UNIVERSITE BRETAGNE LOIRE

UBO université de bretagne occidentale

THÈSE / UNIVERSITÉ DE BRETAGNE OCCIDENTALE

sous le sceau de l'Université Bretagne Loire

pour obtenir le titre de

DOCTEUR DE L'UNIVERSITÉ DE BRETAGNE OCCIDENTALE

Mention : Economie

École Doctorale des Sciences de la Mer et du Littoral

présentée par

Manuel Bellanger

Préparée à l'UMR 6308 AMURE

Modelling institutional arrangements and bio-economic impacts of catch share management systems.

Application to the Bay of Biscay sole fishery.

Thèse soutenue le 18 Mai 2017
devant le jury composé de :

Claire ARMSTRONG
Professeur, University of Tromsø / *Rapporteur*

Jean BONCOEUR
Professeur, Université de Bretagne Occidentale / *Examinateur*

Olivier GUYADER
Directeur de Recherche, Ifremer / *Directeur de thèse*

Dominique LEVIEIL
Dpt. Head of Unit, European Commission / *Examinateur invité*

Claire MACHER
Cadre de Recherche, Ifremer / *Co-directeur de thèse*

Jean-Christophe PEREAU
Professeur, Université de Bordeaux / *Rapporteur*

Olivier THEBAUD
Directeur de Recherche, Ifremer / *Examinateur invité*

Clara ULRICH
Professeur, Technical University of Denmark / *Examinateur*

Ifremer — Région Bretagne — UBO université de bretagne occidentale — AMURE UMR Centre de droit et d'économie de la mer — iuem — École doctorale des sciences de la mer

“Look, you're unhappy? I'm unhappy too. Have you heard of Henry Clay? He was the Great Compromiser. A good compromise is when both parties are dissatisfied, and I think that's what we have here.”

Larry David

Acknowledgements

I would first like to extend my gratitude to Claire and Olivier who supported me scientifically and morally throughout this effort. Many thanks for making yourselves available and for sharing your expertise on many topics. The work and time you spent on supervising me was much appreciated.

I also want to thank Dan Holland and Chris Anderson for the opportunity of what turned out to be a very stimulating stay in Seattle, for having helped me a great deal with my project there, and more generally for all of the discussions we had that contributed to the structure of my PhD research.

I gratefully acknowledge financial support from Région Bretagne and Ifremer.

I thank all the members of my steering committee, Jean Boncoeur, Paul Marchal, Vincent Martinet and Jean-Daniel Rinaudo, who dispensed valuable advice that guided and enriched this research significantly. I am also grateful to all the members of the thesis jury and I feel very privileged that they have accepted to evaluate this dissertation.

I owe a lot to Mathieu Merzéréaud for sharing plenty of the coding burden and I can only corroborate his efficiency reputation. I am also thankful to Katia Frangoudes for a fruitful co-authoring opportunity, and to all the people that provided some proofreading who I shall be forever grateful to.

Thanks to Rachel and Gaël for being my industry insiders and much more.

Thanks to Harold for being my early academic inspiration, and to Pierre, Anne-Charlotte, and Charlène for being my role models and former underground buddies.

Thanks to the basement crew and fellow PhD students, Julien (the friendliest officemate in the business), Adrien, Michel, Océane, Adeline, and Soazig, to my coffee break mates, Antoine, Sophie, Eva, Rachel, and Camille, and to all the other lab members at Ifremer for moral support and benevolence over the years.

Thanks to Julie and Oona who said they would get me a beer if I put their names in the acknowledgements even though they had nothing to do with my PhD work.

Thanks to the UW gang for all the good times in Brisbane, Seattle, Ketchikan, Portland, and Aberdeen.

Thanks to the Kerinou clan, Mika, Gueorgui, Julian, Bryan, Fanny, and Tyler for being wonderful people.

And to all the others that have helped me at some point, I am thankful to each and every one of you.

Abstract

Within the Common Fisheries Policy (CFP), the institutions of the European Union determine total allowable catches (TACs) for the main commercial fisheries that are shared among Member States according to historical allocation keys. Each Member State is responsible for managing its own national quotas and the quota management systems effectively implemented by Member States are various. Notably, these systems include individual transferable quotas (ITQs) and co-management systems where the management of fishing quotas is delegated to producer organizations (POs). In France, where fishing rights are non-transferable, fishing possibilities are managed within a PO-based catch share system where POs are granted collective allocations based on the aggregate fishing rights of their members, and each PO organizes quota redistribution among its members according to self-established rules. The goal of this research, which contains theoretical developments as well as empirical analyses applied to the Bay of Biscay sole fishery, is to determine how outcomes of fisheries management are altered by the presence of POs within institutions as compared to alternative governance systems such as ITQs. This dissertation notably brings together bio-economic approaches and institutional analyses to better anticipate the ecological, economic and social impacts of potential governance options. The research questions are the following: (1) What mechanisms could ensure a high level of compliance and what are the potential gains of placing the POs between the regulator and the fishermen? (2) What are the distributional effects of catch share management by POs? (3) What is the added value of integrating institutional arrangements involving POs into bio-economic modelling for the impact assessment of catch share management options?

Considering traditional economic incentives as well as social preferences in a game-theoretic framework, we first show how a PO-based catch share system associated with a joint liability regime can potentially ensure a high level of compliance and decrease monitoring costs for the regulator. Second, the ex-post analysis of distributional effects of the management of Bay of Biscay sole quota operated by POs shows that the French system prevented the concentration of production while reducing fleet capacity with decommissioning schemes. We find that the strategies developed by POs in terms of quota redistribution were notably influenced by their fishing fleet profiles and their local roots. Third, an individual-based bio-economic model is presented and applied to the Bay of Biscay sole fishery to investigate alternative catch share systems from a multi-criteria perspective. This model integrates several institutional arrangements related to catch share management and their interactions with biological and economic dynamics. The current co-management system with non-transferability is compared to an alternative ITQ system in a context of transition schemes to maximum sustainable yield (MSY). Trade-offs between ecological and socio-economic impacts are highlighted and the effectiveness of different governance options is discussed with regards to the challenge of capacity adjustment.

Keywords: sustainable management of catch shares, producer organizations, co-management, institutional arrangements, regulatory compliance, distributional effects, bio-economic modelling, micro-economic model of fishermen behavior.

Scientific production

Publications

Bellanger, M., Macher, C., Guyader, O. (2016). A new approach to determine the distributional effects of quota management in fisheries. *Fisheries Research*, 181, 116-126.

Frangoudes, K., **Bellanger, M.** (2017). Fishers' opinions on marketization of property rights and the quota system in France. *Marine Policy*, 80, 107-112.

Publications under review

Bellanger, M., Holland, D., Anderson, C., Guyader, O. A game-theoretic model of monitoring and compliance in fishery cooperatives (under review in *Environmental and Resource Economics*).

Bellanger, M., Macher, C., Merzéréaud, M., Guyader, O., Le Grand, C. Investigating trade-offs in alternative catch share systems: an individual-based bio-economic model applied to the Bay of Biscay sole fishery (under review in the *Canadian Journal of Fisheries and Aquatic Sciences*).

Conference papers

Bellanger, M., Holland, D., Anderson, C., Guyader O., Macher, C. A game-theoretic model of monitoring and compliance in fishery cooperatives. 18th Biennial Conference of the International Institute for Fisheries Economics and Trade, Aberdeen, Scotland July 2016.

Macher, C., **Bellanger, M.**, Guyader, O., Merzéréaud, M., Le Grand, C. A bio-economic agent-based model to investigate trade-offs between alternative fisheries quota governance systems. Understanding marine socio-ecological systems: including the human dimension in Integrated Ecosystem Assessments, MSEAS, Brest, France, May 2016.

Bellanger, M., Macher, C., Guyader, O. Distributional effects of quota self-governance by French producer organizations: the case of the Bay of Biscay sole fishery. 8th Biennial Forum of the North American Association of Fisheries Economists, Ketchikan, Alaska May 2015.

Bellanger, M., Macher, C., Merzéréaud, M., Guyader, O. Exploring fisheries dynamics according to different quota governance mechanisms: application to the Bay of Biscay common sole fishery. 17th Biennial Conference of the International Institute for Fisheries Economics and Trade, Brisbane, Australia July 2014.

Guyader, O., Metz, S., Macher, C., Merzereaud, M., Daures, F., Le Floc'h, P., **Bellanger, M.** Self-imposed catch shares by French producers organizations. 17th Biennial Conference of the International Institute for Fisheries Economics and Trade, Brisbane, Australia July 2014.

Contents

List of abbreviations

ACR	Model Adapted from Charness and Rabin
AFPO	Aberdeen Fish Producer Organization
BA	Baseline scenario
BSPO	Brown Shrimp Producer Organization
CBD	Convention on Biological Diversity
CEC	Commission of the European Communities
CFP	Common Fisheries Policy
CNPO	Cobrenord Producer Organization
CPIPA	Catcher-Processor cooperatives Incentive Plan Agreement
CPR	Common-Pool Resource
DPMA	Direction des Pêches Maritimes et de l'Aquaculture
DS	Decommissioning Scheme
EC	European Commission
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
FNPO	FROM Nord Producer Organization
GBCHS	Georges Bank cod hook sector
GES	Good Environmental Status
HCR	Harvest Control Rule
IAM	Impact Assessment Model for fisheries management
ICES	International Council for the Exploration of the Sea
IFREMER	French Research Institute for the Exploitation of the Sea
IA	Impact Assessment
IQ	Individual Quota
ITQ	Individual Transferable Quota
IUU	Illegal, unreported and unregulated
IVQ	Individual Vessel Quota
JORF	Journal officiel de la République Française
JRC	Joint Research Centre
JSLIIP	Joint and Several Liability and Independent Internal Penalty
JSLIO	Joint and Several Liability and Indemnification Only
MP	Management Procedure
MPA	Marine Protected Area
MS	Member State
MSE	Management Strategy Evaluation
MSFD	Marine Strategy Framework Directive
MSIPA	Mothership cooperatives Incentive Plan Agreement

MSY	Maximum Sustainable Yield
MWC	Mothership whiting cooperative
NEFS II	Northeast fishery sector II
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NWFSC	Northwest Fisheries Science Center
OECD	Organisation for Economic Co-operation and Development
PDBPO	Pêcheurs De Bretagne Producer Organization
PO	Producer Organization
RUM	Random Utility Model
SAFS	School of Aquatic and Fishery Sciences
SIPA	Shoreside cooperatives Incentive Plan Agreement
SHL	Strict Historical Landings
SOCIOEC	Socio Economic effects of management measures of the future CFP, FP7 project
SSB	Spawning Stock Biomass
STECF	Scientific, Technical and Economic Committee for Fisheries
UNCLOS	United Nations Convention on the Law of the Sea
US	United States of America
UW	University of Washington
TAC	Total Allowable Catch
TFC	Transferable Fishing Concession
TURF	Territorial Use Rights for Fishing

List of figures

List of tables

Chapter 1. General introduction

1.1 Tragedy of the commons and the necessity of managing fisheries

Fishery resources are classified as common-pool resources (CPRs) that are characterized by their *rival* and *non-excludable* nature. If they are left to be open access, individual incentives to fish as much as possible to maximize short-term profits are generally opposed to collective interests. Initially, it is economically rational for an individual fisherman to increase his fishing effort and/or fishing capacity to catch a maximum amount of fish in a minimum time, a behavior known as the 'race for fish'. Furthermore, in an open-access situation, the existence of an economic rent attracts new fishermen. However, the rival nature of the resource implies that the catches that have been removed from a common stock by a fisherman decrease the availability of the resource to other fishermen. Lowered resource availability causes the cost of fishing effort to increase. Progressively, the difference between the value of landings and the cost of fishing effort shrinks (Gordon, 1954; Scott, 1955). Another characteristic of fishery resources is that it is very difficult and costly to exclude others from exploiting them due to the mobility of the resources and uncertainty in the population dynamics of fish stocks. In economic terms, several firms harvesting a rival and non-excludable resource generate negative mutual externalities associated with the fact that the production functions of these firms are interdependent. Consequently, this gap between individual and collective rationality generally induces overcapacity, a situation often described as too many vessels chasing too few fish. Additionally, overcapacity easily provokes resource overexploitation, i.e. harvests in excess of the natural renewal rate of a resource that can lead to resource depletion. In short, failing to address the negative externalities issues leads to overcapacity and overexploitation, both inducing rent dissipation. This situation is an illustration of the 'tragedy of the commons' described by Hardin (1968).

To limit this prejudicial process, management measures must be implemented. The difficulty of managing fishery resources arises from the fact that these are *renewable* and *common* resources, which raises the issues of their sustainable management and access regulation, respectively. Boncoeur et al. (2006) identify two types of management measures in fisheries: *technical measures* dedicated to ensure preservation of productive and reproductive capacities of stocks, and *access regulation measures* aimed at selecting who can fish and how much (Figure 1.1). Technical measures include total allowable catches (TACs), time-area closures, gear selectivity and minimum landing size, and are traditionally implemented by administrative methods ('command and control'). It is generally acknowledged that these measures, if properly set and enforced, can efficiently constrain stock exploitation. However, they do not eliminate the 'race for fish' phenomenon due to the common-pool nature of the resource. The perpetuation of the competition for access to the resource among fishermen undermines the effectiveness of these measures.

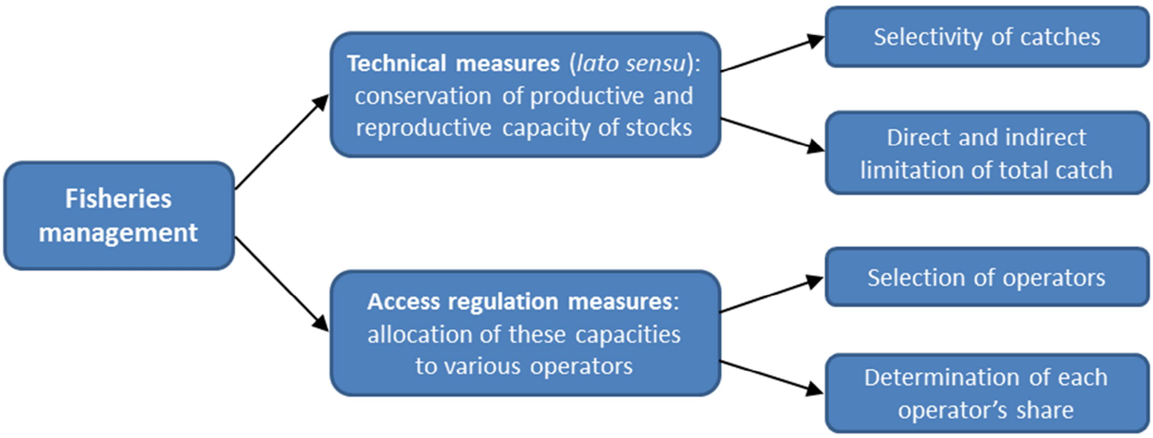


Figure 1.1: The main components of fisheries management (source: Boncoeur et al., 2006)

The control of individual access may rely on an input control (fishing effort) or on an output control (landings). Fishing licenses and fishing rights[1] constitute the main management tools for regulating access to fishery resources (Scott, 1989; Pearse, 1992). Licenses were first introduced for administrative monitoring purposes in an effort to control fleet expansion. In general, the term 'fishing licenses' refers to input-based controls that do not constrain total catches unless they are associated with some sort of fishing rights (output-based controls) (Townsend, 1990). Frequently (though perhaps improperly) qualified as property rights, 'fishing rights' often materialize as a fixed percentage of a TAC (catch share), while the TAC is typically set by a public authority. As opposed to administrative methods, rights-based approaches provide incentives for resource users to adopt certain behaviors and are usually categorized among economic methods (Boncoeur et al., 2006). The characteristics of property rights were reviewed by Scott and Johnson (1985) and by Devlin and Grafton (1998), who listed six key elements that allow evaluation of the 'completeness' of property rights: exclusivity, duration, flexibility, quality of title, transferability and divisibility. More generally, Schlager and Ostrom (1992) theorized that property-rights regimes consist of a 'bundle of rights', five of which they identified as being most relevant to characterize tenure arrangements and the conditions under which they can be exercised. These are access, withdrawal, management, exclusion, and alienation (i.e. the right to sell or lease management and exclusion rights). The

[1] Although fishing licenses may be considered as fishing rights, the notions of 'rights-based approach' or 'rights-based fishing' are more frequently associated with catch share systems. Here, we do not include administrative license schemes without catch shares in rights-based approaches.

philosophy behind rights-based approaches is to try to internalize the costs that a fisherman's actions impose on others. The underlying economic justification for rights-based approaches was significantly inspired by the work of Coase (1960) who analyzed the relevance of using well-defined rights and the market to solve the problems arising from the difference between private and social costs in the domain of environmental pollution. Economic methods also include taxation methods that aim at making the producer of a negative externality internalize the cost induced for other economic agents by means of a tax system on inputs (fishing effort) or outputs (landings). While they have been widely applied in the domain of environmental management (Callan and Thomas, 2013), taxation methods have rarely been used as management tools in fisheries (Boncoeur et al., 2006).

1.2 Failures of the Common Fisheries Policy

In Europe, fishing activities are governed by the Common Fisheries Policy (CFP), which was historically focused on conservation policy based on technical measures and top-down management approaches (see Holden (1994) and Peñas Lado (2016) for fully documented historical perspectives on the CFP). The origins of the CFP are associated with two regulations dated from 1970. The first provided for structural aid to the fishing sector (EEC, 1970a). The second was concerned with the marketing of fishery products (EEC, 1970b). However, it is generally accepted that the beginning of the CFP actually coincides with the regulation established in 1983 that introduced annual TACs for the main commercial species and the concept of relative stability (EEC, 1983), whereby each Member State is attributed fishing possibilities according to their historical fishing activity for each stock (Holden, 1994). In the early stages of the CFP, the *structural policy* provided some financial support to the fishing sector with the objective of modernizing it and increasing competitiveness of the fleets (Hatcher, 2000). In 1992, acknowledging the need for a better balance between the fishery resources available and the fish catching capacity of the Community fleet, the CFP was revised to include a regulation that provided for limited entry license schemes to be progressively implemented and identified the need to control fishing effort (Peñas Lado, 2016). In 2002, the structural policy was reshaped to address apparent contradictions between aids to the construction of new vessels and resource conservation objectives. The regulation then progressed toward longer-term considerations in efforts to achieve ecological, economic and social sustainability. The successive programs put in place to deal with overcapacity, including multi-annual guidance programs and public-aided decommissioning schemes, allowed the steady decrease in global fleet capacity (Cueff, 2007).

Nevertheless, overcapacity remains a persistent issue. Although public aid to build new vessels ceased in 2004, the level of subsidies in EU fisheries remains high. This is well illustrated by the following quote from the Green Paper on the reform of the CFP: "European citizens almost pay for their fish twice: once at the shop and once again through their taxes" (CEC, 2009). Currently, the main financial instrument of the CFP, the European maritime and fisheries fund (EMFF), is portrayed as helping fishermen to transition to sustainable fishing and as supporting coastal communities in diversifying their economies. Further financial assistance also continues to be provided to fishermen in the form of fuel tax exemption, which supports the maintenance of energy intensive fleets (Borrello et al., 2013). Notwithstanding these measures, employment in the fisheries sector has been decreasing for many years (Salz et al., 2006).

Despite a general consensus among scholars and public officials on sustainability targets, the CFP has failed to maintain fish stocks in good shape (Figure 1.2). Historical trends in fish landings indicate that total landings in European seas peaked in the mid-1970s and have mostly been declining ever since (Gascuel et al., 2016). The Green Paper (CEC, 2009) listed the following problems that the CFP failed to prevent: overfishing, fleet overcapacity, heavy subsidies, low economic resilience, decline in the volume of fish caught by European fishermen and poor compliance by the industry. The diagnosis expressed by the European Commission was unambiguous: "An important consequence of the vicious circle of overfishing, overcapacity and low economic resilience is high political pressure to increase short-term fishing opportunities at the expense of the future sustainability of the industry" (CEC, 2009); this assessment being similar to that of a concerted action reported ten years before (Hatcher and Robinson, 1999a).

According to recent scientific evidence, management measures implemented in the last decade under the CFP have led to improvements in the status of some important commercial stocks (Cardinale et al., 2013; Gascuel et al., 2016). Nevertheless, the exploitation of many fish stocks in Europe remains beyond rates that would be suitable to reach sustainability targets (Guillen et al., 2016) and annual TACs are continually set above scientific advice for many stocks (Carpenter et al., 2016). The challenges associated with the TACs and quotas system of the CFP are manifold and persistent: determining which species should be subject to TACs, considering long-term and multispecies approaches, rationalizing the decision-making process and ensuring adequate enforcement of catch limitations (Peñas Lado, 2016). Acknowledging the increase of anthropic pressure on fishery resources and the weaknesses of management solely based on conservation measures, the awareness of public authorities for developing adapted *access regulation* mechanisms has grown. The European Commission has clearly encouraged the use of rights-based management (in the broad sense of allocating fishing rights to fishermen, fishing vessels, enterprises, cooperatives or communities) to achieve the CFP objectives (e.g. Hatcher and Robinson, 1999b; CEC, 2009; MRAG et al., 2009).

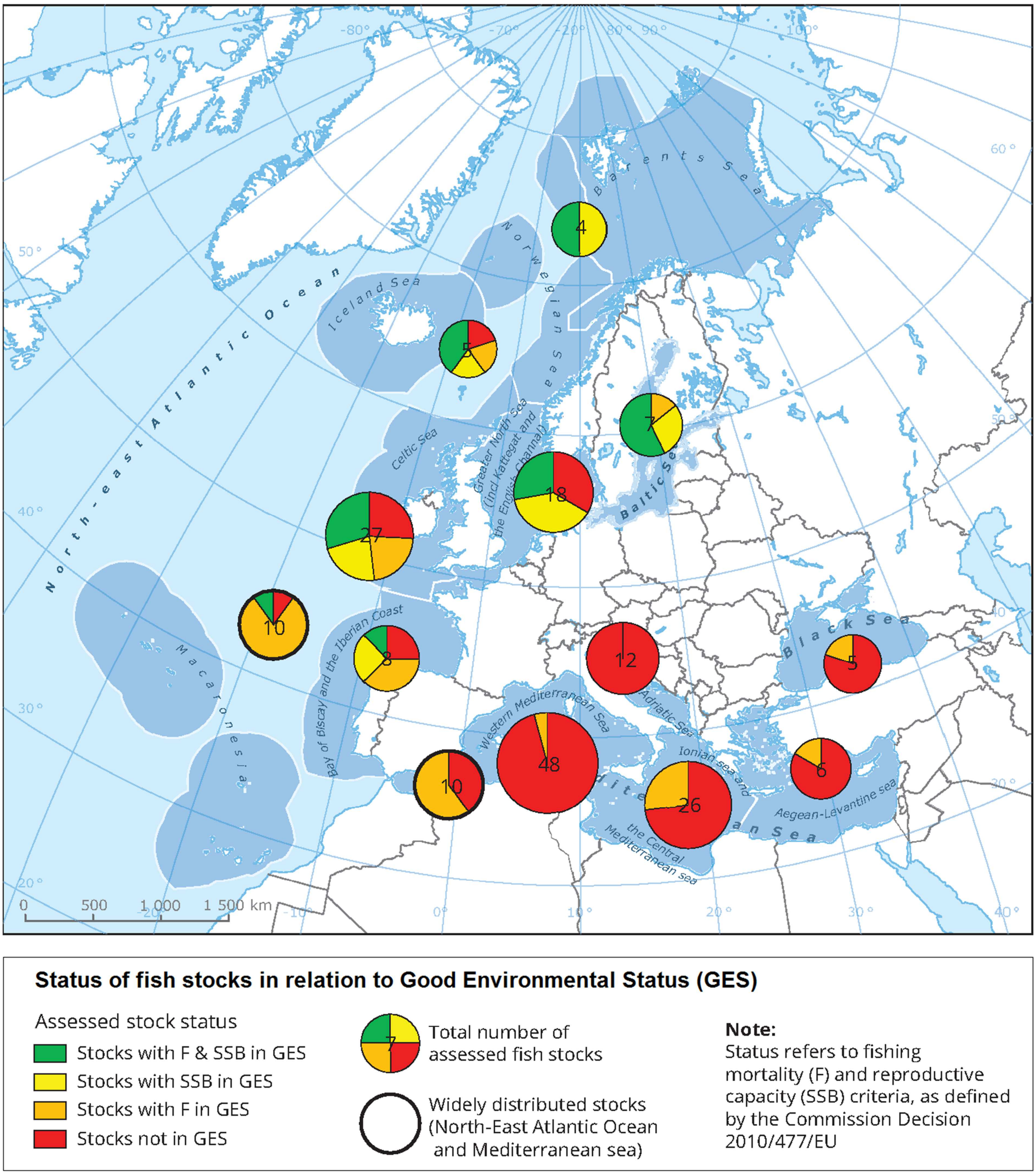


Figure 1.2: Status of fish stocks in regional seas around Europe. Stocks in the Northeast Atlantic and Baltic waters were assessed based on advice from ICES for 2013. Stocks in the Mediterranean and Black seas, and widely distributed stocks, were most recently assessed by GFCM and ICCAT between 2008 and 2012. (source: European Environment Agency, Annual indicators report series 2016)

1.3 Last reform and the new Common Fisheries Policy

The CFP is revised approximately every 10 years and the new CFP has been effective since January 2014 (EU, 2013a). The last reform was initiated when the EC published its Green Paper on the reform of the CFP (CEC, 2009) in a context where the objective of achieving sustainable fisheries by 2015, spelled out at World Summit on Sustainable Development in 2002 and accepted by all Member States, was unlikely to be met for all marine waters (Froese and Proelß, 2010). Therefore, the Green Paper was a call for rethinking the CFP and engaging all stakeholders to take action to secure the effective delivery of the CFP's objectives.

