), 663-689.

Suuronen, P., Lehtonen, E., & Wallace, J. (1997). Avoidance and escape behaviour by herring encountering midwater trawls. *Fisheries Research*, *29*(1), 13-24.

Swartz, W., Sala, E., Tracey, S., Watson, R., & Pauly, D. (2010). The spatial expansion and ecological footprint of fisheries (1950 to present). *PloS one*, *5*(12), e15143.

Tenningen, M., Macaulay, G. J., Rieucau, G., Peña, H., & Korneliussen, R. J. (2017). Behaviours of Atlantic herring and mackerel in a purse-seine net, observed using multibeam sonar. *ICES Journal of Marine Science*, *74*(1), 359-368.

Ter Hofstede, R., & Dickey-Collas, M. (2006). An investigation of seasonal and annual catches and discards of the Dutch pelagic freezer-trawlers in Mauritania, Northwest Africa. *Fisheries Research*, *77*(2), 184-191.

Thorpe, R. B. (2019). What is multispecies MSY? A worked example from the North Sea. *Journal of Fish Biology*, *94*(6), 1011-1018.

Thorpe, A., Reid, C., van Anrooy, R., & Brugere, C. (2005). When fisheries influence national policy-making: an analysis of the national development strategies of major fish-producing nations in the developing world. *Marine Policy*, *29*(3), 211-222.

Tickler, D., Meeuwig, J. J., Palomares, M. L., Pauly, D., & Zeller, D. (2018). Far from home: Distance patterns of global fishing fleets. *Science Advances*, *4*(8), eaar3279.

Trondsen, T., Matthiasson, T., & Young, J. A. (2006). Towards a market-oriented management model for straddling fish stocks. *Marine Policy*, *30*(3), 199-206.

Trouillet, B., Guineberteau, T., Bernardon, M., & Le Roux, S. (2011). Key challenges for maritime governance in West Africa: Fishery-based lessons from Guinea and Mauritania. *Marine Policy*, *35*(2), 155-162.

Ulrich, C., Wilson, D. C., Nielsen, J. R., Bastardie, F., Reeves, S. A., Andersen, B. S., & Eigaard, O. R. (2012). Challenges and opportunities for fleet-and métier-based approaches for fisheries management under the European Common Fishery Policy. *Ocean & Coastal Management*, *70*(2012), 38-47.

United Nations Convention on the Law of the Sea (UNCLOS) (1982). Retrieved from: https://www.iucn.org/theme/marine-and-polar/our-work/international-ocean-governance/unclos

Voss, R., Quaas, M. F., Schmidt, J. O., & Hoffmann, J. (2014). Regional trade-offs from multi-species maximum sustainable yield (MMSY) management options. *Marine Ecology Progress Series*, *498*(2014), 1-12.

Watson, R., Zeller, D., & Pauly, D. (2014). Primary productivity demands of global fishing fleets. *Fish and Fisheries*, *15*(2), 231-241.

Worm, B., Hilborn, R., Baum, J. K., Branch, T. A., Collie, J. S., Costello, C., ... & Zeller, D. (2009). Rebuilding global fisheries. *Science*, *325*(5940), 578-585.

Winemiller, K. O. (2005). Life history strategies, population regulation, and implications for fisheries management. *Canadian Journal of Fisheries and Aquatic Sciences*, *62*(4), 872-885.

Witbooi, E. (2008). The infusion of sustainability into bilateral fisheries agreements with developing countries: The European Union example. *Marine Policy*, *32*(4), 669-679.

Zeeberg, J., Corten, A., Tjoe-Awie, P., Coca, J., & Hamady, B. (2008). Climate modulates the effects of Sardinella aurita fisheries off Northwest Africa. *Fisheries Research*, *89*(1), 65-75.

Zhou, S., Yin, S., Thorson, J. T., Smith, A. D., & Fuller, M. (2012). Linking fishing mortality reference points to life history traits: an empirical study. *Canadian Journal of Fisheries and Aquatic Sciences*, *69*(8), 1292-1301.

Zimmermann, H. (2016). Balancing sustainability and commerce in international negotiation: the EU and its fisheries partnership agreements. *Journal of European Public Policy*, *24*(1), 135-155.