Perhaps the most emblematic measure introduced with the new CFP is the adoption of a landing obligation, aimed at eliminating wasteful discarding practices and improving the implementation of catch limits. Progressively being phased in across fisheries and species between 2015 and 2019, the landing obligation requires all catches of regulated commercial species to be landed and counted against quota (EU, 2013a). However, due to the negative short-term effects on economic performance it induces (Villasente et al., 2015; Prellezo et al., 2016; Veiga et al., 2016), its implementation raises the critical issues of fisheries control and regulatory compliance that have been deficient in EU fisheries. As the Green Paper succinctly states, "fisheries control has generally been weak, penalties are not dissuasive and inspections not frequent enough to encourage compliance" (CEC, 2009). There is no doubt that the landing obligation will be difficult to enforce (Borges, 2015; Veiga et al., 2016; Plet-Hansen et al., 2017), which could lead to negative ecological effects such as unreported catch impacting stock assessment (Villasente et al., 2015). As the continued failure of the control policy contributes to the negative performance of the CFP, the landing obligation potentially augments the need for identifying mechanisms that are able to ensure a high level of compliance.

Another aspect of the last CFP reform that attracted a lot of attention concerned access regulation and the use of rights-based management. The Green Paper's proposition of implementing transferable fishing concessions, a concept somewhat similar to individual transferable quotas (ITQs), at the EU level provoked an intense debate on the relevance of the generalization of market instruments in EU fisheries. As documented by Frangoudes and Bellanger (2017; reproduced in Appendix D), France was strongly opposed to this project and reaffirmed its support to decentralized collective management systems and to the principle of non-transferability established in its national regulations. During the public debates, it appeared that French fishers and other stakeholders viewed individual quotas as a good tool if managed collectively by producer organizations (Frangoudes and Bellanger, 2017). However, most of them were opposed to the transferability of individual quotas that would have had negative impacts on employment and other social aspects within fishing communities. After consideration of national views, the generalized marketization of fishing rights was eventually given up by the EC, which instead left the choice of using a rights-based regime to the discretion of each

Member State. Nonetheless, these access regulation considerations highlighted the need for assessing the effects of rights-based management systems.

The new CFP also established the necessity to move towards a longer-term perspective in fisheries management targets and confirmed the commitment to adapt exploitation rates of marine biological resources so as to restore and maintain fish populations above levels that can generate the maximum sustainable yield[2] (MSY) as the common environmental objective for all EU fisheries. In practice, the tools dedicated to achieve the MSY targets are multi-annual management plans that cover several stocks if these are fished in a multispecies fishery and should be preferred over traditional annual single-stock approaches. These long-term management plans should also consider mixed-fisheries interactions in order to avoid achieving one objective at the expense of failing at another (Kraak et al., 2013; Ulrich et al., 2016). Notably, recent evolutions in multi-annual plans include the introduction of fishing mortality ranges consistent with moving towards MSY as opposed to prescriptive point values, with the aim to bring some flexibility in management targets and accommodate fishing opportunities in the context of mixed fisheries, 'choke-species' effects and landings obligation (Ulrich et al., 2016). An important element of these plans is the regular assessment of their objectives and the impact assessment of new management measures. These necessitate bio-economic tools that integrate the multiple dimensions that may influence the effectiveness of management measures and consider fishermen as responsive agents. Therefore, there is a strong demand from fishery managers and stakeholders to have such tools available in order to evaluate diverse trade-offs between ecological, economic and social objectives.

Furthermore, the new CFP introduced a governance shift toward *regionalization*, giving the industry and local institutions more responsibility with the aim to improve the decision-making system (Symes, 2012; Le Floc'h et al., 2015). The underlying idea is that simultaneously achieving multiple management objectives at a large geographical scale often represents an intractable challenge and that the chances of success may be greater when considering management issues at more regional or local scales. Delegation of decision-making responsibilities to regional institutions can facilitate adaptive management and ameliorate the integration of regional specificities. Regionalization is also intended to increase stakeholder participation in the decision-making process, thereby enhancing the legitimacy and effectiveness of fisheries management (Van Hoof et al., 2012). It relates to the fact that measures taken under the CFP are to be guided by an 'ecosystem approach' as the overarching principle (EC, 2008).

[2] Maximum Sustainable Yield is the maximum catch which can be taken from a fish stock without deteriorating the productivity of the fish stock over an indefinite period.

1.4 Integration of fisheries policy into an ecosystem approach

While early developments about the question of managing fishery resources mostly focused on single target species problems, it is now widely acknowledged that fisheries management should be integrated into a more holistic management approach considering all ecosystem components (e.g. habitat, protected species, non-target species) and their interactions. This new paradigm engendered a number of concepts such as *ecosystem-based fishery management* (EBFM) and *ecosystem approach to fisheries* (EAF). These are somewhat distinct in their operational implementation, but tend to overlap in that they all take a multi-species perspective and promote integrated fisheries management (FAO, 2003; Garcia et al., 2003; Pikitch et al., 2004). Recognizing that the various ocean uses (aquaculture, fisheries, tourism, biotechnology, energy, mining) are interconnected and that they should be managed jointly, concepts like marine/maritime spatial planning (Douvere, 2008; EU, 2014) and blue growth (EC, 2012; Burgess et al., 2017) have also emerged and proposed tools for the implementation of integrated ocean management. The main idea to be drawn from these recent developments is that the management of complex marine social-ecological systems should (i) be more proactive, (ii) be coordinated across sectors and areas, (iii) involve stakeholder engagement, and (iv) be transparent and multi-objective.

At the global level, the main legal instruments regulating the oceans and seas are the UN Convention on the Law of the Sea (UNCLOS), which sets coastal nations' resource claims to 200 nautical miles and provides guidelines for marine environmental protection, and the Convention on Biological Diversity (CBD), which lays down a framework for the ecosystem approach and biodiversity management. In Europe, the Marine Strategy Framework Directive (MSFD) also defines overarching conservation and management goals. The MSFD aims to achieve Good Environmental Status (GES) of the EU's marine waters by 2020 and to protect the fish stocks on which marine socio-economic activities depend. In response to these international and European requirements and the push to develop marine conservation, marine protected areas (MPAs), including Natura 2000 areas and marine reserves, are management instruments established by Member States to limit the ecosystem effects of fishing among other human activities (OSPAR, 2003; De Santo and Jones, 2007; Armstrong and van den Hove, 2008; Rodríguez-Rodríguez et al., 2015). Fisheries policy implemented under the CFP thus needs to be fully embedded in these multiple legal frameworks related to the conservation of marine fauna. This underscores the necessity of developing integrated approaches on the scientific level (Fulton et al., 2014). Furthermore, fisheries management generally involves a combination of measures that should not be limited to conservation policy and it must deal with access regulation issues if it is to achieve multiple objectives simultaneously (Péreau et al., 2012).

1.5 Importance of governance regime and institutions

The implementation of *access regulation measures* is contingent on a governance system that determines rules, mechanisms and institutional structures. Ineffective governance has been identified to be one of the main causes for bad fishery management (FAO, 2002; Hilborn et al., 2005; Jentoft, 2007), leading to dramatic overfishing and considerable economic losses worldwide (World Bank, 2017). It is now widely recognized that rights-based approaches are desirable for providing fishermen with appropriate incentives for stewardship and sustainability (Grafton et al., 2006; OECD, 2006; Hilborn, 2007; Allison et al., 2012). Yet, they may not be a sufficient condition for success if they are not properly adapted to the system to be governed (Jentoft, 2007). Limitations to how effective and systematic a governance system can be in delivering outcomes as planned must also be examined (Jentoft and Chuenpagdee, 2009), which also leads to the consideration of potential alternative or complementary governance approaches involving collective action and co-management arrangements.

1.5.1 Rights-based management systems

Individual transferable quotas (ITQs) are one of the rights-based management systems that have attracted the most attention in the stakeholders, policy-makers and academic spheres over the last decades (Shotton, 2000; OECD, 2006; Chu, 2009; Thébaud et al., 2012). The first advantage of ITQs is the expected end to the race for fish as a result of establishing exclusionary rights (Christy, 1996; Hilborn et al., 2005). ITQs are expected to limit investments and overcapitalization through the rationalization of fishing fleets. Secured individual allocations allow fishermen to focus on minimizing the costs of fishing and maximizing the value of the allotted catch share. The transferability of quota also increases the economic efficiency of the system (Christy, 1973). As the willingness to pay for acquiring quotas theoretically depends on the marginal profits from fishing, the least efficient fishermen (with the highest marginal costs) will rationally be selling or leasing out their quotas to the most efficient fishermen (with lowest marginal costs). If the quota market is perfectly efficient then aggregate economic benefits at equilibrium should be maximized at the sector level (Hatcher et al., 2002). As experience with actual implementation of ITQs progresses, evidence that they can substantially increase profitability accumulates (Grafton, 1996; Arnason, 2002; Jardine and Sanchirico, 2012; Thébaud et al., 2012).

However, there is also empirical evidence that economic efficiency of ITQs may only benefit quota owners, while causing financial hardship for working crews that have to lease quota, and failing to generate any benefits for the general public (Pinkerton and Edwards, 2009). Aside from the question of their economic performance, there are a number of issues associated with ITQs (Copes, 1986).

Individual quotas can generate high-grading and discarding behaviors, selecting landings so as to increase their value (Anderson, 1994). Although transferability allows fishermen to acquire quota portfolios to balance catch, discarding is often considered an unavoidable part of multispecies ITQs (Sanchirico et al., 2006). The social effects of ITQs can also be difficult to overcome (Pálsson and Pétursdóttir, 1997). The economic rationalization of fishing activities generally induces a concentration of fishing rights. Bigger firms that have access to funds are more likely to acquire quotas than smaller firms (Bernal et al., 1999). This can potentially decrease employment in the fishing industry, with social consequences for small-scale fisheries and for local economies if fishing activities are transferred to other regions (Pálsson and Pétursdóttir, 1997; Campbell et al., 2000). Safeguards may thus be needed to limit these social effects (Kroetz and Sanchirico, 2010). Acceptability of ITQs in the fishing industry may depend on the design of these safeguards and on the initial allocation that will be critical for ITQs to be perceived as a legitimate system (Lock and Leslie, 2007; Strauss, 2013). Acceptability of ITQs in the public opinion may also be a concern if rights are given away for free whereas the resource is supposed to be owned by the public (Bromley, 2009). In theory, auction or tax mechanisms can return the rent generated from a common resource to the public. In practice, in order to get support from the industry, regulators mostly use free allocations resulting in 'windfall gains' for the first generation of fishers (Brandt, 2007).

Nonetheless, granting permanent share-based ITQs can potentially promote resource stewardship and compliance of participants (Anderson, 1995). Indeed, the better the health of the fish stocks, the more valuable is the ITQ property. Quota holders thus have an inherent interest in the welfare of the fish stocks (Arnason, 2002; Van Putten et al., 2014). Some authors have challenged the idea of ITQs securing good stewardship, pointing out that empirical evidence largely failed to distinguish the effect of binding TACs from the effect of ITQs, and that ITQs do not solve the problems of setting TACs and ensuring compliance (Copes and Charles 2004; Bromley, 2009; Acheson et al., 2015).

At the end of the 2000s, more than twenty important fishing nations, including the United States, New Zealand, Australia, Iceland, Canada, Norway, Chile, Peru, Namibia, Mozambique, Argentina, and several EU countries (United Kingdom, Denmark, the Netherlands, Spain) were using ITQs as a major component of their fisheries management system (Chu, 2009; Arnason, 2012). Lessons learnt from the multiple experiences with implementation of ITQs over the world indicate that it is a system with the potential to significantly improve economic efficiency and to meet environmental objectives (Costello et al., 2008). However, cases where ITQs have not fully functioned also exist (Chu, 2009; Pinkerton and Edwards 2009; Van Hoof, 2010; Hoefnagel and de Vos, 2017) and are useful to analyze in order to understand the contexts and drivers that lead to successful implementation of ITQ systems.

Although ITQs have been the dominant form of rights-based management institutions, alternative options such as territorial use rights for fishing (TURFs) have also been adopted (Christy, 1982; Poon and Bonzon, 2013). TURFs are generally operated as a spatial form of property rights in which individuals or a group of fishermen are granted exclusive access and fishing rights to exploit fisheries resources within well-defined spatial units (see Quynh et al. (2017) for a critical review of the literature on TURFs including recent evolutions of TURF institutional structures). Empirical evidence showed that TURFs are often associated with collective action and autonomous self-managing local institutions, so that they make it possible to mitigate various residual externalities related to space and multispecies interactions that remain unresolved in a typical ITQ (Cancino et al., 2007; Wilen et al., 2012). While TURFs have been successful in a number of fisheries around the globe (Cancino et al., 2007), their use in North-East Atlantic European waters has been restricted to small-scale artisanal fisheries and limited in their geographical coverage (Spagnolo, 2012).

The transition to rights-based systems is almost always preceded by some sort of ‘limited entry’ system. Under a limited entry system, a fisherman owns a permit or a license entitling him to participate in the fishery, and the fishery regulator employs complementary tools (such as restricting season length and vessel-gear characteristics) to constrain the catch (Townsend, 1990). When permits are transferable, the market permit price indicates capitalized profitability to the marginal fisherman (Grainger and Costello, 2016). However, under limited entry only, participants usually have strong incentives to race to capture the largest share possible and evidence has demonstrated that it does not prevent rent dissipation (Wilen, 1988). For example, Casey et al. (1995) report that, despite the limited entry program, the fishing capacity of the British Columbia halibut fishery increased drastically in the 1980s so that the length of the fishing season had been reduced from 60 days in 1982 to 6 days in 1990, even with a larger TAC. This type of phenomenon has consequences for the hazardousness of crew working conditions and for the downstream stages of the supply chain (e.g. necessity to freeze and store the catch for most of the year). This can also limit the adaptive capacity of fishermen by locking them into a restrictive regulatory framework (Boncoeur and Guyader, 1995). Therefore, it is now widely recognized that limited entry schemes should be associated with some fishing rights to provide appropriate incentives (Grafton et al., 2006).

1.5.2 Co-management and collective action

In her classic book, Elinor Ostrom (1990) started developing her influential theory on common-pool resources (CPRs) and collective action. Her approach describes how rules, operating at multiple social organization levels, influence the outcome achieved by individual users of natural resources. Ostrom showed that central government authorities and market-based tools are not the only institutional answers to the tragedy of the commons. Users of a common-pool resource can, outside of any legal framework, agree on rules that are beneficial to all and thereby prevent over-exploitation. Her conception of institutions as a means of reducing uncertainty in complex environments makes it possible to understand under what conditions trust and norms of reciprocity can be established to stimulate collective action. The factors that affect the likelihood of self-organization and the successful management of a CPR over time include: the importance of the resource to users, knowledge of the socio-ecological system, predictability of its dynamics, autonomy in implementing and enforcing collective-choice rules, size and homogeneity of the group, leadership, and social capital (Ostrom, 2007, 2009).

Following Ostrom's work, many authors have argued that community-based co-management can result in sustainable fisheries (Dietz et al., 2003; Beddington et al., 2007; Berkes, 2009; Gutiérrez et al., 2011). Co-management is a system of collaborative governance of resources in which resource management responsibility is shared between government agencies, resource users and other stakeholders (Jentoft, 1989). Resource users are thus involved in the management process and participate in regulatory decision-making, implementation and enforcement. As opposed to bureaucratic 'top-down' approaches, co-management delegates management to user-organizations at national, regional and local levels and promotes the autonomy of users within an overall institutional framework. Co-management systems can be structured in a variety of ways (Sen and Nielsen, 1996). At the end of the spectrum of co-management arrangements is found self-management, where authority and responsibility is entirely decentralized and all governance decisions are made by resource users themselves (Townsend et al., 2008).

Granting harvest rights to user organizations rather than to individuals can facilitate coordination and collective action (Deacon, 2012). This requires that the group holds the rights to control their members' actions. Identified attributes of successful co-management systems include clearly-defined access rights, legal recognition, exclusive use rights to communities (Allison et al., 2012), and strong leadership (Gutiérrez et al., 2011). It is generally considered that co-management approaches have advantages over technical measures alone (command and control) in cases where the capacity of the regulator to monitor and enforce rules is weak, or where institutional capacity to implement market-based tools is deficient. However, the success of co-management has its limits. Identified reasons for limited success include potential failures of internal governance to adapt to technological or socio-economic changes (Willmann, 2000), as well as a lack of trust between groups of fishermen and regulatory agencies (Pomeroy et al., 2001).

It is common for many authors and stakeholders to oppose co-management and ITQ systems because of their antagonistic underlying principles (Copes and Charles, 2004). However, ITQs and co-management systems are theoretically non-exclusive. For instance, the Dutch system is a good example where ITQs have been embedded in co-management arrangements (Van Hoof, 2010;

Hoefnagel and de Vos, 2017). Thus, the distinction between ITQs and co-management can sometimes be ambiguous. Additionally, co-management systems are sometimes referred to as *hybrid systems* of governance of common-pool resources. According to Williamson (1991), hybrid systems combine the responsiveness, efficiency and low transaction costs of markets with the administrative and cooperative capacity within the firm. This definition would, for example, be relevant to the Dutch co-management system that combines ITQs and user organizations that play a formal role in quota management and law enforcement. Alternatively, German and Keeler (2009) define hybrid systems as the combination a regulator's ability to implement regulations and the self-organization of users to manage their resources, which broadly characterize co-management systems regardless of whether they include transferability of fishing rights.

1.6 Fishery cooperatives / Producer Organizations

Fishery cooperatives, also known as Producer Organizations (POs) in Europe and sectors on the East Coast of the US, are major stakeholders of the governance in many fisheries around the world (Ovando et al., 2013). Fishery cooperatives are groups of harvesters that collectively manage their fishing activities. Regulatory competencies delegated by an administration to fishery cooperatives can include fishing rights management, monitoring and control of activity, commercialization and representation. The extent of these competencies can be established in many different ways, which in turn constitutes different forms of co-management (Jentoft, 1989; Sen and Nielsen, 1996; Pomeroy and Berkes, 1997). In practice, cooperatives can be responsible for quota distribution among members, thereby influencing the economic efficiency of a fishery and producing distributional effects. The mechanisms by which cooperatives may influence outcomes positively include: facilitating quota exploitation, addressing unresolved externalities in a traditional ITQ, information sharing, reducing monitoring costs and improving compliance.

<u>Facilitating quota exploitation</u>

There are examples of partial TAC utilization in ITQ fisheries, e.g. in US West Coast and New Zealand fisheries (NRC, 1999; Holland, 2016). The reasons why the market would be inefficient in allocating quota or why are TACs only partially utilized in some ITQ fisheries include high transaction costs (Squires et al., 1995) that may arise because of imperfect and asymmetric information, bounded rationality, and externalities (Coase, 1960; Williamson, 1981; Greenwald and Stiglitz, 1986). Indeed, if transaction costs are high and the quota value is low, fishermen may be reluctant to participate in the market (Squires et al., 1995). In practice, a number of behaviors explaining why some fishermen do not lease their quota out when they do not fish it can be identified (Boyd and Dewees, 1992; NRC, 1999). First, fishermen may think they might need the quota themselves later, or they may not want their quota to be used for free because it might reduce the productivity of stock for the future. In multispecies ITQ fisheries, fishermen may be undercatching some species because of the limiting effect of insufficient quota availability for other species and the difficulty of determining what they should pay for a given species to balance catch and quota in their species mix. If ITQs do not cover all species, fishermen may also try to build catch history in other fisheries (Barbara, 1995). In addition, there is anecdotal evidence of fishermen that did not want to lease out their quota for less than they had paid for the cost recovery fee. A cooperative may not be able to fully change these behaviors, but the collective management of fishing possibilities can materialize as collective decisions on an exploitation rate to balance catch and quota, with possible in-season quota reallocations and reduced transaction costs (Abdullah et al., 1998).

Addressing unresolved externalities in a traditional ITQ

The potential of cooperatives to implement real time management can also help to address externalities such as temporal congestion due to in-season catchability variations and spatial resource depletion (Copes, 1986). Indeed, a traditional ITQ management system will not generally achieve the coordination required to optimize the spatial and temporal deployment of fishing effort across an entire fleet (Costello and Deacon, 2007). Deacon et al. (2013) show that cooperatives can help resolve temporal and spatial externalities by coordinating their input actions (i.e. fishing effort).

Information sharing

Fishery cooperatives can facilitate the sharing of information such as productivity of competing fishing sites and bycatch locations. For example, Carpenter and Seki (2005) report anecdotal evidence of increased catch rates among Japanese shrimp fishermen who share information within self-organized groups. Haynie et al. (2009) also observe that fishermen in the Bering Sea cooperate to avoid halibut bycatch and extend the length of the target groundfish fishing season. Evans and Weninger (2014) show that information sharing is sub-optimal in an ITQ and that a cooperative can resolve this partially, but presumably not fully, because of issues of free-riding (each cooperative member wish that the cost of the search for information be incumbent upon other members).

Reducing monitoring costs and improving compliance

The internal monitoring and control of activity operated by cooperatives can substantially reduce enforcement costs for the regulator (Smit, 1997; Van Hoof, 2010). Additionally, cooperative-based co-management can increase the legitimacy of regulations and social norms (Jentoft, 1989; Nielsen, 2003), thereby enhancing regulatory compliance in general. Fishery cooperatives can also impact ecological sustainability by participating in co-management decision-making to promote environmental stewardship and engaging the industry in data collection and monitoring (Van Putten et al., 2014).

In France, the first POs were created in the 1970s and POs have since increasingly established their socio-economic influence on the fishing sector (Lebon Le Squer, 1998). Their role was initially determined by the CFP and was focused on market intervention (EEC, 1970b). Their missions notably included the adaptation of fishing plans to the demand of fish markets in order to stabilize fish prices. They also operated a minimum price mechanism that consisted in withdrawal from the market of any production whose auction price fell under a fixed threshold, thereby guaranteeing a minimum price for many commercial species. This minimum price mechanism has been, however, prohibited since 2014 (EU, 2013b). Initially being an element of security, most POs have progressively evolved to a more dynamic intervention such as downstream commercialization actions and aiming at better anticipation of landings. In the 2000s, a transfer of regulatory competencies from the national fisheries administration to POs, including fishing rights management, was gradually implemented, thereby making POs a cornerstone of the quota management system in relation to the TAC and quota system of the CFP (JORF, 2006; JORF[3], 2010a). Each year, POs are attributed collective sub-quotas based on the aggregated fishing rights (also known as *track records*, corresponding to historical landings of vessels on the period 2001-2003) of their members[4], and POs are then responsible for managing quota allocations to their members (Larabi et al., 2013). For instance, most POs have developed internal rules establishing individual quota allocations outside administrative regulatory constraints (Guyader et al., 2014). POs also have a representative role in various fisheries committees that are formally involved in national decision-making and have authority in various regional management aspects. Therefore, the role of POs[5] and their socio-economic influence in the French fisheries governance system are critical.

1.7 Dissertation objectives and research questions

In the context of the discussions on the pros and cons of different governance systems and their ability to tackle the challenges identified during the last CFP reform, this dissertation explores several issues related to PO-based catch share management systems from both an analytical and empirical perspective. The goal of this research is to determine how outcomes (ecological, socio-economic, and compliance) are altered if the regulator chooses a PO-based system over a system without POs. As such, the standpoint is purposely more positive than normative: rather than trying to

[3] Code rural et de la pêche maritime, articles L912-11 à L912-14.

[4] Each PO also holds a 'reserve' of historical landings track records that were created alongside decommissioning schemes, fishery exits and vessel sells from one PO to another. These reserves are somewhat important for quota management as they increase the POs' collective quotas.

[5] Since 2010, the role of French POs is complementary to that of the national and local fisheries committees that are in charge of resource management within the 12 nautical miles coastal band (JORF, 2010b). These committees have essentially developed license schemes (e.g. for scallop, abalone, algae, etc.) that notably concern some small-scale fisheries.

explain if and why a PO-based catch share system is the best governance system for managing fisheries, we acknowledge that it is an option that has been widely applied and investigate the effects of having POs in the system. To this end, this dissertation notably brings together bio-economic approaches and institutional analyses to better anticipate the ecological, economic and social impacts of potential governance options. The research questions are the following:

(1) What mechanisms could ensure a high level of compliance and what are the potential gains of having the POs between the regulator and the fishermen?

(2) What are the effects of quota management by POs on fisheries dynamics including distributional effects? Are distributional effects empirically quantifiable?

(3) What is the added value of integrating institutional arrangements involving POs into bio-economic modelling for the impact assessment of catch share management options?

1.7.1 Structure of the manuscript

This manuscript is structured around these 3 research questions, each having been addressed in one paper that constitutes chapters 2, 3 and 4 respectively. The rest of this introductory chapter presents the main case study used in this dissertation and details the background context of each paper, from the initial research questions to the more focused questions that were addressed. This is also an opportunity to include some background literature review that puts each paper into a broader context and complements the material developed in the papers. The manuscript ends with a general conclusion chapter that summarizes the main findings and methodological contributions, stresses the limitations of this work and suggests perspectives for future work.

1.7.2 Circumstances of the PhD research

This dissertation work was co-funded by the French Institute for the Exploration of the Sea (Ifremer) and Region Bretagne, and partly integrated in the EU FP7 SOCIOEC project (Grant no. 289192) that aimed to investigate the socio-economic effects of management measures of the CFP. The main host research unit during the PhD was the UMR 6308 AMURE based in Ifremer Centre de Bretagne, Plouzané, France. Early in the research process, the relevance to gain international perspectives on POs was established. After a literature review on fishery cooperatives worldwide, it appeared that a number of fisheries in the US share significant similarities with the French system. For example, the New England groundfish fishery management system is based on harvest cooperatives whose duties include quota allocations, monitoring, enforcement and membership management (Holland et al., 2013; Scheld and Anderson, 2014). After engaging a research discussion and identifying a strong shared interest for issues related to fishery cooperatives, a collaborative work with Dr. Dan Holland (NWFSC, NOAA) and Dr. Christopher Anderson (SAFS, UW) started and led to a four month stay as a visiting doctoral student at the School of Aquatic and Fishery Sciences at the University of Washington between May and August 2015. The work initiated during this mobility eventually materialized as the first paper of this dissertation. Consequently, the first paper of this dissertation takes a general perspective on cooperative-based catch-share systems and is not focused on one case study in particular, whereas the second and third papers explore empirical questions applied to the Bay of Biscay common sole fishery (one of the case studies of the SOCIOEC project). Additionally, the term 'fishery cooperatives', somewhat broadly employed in the literature to refer to these user groups worldwide, was preferred in the first paper, whereas 'producer organizations', usually preferred in France and in Europe, was used in the second and third papers.

1.7.3 Material and methods

Data needed for the different parts of the research were diversified in terms of their nature, source and collection method. Institutional details on French POs and on a number of fishery cooperative programs worldwide were obtained by reviewing a variety of regulations established at different levels (e.g. EU and national legislations, cooperative internal agreements), either available online or collected from stakeholders. To complement and update the few available references on the functioning of French POs (Lebon Le Squer, 1998; Larabi et al., 2013), a number of targeted interviews were conducted with PO managers and fishermen throughout the research process. Notably, some of the interviews were directly conducted as part of this dissertation work while others were conducted and made available by collaborators from the AMURE research team (Lagière, 2012). Institutional and socio-economic background information collected through field work contributed to the analyses as well as structured the general thinking of this dissertation. The main source of quantitative data was Ifremer's fisheries information database, which constitutes an extensive source of disaggregated data including vessels' characteristics, fishing activity, catches-landings and economic information for French fisheries (see http://www.ifremer.fr/sih for details on Ifremer's fisheries information system). In addition, the historical landings track record, used by the administration for computation of catch shares allocated to POs, was also an important material for this work.

In order to address the various research questions, the analytical and empirical approaches developed in this dissertation are diversified: formalization of institutional mechanisms, game-theoretic modelling, distribution analysis, integrated bio-economic modelling and simulations. In particular, the bio-economic developments build on the model IAM (Impact Assessment Model for fisheries management) that was developed by the AMURE research team to assess impacts of management scenarios (Merzéréaud et al., 2011; Raveau et al., 2012; Guillen et al., 2013, 2015) in the context of the CFP reform and the implementation of multi-annual management plans with MSY objectives (EC, 2010). Each of the chapters 2, 3, and 4 contains a section providing the methodological details relevant to the analyses carried out in each of the three papers of this dissertation.

1.7.4 Main case study: the Bay of Biscay sole fishery

The Bay of Biscay sole fishery was used as a case study for the second and third paper of this dissertation. It is one of the main French fisheries and provides an example of a multi-species fishery where multiple fleets interact. The common sole (*Solea solea*) is a species of flatfish distributed across the North East Atlantic, from the south of Norway to Senegal, and the Mediterranean Sea (Desoutter, 1992). Ranked as either first- or second-most important species in French fisheries in terms of landing value between 2012 and 2016 (FranceAgriMer, 2017), the common sole is an essential species for netters and trawlers operating in the Bay of Biscay.

The Bay of Biscay sole in ICES areas VIIIab is subject to a multi-annual management plan since 2002 that was decided after high fishing mortalities and risks of collapse. The health of the stock has since improved, but it is still being fished beyond MSY despite the declared management plan objective of achieving MSY by 2015 and at the latest by 2020 (STECF, 2015). The stock is managed by an EU TAC since 1984, of which the French share is equal to 92%. In accordance with the French catch share system, the management of sole quotas is operated by the fisheries administration and by POs. Notably, it was one of the very first fisheries where individual quotas (also referred to as vessel quotas) have been implemented in France as a consequence of increased constraints on PO collective quotas versus resource availability and threats of penalties for quota overruns under the CFP and national regulations (EC, 2009a; De Vos et al., 2014). While there were nine POs operating in the Bay of Biscay sole fishery in 2011, three PO mergers have occurred between 2011 and 2014 so that there are now six POs of various sizes and fleet compositions spread all along the Bay of Biscay coastline.

1.8 Background of the first paper on compliance regimes in fishery cooperatives

Initial research question: *What mechanisms could ensure a high level of compliance and what are the potential gains of having the POs between the regulator and the fishermen?*

Illegal, unreported and unregulated (IUU) fishing is a serious obstacle to the sustainable development of fisheries (OECD, 2005). IUU fishing dilutes the effect of conservation management and policy measures, erodes labor standards, impairs markets for legally harvested fish, favors corruption, and lowers prospects for food security, economic growth and stability. IUU fishing tends to occur where enforcement capacity is weak, e.g. in developing coastal nations and where small-scale fisheries are prevalent (UNODC, 2011). In some important fisheries worldwide, including in European community waters, IUU fishing accounts for a large share of total catches (CEC, 2007; Agnew et al., 2009). Beyond the problem of illegal fishing in high seas, the poor compliance by the industry within European community waters raises the question of finding appropriate institutional mechanisms that can ensure a high level of compliance (CEC, 2009).

Enforcement is one of the most critical problems with catch share systems (Copes, 1986). In a catch share system without fishery cooperatives, the regulator decides on some level of monitoring and penalties in order to generate deterrence. However, there are a number of things that can limit penalties (e.g. the firm's net worth), which then require a higher level of costly monitoring. In reality, in most cases monitoring and enforcement expenditures are very limited and economic incentives to comply are not high enough to produce adequate deterrence (King and Sutinen, 2010). According to OECD estimates, penalties paid within the European community only averaged between 1.0 and 2.5 percent of the value of illegal and unreported landings (OECD, 2005). However, given the fact that illegal and unreported fishing appears to be particularly profitable, estimated current compliance levels are not as bad as the basic deterrence model (Becker, 1968) based on traditional economic incentives would predict (that is, we do not observe that all fishermen violate the rules all the time whenever it is profitable to do so). Acknowledging incompleteness in the basic deterrence model applied to fisheries, Sutinen and Kuperan (1999) introduced an enriched model of compliance that accounts for the influence of legitimacy and social norms in the utility function of fishermen (Figure 1.3). The expected penalty is determined by the probability of being detected and prosecuted, the penalty level incurred, and the final settlement amount (i.e. the percentage of the incurred penalty actually paid). While the expected penalty presumably has a positive effect on legitimacy overall, penalty levels that are perceived as extreme are in fact likely to decrease settlement rates. This implies that a regulator cannot rely on setting an extremely large penalty level to ensure compliance. One of the key conclusions of Sutinen and Kuperan's paper was that co-management regimes may be a means of strengthening legitimacy and voluntary compliance. Based on a similar framework, we intend to explore the mechanisms by which fishery cooperatives could help improve compliance in a catch share program, e.g. lowering monitoring costs (information asymmetry), increasing detection (information sharing), enhancing legitimacy and social norms.

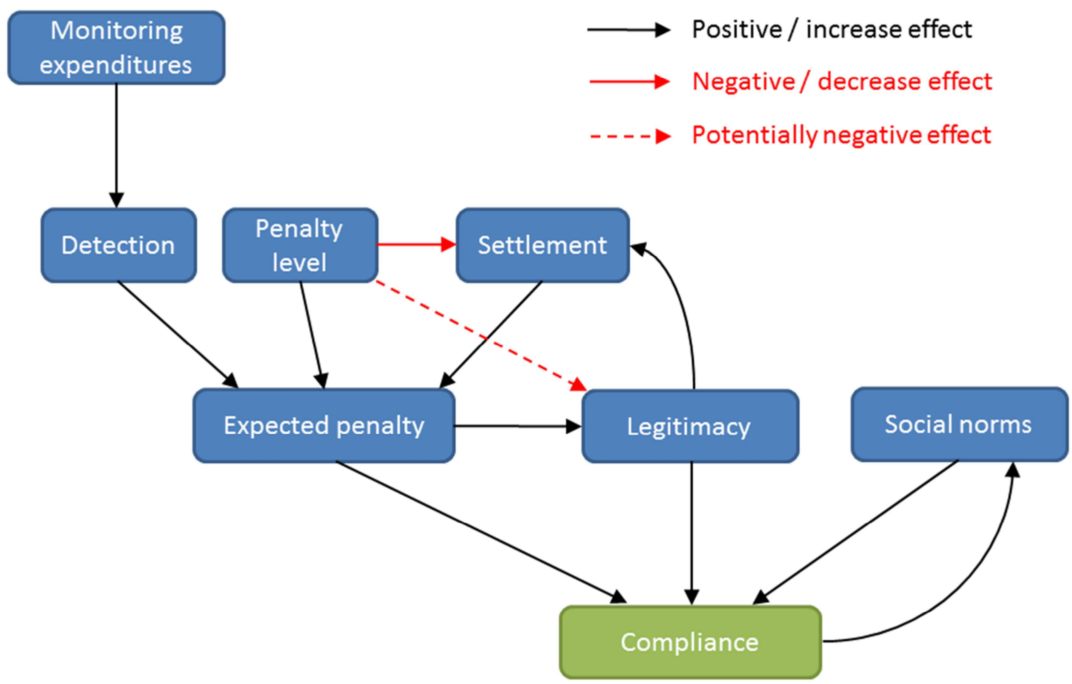


Figure 1.3: Diagram of the main factors influencing regulatory compliance in fisheries (adapted from Sutinen and Kuperan, 1999)

Sutinen and Kuperan's model focuses on individuals' decisions whether to comply with a given set of regulations. However, there are a number of fisheries where groups of harvesters (cooperatives) are jointly liable for not exceeding collectively assigned fishing rights (and sometimes they are jointly liable for other types of violations as well). These cooperatives can implement their own internal compliance regime (monitoring, penalties), thus modifying the deterrence scheme from a principal-agent problem (regulator → fishermen) into a nested problem (regulator → cooperative & cooperative → fishermen). In a situation where the regulator can punish a cooperative (or all members) for the actions of one individual member (joint and several liability), each member of a cooperative wants the other members to comply but also does not want them to get caught when they violate regulations. Therefore, one can wonder if the joint and several liability mechanism provides appropriate incentives for the cooperative to develop an effective internal compliance regime.

In general, joint and several liability is a designation of liability by which members of a group are mutually responsible for the damages caused by one or more members. Under joint and several liability, a plaintiff has the option to sue one or more defendants severally, or all jointly. The potential reasons for the imposition of joint and several liability include that joint tortfeasors may serve as insurers for each other, and dealing with situations where the plaintiff cannot determine which of the defendants caused the harm and the defendants are best-positioned to apportion damages amongst themselves (Kornhauser, 2013). For instance, joint and several liability has been applied in environmental pollution cases such as those involving Superfund sites where it has been demonstrated that it influenced parties to reduce the likelihood of damages (Kornhauser and Revesz, 1994). In the context of fishery cooperatives, the contracts or internal agreements of a cooperative can include a regime of joint and several liability. Offenses that are jointly and severally liable typically include quota violations and misreporting of catches. However, information on the exercise of joint and several liability in fisheries is very limited[6].

The current control regulation of the CFP does not explicitly mention the question of the liability regime (EC, 2009a), which has not been addressed in the literature on compliance in fisheries either. Considering traditional economic incentives as well as social preferences in a game-theoretic framework, the paper presented in chapter 2 shows that, under specific conditions, the joint and several liability mechanism has potential to ensure a high level of compliance while possibly decreasing monitoring costs for the regulator. Although intended to be general in the specification of the problem and not directly applied to one particular fishery, the paper in fact addresses, from an angle that has not been investigated yet, what the EC considered as one of the structural failures of the CFP. As such, the paper provides new insights that are highly relevant to EU fisheries.

1.9 Background of the second paper on the distributional effects of quota management by POs

Initial research question: *What are the effects of quota management by POs on fisheries dynamics including distributional effects? Are distributional effects empirically quantifiable?*

As experience on implementation of rights-based approaches in a variety of biological, technological, and institutional settings has accumulated, evidence of increased economic and ecological performance from these approaches has consolidated (Arnason, 1993; Pascoe, 1993; Grafton, 1996; Arnason, 2002; Newell et al., 2005; Costello et al., 2008; Jardine and Sanchirico, 2012), and the policy debate has somewhat shifted away from the questions of economic efficiency or sustainability and toward questions of institutional design and distributional effects (Grainger and Costello, 2016). The introduction of rights-based management may trigger significant transformations in the socio-economic organization of the fishery, possibly modifying who fishes, fishing locations, gear types and seasonality, the size of fishing rents, the balance of influence among sectors, and the location of coastal economic activities (Bromley and Bishop, 1977; Copes and Charles, 2004; Huppert, 2005). Critical issues related to fishing rights notably include controversies over the distribution of rights

[6] In fact, although there are cooperative contracts (e.g. in the New England sector program) that clearly stipulate the enactment of a ‘joint and several liability’ regime, it is unclear how it differs from a ‘joint liability’ regime in the way that it is actually implemented.

and associated economic return, and concern for disruptions imposed on fishermen who are historically dependent on the former system. As pointed out by Karpoff (1987) and Johnson and Libecap (1982), if the institutional change is not Pareto improving (i.e. if there are fishermen that are better off with staying in the previous system), large aggregate benefits of introducing a new rights-based regime may not be sufficient to ensure that an institutional reform will be successful. In practice, if not properly addressed, distributional issues may impede the legitimacy and performance of rights-based instruments (Copes, 1986; Guyader and Thébaud, 2001), and potentially provoke their termination (Criddle and Macinko, 2000). If quota allocation is not seen to be legitimate and is not accepted, then compliance with rights-based management is likely to be low (Nielsen, 2003). We here review the main concepts underlying the 'fairness issue'.

Issues around the initial allocation process, conferring windfall gains on those receiving fishing rights to the exclusion of everyone else, have long been a subject of controversies (Copes 1986, Matulich and Sever 1999, Macinko and Bromley 2002, Bromley 2009). Copes (1986) identified three ways to initially allocate quota shares: giving quotas away for free, selling quotas at a fixed price, and quota auctions. In reality, due to considerations of political acceptability, most rights-based systems start off by granting free quota shares to past participants, a practice known as *grandfathering*. According to Anderson et al. (2010), grandfathering can increase expected rates of return for investment, lower capital costs, and provide incentives for collective action. However, the traditional method of allocating rights based upon historic fishing participation can leave some fishermen feeling duped. For example, some may claim that their records are imperfectly represented in the official database or that they are being treated unfairly for having fished less than ordinary during a randomly selected qualification period. These claims can even lead to legal actions, as it has been the case in the early stages of the implementation of the ITQ system in New Zealand (Dewees, 1989). Hannesson (2004) further argues that grandfathering tends to be rather undemocratic, often related to family networks, inheritance, or position in the local community. Additionally, allocations that are proportional to historic catches do not imply that they are proportional to the merit of the fishermen, e.g. large catches are not necessarily linked to sustainable and ecosystem-friendly fishing practices (Doering et al., 2016). Finally, if auctioning quotas off at the beginning of a new catch share system is difficult for political acceptability reasons, this does not justify the continued give-away of resource rent over time, which could be readdressed once acceptability has been achieved (Kahui et al., 2016).

Beyond the fact that gifting allocation fails to capture any resource rent for the public, only the first recipients of quota shares receive the windfall gains from the new rights regime and the fishermen that enter the fishery after the initial distribution have to pay for their rights, extending the issue of fairness to inter-generational equity (Copes, 1986; Bromley, 2009; Doering et al., 2016). In theory, shares could have limited duration after which rights are revoked and redistributed (a concept sometimes referred to as 'sunset clauses'), but this could undermine stewardship (Costello and

Kaffine, 2008). Alternatively, some quota reserves could be put aside for newcomers to the fishery, as is the case in Denmark (Andersen, 2012), although this could also weaken conservation and investment incentives (Deacon et al., 2013). An additional consideration is whether quota holders must remain active in the fishery to avoid ‘armchair fishermen’ that stop fishing and lease out their gifted allocation. These issues could partly be addressed by progressively shifting the allocation system from free allocations to an auction system (Bromley, 2015).

Another important debate associated with the implementation of rights-based systems concerns the concentration of rights and the inevitable social changes that it implies (e.g. Sumaila, 2010; Olson, 2011; Matthíasson et al., 2015). Although some concentration may be desirable to achieve economic objectives, excessive concentration can lead to the extension of corporate control, at the expense of small-scale local interests, and unfair outcomes (Pálsson and Helgason, 1995; Pinkerton and Edwards, 2009). High concentrations of fishing rights are often accompanied by the loss of, or more expensive, access for small-scale fishermen, which in turn may jeopardize employment level, working conditions, food security and the persistence of local communities (Copes, 1986; Copes and Charles 2004; Bromley, 2015). In several ITQ systems, regulations that restrict the trading of quotas were introduced to avoid the concentration of rights in a few hands (Kroetz and Sanchirico, 2010). For example, Denmark and Norway restricted the spatial tradability of quota shares to preserve coastal communities (Andersen, 2012; Armstrong et al., 2014). However, these limitations come at the expense of economic efficiency.

Most of the literature on distributional effects of rights-based system in fisheries has focused on ITQs. However, anecdotal evidence shows that implementation of rights-based fishing in a co-management context has, in some cases, led to less poverty, greater equity and empowerment of fishing communities (Pomeroy and Ahmed, 2006). Sullivan (2000) also reports evidence fishery cooperatives can ease quota assignment issues. Once the catch shares for these cooperatives were determined by the fisheries administration, the groups internally negotiated allocation arrangements among members. The general idea behind this approach is that leaving share allocation to the fishery participants internalizes the conflicts associated with selecting individual winners and losers, and prevents granting individual interests in public resources to private parties (Deacon et al., 2013). In France, a PO-based catch share system was effectively created in 2006 (JORF, 2006). This system is characterized by a historical rights-pooling mechanism operated at the PO level, whereby each PO is granted a collective allocation determined by the cumulated historical rights of its members and organizes quota redistribution among its members according to self-established rules. The French case offers a unique perspective on the implementation of PO-based catch share system because individual allocations operated by POs are non-transferable, as national regulations prohibit marketed exchanges of fishing allocations. The second paper of this dissertation (chapter 3) therefore addresses the issue of the distributional effects of catch share management by POs in a context of non-transferability of rights and heterogeneity of quota management practices across POs. The paper will use the Bay of Biscay common sole fishery as a case study. The basic idea underlying the analysis is to compare how historical rights are distributed in the fishery with how actual landings are distributed in the fishery for a given year, considering that the difference between these two distributions is the result of quota management by POs and their impacts on the strategies of producers.

1.10 Background of the third paper on the added value of integrating institutional arrangements in bio-economic simulation frameworks

Initial research question: *What is the added value of integrating institutional arrangements involving POs into bio-economic modelling for the impact assessment of catch share management options?*

In EU regulations, impact assessment is defined as a set of logical steps to be followed to prepare new management measures (EC, 2009b). This process, which is mandatory before implementing any new measure, is intended to highlight the advantages and disadvantages of different potential management options by analyzing their likely impacts in order to provide political decision-makers with scientific evidence and allow them to elaborate strategic policies.

In EU fisheries, impact assessment is operated by the Scientific, Technical and Economic Committee for Fisheries (STECF) according to a methodology following the European impact assessment guidelines (EC, 2009b) adapted to fisheries management by STECF (STECF, 2010). The first step of the process is a scoping meeting aimed at determining management objectives and potential management options in cooperation with stakeholders, and identifying available methodologies or developing new ones to be used for impact assessment. The second step is the impact assessment itself where the scientific elements that will be used for decision-making are generated (STECF, 2010). These analyses necessitate the development of appropriate methodologies and integrated ecological-socioeconomic models that are operational to perform multi-criteria analyses and highlight the advantages and shortcomings of potential management actions (Fulton et al., 2014; Thébaud et al., 2014; Nielsen et al., forthcoming).

The delimitation of the mechanisms to be incorporated into bio-economic models, the trade-offs between complexity, realism and practical use in an operational application context, have long been challenging for fisheries scientists (Kraak et al., 2010). These issues are even more critical in the new paradigm of ecosystem approach to fisheries management (Garcia et al., 2003; Garcia and Cochrane, 2005; Fulton, 2010; Hilborn, 2011).

Bio-economic models for fisheries management have generally been directed at simulating the effects of management measures and evaluating different scenarios according to their ecological and socio-economic impacts (see Prellezo et al. (2012) for a review of bio-economic models applied to EU fisheries and Nielsen et al. (forthcoming) for a comparative evaluation of 35 integrated ecological-socioeconomic fisheries models that have been developed and used worldwide). Acknowledging issues related to uncertainties linked to observation and decision-making process and the need to integrate them in models, the development of management strategy evaluation (MSE) approaches (Holland, 2010; Bunnefeld et al. 2011; Ives et al., 2013; Fulton et al., 2014; Punt et al., 2014) enabled the enhancement of the realism of bio-economic models. MSE involves the two-way coupling of an operating model simulating ecosystem dynamics with a management procedure (MP) commanding fisheries management measures such as TACs. The key element of the MP is a decision rule, which dynamically adjusts management measures based on the outputs of the operating model. MSEs generally incorporate bio-economic models to produce assessments of economic efficiency together with biological performance and to consider the impact of human behavior on the effectiveness of management measures (Holland, 2010). However, as opposed to traditional bio-economic models, MSEs are explicitly designed to account for error and uncertainty in observation and implementation of the MP. Additionally, MSEs generally assess the effectiveness of a management option based on multiple objectives rather than focusing uniquely on optimal economic performance. However, practical applications of MSE approaches are generally limited to considering uncertainties on initial parameters and in the modelling steps associated with stock status observation, TAC decision-making and implementation (Garcia et al., 2011).

Similarly, considering the behavior of fishermen can be a means of explaining the differences between expected impacts of a management measure and their actual effects once implemented (Smith and Wilen, 2003; Fulton et al., 2011; Kraak et al., 2013). The modelling of fleet dynamics via effort allocation mechanisms has allowed improvement of impact assessment by considering short-term fishermen behavior (Holland and Sutinen, 1999; Hutton et al., 2004; Ulrich et al., 2007; Vermard et al., 2008; Marchal et al., 2011; Van Putten et al., 2012; Tidd et al., 2015). This approach, typically based on discrete-choice models such as random utility models (RUMs), has been applied in many empirical studies investigating trip-based choice behavior in terms of metier[7] and/or fishing location for individual fishers (see Girardin et al. (2016) for a recent review of literature on this topic). Similar methodologies based on discrete-choice models (though not necessarily RUMs) have also been used to simulate the long-term fleet dynamics associated with investment and disinvestment decisions, where the alternatives for a vessel include entering, staying in, or exiting a fleet (Ward and Sutinen, 1994; Pradhan and Leung, 2004; Guyader et al., 2004, 2007; Nøstbakken et

[7] The concept of metier is used to characterize the fishing activity (e.g. gear and mesh size used, target species, fishing ground) of a vessel in a fleet during a given period.

al., 2011). These longer-term considerations also relate the issue of irreversible investment due to imperfect capital malleability, which is an important element of the capacity adjustment problem (Clark et al., 1979; Boyce, 1995; Singh et al., 2006).

However, the impacts of governance systems at the national and the local levels on management performance have not been integrated into fisheries bio-economic models yet. The role played by institutional arrangements in catch share systems, including the distribution of quota to fishermen, and their impacts on fishermen behavior and on the effectiveness of management measures are not explicitly incorporated in models (Gutiérrez et al., 2011). Yet, as previously established in this introductory chapter, there exists complex co-management systems and a wide variety of catch share systems (MRAG et al., 2009; Le Floc'h et al., 2015). The description of the French quota management system, including the fishing rights reserves arrangements, highlighted the role played by POs and the solutions available to fishermen to adjust their strategies in a context of non-transferability (Larabi et al., 2013). Nonetheless, existing or potential institutional arrangements must be formalized and analyzed to best evaluate the ecological and socio-economic impacts of different management options.

The aim of the third article is to test the ecological and socio-economic impacts of alternative catch share systems by integrating institutional arrangements involving POs in the management procedure part of a bio-economic model. The case study is the Bay of Biscay common sole fishery and the simulations were performed with the bio-economic modelling platform IAM (Merzéréaud et al., 2011). Several elements make this contribution original with regard to the existing literature in bio-economic simulation modelling. Remarkably, the model explicitly represents quota management mechanisms from harvest control rules to individual quota allocations according to existing institutional arrangements and a potential alternative ITQ system. Moreover, the model is individual-based which allows taking into account the heterogeneity of fishermen profiles, their individual constraints, and their interactions via stock externalities (the production function is based on the Baranov catch equation). The behavior of fishermen regarding the choice of metier and (dis)investment decisions (adjustment of fleet capacity) are also endogenously integrated through short-term and long-term behavior models. However, as opposed to most MSE models, uncertainty on initial parameters and stochastic processes were not integrated in the simulations. Besides, the model is not spatially explicit. These choices were driven by the necessity of keeping an appropriate level of complexity in order to generate results that allow for unambiguous interpretation (Plagányi et al., 2014), and by computation time complexity, as the model is individual-based and considers interactions between individuals through the Baranov catch equation. In relation to the ecosystem approach and the multi-objective perspective promoted in the CFP, the impact assessment of potential management options includes the selection of indicators for each of the ecological, economic and social dimensions, and the comparison of each option with the baseline and against one another.

References

Abdullah, N.M.R., Kuperan, K., Pomeroy, R.S. (1998). Transaction costs and fisheries co-management. Marine Resource Economics, 13(2), 103-114.

Acheson, J., Apollonio, S., Wilson, J. (2015). Individual Transferable Quotas and Conservation: A Critical Assessment. Ecology and Society, 20(4).

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.

Allison, E.H., Ratner, B.D., Åsgård, B., Willmann, R., Pomeroy, R., Kurien, J. (2012). Rights-based fisheries governance: from fishing rights to human rights. Fish and Fisheries, 13(1), 14-29.

Andersen, J.L. (2012). Danish fisheries: Management, fleet structure and economic performance. Copenhagen, Mar 01 2012, FOI Udredning, No. 2012/2, 11pp.

Anderson, L.G. (1994). An economic analysis of highgrading in ITQ fisheries regulation programs. Marine Resource Economics, 209-226.

Anderson, L.G. (1995). A commentary on the views of environmental groups on access control in fisheries. Ocean and Coastal Management, 28, 165-188.

Anderson, T.L., Arnason, R., Libecap, G.D. (2010). Efficiency advantages of grandfathering in rights-based fisheries management (No. w16519). National Bureau of Economic Research.

Armstrong, C.W., van den Hove, S. (2008). The formation of policy for protection of cold-water coral off the coast of Norway. Marine Policy, 32(1), 66-73.

Armstrong, C.W., Eide, A., Flaaten, O., Heen, K., Kaspersen, I.W. (2014). Rebuilding the Northeast Arctic Cod Fisheries – Economic and Social Issues. Arctic Review on Law and Politics, 5(1).

Arnason, R. (1993). The Icelandic individual transferable quota system: a descriptive account. Marine Resource Economics, 8(3), 201-218.

Arnason, R. (2002). A review of international experiences with ITQs. Annex to Future Options for UK Fishing Management, Report to the Department for the Environment, Food and Rural Affairs, CEMARE, University of Portsmouth, UK.

Arnason, R. (2012). Property rights in fisheries: How much can Individual Transferable Quotas accomplish?. Review of Environmental Economics and Policy, 6(2), 217-236.

Barbara, R. (1995). Scotia-Fundy inshore mobile gear groundfish ITQ program. Department of fisheries and Oceans, unpublished paper, 29 p.

Becker, G.S. (1968). Crime and punishment: An economic approach. Journal of Political Economy, 76(2).

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

Berkes, F. (2009). Evolution of co-management: role of knowledge generation, bridging organizations and social learning. Journal of environmental management, 90(5), 1692-1702.

Bernal, P.A., Oliva, D., Aliaga, B., Morales, C. (1999). New regulations in Chilean fisheries and Aquaculture: ITQ's and Territorial Users Rights. Ocean and Coastal Management, 42, 119-142.

Boncoeur, J., Guyader, O. (1995). Management alternatives for a recovery of fishing activity: the case of scallop fishing in the Bay of Brest (France). VII EAFE Conference - European Association of Fisheries Economists Conference- 10-12 April 1995, University of Portsmouth, UK.

Boncoeur, J., Guyader, O., Thébaud, O. (2006). A typology of fisheries management tools. Amure. Working Paper, Brest, France.

Borges, L. (2015). The evolution of a discard policy in Europe. Fish and Fisheries, 16, 534-540.

Borrello, A., Motova, A., Dentes de Carvalho, N. (2013). Fuel subsidies in the EU fisheries sector. In: Policy Department B: Structural and Cohesion Policies. European Parliament, Italy.

Boyce, J.R. (1995). Optimal capital accumulation in a fishery: A nonlinear irreversible investment model. Journal of Environmental Economics and Management, 28, 324-339.

Boyd, R.O., Dewees, C.M. (1992). Putting theory into practice: individual transferable quotas in New Zealand's fisheries. Society & natural resources, 5(2), 179-198.

Brandt, S. (2007). Evaluating tradable property rights for natural resources: The role of strategic entry and exit. Journal of Economic Behavior & Organization, 63, 158-176.

Bromley, D.W., Bishop, R.C. (1977). From economic theory to fisheries policy: conceptual problems and management prescriptions. In: Anderson, L.G. (Ed.), Economic Impacts of Extended Fisheries Jurisdiction. Ann Arbor MI: Ann Arbor Science Publishers.

Bromley, D.W. (2009). Abdicating responsibility: the deceits of fisheries policy. Fisheries, 34(6), 280-290.

Bromley, D.W. (2015). Correcting the Whimsies of U.S. Fisheries Policy. Choices, Quarter 4.

Bunnefeld, N., Hoshino, E., Milner-Gulland, E.J. (2011). Management strategy evaluation: a powerful tool for conservation?. Trends in ecology & evolution, 26(9), 441-447.

Burgess, M.G., Clemence, M., McDermott, G.R., Costello, C., Gaines, S.D. (2017). Five rules for pragmatic blue growth. Marine Policy (in press).

Callan, S.J., Thomas, J.M. (2013). Environmental economics and management: Theory, policy, and applications. South Western, Cengage Learning.

Campbell, D., Brown, D., Battaglene, T. (2000). Individual transferable catch quotas: Australian experience in the southern bluefin tuna fishery. Marine Policy, 24, 109-117.

Cancino, J.P., Uchida, H., Wilen, J. E. (2007). TURFs and ITQs: collective vs. individual decision making. Marine Resource Economics, 22(4), 391-406.

Cardinale, M., Dörner, H., Abella, A., Andersen, J.L., Casey, J., Döring, R., Kirkegaard, E., Motova, A., Anderson, J., Simmonds, E.J., Stransky, C. (2013). Rebuilding EU fish stocks and fisheries, a process under way?. Marine Policy, 39, 43-52.

Carpenter, J., Seki, E. (2005). Do social preferences increase productivity? Field experimental evidence from fishermen in Toyama Bay. IZA DP No. 1697. Institute for the Study of Labor (IZA), Bonn.

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, 9-15.

Casey, K.E., Dewees, C.M., Turris, B.R., Wilen, J.E. (1995). The effects of individual vessel quotas in the British Columbia halibut fishery. Marine Resource Economics, 10(3), 211-230.

CEC. (2007). Commission of the European Communities establishing a Community system to prevent, deter and eliminate illegal, unreported and unregulated fishing. EC COM(2007) 602 final, Brussels.

CEC. (2009). Commission of the European Communities. Green paper: reform of the Common Fisheries Policy. COM (2009)163 final CEC, Brussels.

Christy, F.T. (1973). Fisherman quotas: a tentative suggestion for domestic management. Law of the sea institute, Rhode Island.

Christy, F.T. (1982). Territorial Use Rights in Marine Fisheries: Definitions and Conditions. FAO Fisheries technical paper 227. FAO, Rome, Italy.

Christy, F.T. (1996). The death rattle of open access and the advent of property rights regimes in fisheries. Marine Resource Economics, 11, 287–304.

Chu, C. (2009). Thirty years later: the global growth of ITQs and their influence on stock status in marine fisheries. Fish and Fisheries, 10, 217-230.

Clark, C.W., Clarke, F.H., Munro, G.R. (1979) The optimal exploitation of renewable resource stocks: problems of irreversible investment. Econometrica, 47, 25-47.

Coase, R.H. (1960). The problem of social cost. The Journal of Law & Economics, 3, 1-44.

Copes, P. (1986). A critical review of the individual quota as a device in fisheries management. Land economics, 62(3), 278-291.

Copes, P., Charles, A. (2004). Socioeconomics of Individual Transferable Quotas and Community-Based Fishery Management. Agricultural & Resource Economics Review, 33, 171-181.

Costello, C., Deacon, R.T. (2007). The Efficiency Gains from Fully Delineating Rights in an ITQ Fishery. Marine Resource Economics, 22, 347-361.

Costello, C., Gaines, S.D., Lynham, J. (2008). Can catch shares prevent fisheries collapse?. Science, 321(5896), 1678-1681.

Costello, C., Kaffine, D. (2008). Natural resource use with limited-tenure property rights. Journal of Environmental Economics and Management, 55(1), 20-36.

Criddle, K.R., Macinko, S. (2000). A Requiem for the IFQ in US Fisheries?. Marine Policy, 24(6), 461-469.

Cueff, J.C. (2007). A case study of fishing vessel capacity management public buyout schemes: community experience through the Multi-Annual Guidance Programmes and ways forward. In: Curtis, R., Squires, D. (Eds) Fisheries buybacks, Wiley-Blackwell, Ames, IA., 75-80.

Deacon, R.T. (2012). Fishery management by harvester cooperatives. Review of Environmental Economics and Policy, 6(2), 258-277.

Deacon, R.T., Parker, D.P., Costello, C. (2013). Reforming fisheries: lessons from a self-selected cooperative. Journal of Law and Economics, 56(1), 83-125.

De Santo, E.M., Jones, P.J.S. (2007). Offshore marine conservation policies in the North East Atlantic: emerging tensions and opportunities. Marine Policy, 31, 336-347.

Desoutter, M. (1992). Soleidae. p. 860-865. In Levêque, C., Paugy, D., Teugels, G.G. (eds.) Faune des poissons d'eaux douces et saumâtres d'Afrique de l'Ouest Tome 2. Faune Tropicale n° 28. Musée Royal de l'Afrique Centrale, Tervuren, Belgique and O.R.S.T.O.M., Paris, France, 902.

Devlin, R.A., Grafton, R.Q. (1998). Economic Rights and Environmental Wrongs. Edward Elgar: Cheltenham.

De Vos, B., Aranda, M., Duzgunes, E., Fitzpatrick, M., Goti, L., Guyader, O., Hatcher, A., Le Floc'h, P., Macher, C., Malvarosa, L., Murillas, A., Sabatella, R. (2014). Socio-economic effects of management measures of the future CFP: Analysis of current management measures and their incentives in the various case studies. SOCIOEC [289192] - Delivrable D 3.3, 102 pp.

Dewees, C.M. (1989). Assessment of the implementation of individual transferable quotas in New Zealand's inshore fishery. North American Journal of Fisheries Management, 9(2), 131-139.

Dietz, T., Ostrom, E., Stern, P. C. (2003). The struggle to govern the commons. science, 302(5652), 1907-1912.

Doering, R., Goti, L., Fricke, L., Jantzen, K. (2016). Equity and ITQs: About fair distribution in quota management systems in fisheries. Environmental Values, 25(6), 729-749.

Douvere, F. (2008). The importance of marine spatial planning in advancing ecosystem-based sea use management. Marine policy, 32(5), 762-771.

EC. (2008). Communication from the Commission to the Council and the European Parliament. The role of the CFP in implementing an ecosystem approach to marine management. European Commission, Brussels, 11.4.2008, COM(2008) 187 final.

EC. (2009a). Council regulation (EC) No 1224/2009 of 20 November 2009 establishing a Community control system for ensuring compliance with the rules of the common fisheries policy. Official Journal of European Union, L343/1, 22.12.2009.

EC. (2009b). European Commission Impact Assessment Guidelines, 15 January 2009, SEC(2009) 92.

EC. (2010). Development of Protocols for Multi-annual Plan Impact Assessments. Scientific, Technical and Economic Committee for Fisheries (STECF), SGMOS-10-0.

EC. (2012). Communication from the Commission to the European parliament, the Council, the European economic and social committee and the committee of the regions. Blue growth: opportunities for marine and maritime sustainable growth. European Commission, Brussels, 13.9.2012, COM(2012) 494 final.

EEC. (1970a). Regulation No 2141:70 OF THE COUNCIL of 20 October 1970 laying down a common structural policy for the fishing industry. OJ. No L 236 of 27 October 1970, p. 1-4.

EEC. (1970b). Council Regulation No 2142/70 on the common organisation of the market in fishery products. OJ L236, 27,10,70, p. 5.

EEC. (1983). Council Regulation No 170/83 of 25 January 1983 establishing a Community system for the conservation and management of fishery resources. OJ. No L 24. 27 January 1983.

EU. (2013a). Regulation (EU) 1380/2013 of the European Parliament and the Council of the 11 of December 2013 on the Common Fisheries Policy. Official Journal of European Union, L354/22, 28.12.2013.

EU. (2013b). Regulation (EU) 1379/2013 of the European Parliament and the Council of 11 December 2013 on the common organisation of the markets in fishery and aquaculture products, amending Council Regulations (EC) No 1184/2006 and (EC) No 1224/2009 and repealing Council Regulation (EC) No 104/2000. Official Journal of European Union, L354/1, 28.12.2013.

EU. (2014). Directive 2014/89/EU of the European Parliament and of the Council of 23 July 2014 establishing a framework for maritime spatial planning. Official Journal of European Union, L257/135, 28.8.2014.

Evans, K.S., Weninger, Q. (2014). Information sharing and cooperative search in fisheries. Environmental and Resource Economics, 58(353), 1-20.

FAO. (2002). Report and Documentation of the International Workshop on Factors of Unsustainability and Overexploitation in Fisheries (Bangkok, Thailand 4-8 February 2002). FAO, Rome, Italy.

FAO. (2003). Fisheries management 2: the ecosystem approach to fisheries. FAO Technical Guidelines for responsible fisheries No. 4 (Suppl. 2). FAO Fisheries Department, Rome, Italy.

FranceAgriMer. (2017). Données et Bilan de FranceAgriMer. Les filières pêche et aquaculture, bilan 2016. Janvier 2017, 24 pp.

Frangoudes, K., Bellanger, M. (2017). Fishers' opinions on marketization of property rights and the quota system in France. Marine Policy, 80, 107-112.

Froese, R., Proelß, A. (2010). Rebuilding fish stocks no later than 2015: will Europe meet the deadline?. Fish and fisheries, 11(2), 194-202.

Fulton, E.A. (2010). Approaches to end-to-end ecosystem models. Journal of Marine Systems, 81(1), 171-183.

Fulton, E.A., Smith, A.D., Smith, D.C., Van Putten, I.E. (2011). Human behaviour: The key source of uncertainty in fisheries management. Fish and Fisheries, 12(1), 2-17.

Fulton, E.A., Smith, A.D., Smith, D.C., Johnson, P. (2014). An integrated approach is needed for ecosystem based fisheries management: insights from ecosystem-level management strategy evaluation. PLoS One, 9(1), e84242.

Garcia, D., Prellezo, R., Santurtun, M., Arregi, L. (2011). Winners and losers of a technical change: A case study of long-term management of the northern european hake. Fisheries Research, 110(1), 98-110.

Garcia, S.M., Zerbi, A., Aliaume, C., Do Chi, T., Lasserre, G. (2003). The ecosystem approach to fisheries. Issues, terminology, principles, institutional foundations, implementation and outlook. FAO fisheries technical paper no. 443, Rome, FAO; 2003. 71 pp.

Garcia, S.M., Cochrane, K.L. (2005). Ecosystem approach to fisheries: a review of implementation guidelines. ICES Journal of Marine Science, 62(3), 311-318.

Gascuel, D., Coll, M., Fox, C., Guénette, S., Guitton, J., Kenny, A., Knittweis, L., Nielsen, J.R., Piet, G., Rais, T., Travers-Trolet, M., Shephard, S. (2016). Fishing impact and environmental status in European seas: a diagnosis from stock assessments and ecosystem indicators. Fish and Fisheries, 17, 31-55.

German, L., Keeler, A. (2009). "Hybrid institutions": Applications of common property theory beyond discrete tenure regimes. International Journal of the Commons, 4(1).

Girardin, R., Hamon, K.G., Pinnegar, J., Poos, J.J., Thébaud, O., Tidd, A., Vermard, Y., Marchal, P. (2016). Thirty years of fleet dynamics modelling using discrete-choice models: What have we learned?. Fish and Fisheries (in press).

Gordon, H.S. (1954). The economic theory of a common-property resource: the fishery. In Classic Papers in Natural Resource Economics (pp. 178-203). Palgrave Macmillan UK.

Grafton, R.Q. (1996). Individual transferable quotas: theory and practice. Reviews in Fish Biology and Fisheries 6(1), 5-20.

Grafton, R.Q., Arnason, R., Bjørndal, T., Campbell, D., Campbell, H.F., Clark, C.W., Connor, R., Dupont, D.P., Hannesson, R., Hilborn, R., Kirkley, J.E., Kompas, T., Lane, D.E., Munro, G.R., Pascoe, S., Squires, D., Steinshamn, S.I., Turris, B.R., & Weninger, Q. (2006). Incentive-based approaches to sustainable fisheries. Canadian Journal of Fisheries and Aquatic Sciences, 63(3), 699-710.

Grainger, C.A., Costello, C. (2016). Distributional effects of the transition to property rights for a common-pool resource. Marine Resource Economics, 31(1), 1-26.

Greenwald, B., Stiglitz, J. (1986). Externalities in economies with imperfect information and incomplete markets. Quarterly Journal of Economics, 101(2), 229-264.

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, 64-74.

Guillen, J., Macher, C., Merzéréaud, M., Boncoeur, J., Guyader, O. (2015). Effects of the Share Remuneration System on Fisheries Management Targets and Rent Distribution. Marine Resource Economics, 30(2), 123-138.

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

Gutiérrez, N.L., Hilborn, R., Defeo, O. (2011). Leadership, social capital and incentives promote successful fisheries. Nature, 470(7334), 386-389.

Guyader, O., Thébaud, O. (2001). Distributional issues in the operation of rights-based fisheries management systems. Marine Policy, 25(2), 103-112.

Guyader, O., Daures, F., Fifas, S. (2004). A bioeconomic analysis of the impact of decommissioning programs: application to a limited-entry French scallop fishery. Marine Resource Economics, 19(2), 225-242.

Guyader, O., Berthou, P., Daurès, F. (2007). Decommissioning Schemes and Capacity Adjustment: A Preliminary Analysis of the French Experience. In Curtis, R., Squires, D. (eds.) Fisheries Buybacks, Ch. 7. Ames, IA: Wiley-Blackwell.

Guyader, O., Metz, S., Macher, C., Merzereaud, M., Daures, F., Le Floc'h, P., Bellanger, M. (2014). Self-imposed catch shares by French producers organizations. IIFET 2014, International Institute of Fisheries Economics & Trade. 7-11 July 2014, Brisbane, Australia.

Hannesson, R. (2004). The Privatization of the Oceans. The MIT Press, Cambridge, MA.

Hardin, G. (1968). The Tragedy of the Commons. Science, 162(3859), 1243-1248.

Hatcher, A., Robinson, K. (Eds) (1999a). Overcapacity, Overcapitalisation and Subsidies in European Fisheries. Proceeding of the first Concerted Action workshop on economics and the Common Fisheries Policy, 28-30 October 1998. CEMARE, Portsmouth, UK.

Hatcher, A., Robinson, K. (Eds) (1999b). The definition and allocation of use rights in European fisheries. Proceedings of the second Concerted Action workshop on economics and the Common Fisheries Policy, 5-7 May 1999, Brest, France.

Hatcher, A., (2000). Subsidies for European fishing fleets: the European Community's structural policy for fisheries 1971-1999. Marine Policy, 24, 129-140.

Hatcher, A., Pascoe, S., Banks, R., Arnason, R. (2002). Future Options for UK Fishing Management. A Report to the Department for the Environment, Food and Rural Affairs. CEMARE report 58, Portsmouth, UK.

Haynie, A.C., Hicks, R.L., Schnier, K.E. (2009). Common property, information, and cooperation: commercial fishing in the Bering Sea. Ecological Economics, 69, 406-413.

Hilborn, R., Orensanz, J.M., Parma, A. (2005). Institutions, incentives and the future of fisheries. Philosophical Transactions of the Royal Society B 360, 47-57.

Hilborn, R. (2007). Defining success in fisheries and conflicts in objectives. Marine Policy, 31, 153-158

Hilborn, R. (2011). Future directions in ecosystem based fisheries management: A personal perspective. Fisheries Research, 108 (2011) 235-239.

Hoefnagel, E., de Vos, B. (2017). Social and economic consequences of 40 years of Dutch quota management.

Marine Policy, 80, 81-87.

Holden, M. (1994). The Common Fisheries Policy. Origin, Evaluation and Future. Fishing News Books. Blackwell Scientific Publications Ltd., Oxford. 274 p.

Holland, D.S., Sutinen, J.G. (1999). An empirical model of fleet dynamics in New England trawl fisheries. Canadian Journal of Fisheries and Aquatic Sciences, 56(2), 253-264.

Holland, D.S. (2010). Management Strategy Evaluation and Management Procedures: Tools for Rebuilding and Sustaining Fisheries, OECD Food, Agriculture and Fisheries Working Papers, No. 25, OECD Publishing. http://dx.doi.org/10.1787/5kmd77jhvkjf-en.

Holland, D.S., Kitts, A.W., Pinto Da Silva, P., Wiersma, J. (2013). Social capital and the success of harvest cooperatives in the New England groundfish fishery. Marine Resource Economics, 28(2), 133-153.

Holland, D.S. (2016). Development of the Pacific Groundfish Trawl IFQ Market. Marine Resource Economics, 31(4), 453-464.

Huppert, D.D. (2005). An Overview of fishing rights. Reviews in Fish Biology and Fisheries, 15(3), 201-215.

Hutton, T., Mardle, S., Pascoe, S., Clark, R.A. (2004). Modelling fishing location choice within mixed fisheries: English North Sea beam trawlers in 2000 and 2001. ICES Journal of Marine Science, 61(8), 1443-1452.

Ives, M.C., Scandol, J.P., Greenville, J. (2013). A bio-economic management strategy evaluation for a multi-species, multi-fleet fishery facing a world of uncertainty. Ecological modelling, 256, 69-84.

Jardine, S.L., Sanchirico, J.N. (2012). Catch share programs in developing countries: A survey of the literature. Marine Policy, 36(6), 1242-1254.

Jentoft, S. (1989). Fisheries co-management: delegating government responsibility to fishermen's organizations. Marine policy, 13(2), 137-154.

Jentoft, S. (2007). Limits of governability : Institutional implications for fisheries and coastal governance. Marine Policy, 31(4), 360-370.

Jentoft, S., Chuenpagdee, R. (2009). Fisheries and coastal governance as a wicked problem. Marine Policy, 33(4), 553-560.

Johnson, R.N., Libecap, G.D. (1982). Contracting problems and regulation: the case of the fishery. The American Economic Review, 72(5), 1005-1022.

JORF. (2006). Journal Officiel de la République Française N°301 du 29 décembre 2006 page 19953 texte n°104: Arrêté du 26 décembre 2006 établissant les modalités de répartition et de gestion collective des possibilités de pêche (quotas de captures et quotas d'effort de pêche) des navires français immatriculés dans la Communauté européenne. NOR: AGRM0602585A.

JORF. (2010a). Journal Officiel de la République Française N°0106 du 7 mai 2010 page 8304 texte n°49: Ordonnance n° 2010-462 du 6 mai 2010 créant un livre IX du code rural relatif à la pêche maritime et à l'aquaculture marine. NOR: AGRS1007353R.

JORF. (2010b). Journal Officiel de la République Française N°0172 du 28 juillet 2010 page 13925: Loi n°2010-874 du 27 juillet 2010 de modernisation de l'agriculture et de la pêche. NOR: AGRS0928330L.

Kahui, V., Armstrong, C.W., Foley, N.S. (2016). An International View on 'Correcting the Whimsies of U.S. Fisheries Policy.' Choices, Quarter 3.

Karpoff, J.M. (1987). Suboptimal controls in common resource management: the case of the fishery. Journal of Political Economy, 95(1), 179–194.

King, D.M., Sutinen, J.G. (2010). Rational noncompliance and the liquidation of Northeast groundfish resources. Marine Policy, 34(1), 7-21.

Kornhauser, L.A., Revesz, R.L. (1994). Multidefendant settlements: The impact of joint and several liability. The Journal of Legal Studies, 23(1), 41-76.

Kornhauser, L.A. (2013). Economic analysis of joint and several liability. In Arlen, J.H (Ed.) Research Handbook on the Economics of Torts, 199-233.

Kraak, S.B.M., Kelly, C.J., Codling, E.A., Rogan, E. (2010). On scientists' discomfort in fisheries advisory science: the example of simulation-based fisheries management-strategy evaluations. Fish and Fisheries 11, 119-132.

Kraak, S.B.M., Bailey, N., Cardinale, M., Darby, C., De Oliveira, J.A., Eero, M., Graham, N., Holmes, S., Jakobsen, T., Kempf, A., Kirkegaard, E., Powell, J., Scott, R.D., Simmonds, E.J., Ulrich, C., Vanhee, W., Vinther, M. (2013). Lessons for fisheries management from the EU cod recovery plan. Marine Policy, 37, 200-213.

Kroetz, K., Sanchirico, J.N. (2010). Economic insights into the costs of design restrictions in ITQ programs. RFF Report, Resources for the Future, 46p.

Lagière, R. (2012) Evolution du système de gestion de la pêcherie de sole du golfe de Gascogne et analyse préliminaire de la dynamique des flottilles. Agrocampus Ouest, Rennes.

Larabi, Z., Guyader, O., Macher, C., Daurès, F. (2013). Quota management in a context of non-transferability of fishing rights: the French case study. Ocean and Coastal Management, 84, 13-22.

Lebon Le Squer, D. (1998). Les organisations de producteurs des pêches maritimes françaises. La recherche d'une échelle pertinente d'intervention. Thèse de doctorat, Université de Nantes.

Le Floc'h, P., Murillas, A., Aranda, M., Daurès, F., Fitzpatrick, M., Guyader, O., Hatcher, A., Macher, C., and Marchal, P. (2015). The regional management of fisheries in European Western Waters. Marine Policy, 51, 375-384.

Lock, K., Leslie, S. (2007). New Zealand's Quota Management System: A History of the First 20 Years. Motu Working Paper 07-02; Motu Economic and Public Policy Research.

Macinko, S., Bromley, D.W. (2002). Who owns America's fisheries?. Island Press: Washington, D.C.

Marchal P., Little R., Thébaud O. (2011). Quota allocation in mixed fisheries: a bioeconomic modelling approach applied to the Channel flatfish fisheries. Ices Journal Of Marine Science, 68(7), 1580-1591.

Matthíasson, T., Giry, F., Agnarsson, S. (2015). Individual Transferable Quotas Allocation in Icelandic Fisheries: a Community-Oriented Inequality Analysis. Rannsóknir í félagsvísindum XVI.

Matulich, S.C., Sever, M. (1999). Reconsidering the initial allocation of ITQs: the search for a Pareto-safe allocation between fishing and processing sectors. Land Economics, 203-219.

Merzéréaud, M., Macher, C., Bertignac, C., Frésard, M., Le Grand, C., Guyader, O., Daurès, F., Fifas, S. (2011). Description of the Impact Assessment bio-economic Model for fisheries management (IAM), Amure Electronic Publications, Working Papers Series D-29-2011, 19 pp. Available at: http://www.umr-amure.fr/electro_doc_amure/D_29_2011.pdf.

MRAG, IFM, CEFAS, AZTI Tecnatio, PolEM. (2009). An analysis of existing rights based management (RBM) instruments in Member States and on setting up best practices in the EU, Final Report. London.

Newell, R.G., Sanchirico, J.N., Kerr, S. (2005). Fishing quota markets. Journal of Environmental Economics and Management, 49(3), 437-462.

Nielsen, R.J. (2003). An analytical framework for studying: compliance and legitimacy in fisheries management. Marine Policy, 27(5), 425-432.

Nielsen, J.R., Thunberg, E., Holland, D.S., Schmidt, J.O., Fulton, E.A., Bastardie, F., Punt, A.E, Allen, I., Bartelings, H., Bertignac, M., Bethke, E., Bossier, S., Buckworth, R., Carpenter, G., Christensen, A., Christensen, V., Da Rocha, J.M., Deng, R., Dichmont, C.M., Doering, R., Esteban, A., Fernandes, J.A., Frost, H., Garcia, D., Gasche, L., Gascuel, D., Gourguet, S., Groeneveld, R.A., Guillen, J., Guyader, O., Hamon, K., Hoff, A., Horbowy, J., Hutton, T., Lehuta, S., Little, L.R., Lleonart, J., Macher, C., Mackinson, S., Mahevas, S., Marchal, P., Mato-Amboage, R., Mapstone, B., Maynou, F., Merzéréaud, M., Palacz, A., Pascoe, S., Paulrud, A., Plaganyi, E., Prellezo, R., van Putten, E.I., Quaas, M., Ravn-Jonsen, L., Sanchez, S., Simons, S., Thébaud, O., Tomczak, M.T., Ulrich, C., Van Dijk, D., Vermard, Y., Voss, R., Waldo, S. (forthcoming). Integrated Ecological-Socioeconomic Fisheries Models – Evaluation, Review and Challenges for Implementation. Fish and Fisheries.

Nøstbakken, L., Thébaud, O., Sorensen, L-C. (2011). Investment Behaviour and Capacity Adjustment in Fisheries: A Survey of the Literature. Marine Resource Economics, 26, 95-117.

NRC. (1999). Sharing the fish: toward a national policy on individual fishing quotas. National Research Council. National Academies Press.

OECD. (2005). Why fish piracy persists: The economics of illegal, unreported and unregulated fishing. OECD

Technical report, Paris, 2005.

OECD (2006). Using market mechanisms to manage fisheries: smoothing the path. OECD Technical report, Paris, 2006.

Olson, J. (2011). Understanding and contextualizing social impacts from the privatization of fisheries: An overview. Ocean and Coastal Management, 54, 353-363.

OSPAR. (2003). Convention for the protection of the marine environment of the Northeast Atlantic. OSPAR Recommendation 2003/3 on a Network of Marine Protected Areas.

Ostrom, E. (1990). Governing the Commons: The Evolution of Institutions for Collective Action. Cambridge University press.

Ostrom, E. (2007). A diagnostic approach for going beyond panaceas. Proceedings of the national Academy of sciences, 104(39), 15181-15187.

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

Ovando, D.A., Deacon, R.T., Lester, S.E., Costello, C., Van Leuvan, T., McIlwain, K., Strauss, C.K., Arbuckle, M., Fujita, R., Gelcich, S., Uchida, H. (2013). Conservation incentives and collective choices in cooperative fisheries. Marine Policy, 37, 132-140.

Pálsson, G., Helgason, A. (1995). Figuring fish and measuring men: the individual transferable quota system in the Icelandic cod fishery. Ocean and Coastal Management, 28(1-3), 117-146.

Pálsson, G., Pétursdóttir, G. (1997). Social implications of quota systems in fisheries. Copenhagen: TemaNord, Nordic Council of Ministers. 353 p.

Pascoe, S. (1993). Thalassorama. Marine Resource Economics, 8(4), 395-401.

Pearse, P. H. (1992). From open access to private property: recent innovations in fishing rights as instruments of fisheries policy. Ocean Development & International Law, 23(1), 71-83.

Peñas Lado, E. (2016). The Common Fisheries Policy: The Quest for Sustainability. John Wiley & Sons, Oxford.

Péreau, J.C., Doyen, L., Little, L.R., Thébaud, O. (2012). The triple bottom line: Meeting ecological, economic and social goals with individual transferable quotas. Journal of Environmental Economics and Management, 63(3), 419-434.

Pikitch, E., Santora, C., Babcock, E.A., Bakun, A., Bonfil, R., Conover, D.O., Dayton, P., Doukakis, P., Fluharty, D., Heneman, B., Houde, E.D., Link, J., Livingston, P.A., Mangel, M., McAllister, M.K., Pope, J., Sainsbury, K.J. (2004). Ecosystem-based fishery management. Science, 305(5682), 346-347.

Pinkerton, E., Edwards, D.N. (2009). The elephant in the room: the hidden costs of leasing individual transferable quotas. Marine Policy, 33, 707-713.

Plagányi, É.E., Punt, A.E., Hillary, R., Morello, E.B., Thébaud, O., Hutton, T., Pillans, R.D., Thorson, J.T., Fulton, E.A., Smith, A.D.M., Smith, F., Bayliss, P., Haywood, M., Lyne, V., Rothlisberg, P.C. (2014). Multispecies fisheries management and conservation: tactical applications using models of intermediate complexity. Fish and Fisheries, 15(1), 1-22.

Plet-Hansen, K.S., Eliasen, S.Q., Mortensen, L.O., Bergsson, H., Olesen, H.J., Ulrich, C. (2017). Remote electronic monitoring and the landing obligation–some insights into fishers' and fishery inspectors' opinions. Marine Policy, 76, 98-106.

Pomeroy, R.S., Berkes, F. (1997). Two to tango: the role of government in fisheries co-management. Marine Policy, 21(5), 465-480.

Pomeroy, R.S., Katon, B.M., Harkes, I. (2001). Conditions affecting the success of fisheries co-management: lessons from Asia. Marine Policy, 25, 197-208.

Pomeroy, R.S., Ahmed, M. (2006). Fisheries and Coastal Resources Co-management in Asia: Selected Results from a Regional Research Project (WorldFish Center Studies and Reviews, no. 30). WorldFish Center, Penang.

Poon, S.E., Bonzon, K. (2013). Catch Share Design Manual, Volume 3: Territorial Use Rights for Fishing. Environmental Defense Fund.

Pradhan, N.C., Leung, P. (2004). Modeling entry, stay, and exit decisions of the longline fishers in Hawaii. Marine Policy, 28(4), 311-324.

Prellezo, R., Accadia, P., Andersen, J.L., Andersen, B.S., Buisman, E., Little, A., Nielsen, J.R., Poos, J.J., Powell, J., Röckmann, C. (2012). A review of EU bio-economic models for fisheries: The value of a diversity of models. Marine Policy, 36(2), 423-431.

Prellezo, R., Carmona, I., García, D. (2016). The bad, the good and the very good of the landing obligation implementation in the Bay of Biscay: A case study of Basque trawlers. Fisheries Research, 181, 172-185.

Punt, A.E., Butterworth, D.S., Moor, C.L., De Oliveira, J.A., Haddon, M. (2014). Management strategy evaluation: best practices. Fish and Fisheries, 17, 303-334.

Quynh, C.N.T., Schilizzi, S., Hailu, A., Iftekhar, S. (2017). Territorial Use Rights for Fisheries (TURFs): State of the art and the road ahead. Marine Policy, 75, 41-52.

Raveau, A., Macher, C., Mehault, S., Merzereaud, M., Le Grand, C., Guyader, O., Bertignac, M., Fifas, S., Guillen, J. (2012). A bio-economic analysis of experimental selective devices in the Norway lobster (Nephrops norvegicus) fishery in the Bay of Biscay. Aquatic Living Resources, 25(3), 215-229.

Rodríguez-Rodríguez, D., Rees, S., Mannaerts, G., Sciberras, M., Pirie, C., Black, Aulert, C., Sheehan, E.V., Carrier, S., Attrill, M.J. (2015). Status of the marine protected area network across the English channel (La Manche): Cross-country similarities and differences in MPA designation, management and monitoring. Marine Policy, 51, 536-546.

Salz, P., Buisman, E., Smit, J., De Vos, B. (2006). Employment in the fisheries sector: current situation. Report FISH/2004/4, European Commission, Brussels.

Sanchirico, J.N., Holland, D., Quigley, K., Fina, M. (2006). Catch-quota balancing in multispecies individual fishing quotas. Marine Policy, 30(6), 767-785.

Scheld, A.M., Anderson, C.M. (2014). Market effects of catch share management: the case of New England multispecies groundfish. ICES Journal of Marine Science, 71(7), 1835-1845.

Schlager, E., Ostrom, E. (1992). Property-rights regimes and natural resources: a conceptual analysis. Land economics, 249-262.

Scott, A.D. (1955). The fishery: the objectives of sole ownership. Journal of political Economy, 63(2), 116-124.

Scott, A.D., Johnson, J. (1985). Property Rights: Developing the Characteristics of Interest in Natural Resources. In A.D. Scott (Ed.) Progress in Natural Resource Economics Clarendon Press: Oxford.

Scott, A.D. (1989). Conceptual origins of rights based fishing. In: Neher, P.A., Arnason, R., Mollett N. (Eds.) Rights based fishing. NATO ASI series, Vol. 169, Kluwer Academic Publishers.

Sen, S., Nielsen, J.R. (1996). Fisheries co-management: a comparative analysis. Marine policy, 20(5), 405-418.

Shotton, R. (ed.) (2000). Use of Property Rights in Fisheries Management (FAO Fisheries Technical Paper No. 404 – Proceedings of the FishRights99 Conference, Fremantle (Australia), 11–19 Nov 1999). FAO, Rome.

Singh, R., Weninger, Q., Doyle, M. (2006). Fisheries management with stock growth uncertainty and costly capital adjustment. Journal of Environmental Economics and Management, 52(2), 582-599.

Smit, W. (1997). Common fishery policy and national fisheries management. Marine Resource Economics, 12(4), 355-359.

Smith, M.D., Wilen, J.E. (2003). Economic impacts of marine reserves: the importance of spatial behavior. Journal of Environmental Economics and Management, 46(2), 183-206.

Spagnolo, M. (2012). What kind of management for Mediterranean Fisheries? Irepa Onlus, DG Internal Policies, Policy Department B: Structural and Cohesion Policies. IP/B/PECH/IC/2012-068, November 2012, 52 pp.

Squires, D., Kirkley, J., Tisdell, C.A. (1995). Individual transferable quotas as a fisheries management tool. Reviews in Fisheries Science, 3(2), 141-169.

STECF. (2010). Development of protocols for Multi-annual Plan Impact Assessments. Report of the STECF SGMOS 10-1 meeting, 1-5 February 2010, Hamburg, Germany, 48 pp.

STECF. (2015). Multiannual management plans SWW and NWW (STECF-15-08). Publications Office of the

European Union, Luxembourg, EUR 27406 EN, JRC 96964, 82 pp.

Strauss, K. (2013). Catch Shares in Action: Danish Pelagic and Demersal Individual Transferable Quota Programs. Environmental Defence Fund.

Sullivan, J.M. (2000). Harvesting cooperatives and US antitrust law: Recent developments and implications. International Institute of Fisheries Economics & Trade Conference, Corvallis, OR, 2000, July 10-15.

Sumaila, U.R. (2010). A Cautionary Note on Individual Transferable Quotas. Ecology and Society, 15(3), 36.

Sutinen, J.G., Kuperan, K. (1999). A socio-economic theory of regulatory compliance. International journal of social economics, 26(1/2/3), 174-193.

Symes, D. (2012). Regionalising the Common Fisheries Policy: context, content and controversy. Maritime Studies, 11(1), 6.

Thébaud, O., Innes, J., Ellis, N. (2012). From anecdotes to scientific evidence? A review of recent literature on catch share systems in marine fisheries. Front. Ecol. Environ. 10(8), 433-437.

Thébaud, O., Doyen, L., Innes, J., Lample, M., Macher, C., Mahevas, S., Mullon, C., Planque, B., Quaas, M., Smith, T., Vermard, Y. (2014). Building ecological-economic models and scenarios of marine resource systems: Workshop report. Marine Policy, 43, 382-386.

Tidd, A.N., Vermard, Y., Marchal, P., Pinnegar, J., Blanchard, J.L., Milner-Gulland, E.J. (2015). Fishing for space: fine-scale multi-sector maritime activities influence fisher location choice. PloS one, 10(1), e0116335.

Townsend, R. (1990). Entry restrictions in the fishery: a survey of the evidence. Land Economics, 66(4), 359-378.

Townsend, R., Shotton, R., Uchida, H. (2008). Case studies in fisheries self-governance. Technical report, FAO Paper. No. 504., Rome, 2008.

Ulrich, C., Andersen, B.S., Sparre, P.J., Nielsen, J.R. (2007). TEMAS: fleet-based bio-economic simulation software to evaluate management strategies accounting for fleet behaviour. ICES Journal of Marine Science, 64, 647-651.

Ulrich, C., Vermard, Y., Dolder, P.J., Brunel, T., Jardim, E., Holmes, S.J., Kempf, A., Mortensen, L.O., Poos, J.-J., Rindorf, A. (2016). Achieving maximum sustainable yield in mixed fisheries: a management approach for the North Sea demersal fisheries. ICES Journal of Marine Science, fsw126.

UNODC. (2011). Transnational organized crime in the fishing industry. Focus on: Trafficking in Persons Smuggling of Migrants Illicit Drugs Trafficking. Technical report, United Nations Office on Drugs and Crime. Vienna.

Van Hoof, L. (2010). Co-management: an alternative to enforcement?. ICES Journal of Marine Science, fsp239.

Van Hoof, L., Van Leeuwen, J., Van Tatenhove, J. (2012). All at sea; regionalisation and integration of marine policy in Europe. Maritime Studies, 11(1), 9.

Van Putten, I.E., Kulmala, S., Thébaud, O., Dowling, N., Hamon, K.G., Hutton, T., Pascoe, S. (2012). Theories and behavioural drivers underlying fleet dynamics models. Fish and Fisheries, 13(2), 216-235.

Van Putten, I.E., Boschetti, F., Fulton, E.A., Smith, A.D., Thébaud, O. (2014). Individual transferable quota contribution to environmental stewardship: a theory in need of validation. Ecology and Society, 19(2), 1-13.

Veiga, P., Pita, C., Rangel, M., Gonçalves, J.M., Campos, A., Fernandes, P.G., Sala, A., Virgili, M., Lucchetti, A., Brčić, J., Villasante, S., Ballesteros, M.A., Chapela, R., Santiago, J.I., Agnarsson, S., Ögmundarson, Ó., Erzini, K. (2016). The EU landing obligation and European small-scale fisheries: What are the odds for success?. Marine Policy, 64, 64-71

Vermard, Y., Marchal, P., Mahévas, S., Thébaud, O. (2008). A dynamic model of the Bay of Biscay pelagic fleet simulating fishing trip choice: the response to the closure of the European anchovy (Engraulis encrasicolus) fishery in 2005. Canadian journal of fisheries and aquatic sciences, 65(11), 2444-2453.

Villasante, S., Pazos Guimeráns, C., Rodrigues, J., Antelo, M., Rivero Rodríguez, S., Da Rocha, J.M., Coll, M., Pita, C., Pierce, G., Hastie, L., Sumaila, R. (2015). Small-scale fisheries and the zero discard target. DG Internal Policies, Policy Department B: Structural and Cohesion Policies, Fisheries, European Parliament, Brussels.

Ward, J.M., Sutinen, J.G. (1994). Vessel entry-exit behavior in the Gulf of Mexico shrimp fishery. American Journal of Agricultural Economics, 76(4), 916-923.

Wilen, J.E. (1988). Limited entry licensing: a retrospective assessment. Marine Resource Economics, 5(4), 313-324.

Wilen, J.E., Cancino, J., Uchida, H. (2012). The economics of territorial use rights fisheries, or TURFs. Review of Environmental Economics and Policy, 6(2), 237-257.

Williamson, O.E. (1981). The economics of organization: The transaction cost approach. American Journal of Sociology, 87(3), 548-577.

Williamson, O.E. (1991). Comparative economic organization: The analysis of discrete structural alternatives. Administrative science quarterly, 269-296.

Willmann, R. (2000). Group and community-based fishing rights. In: Use of Property Rights in Fisheries Management. Proceedings of the FishRights99 Conference, Fremantle (Australia), 11-19 November 1999. (ed. R. Shotton), FAO Fisheries Technical Paper No. 404 (1) FAO, Rome, 51-57.

World Bank. (2017). The Sunken Billions Revisited: Progress and Challenges in Global Marine Fisheries. Environment and Development, Washington, DC. World Bank.

Chapter 2. A game-theoretic model of monitoring and compliance in fishery cooperatives

Submitted to *Environmental and Resource Economics*

Bellanger, M., Holland, D., Anderson, C., Guyader, O.

Abstract

Cooperative-based catch share systems can be implemented such that the members of the same cooperative are jointly and severally liable for not exceeding collectively assigned fishing rights. Fishery cooperatives then typically have their own internal compliance regime that includes monitoring and penalties. This paper analyzes how incentives to comply may be different for an individual fisherman operating in a fishery cooperative where joint and several liability applies as compared to an individual fishing quota baseline situation without fishery cooperative. We formalize alternative monitoring-penalty mechanisms and develop a game-theoretic model. The analytical results, establishing whether and how cooperative systems may be a means of improving compliance and reducing the monitoring costs for the regulator, are complemented by an analysis of the commonalities and differences in the way compliance regimes are actually structured in a number of internal agreements from fishery cooperatives in the US and in the EU.

Keywords: compliance; fisheries cooperatives; joint and several liability; monitoring; social preferences.

JEL codes: C72, K42, Q22

2.1 Introduction

Problems of non-compliance may undermine the sustainable management of fish stocks (Bray, 2001; Corveler, 2002; Pauly et al., 2002; Pitcher et al., 2002; Beddington et al., 2007; Borg, 2008). A number of studies have empirically demonstrated that 'conventional' economic incentives predominate in fisheries regulatory compliance decisions (Becker, 1968; Sutinen et al., 1989, 1990; Furlong, 1991; Kuperan and Sutinen, 1998; Nielsen and Mathiesen, 2003; Hatcher and Gordon, 2005; Van Hoof, 2010) and deterrence models applied to fisheries have been developed (Anderson and Lee, 1986; Anderson, 1989; Charles et al., 1999; Kronbak and Lindroos, 2006; Hatcher, 2014). The key conclusions to be drawn from these concern the probability of detection and sanction, and one of the main policy prescriptions is that the size of the penalty level should be set as high as possible to increase deterrence (Polinsky and Shavell, 1979, 1992; Shavell, 1993). However, there are a number of factors that can limit the penalty. The penalty imposed on an individual fishing firm cannot exceed the firm's net worth and in reality levels of penalties are much lower because courts are reluctant to execute sanctions perceived as excessive. Consequently, it appears that in most fisheries the frequency of inspections (and more generally the levels of monitoring) and the levels of penalties imposed by the regulator are insufficient to ensure adequate deterrence in comparison to the potential economic payoff from non-compliance with fishing regulations and quotas (NAO, 2003; Hatcher and Gordon, 2005; Sumaila et al., 2006; King and Sutinen, 2010).

Acknowledging that economic incentives are not the only factors influencing regulatory compliance in fisheries, Sutinen and Kuperan (1999) argued for the development of more complete models that include social factors. This is typically achieved by adding a set of variables related to personal normative judgments and social influences such as the opinion of others to the traditional financial incentives to violate (Sutinen and Kuperan, 1999; Hatcher et al., 2000). More specifically the utility derived from the additional benefit of violation is decreased by the individual's social preferences against violation.

Many authors have supported the idea that co-management systems are a means of improving compliance in fisheries (Jentoft, 1989; Pinkerton, 1989; Nielsen, 1994; Jentoft and McCay, 1995; Ostrom, 1995; Nielsen and Vedsmand, 1997; Hanna, 1999; Nielsen and Mathiesen, 2003; Van Hoof, 2010). Co-management classically refers to a collaborative process of decision-making combining the capacities and interests of professional organizations such as fishery cooperatives (often referred to as *producer organizations* in many European countries or as *sectors* in the US) with the ability of an administration to implement regulations and provide coordination. Such systems have actually been implemented in many fisheries around the world. Previous studies have often focused on how co-management brings legitimacy to the system, helping to create positive behavioral norms and voluntary compliance (Jentoft, 1989; Ostrom, 1990; Berkes, 1994; Eggert and Ellegård, 2003; Nielsen and Mathiesen, 2003; Van Hoof, 2010).

Although fishery cooperatives programs are structured in a variety of ways, many share the characteristic that the members of the same cooperative are jointly and severally liable for not exceeding collectively assigned fishing rights (and sometimes they are jointly and severally liable for other types of violation as well). Literature on the incentive effects of joint and several liability typically focuses on recovering damages and how it influences parties to reduce the likelihood of damages, for example in environmental pollution cases such as those involving Superfund sites (Kornhauser and Revesz, 1994; Klee and Kornhauser, 2007). In the context of fishery cooperatives, joint and several liability usually means that the regulator can hold the members of a cooperative collectively liable for the damages caused by one or more members. Literature in economics of compliance in fisheries has not analyzed the role played by the joint and several liability mechanism in enhancing (or potentially undermining) regulatory compliance. Joint and several liability allows for higher penalty levels and may reduce enforcement costs for the regulator, but this may depend on internal arrangements and behavior inside the cooperative.

Fishery cooperatives typically implement their own internal compliance regime (monitoring, penalties), thus modifying the deterrence scheme from a 'classical' principal-agent problem (regulator → harvesters; see Vestergaard (2010) for a review of applications of the principal-agent approach in fisheries) into a nested problem (regulator → cooperative & cooperative → fishermen). This paper explores how economic incentives are altered in such situations by formalizing two alternative fishery cooperative monitoring-penalty mechanisms and developing a game-theoretic model. Catch is considered to be effectively exogenous, which for example relates to situations where bycatch is highly uncertain (Holland and Jannot, 2010). Therefore, rather than focusing on avoidance behavior and recovering damages, the aim of the model is to address the question of how to ensure better reporting. This is, for instance, one of the very significant concerns related to the European small-scale fisheries adopting the discard ban of the new EU common fisheries policy and the push to monitor total catch (Veiga et al., 2016). As joint and several liability for quota overage and for misreporting is a very common characteristic for fishery cooperatives, for example in the US and in Europe, the question of whether and how it may be a means of improving compliance is critical to inform the design of institutions, which has been identified as one of the key challenges of successful fisheries management (Burgess et al., 2017).

2.2 The model

We consider unpredictable fishing events where a fisherman catches an unexpected large amount of some species he does not hold quota for. The fisherman then faces a choice to either (i) comply with regulations, that is he lands and reports his catches or, if possible, discards *legally*; or (ii) violate regulations, *e.g.* misreporting landings or illegally discarding (to avoid the consequences of catching species he does not hold quota for). We summarize these different possibilities by assuming that an individual fisherman is considering violating for an additional benefit X where the decision is made at the trip level. This setting can also encompass violations for which joint and several liability can potentially apply such as non-compliance with area restrictions. In an ITQ situation, violations at the fishing season level such as overharvesting an individual fishing quota when catch is predictable would require a slightly different setting unless the marginal cost of buying more quota is higher than the expected penalty.

We consider 2 players, i and j. Without loss of generality we assume $X_j \leq X_i$. The regulator has a probability p_r of detecting a violation, and imposes a fine V_r if a violation is detected.

The aim of our model is to investigate how the incentives to comply may be different for an individual fisherman operating in a fishery cooperative where joint and several liability applies as compared to an ITQ baseline situation where there is no fishery cooperative structure. Since fishery cooperatives typically have internal compliance arrangements that include monitoring and penalties, we specify and formalize a couple of monitoring-penalty mechanisms that a cooperative may implement. As a starting point for analyzing how the co-op structure can alter economic incentives, we first focus on the monetary costs and benefits of the compliance/violation decision, following a utilitarian model of fishermen's behavior due to the economics of crime literature (see Becker, 1968; Ehrlich, 1972, 1973; Block and Heineke, 1975). In Section 2.3 we will investigate how the social capital may enhance the effects of the standard economic incentives. This development will draw on other-regarding preferences theories (Fehr and Schmidt, 1999; Charness and Rabin, 2002). The model is presented in the normal form of a game-theoretic model, *i.e.* the payoff matrix of all strategies available to both players, and the preferred strategies of players are obtained by computing the Nash equilibria (best mutual responses). The level of violation by a player is then the sum of the probabilities associated with the strategies involving a violation in the pure Nash or mixed-strategy equilibria. It is assumed that each player makes decisions independently (non-cooperative game) and that they know the equilibrium strategies of the other players (complete information) – assumptions that shall be later discussed.

Proposition 0 – ITQ *homo œconomicus* baseline

In a traditional ITQ situation (*i.e.* when there is no co-op structure and players are not jointly liable for violations), each player complies if and only if $X \leq p_r V_r$.

Note: Proposition 0 is a straightforward application of Becker's framework to an ITQ situation without co-ops.

Now suppose a fishery cooperative setting where fishermen are jointly and severally liable for violations, so that if the regulator detects a violation by any of the 2 players, the fine is equally supported by i and j. We will also suppose that a fishery cooperative can implement some internal monitoring mechanism aiming at incentivizing regulatory compliance. Example of mechanism: watching to be able to bring proof that you are not the violator or to be able to convict a violator. We will consider 2 of such mechanisms that we describe in the following scenarios:

<u>Joint and Several Liability & Indemnification Only (JSLIO) scenario</u>:

Within a cooperative setting, by watching i at cost α, j can protect self against regulator penalties through an indemnification mechanism. When i violates and j watches, j has a probability p_c of detecting the violation. Co-op members are jointly and severally liable for some violation (regulator penalties are equally supported by co-op members) and the co-op internal agreements do not include internal penalties other than indemnification against regulator penalties. Indemnification occurs when the regulator detects a violation by i that was also detected by j, in which case the regulator penalty is entirely supported by i (as i is required to indemnify j).

<u>Joint and Several Liability & Independent Internal Penalty (JSLIIP) scenario</u>:

Within a cooperative setting, by watching i at cost α, j can detect a violation by i and collect a fine V_c from i. When i violates and j watches, j has a probability p_c of detecting the violation. Co-op members are jointly and severally liable for some violation (regulator penalties are equally supported by co-op members) and the co-op internal agreements include internal penalties that are imposed independent of detection by the regulator. Internal penalty occurs when a violation by i is detected by j, in which case j collects a fine V_c from i.

i chooses among the 4 following strategies:

- $i(0,0)$: i does not violate and does not watch
- $i(0,1)$: i does not violate and watches
- $i(1,0)$: i violates and does not watch
- $i(1,1)$: i violates and watches

Similarly, j chooses among $j(0,0)$, $j(0,1)$, $j(1,0)$ and $j(1,1)$.

Although the model is limited to a 2 players situation, the 'second player' may be considered as 'the rest of the cooperative', *i.e.* an aggregation of the other fishermen. However, an analysis of the sensitivity of the probability of detection and the monitoring costs to the size of the co-op, including free-riding issues, is beyond the scope of this analysis.

We make the two following extra assumptions:

$$\frac{1}{2}p_rV_r < p_cV_c \qquad \text{(A1)}$$

$$0 < \alpha < p_cV_c \qquad \text{(A2)}$$

A1 means that the expected penalty that may be imposed internally by the co-op is greater than half the expected penalty that may be imposed by the regulator. This is consistent with the idea that the probability of detection by the co-op is likely to be much greater than the probability of detection by the regulator (whereas $\frac{1}{2}V_r$ and V_c presumably have the same order of magnitude). A2 means that watching is cheaper than the expected penalty that may be imposed internally by the co-op in the *JSLIIP scenario*. In fact, $\alpha > p_cV_c$ would simply induce no watching and the same level of violation as in the baseline case.

Proposition 1
Under the *JSLIO scenario*, rational economic incentives to comply are not higher than in the ITQ *homo œconomicus* baseline case.

Proposition 2-a
Under the *JSLIIP scenario*, symmetric players have no incentive to effectively implement an internal monitoring system when $X < \frac{1}{2}p_rV_r$ or $X > \left(1 - \frac{\alpha}{2p_cV_c}\right)p_rV_r$.

Proposition 2-b
Under the *JSLIIP scenario* and assuming asymmetric players such that $X_j < \frac{1}{2}p_rV_r < X_i$, player *j* has an interest in the effective implementation of an internal monitoring system.

Proposition 3
Under the *JSLIIP scenario* and assuming asymmetric players such that $X_j < \frac{1}{2}p_rV_r < X_i < \frac{1}{2}p_rV_r + p_cV_c$, rational economic incentives to comply increase.

Proof of Proposition 1:

The payoff matrix of the game being played under the *JSLIO scenario* is given in Table 2.1.

If $X_j \leq X_i < p_r V_r$:

Proposition 0 implies that both players do not violate in the baseline case. Therefore incentives to comply under the *JSLIO scenario* cannot be higher than in the baseline case.

If $X_j < p_r V_r < X_i$:

Strategy $i(0,0)$ is strictly dominated by $i(1,0)$, and strategy $i(0,1)$ is strictly dominated by $i(1,1)$. That is because $\frac{1}{2}p_r + \frac{1}{2}p_r\, p_c \leq\ p_r$. As strictly dominated strategies cannot be a part of a Nash equilibrium, the optimal strategy for i therefore involves a violation. Hence incentives to comply under the *JSLIO scenario* cooperative mechanism are not higher than in the ITQ baseline case.

If $p_r V_r < X_j \leq X_i$:

Strategy $i(0,0)$ is strictly dominated by $i(1,0)$, and strategy $i(0,1)$ is strictly dominated by $i(1,1)$. Strategy $j(0,0)$ is strictly dominated by $j(1,0)$, and strategy $j(0,1)$ is strictly dominated by $j(1,1)$. After eliminating the dominated strategies, we find that $(i(1,0), j(1,0))$ is a pure Nash Equilibrium when $\alpha > \frac{1}{2}p_r\, p_c V_r$, and $(i(1,1), j(1,1))$ is a pure Nash Equilibrium when $\alpha < \frac{1}{2}p_r\, p_c V_r$. Either way, the optimal strategy for i and j involves a violation and incentives to comply under the *JSLIO scenario* cooperative mechanism are not higher than in the ITQ baseline case[8]. ☒

Proof of Propositions 2-a & 2-b:

The payoff matrix of the game being played under the *JSLIIP scenario* is given in Table 2.2. The first part of this proof establishes three general results relative to the *JSLIIP scenario* that are then used to prove the propositions.

$(*)$ If $X_j \leq X_i < \frac{1}{2}p_r V_r$:

Strategy $i(1,0)$ is strictly dominated by $i(0,0)$, and strategy $i(1,1)$ is strictly dominated by $i(0,1)$. Strategy $j(1,0)$ is strictly dominated by $j(0,0)$, and strategy $j(1,1)$ is strictly dominated by $j(0,1)$. Then, after eliminating the dominated strategies, we find that $(i(0,0), j(0,0))$ is the only pure Nash Equilibrium, *i.e.* both players do not violate and do not watch.

[8] if we consider that the regulator can increase the penalty level V_r in the case of the co-op then the Proposition 1 requires that $\alpha > \frac{1}{2}p_r\, p_c V_r$ to hold unconditionally. Otherwise, if we define V_r^{ITQ} and V_r^{COOP} to be the regulator penalty in the ITQ baseline and in the co-op scenario respectively, and supposing $V_r^{ITQ} < V_r^{COOP}$ and $\alpha < \frac{1}{2}p_r\, p_c V_r^{COOP}$, the ITQ baseline outcome would imply a violation whereas the co-op scenario outcome may involve some mixed strategies that would slightly reduce the level of violation on the interval $p_r V_r^{ITQ} < X < p_r V_r^{COOP}$. In that very particular case Proposition 1 would need to be mitigated but the result would be essentially similar.

$(**)$ If $\frac{1}{2}p_r V_r + p_c V_c < X_j \le X_i$:

Strategy $i(0,0)$ is strictly dominated by $i(1,0)$, and strategy $i(0,1)$ is strictly dominated by $i(1,1)$. Strategy $j(0,0)$ is strictly dominated by $j(1,0)$, and strategy $j(0,1)$ is strictly dominated by $j(1,1)$. Then, after eliminating the dominated strategies, assumption (A2) gives us that $(i(1,1), j(1,1))$ is the only pure Nash Equilibrium. However, since $\pi_i(i(1,1), j(1,1)) < \pi_i(i(1,0), j(1,0))$ and $\pi_j(i(1,1), j(1,1)) < \pi_j(i(1,0), j(1,0))$, both players would be better off if there was no internal monitoring system. Therefore, both co-op members have no incentive to participate in the implementation of an effective monitoring system.

$(***)$ If $\frac{1}{2}p_r V_r < X_j \le X_i < \frac{1}{2}p_r V_r + p_c V_c$:

There is no pure Nash Equilibrium; in particular, $(i(0,1), j(0,1))$ cannot be a Nash Equilibrium since $\alpha > 0$. We therefore need to compute the mixed-strategy equilibria to determine the players' mutual best responses. Suppose player i chooses strategy $i(0,0)$ with probability m, strategy $i(0,1)$ with probability n, strategy $i(1,0)$ with probability l and strategy $i(1,1)$ with probability $1 - m - n - l$. Similarly, let p, q, t and $1 - p - q - t$ be the probabilities associated with j's strategies $j(0,0)$, $j(0,1)$, $j(1,0)$ and $j(1,1)$.

Player i's expected payoff is:

$$\begin{aligned} E(\pi_i) = &\left(-\tfrac{1}{2}p_r V_r(1-p-q)\right) \times m + \left(-\tfrac{1}{2}p_r V_r(1-p-q) + p_c V_c(1-p-q) - \alpha\right) \\ &\times n + \left(X_i - \tfrac{1}{2}p_r V_r(2-p-q) - p_c V_c(1-p-t)\right) \times l \\ &+ \left(X_i - \tfrac{1}{2}p_r V_r(2-p-q) - p_c V_c(1-p-t) - \alpha\right) \times (1-m-n-l) \end{aligned} \tag{2.1}$$

Player i wants to maximize its expected payoff, so the partial derivative of $E(\pi_i)$ with respect to m, n and l must be zero.

$$\begin{cases} \dfrac{\partial E(\pi_i)}{\partial m} = 0 \\ \dfrac{\partial E(\pi_i)}{\partial n} = 0 \\ \dfrac{\partial E(\pi_i)}{\partial l} = 0 \end{cases} \Leftrightarrow \begin{cases} q = t + \dfrac{X_i - \frac{1}{2}p_r V_r - \alpha}{p_c V_c} & \text{(C1)} \\ p = 1 - t - \dfrac{X_i - \frac{1}{2}p_r V_r}{p_c V_c} & \text{(C2)} \\ 1 - p - q = \dfrac{\alpha}{p_c V_c} & \text{(C3)} \end{cases} \tag{2.2}$$

There may be multiple mixed-strategy equilibria but they all must satisfy conditions (C1), (C2) and (C3), which is sufficient to determine the probability of violating and the probability of watching in the mutual best responses. From (C3) we have that the sum of the probabilities associated with strategies $j(0,0)$ and $j(0,1)$ is $p + q = 1 - \frac{\alpha}{p_c V_c}$ in the mixed-strategy equilibria. Thus the non-compliant strategies are played by j with a probability $\frac{\alpha}{p_c V_c}$. From (C2) we have that the sum of the probabilities associated with strategies $j(0,1)$ and $j(1,1)$ is $1-p-q=\frac{X_i-\frac{1}{2}p_rV_r}{p_cV_c}$. This is the probability of j watching i in mixed-strategy equilibria.

Proposition 2-a asserts that symmetric players have no incentive to implement an internal monitoring system when $X<\frac{1}{2}p_rV_r$ or $X>\left(1-\frac{\alpha}{2p_cV_c}\right)p_rV_r$. There can be two reasons as to why players may have no incentive to implement an effective internal monitoring system: either watching is useless because no player has an incentive to violate, or there is no player for whom the *JSLIIP scenario* situation is more profitable than a situation where fishermen are joint and severally liable for violations but watching is not possible.

Suppose symmetric players (*i.e.* $X_i=X_j=X$). Based on the results $(*)$, $(**)$ and $(***)$, we have that:

- if $X<\frac{1}{2}p_rV_r$, watching is useless because no player has an incentive to violate.
- if $X>\frac{1}{2}p_rV_r+p_cV_c$, both players would be better off if there was no internal monitoring system.
- if $\frac{1}{2}p_rV_r<X<\frac{1}{2}p_rV_r+p_cV_c$, the expected payoff of each player in the mixed-strategy equilibria is the expected gains related to their own non-compliant behavior minus the expected cost related to the non-compliant behavior of the other player minus the expected cost of watching:

$$E(\pi(X))=\frac{\alpha}{p_cV_c}\times\left(X-\frac{1}{2}p_rV_r\right)-\frac{\alpha}{p_cV_c}\times\frac{1}{2}p_rV_r-\alpha\times\left(\frac{X-\frac{1}{2}p_rV_r}{p_cV_c}\right)=-\frac{\alpha}{p_cV_c}\times\frac{1}{2}p_rV_r \tag{2.3}$$

  Then, for both players the *JSLIIP scenario* situation is less profitable than a situation where fishermen are joint and severally liable for violations but watching is not possible if and only if

$$-\frac{\alpha}{p_cV_c}\times\frac{1}{2}p_rV_r<X-p_rV_r \tag{2.4}$$

$$\Leftrightarrow\quad X>\left(1-\frac{\alpha}{2p_cV_c}\right)p_rV_r. \tag{2.5}$$

Bringing these three cases together, we conclude that symmetric players have no incentive to implement an effective internal monitoring system when $X<\frac{1}{2}p_rV_r$ or $X>\left(1-\frac{\alpha}{2p_cV_c}\right)p_rV_r$. This completes the proof of proposition 2-a[9].

[9] Since $X>p_rV_r$ is a sufficient condition to ensure $X>p_rV_r\times\left(1-\frac{\alpha}{2\,p_cV_c}\right)$ and there are some evidence that in reality most fisheries are such that $X>p_rV_r$, the consequence of proposition 2-a is that it is the asymmetry among the cooperative members that calls for the implementation of an internal monitoring system.

To complete the proof of proposition 2-b, we now assume asymmetric players such that $X_j < \frac{1}{2}p_rV_r < X_i$. Once again it is useful to consider 2 different cases that cover the range of X_i:

- if $X_i > \frac{1}{2}p_rV_r + p_cV_c$, we find that $(i(1,0), j(0,1))$ is the only pure Nash Equilibrium. The expected payoff of player j is $\pi_j = -\frac{1}{2}p_rV_r + p_cV_c - \alpha$ and we have from assumption (A2) that $\pi_j > -\frac{1}{2}p_rV_r$. Hence player j has an interest in the implementation of an internal monitoring system since for j the *JSLIIP scenario* situation is more profitable than a situation where fishermen are joint and severally liable for violations but watching is not possible.

- if $\frac{1}{2}p_rV_r < X_i < \frac{1}{2}p_rV_r + p_cV_c$, there is no pure Nash equilibrium. Following a similar argument as the one developed in (∗∗∗), we find that the unique mixed-strategy equilibrium is such that player i plays strategy $i(1,0)$ with probability $\frac{\alpha}{p_cV_c}$ and strategy $i(0,0)$ with probability $1-\frac{\alpha}{p_cV_c}$, and player j plays strategy $j(0,1)$ with probability $\left(\frac{X_i-\frac{1}{2}p_rV_r}{p_cV_c}\right)$ and strategy $j(0,0)$ with probability $1-\left(\frac{X_i-\frac{1}{2}p_rV_r}{p_cV_c}\right)$. Therefore the expected payoff of player j is:

$$E(\pi_j) = \left(\frac{X_i-\frac{1}{2}p_rV_r}{p_cV_c}\right)\times\left(\frac{\alpha}{p_cV_c}\times\left(-\frac{1}{2}p_rV_r + p_cV_c - \alpha\right) + \left(1-\frac{\alpha}{p_cV_c}\right)\times(-\alpha)\right) + \left(1-\left(\frac{X_i-\frac{1}{2}p_rV_r}{p_cV_c}\right)\right)\times\frac{\alpha}{p_cV_c}\times\left(-\frac{1}{2}p_rV_r\right). \quad (2.6)$$

The expression collapses to

$$E(\pi_j) = -\frac{1}{2}p_rV_r\times\frac{\alpha}{p_cV_c} \quad (2.7)$$

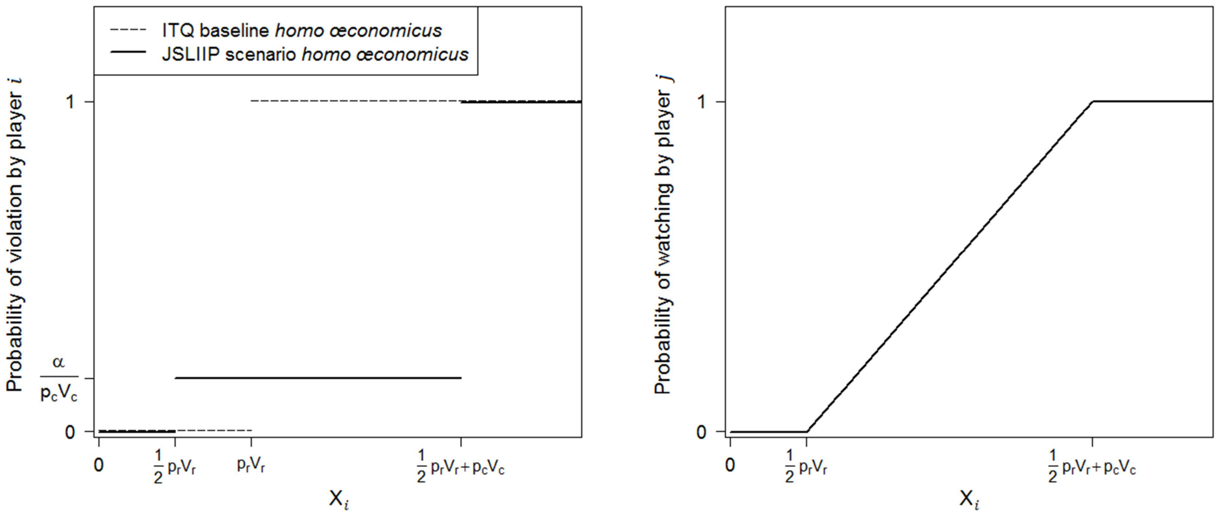
so that $E(\pi_j) > -\frac{1}{2}p_rV_r$ and player j has an interest in the effective implementation of an internal monitoring system. ☒

Proof of Proposition 3:

We suppose $X_j < \frac{1}{2}p_rV_r < X_i < \frac{1}{2}p_rV_r + p_cV_c$. We already established in the proof of the *Proposition 2-b* that the unique mixed-strategy equilibrium is such that player i plays strategy $i(1,0)$ with probability $\frac{\alpha}{p_cV_c}$ and strategy $i(0,0)$ with probability $1-\frac{\alpha}{p_cV_c}$, and player j plays strategy $j(0,1)$ with probability $\left(\frac{X_i-\frac{1}{2}p_rV_r}{p_cV_c}\right)$ and strategy $j(0,0)$ with probability $1-\left(\frac{X_i-\frac{1}{2}p_rV_r}{p_cV_c}\right)$. Note that X_i only influences player j's mixed strategy, while i's depends only on $\frac{\alpha}{p_cV_c}$. In other words, one player's mixed-strategy equilibrium depends only on the other player's payoffs, as it is always the case in mixed-strategy equilibria (see for example Camerer, 2003).

- When $p_r V_r < X_i < \frac{1}{2} p_r V_r + p_c V_c$, the probability of violation by i is $\frac{\alpha}{p_c V_c}$ under the *JSLIIP scenario*, and 1 under the baseline ITQ (Figure 2.1). From (A2) we have that $\frac{\alpha}{p_c V_c} < 1$, we thus conclude that the compliance increases under the *JSLIIP scenario* as compared to the baseline ITQ.
- When $\frac{1}{2} p_r V_r < X_i < p_r V_r$, there is no violation in the ITQ baseline case whereas the probability of violation by i is greater than zero under the *JSLIIP scenario*. That is because joint and several liability applies and the fine for a violation detected by the regulator is equally supported by i and j. Therefore, the joint and several liability mechanism may actually make things worse on this interval. However, this goes away if we consider that the regulator can increase the penalty level V_r in the case of the *JSLIIP scenario*, *e.g.* $V_r^{COOP} = 2V_r^{ITQ}$, which is a reasonable assumption as joint and several liability allows for higher penalty.

Therefore we derived that the compliance increases under the *JSLIIP scenario* as compared to the baseline ITQ when $X_j < \frac{1}{2} p_r V_r < X_i < p_r V_r + p_c V_c$. ☒



(a) level of violation by i *(b) level of watching by j*

Figure 2.1: Probability of violation and probability of watching in the Joint and Several Liability & Independent Internal Penalty (JSLIIP) scenario's mixed-strategy equilibrium when $X_j < \frac{1}{2} p_r V_r$

Table 2.1: Payoff matrix of the non-cooperative complete information game under the Joint and Several Liability & Indemnification Only (JSLIO) scenario (the regulator has a probability p_r of detecting a violation, and imposes a fine V_r if a violation is detected; by watching i at cost α, j can protect self against regulator penalties when i violates with a probability p_c)

		Player j			
		(0,0)	(0,1)	(1,0)	(1,1)
Player i	(0,0)	$\begin{cases}\pi_i = 0\\ \pi_j = 0\end{cases}$	$\begin{cases}\pi_i = 0\\ \pi_j = -\alpha\end{cases}$	$\begin{cases}\pi_i = -\frac{1}{2}p_rV_r\\ \pi_j = X_j - \frac{1}{2}p_rV_r\end{cases}$	$\begin{cases}\pi_i = -\frac{1}{2}p_rV_r\\ \pi_j = X_j - \frac{1}{2}p_rV_r - \alpha\end{cases}$
	(0,1)	$\begin{cases}\pi_i = -\alpha\\ \pi_j = 0\end{cases}$	$\begin{cases}\pi_i = -\alpha\\ \pi_j = -\alpha\end{cases}$	$\begin{cases}\pi_i = -\left(\frac{1}{2}p_r(1-p_c)\right)V_r - \alpha\\ \pi_j = X_j - \left(\frac{1}{2}p_r + \frac{1}{2}p_r p_c\right)V_r\end{cases}$	$\begin{cases}\pi_i = -\left(\frac{1}{2}p_r(1-p_c)\right)V_r - \alpha\\ \pi_j = X_j - \left(\frac{1}{2}p_r + \frac{1}{2}p_r p_c\right)V_r - \alpha\end{cases}$
	(1,0)	$\begin{cases}\pi_i = X_i - \frac{1}{2}p_rV_r\\ \pi_j = -\frac{1}{2}p_rV_r\end{cases}$	$\begin{cases}\pi_i = X_i - \left(\frac{1}{2}p_r + \frac{1}{2}p_r p_c\right)V_r\\ \pi_j = -\left(\frac{1}{2}p_r(1-p_c)\right)V_r - \alpha\end{cases}$	$\begin{cases}\pi_i = X_i - p_rV_r\\ \pi_j = X_j - p_rV_r\end{cases}$	$\begin{cases}\pi_i = X_i - \left(p_r + \frac{1}{2}p_r p_c\right)V_r\\ \pi_j = X_j - \left(p_r - \frac{1}{2}p_r p_c\right)V_r - \alpha\end{cases}$
	(1,1)	$\begin{cases}\pi_i = X_i - \frac{1}{2}p_rV_r - \alpha\\ \pi_j = -\frac{1}{2}p_rV_r\end{cases}$	$\begin{cases}\pi_i = X_i - \left(\frac{1}{2}p_r + \frac{1}{2}p_r p_c\right)V_r - \alpha\\ \pi_j = -\left(\frac{1}{2}p_r(1-p_c)\right)V_r - \alpha\end{cases}$	$\begin{cases}\pi_i = X_i - \left(p_r - \frac{1}{2}p_r p_c\right)V_r - \alpha\\ \pi_j = X_j - \left(p_r + \frac{1}{2}p_r p_c\right)V_r\end{cases}$	$\begin{cases}\pi_i = X_i - p_rV_r - \alpha\\ \pi_j = X_j - p_rV_r - \alpha\end{cases}$

Table 2.2: Payoff matrix of the non-cooperative complete information game under the Joint and Several Liability & Independent Internal Penalty (JSLIIP) scenario (the regulator has a probability p_r of detecting a violation, and imposes a fine V_r if a violation is detected; by watching i at cost α, j can detect a violation by i and collect a fine V_c from i when i violates with a probability p_c).

		Player j			
		(0,0)	(0,1)	(1,0)	(1,1)
Player i	(0,0)	$\begin{cases}\pi_i = 0 \\ \pi_j = 0\end{cases}$	$\begin{cases}\pi_i = 0 \\ \pi_j = -\alpha\end{cases}$	$\begin{cases}\pi_i = -\frac{1}{2}p_rV_r \\ \pi_j = X_j - \frac{1}{2}p_rV_r\end{cases}$	$\begin{cases}\pi_i = -\frac{1}{2}p_rV_r \\ \pi_j = X_j - \frac{1}{2}p_rV_r - \alpha\end{cases}$
	(0,1)	$\begin{cases}\pi_i = -\alpha \\ \pi_j = 0\end{cases}$	$\begin{cases}\pi_i = -\alpha \\ \pi_j = -\alpha\end{cases}$	$\begin{cases}\pi_i = -\frac{1}{2}p_rV_r + p_cV_c - \alpha \\ \pi_j = X_j - \frac{1}{2}p_rV_r - p_cV_c\end{cases}$	$\begin{cases}\pi_i = -\frac{1}{2}p_rV_r + p_cV_c - \alpha \\ \pi_j = X_j - \frac{1}{2}p_rV_r - p_cV_c - \alpha\end{cases}$
	(1,0)	$\begin{cases}\pi_i = X_i - \frac{1}{2}p_rV_r \\ \pi_j = -\frac{1}{2}p_rV_r\end{cases}$	$\begin{cases}\pi_i = X_i - \frac{1}{2}p_rV_r - p_cV_c \\ \pi_j = -\frac{1}{2}p_rV_r + p_cV_c - \alpha\end{cases}$	$\begin{cases}\pi_i = X_i - p_rV_r \\ \pi_j = X_j - p_rV_r\end{cases}$	$\begin{cases}\pi_i = X_i - p_rV_r - p_cV_c \\ \pi_j = X_j - p_rV_r + p_cV_c - \alpha\end{cases}$
	(1,1)	$\begin{cases}\pi_i = X_i - \frac{1}{2}p_rV_r - \alpha \\ \pi_j = -\frac{1}{2}p_rV_r\end{cases}$	$\begin{cases}\pi_i = X_i - \frac{1}{2}p_rV_r - p_cV_c - \alpha \\ \pi_j = -\frac{1}{2}p_rV_r + p_cV_c - \alpha\end{cases}$	$\begin{cases}\pi_i = X_i - p_rV_r + p_cV_c - \alpha \\ \pi_j = X_j - p_rV_r - p_cV_c\end{cases}$	$\begin{cases}\pi_i = X_i - p_rV_r - \alpha \\ \pi_j = X_j - p_rV_r - \alpha\end{cases}$

2.3 Other-regarding preferences in social groups

There is an extensive literature supporting the idea that the deterrence models following Becker's framework (1968) for explaining criminal activity (*i.e*. models relying on costs and revenues associated with illegal behavior) are somewhat incomplete to predict regulatory compliance in that they do not account for the social factors that influence the behavior of agent (Sutinen and Kuperan, 1999; Hatcher et al., 2000; Casari and Plott, 2001; Nielsen, 2003; Eggert and Lokina, 2010; Cardenas, 2011; Jackson et al., 2012; Weber, 2013). There is also some evidence that self-organization and co-management systems may be a means of strengthening cooperation and social capital (Ostrom, 1990; Libecap, 1994; Jentoft, 2000; Velez et al., 2010; Travers et al., 2011; Soma et al., 2015). Behavioral economics theories, that often substitute a social utility for a vector of payoffs to account for other-regarding preferences in social groups (Bolton, 1991; Camerer, 2003), offer interesting modelling frameworks for including some social capital component into our game-theoretic model. Typically, preferences are treated as exogenously given. In this section we apply a model of other-regarding preferences to the *JSLIIP scenario* complete information game we presented in Section 2.2. This model is adapted from Charness and Rabin (2002) that mixes reciprocity and inequality aversion (Fehr and Schmidt, 1999) where group members are assumed to care about their own payoff and their relative payoff.

For ease of analysis, we focus on the most essential case where players are asymmetric. Let X_i be such that $\frac{1}{2}p_rV_r < X_i < 2V_c - \alpha$. We also assume that $X_j < \frac{1}{2}p_rV_r$ and $\alpha < p_cV_c$ so that Player j never violates and Player i never watches. We recall that the payoff matrix is:

		Player j	
		(0,0)	(0,1)
Player i	(0,0)	$\begin{cases}\pi_i = 0\\ \pi_j = 0\end{cases}$	$\begin{cases}\pi_i = 0\\ \pi_j = -\alpha\end{cases}$
	(1,0)	$\begin{cases}\pi_i = X_i - \frac{1}{2}p_rV_r\\ \pi_j = -\frac{1}{2}p_rV_r\end{cases}$	$\begin{cases}\pi_i = X_i - \frac{1}{2}p_rV_r - p_cV_c\\ \pi_j = -\frac{1}{2}p_rV_r + p_cV_c - \alpha\end{cases}$

The approach developed by Charness and Rabin (2002) intends to model preferences for fair outcome (inequality aversion) and fair intentions (reciprocity) simultaneously. Taking intention-based reciprocity into account seems relevant to the monitoring and compliance decisions since it has been widely identified that individuals may dislike violations of a shared norm and actions that produce negative effects on other subjects.

We suppose the following utility functions adapted from their general modelling framework:

$$\begin{cases} U_i(\boldsymbol{\pi}) = \pi_i - \beta_i \times \max(\pi_i - \pi_j, 0) \times \rho \\ U_j(\boldsymbol{\pi}) = \pi_j - \gamma_j \times \max(\pi_i - \pi_j, 0) \times \rho \end{cases} \quad \text{with} \quad \rho = \begin{cases} 1 & \text{if } i \text{ misbehaved} \\ 0 & \text{otherwise} \end{cases} \qquad \text{(ACR)}$$

The parameters β_i and γ_j are defined as in Fehr and Schmidt (1999), that is $0 \leq \beta_k < 1$ and $\beta_k \leq \gamma_k$, $k = i, j$. Players dislike having lower payoffs than other (with weight γ_k) and also dislike having higher payoffs (with weight β_k). Intuitively, $\beta_k \leq \gamma_k$ means that a player's *envy* parameter is supposed greater than its *guilt* parameter.

The normal form of the *JSLIIP scenario* game taking the ACR utility functions into account is presented in Table 2.3.

Table 2.3: Social utility matrix of the model adapted from Charness and Rabin (ACR) applied to the non-cooperative complete information game under the JSLIIP scenario (the regulator has a probability p_r of detecting a violation, and imposes a fine V_r if a violation is detected; by watching i at cost α, j can detect a violation by i and collect a fine V_c from i when i violates with a probability p_c).

		Player j	
		(0,0)	(0,1)
Player i	(0,0)	$\begin{cases} U_i = 0 \\ U_j = 0 \end{cases}$	$\begin{cases} U_i = 0 \\ U_j = -\alpha \end{cases}$
	(1,0)	$\begin{cases} U_i = (1-\beta_i)X_i - \frac{1}{2}p_rV_r \\ U_j = -\gamma_jX_i - \frac{1}{2}p_rV_r \end{cases}$	† $\begin{cases} U_i = (1-\beta_i)X_i - \frac{1}{2}p_rV_r - p_cV_c - (1-p_c)\alpha \\ U_j = -\gamma_j(1-p_c)X_i - \frac{1}{2}p_rV_r + p_cV_c - \big(1+(1-p_c)\gamma_j\big)\alpha \end{cases}$

† When i plays (1,0) and j plays (0,1), whether $\pi_i > \pi_j$ or $\pi_i < \pi_j$ depends on whether j detected the violation. Let π_i^D and π_j^D denote respectively i and j's payoffs when the violation is detected by j (*i.e.* $\pi_i^D = X_i - \frac{1}{2}p_rV_r - V_c$ and $\pi_j^D = -\frac{1}{2}p_rV_r + V_c - \alpha$), and $\pi_i^{\bar{D}}$ and $\pi_j^{\bar{D}}$ their payoffs when the violation was not detected ($\pi_i^{\bar{D}} = X_i - \frac{1}{2}p_rV_r$ and $\pi_j^{\bar{D}} = -\frac{1}{2}p_rV_r - \alpha$). Then, using the ACR model, U_i is computed as $U_i(\boldsymbol{\pi}) = p_c \times \pi_i^D + (1-p_c) \times \left(\pi_i^{\bar{D}} - \beta_i\big(\pi_i^{\bar{D}} - \pi_j^{\bar{D}}\big)\right)$ and U_j is computed as $U_j(\boldsymbol{\pi}) = p_c \times \pi_j^D + (1-p_c) \times \left(\pi_j^{\bar{D}} - \gamma_j\big(\pi_j^{\bar{D}} - \pi_i^{\bar{D}}\big)\right)$.

First, we search for the conditions for perfect compliance, *i.e.* the conditions ensuring that strategy $i(1,0)$ is strictly dominated by $i(0,0)$ in Table 2.3. Perfect compliance occurs when $i(0,0)$ is the best strategy for i regardless of what j does, that is when $U_i\left(\boldsymbol{\pi}\big(i(0,1), j(0,0)\big)\right) < U_i\left(\boldsymbol{\pi}\big(i(0,0), j(0,0)\big)\right)$ and $U_i\left(\boldsymbol{\pi}\big(i(0,1), j(0,1)\big)\right) < U_i\left(\boldsymbol{\pi}\big(i(0,0), j(0,1)\big)\right)$. Thus, strategy $i(1,0)$ is strictly dominated by $i(0,0)$ if and only if both the following conditions are met:

$$\begin{cases} (1-\beta_i)X_i - \frac{1}{2}p_rV_r < 0 & (2.8) \\ (1-\beta_i)X_i - \frac{1}{2}p_rV_r - p_cV_c - (1-p_c)\alpha < 0 & (2.9) \end{cases}$$

As (2.8) ⇒ (2.9), we deduce that (2.8) is actually the binding condition determining whether the probability of violation is 0, which can be rewritten as:

$$\beta_i > 1 - \frac{\frac{1}{2}p_rV_r}{X_i} \tag{2.10}$$

We note that the right hand side in (2.10) tends to 0 when X_i tends to $\frac{1}{2}p_rV_r$ (*i.e.* when violating is not so profitable). Great values of β_i, the guilt parameter of player i, can therefore induce perfect compliance provided that X_i is not too big as compared to $\frac{1}{2}p_rV_r$. If satisfied, condition (2.10) implies that $(i(0,0), j(0,0))$ is the only pure Nash equilibrium.

If conditions for perfect compliance are not met, then we need to compute the mixed-strategy equilibrium to determine the effects of ACR other-regarding preferences on the level of violation by i and the level of monitoring by j. Suppose player i chooses strategy $i(0,0)$ with probability m and strategy $i(1,0)$ with probability $1-m$. Similarly, let y and $1-y$ be the probabilities associated with j's strategies $j(0,0)$ and $j(0,1)$.

Player j is indifferent when:

$$\begin{aligned} & m \times 0 + (1-m) \times \left(-\gamma_j X_i - \tfrac{1}{2}p_rV_r\right) \\ & \qquad = m \times (-\alpha) + (1-m) \times \left(-\gamma_j(1-p_c)X_i - \tfrac{1}{2}p_rV_r + p_cV_c - \left(1+(1-p_c)\gamma_j\right)\alpha\right) \end{aligned} \tag{2.11}$$

from which we derive the level of violation:

$$1 - m = \frac{\alpha}{p_cV_c + p_c\gamma_jX_i - (1-p_c)\gamma_j\alpha} \tag{2.12}$$

Similarly, player i is indifferent when:

$$y \times \left((1-\beta_i)X_i - \tfrac{1}{2}p_rV_r\right) + (1-y) \times \left((1-\beta_i)X_i - \tfrac{1}{2}p_rV_r - p_cV_c - (1-p_c)\alpha\right) = 0 \tag{2.13}$$

from which we derive the level of monitoring:

$$1 - y = \frac{(1-\beta_i)X_i - \frac{1}{2}p_rV_r}{p_cV_c + (1-p_c)\beta_i\alpha} \tag{2.14}$$

The ACR model predicts that the level of violation by i is a decreasing function of X_i, and a decreasing function of γ_j if $p_cX_i > (1-p_c)\alpha$. Thus the inequality aversion of j decreases i's incentives to violate at equilibrium. As for the level of monitoring by j, it is a decreasing function of β_i. Intuitively, j lowers his level of monitoring because i's level of violation is lowered by guilt.

2.4 Numerical simulation

In this section we present some results from a set of numerical simulations to illustrate the effects of other-regarding preferences on the outcomes of the *JSLIIP scenario* complete information game. The aim here is to make clearer the analytical results that were derived in Section 2.3. We make the same assumptions we made in Section 2.3, that is X_i and X_j are such that $X_j < \frac{1}{2}p_rV_r < X_i < 2V_c - \alpha$. Thus, j never violates and i never watches. We also suppose that condition for perfect compliance (2.10) is not satisfied so that the equilibrium of the game deals with mixed-strategies. We specify the parameter values for the *JSLIIP scenario* game as follows.

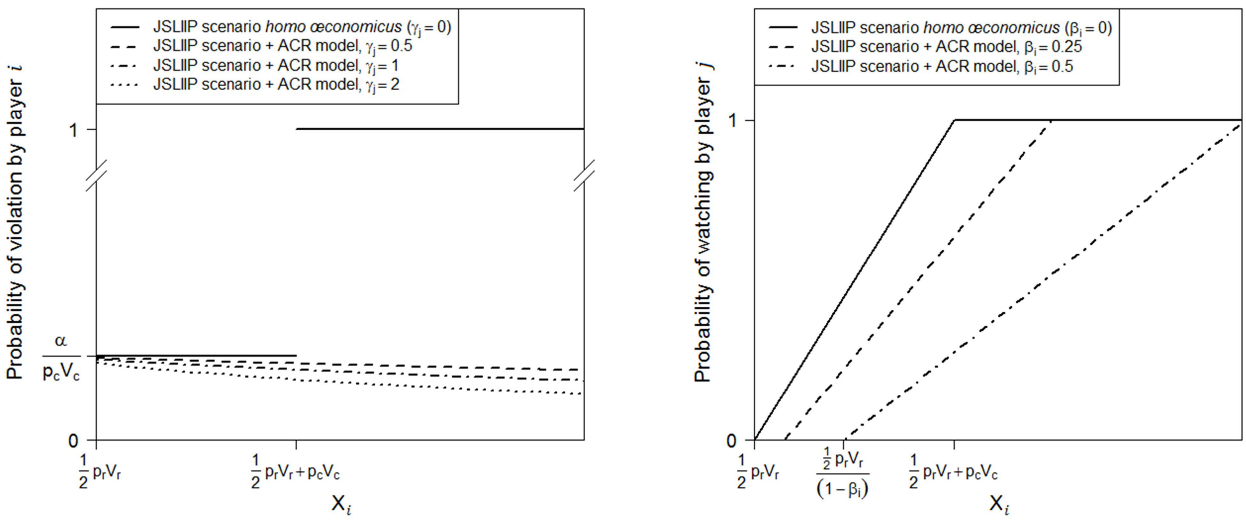
Probability of detection by the regulator	p_r	2%
Penalty imposed by the regulator ($ 000)	V_r	200
Probability of detection by the cooperative	p_c	15%
Penalty imposed by the cooperative ($ 000)	V_c	30
Cost of watching for the cooperative ($ 000)	α	0.1

The penalty structure fits a number of US fishery cooperatives and EU producer organizations programs in a stylized way. The cost of watching is set to be relatively small as compared to the expected penalties, which for example fits a situation where someone is sent at the time of landing to watch whether landings declarations are lawful and fish sizes meet legal requirements. In reality, these parameter values may vary greatly according to the fishery and the type of offense we are interested in, however this is not critical to the conclusions that will be drawn from the simulations.

The other-regarding preferences profiles of i and j will be varied throughout the simulations by using different values for the inequality aversion parameters γ and β. Fehr and Schmidt (1999) calibrated the distributions of γ and β in the population and found that the ranges were respectively $\gamma \in [0,4]$ and $\beta \in [0,0.6]$. The values of γ and β we tested are drawn within these ranges: $\gamma_j \in \{0,0.5,1,2\}$, $\beta_i \in \{0,0.25,0.5\}$.

The application of the ACR model to the *JSLIIP scenario* game introduces a reciprocity mechanism by which i's utility is decreased by guilt and j's utility is decreased by envy respectively when i chooses a course of action that is considered as unfair behavior. As expected, we observe that the level of violation is a decreasing function of γ_j and X_i (Figure 2.2a). This outcome is rather intuitive as j's intrinsic motivations to watch are increased by his aversion to unfair behavior and disadvantageous inequality, which induces a lower level of violation by i in the mixed-strategy equilibrium when γ_j and X_i increase. Concurrently, when $\beta_i > 0$, i's intrinsic motivations to violate are determined by a combination of utilities from own payoff and disutilities from choosing a course of action that produces negative effects on i. Therefore, an increase of the guilt parameter β_i results in lower levels of watching by j in the mixed-strategy equilibrium (Figure 2.2b).

In summary, ACR preferences tend to decrease both the level of violation and the level of watching. Notably, the level of violation is maintained at a fairly low level even if $X_i > \frac{1}{2}p_r V_r + p_c V_c$ (inasmuch as $X_i < 2V_c - \alpha$, which can always be achieved by simply increasing V_c). As such, the outcomes of this other-regarding preferences model essentially show that the monitoring-penalty mechanism defined in the *JSLIIP scenario* associated with social preferences has the potential to significantly improve compliance as compared to the ITQ baseline situation, even when the potential additional benefit from violating is large.



(a) level of violation by i, ACR model *(b) level of monitoring by j, ACR model*

Figure 2.2: Probability of violation and probability of watching in the Joint and Several Liability & Independent Internal Penalty (JSLIIP) scenario's mixed-strategy equilibrium when $X_j < \frac{1}{2}p_r V_r$ under alternative other-regarding preferences profiles ($\gamma_j \in \{0, 0.5, 1, 2\}$, $\beta_i \in \{0, 0.25, 0.5\}$).

2.5 Internal compliance systems used by fishery cooperatives in the US and in the EU

This section describes the way compliance systems are structured in contracts and agreements from fishery cooperatives in the US and in the EU. The main characteristics of the internal compliance systems of various cooperative agreements that have been collected are presented in Table 2.4.

Institutional context

Fishery cooperative programs in the US and in the EU are managed under the National Marine Fisheries Service (NMFS) regulations and the Common Fisheries Policy (CFP) regulations respectively. In the US, legal actions brought by NMFS against a cooperative are taken to federal district courts that are deemed to have jurisdiction to enforce NMFS regulations. In the EU, cooperative programs are managed at the Member State level, and each Member State has jurisdiction and responsibility to enforce the CFP regulations. One interesting aspect of cooperative programs is that the regulator can design the rules such that members of the same cooperative are jointly and severally liable for certain types of offense. In the context of fishery cooperatives, joint and several liability usually means that the regulator can hold the members of a cooperative collectively liable for the damages caused by one or more members. All the cooperative agreements listed in the Table 2.4 contain joint and several liability for quota overages. In practice, if a cooperative exceeds one of its quotas, the regulator may impose a permanent or temporary reduction of fishing opportunities for the whole co-op including stop fishing orders, loss of quota units and termination of the co-op authorization. In the US, the members of the North East fishery sectors are also jointly and severally liable for fines, penalties and forfeitures related to discarding of legal-sized fish and misreporting of catch landings and discards. On the West coast, WMC members may be held jointly and severally liable for non-compliance with the fishery observer requirements and for violations of the cooperative's non-whiting species management rules.

Observation

The contracts of the MWC, CPIPA, MSIPA and SIPA require Federal observers to be placed on all vessels in the cooperative at all times. Each cooperative is responsible for the cost of these observers. In cooperatives that do not contractually require members to carry observers, members are typically required to have their fishing activity monitored at-sea with some electronic equipment that can include GPS and remote cameras. NEFS II, GBCHS and BSMP also have dockside observers that monitor landings at pre-approved landings stations and pre-approved times. Having 100% observer coverage has enabled cooperatives in US Pacific Coast and Alaskan fisheries to develop bycatch reduction programs requiring vessels to meet standards, follow specified bycatch avoidance practices, and share information.

Reporting

All cooperative agreements require some form of accurate reporting. Besides observation, an accountable system of reporting seems to provide a critical means to ensure compliance with the cooperative's rules. Most cooperatives require two complementary reporting elements on a timely basis: catch logs and dealers reports. Besides, cooperative typically have a monitoring agent whose

Table 2.4: Main characteristics of internal compliance systems in various fishery cooperative agreements in the US and in the EU

Cooperative agreement designation [number of members]	Fishery	Regulator's jurisdiction and governing law	Joint and several liability offenses	Observation and electronic monitoring	Reporting requirements	Internal penalties	Internal enforcement authority	Indemnification mechanisms	Additional considerations
Northeast fishery sector II (NEFS II) [80]	US North East multispecies fishery	US federal, NMFS regulations	Quota overages, Misreporting of catches landings and discards, Discarding of legal-sized fish	At-sea eletronic monitoring or actual observer, dockside observers (pre-approved landing stations)	Catch logs, dealer reports	Monetary penalties (ramping up for repeat offense), stop fishing order, expulsion	Manager or committee appointed by the Board	Damages awarded to the cooperative for overharvest is distributed pro rata among the members whose harvest was reduced; violating party must indemnify other parties against governmental penalties	
Georges Bank cod hook sector (GBCHS) [20]	US North East cod fishery	US federal, NMFS regulations	Quota overages, Misreporting of catches landings and discards, Discarding of legal-sized fish	At-sea eletronic monitoring or actual observer, dockside observers (pre-approved landing stations)	Catch logs, dealer reports	Monetary penalties (ramping up for repeat offense), stop fishing order, expulsion	Manager or committee appointed by the Board	Violating members must indemnify the other members in respect of their respective losses; indemnification shall be several and not joint and several	
Mothership whiting cooperative (MWC) [35]	US Pacific whiting fishery	US federal, NMFS regulations	Quota overages, violations of the Cooperative's Non-Whiting Species management rules, non-compliance with observer requirements	At-sea observers (100% coverage)	Catch logs, dealer reports	Monetary penalties (up to 300% of the ex-vessel value of landings), stop fishing order, expulsion	The Board or the monitoring agent	Damages awarded to the cooperative for overharvest is distributed pro rata among the members whose harvest was reduced; violating party must indemnify other parties against governmental penalties	Members waive any claim against the Manager and the monitoring agent; members are jointly and severally liable for any third party claims asserted against the Manager or the monitoring agent
Alaska Catcher-Processor cooperatives - incentive plan agreement (CPIPA) [24]	Alaska pollock fishery	US federal, NMFS regulations	Quota overages	At-sea observers (100% coverage)	Catch logs	Monetary penalties (ramping up for repeat offense), stop fishing order	The technical representative or the coop representatives group	No monetary damages for losses associated with fishery shutdown; collected penalties shall be used to support research; indemnification for legal fees	spatial access incentives to keep chinook bycatch low
Alaska Mothership cooperatives - incentive plan agreement (MSIPA) [19]	Alaska pollock fishery	US federal, NMFS regulations	Quota overages	At-sea observers (100% coverage)	Catch logs	Monetary penalties, penalties in quota tonnes	The technical representative or the coop representatives group	Unspecified	collective and individual chinook bycatch allocations
Alaska shoreside cooperatives - incentive plan agreement (SIPA) [98]	Alaska pollock fishery	US federal, NMFS regulations	Quota overages	At-sea observers (100% coverage)	catch logs	Monetary penalties (ramping up for repeat offense), stop fishing order	The technical representative or the coop representatives group	No monetary damages for losses associated with forgone pollock fishing opportunities; indemnification against governmental penalties	bycatch risk pools
Les Pêcheurs de Bretagne producer organization - articles of association (PDBPO) [800]	Western Europe whitefish species and nephrops fisheries	France, CFP regulations	Quota overages	At-sea eletronic monitoring	Catch logs, dealer reports	Monetary penalties (up to 100% of the ex-vessel value of non-compliant landings), stop fishing order, expulsion	The Board or the president	Unspecified	
Cobrenord producer organization - articles of association (CNPO) [210]	Western Europe whitefish species and scallop fisheries	France, CFP regulations	Quota overages	At-sea eletronic monitoring	Catch logs, dealer reports	Seizure of catch, stop fishing order, expulsion	The Board	Unspecified	No monetary penalty
FROM nord producer organization - articles of association (FNPO) [200]	Western Europe whitefish species and scallop fisheries	France, CFP regulations	Quota overages	At-sea eletronic monitoring	Catch logs, dealer reports	Monetary penalties (equal to 100% of the ex-vessel value of landings), stop fishing order, expulsion	The Board	Damages awarded to the PO for overharvest is distributed pro rata among the members whose harvest was reduced	
Cooperative association of Brown shrimp producer organizations - management plan (BSMP) [225]	North sea brown shrimp fishery	The Netherlands, CFP regulations	Quota overages	At-sea eletronic monitoring, dockside observers (pre-approved landing stations)	Catch logs, dealer reports	Monetary penalties up to €250,000	The Board	Unspecified	MSC management plan and certificate
Aberdeen fish producer organization - articles of association (AFPO) [19]	Western Europe whitefish species and nephrops fisheries	UK, CFP regulations	Quota overages	At-sea eletronic monitoring	E-logs and e-declarations	Monetary penalties up to £250,000, penalties in quota tonnes, expulsion, loss of quota units	Disciplinary committee appointed by the Board	Unspecified	

job is to track the co-op quota consumption but also to notify apparent violations that could be detected out of the catch logs and dealers reports. Regulations may require that the monitoring agent is a third-party to ensure neutrality (as in MWC and CPIPA).

Penalty structures

A critical element of the cooperative agreements is the penalty structure. In the US, courts generally will not enforce punitive penalties in contracts that are meant to be like fines, however if penalties are related to damages they may be upheld. Penalties for noncompliance with cooperative rules are in fact included in almost all of the cooperative contracts in the US and in the EU. The complexity of this structure varies by cooperative, ranging from stipulated penalties to graduated sanctions.

Overharvest penalties can be proportional to the ex-vessel value of landings (*e.g.* 300% in MWC, 100% in PDBPO and FNPO) or equal to a forfeiture amount defined per species multiplied by the number of metric tons harvested in excess. Penalties in quota tons for the next year or permanent loss of quota units are also frequently used by cooperatives. Most cooperatives are also allowed to impose stop fishing orders. CNPO cannot impose monetary penalties on its members and use seizure of catches that are in contravention with its agreements to sanction offending members. This seems less dissuasive than monetary penalties as it is only applicable when violators are caught in the act.

Generally, penalty structures also include graduated sanctions to deal with infractions such as misreporting landings, illegally discarding, non-compliance with gear, time and area restrictions. The internal enforcement authority is usually a disciplinary committee appointed by the Board or the Board itself. Infractions may be dealt with anonymously to ensure objectivity in the sanctions process. In determining sanctions, the enforcement authority evaluates the infraction history of the offending member and the severity of a given infraction. The degree of sanction imposed increases with the frequency of infractions and the severity of an infraction, and most cooperative agreements establish the expulsion of the offending member as one of the ultimate sanctions.

Indemnification

One of the aspects where cooperative agreements may greatly differ is whether members who suffered losses due to the actions of an offending member are indemnified. In NEFS II, GBCHS, MWC, and FNPO, damages that are awarded to the cooperative are to be disbursed on a pro-rata basis to those members who have harvested less than their allocations. Here we see that indemnification against quota overage by other members can be found in some cooperatives on both coasts of the US and in some EU producer organizations as well. To the contrary, CPIPA and SIPA explicitly specify that there can be no damages associated with someone shutting down the fishery early. They however include indemnification against legal fees and governmental penalties. The other cooperative agreements do not mention indemnification, which suggests that members cannot sue each other for damages. MSW specifies that members cannot sue the manager and the monitoring agent in order to let them exercise their independent responsibility and judgment in fulfilling the terms of the agreement. Indemnification could effectively negate joint and several liability to some degree since it partially insulates cooperative members from penalties due to actions of other cooperative members.

2.6 Policy considerations

Perhaps the most fundamental compliance related benefit of cooperative-based catch share systems with joint and several liability is that the size of the penalty that can be recovered from a cooperative is likely to be higher than from an individual in an ITQ system. The latter is limited by the individuals' net worth and potentially by limits on the size of fines courts will allow. The ability of the regulator to take away catch privileges for one or more years from the entire cooperative may effectively create a penalty much larger than could be recovered with an individual fine. Enabling a higher maximum fine can increase the level of compliance for a given probability of observing a violation and thereby increase compliance for a given enforcement expenditure.

However, proposition 1 implies that, to promote compliance, the cooperative internal agreements should include the collection by the cooperative of fines for breaching even if the violation was not detected by the regulator. We saw in Section 2.5 that in reality most fishery cooperatives that are jointly and severally liable for quota overages do have these dispositions in their internal agreements. In some of these agreements, fines increase with 2^{nd} or 3^{rd} offences. This could have the effect of creating or increasing asymmetry in payoffs for different cooperative members. As propositions 2-a, 2-b and 3 show, this is a good property as it strengthens incentives of internal monitoring. Regulators may want to require and review internal cooperative compliance programs as a condition of allocating quota to a cooperative.

Propositions 2-a and 2-b imply that the regulator must make sure that the incentives of the cooperative push towards implementing and enforcing an effective internal compliance regime. If there is no member that may benefit from having strict internal rules enforced, then the cooperative as an entity has little incentive to implement such compliance regime. Also, if the cooperative members perceive the regulations as illegitimate, the cooperative may have mixed incentives. That is, if the incentives of the cooperative and the regulator are not aligned, its primary concern will be that no member gets caught doing something wrong, which happens either when all members comply or when the violators do not get caught. The latter implies the cooperative may develop 'inside strategies' where members can share information on how to avoid getting caught, making the regulator's life harder. Therefore, if there is no heterogeneity among fishermen, one can wonder if the regulator gains something from having cooperatives and the joint and several liability mechanism in the management system. In the recent news, the biggest vessel owner in the New England groundfish industry was arrested on "charges of conspiracy and submitting falsified records to the federal government to evade federal fishing quotas" (McKiernan and Tomolonis, 2016). This vessel owner has the largest quota share for many groundfish species in New England, and also leases quota from many smaller quota holders as well. He actually controlled at least one of the Northeast fishery sectors ('NEFS IX'), which underscores the critical point that if the sector's and regulator's interests are not aligned, then the cooperative may develop inside strategies.

Proposition 3 shows that, when effectively implemented and enforced, the internal monitoring mechanism in the *JSLIIP scenario* reduces the level of non-compliance by i. If the cost of watching α is sufficiently small compared to $p_c V_c$, the expected probability of violation by i may be low. Therefore, such co-op system has the potential to significantly reduce non-compliance on the interval $p_r V_r < X_i < \frac{1}{2} p_r V_r + p_c V_c$. As $X_i < p_c V_c$ is a sufficient condition to ensure that $X_i < \frac{1}{2} p_r V_r + p_c V_c$ and that therefore the probability of violation by i is less or equal to $\frac{\alpha}{p_c V_c}$, the cooperative controls the main parameters, namely p_c and V_c, that can create the conditions for reducing non-compliance. In some cases the regulator may be able to help reduce α for the cooperative. For example, by allowing the cooperative to have access to information collected by observers or electronic observing equipment. This is in fact done on for US Pacific Coast and Alaskan fisheries. Since the probability of violation by i is independent of p_r, $X_i < p_c V_c$ implies that the regulator can actually reduce its monitoring effort (*i.e.* reduce p_r) without affecting the probability associated with non-compliance strategies in mixed-strategy equilibria.

The analysis in Section 2.3 demonstrated that other-regarding preferences may help improve compliance. Such social motivations are probably more likely when members of a cooperative have social relationships and histories of working together (*i.e.* social capital). Notably, most fishery cooperatives are self-forming and have the ability to exclude unwanted members. They are often formed on the basis of existing relationships such as common membership in an association. Some level of trust is probably required for members to agree to join a cooperative with joint and several liability, but this characteristic also may help strengthen incentives for compliance. While these results suggest that regulators may want to allow cooperatives to choose and exclude members, care must also be taken to ensure that the members' interests are not so closely aligned that they have the incentive to conspire to evade regulations.

2.7 Concluding remarks

Full compliance cannot generally be expected unless the expected penalty that may be imposed by the regulator is greater than the expected gains of non-compliance for all individuals. When the regulator cannot support the costs of monitoring and enforcement that are necessary to create such conditions or the size of fines is limited, the fishery cooperatives approach, including joint and several liability mechanisms, is a potential means of effectively improving compliance. Compliance may be enhanced if social pressures enhance incentives for compliance with internally agreed rules and behavioral norms. Indeed, our model predicts that, in a system involving fishery cooperatives and some appropriate internal monitoring/enforcement mechanisms, the equilibrium is a mix of compliant and non-compliant behavior and that non-compliance levels are likely to be low if the cost of internal monitoring by the co-op is sufficiently small compared to the expected penalty that may be imposed by the co-op. Regulators may be able to increase compliance rates and reduce their own compliance expenditures by ensuring cooperatives have well designed internal compliance systems. They may also be able to make these systems more effective and desirable to cooperatives if they can help reduce the cooperatives costs of observing non-compliance. This might involve sharing of information from observers or electronic observation equipment, though this may be problematic if the cooperative was inclined to use this information to reduce detection of non-compliance by regulators.

The case of the Dutch fisheries, where a co-management regime was laid on top of a pre-existing individual quota system (Hoefnagel and de Vos, 2017), constitutes perhaps the most convincing empirical evidence supporting the analytical results presented in this paper. Indeed, self-organized groups of fishers (with joint and several liability, internal monitoring and penalty systems) were introduced well after the development of the ITQ system, which makes the before-after comparison quite meaningful. According to Van Hoof (2010), the introduction of co-management groups allowed to reduce monitoring costs for the regulator by 45% as well as drastically decrease the number of registered infringements (-90%) in the Dutch fisheries. The co-management arrangements thus induced a shift in the economic and social normative rationales for compliance so that a situation where non-compliance was the rule became what was considered as a best-practice model by the EU (Hentrich and Salomon, 2006; Van Hoof, 2010).

One of the main limitations to our approach is that we analyzed a one-shot game whereas the environment modeled is actually repeated. In reality, penalties are likely to be ramped up for 2nd or 3rd violations, and fishermen might be more likely to be watched and thus caught. This should help improve compliance, both for ITQs and cooperatives. It also can create a source of asymmetry in the net benefit from non-compliance as a fisherman that has been caught violating endure a penalty that is higher than the fishermen that have not. Our analysis indicates that such asymmetry is an important condition for there to be a compliance advantage for cooperative management with joint and several liability.

The non-cooperative game modelling assumed that each player makes decisions independently. Given the fact that we are analyzing cooperatives, it could also make sense to look at the cooperative game solution. Yet there are some elements that might push back to a non-cooperative game, for example the cooperative members might not be very cooperative with each other or there could be additional penalties against collusion (if it could be proven). Also, regulatory compliance decisions are widely regarded as non-cooperative issues in the literature. This paper therefore focused on the non-cooperative game solutions. Another assumption was that players know the equilibrium strategies of the other players. Further developments on incomplete information games are included in Appendix A. These show that uncertainty tends to increase the level of violation as compared to the complete information game. However, the outcomes of the complete and incomplete information games are essentially similar as they both predict a decrease of non-compliance as compared to the ITQ baseline for the same range of parameters.

Finally, some of the key model predictions rely on mixed-strategy equilibria that have sometimes been contested for their ambiguous interpretation. It is not the purpose of this paper to claim that the model presented should be used as a prediction tool. However, the mixed-strategy solutions that were computed can certainly be used to make relative comparisons of the probability associated with the different pure strategies in alternative situations and analyze how a fishery cooperative structure where joint and several liability applies may alter the incentives to comply as compared to an individual fishing quota baseline situation. The real value of the model thus lies in that it shows how the switch from a principal-agent problem to a nested problem can significantly improve the outcomes from the regulators' point of view. In particular, it appears that joint and several liability is a critical component of fishery cooperative programs that has important policy implications. The conclusions generated by our analysis underscore that it is mostly beneficial to compliance. However, the regulator cannot only rely on having the cooperatives ensure that there is compliance.

References

Anderson, L.G., Lee, D.R. (1986). Optimal governing instrument, operation level, and enforcement in natural resource regulation: the case of the fishery. American Journal of Agricultural Economics, 68(3), 678-690.

Becker, G.S. (1968). Crime and punishment: An economic approach. Journal of Political Economy, 76(2), 169-217.

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

Berkes, F. (1994); Co-management: bridging the two solitudes. Northern Perspectives, 22(2-3), 18-20.

Block, M.K., Heineke, J.M. (1975). A labor theoretic analysis of the criminal choice. American Economic Review, 65(3), 314-325.

Bolton, G.E. (1991). A comparative model of bargaining: Theory and evidence. American Economic Review, 81(5), 1096-1136.

Borg, J. (2008). Developing a culture of compliance is key to sustainable and equitable fisheries. Press Release EC DGMARE 18.

Bray, K. (2001). A global review of illegal, unreported and unregulated (IUU) fishing. FAO fisheries reports, 88-134.

Camerer, C. (2003). Behavioral game theory: Experiments in strategic interaction. Princeton University Press.

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.

Charness, G., Rabin, M. (2002). Understanding social preferences with simple tests. Quarterly Journal of Economics, 117(3), 817-869.

Corveler, T. (2002). Illegal, Unreported and Unregulated Fishing, Taking Action for Sustainable Fisheries. WWF New Zealand, Wellington.

Eggert, H., Ellegård, A. (2003). Fishery control and regulation compliance: a case for co-management in Swedish commercial fisheries. Marine Policy, 27(6), 525-533.

Ehrlich, I. (1972). The deterrent effect of criminal law enforcement. Journal of Legal Studies, 1(2), 259-276.

Ehrlich, I. (1973). Participation in illegitimate activities: A theoretical and empirical investigation. Journal of Political Economy, 81(3), 521-565.

Fehr, E., Schmidt, K.M. (1999). A theory of fairness, competition, and cooperation. Quarterly Journal of Economics, 114(3), 817-868.

Fehr, E., Schmidt, K.M. (2004). Fairness and Incentives in a Multi-task Principal–Agent Model. Scandinavian Journal of Economics, 106(3), 453-474.

Furlong, W.J. (1991). The deterrent effect of regulatory enforcement in the fishery. Land Economics, 67(1), 116-129.

Hanna, S. (1999). Strengthening governance of ocean fishery resources. Ecological Economics, 31(2), 275-286.

Hatcher, A., Jaffry, S., Thébaud, O., Bennett, E. (2000). Normative and social influences affecting compliance with fishery regulations. Land Economics, 76(3), 448-461.

Hatcher, A., Gordon, D. (2005) Further investigations into the factors affecting compliance with UK fishing quotas. Land Economics, 81(1), 71-86.

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

Hentrich, S., Salomon, M. (2006). Flexible management of fishing rights and a sustainable fisheries industry in Europe. Marine Policy, 30, 712-720.

Hoefnagel, E., de Vos, B. (2017). Social and economic consequences of 40 years of Dutch quota management. Marine Policy, 80, 81-87.

Holland, D.S., Jannot, J.E. (2012). Bycatch risk pools for the US West coast groundfish fishery. Ecological Economics, 78, 132-147.

Jentoft, S. (1989). Fisheries co-management: delegating government responsibility to fishermen's organizations. Marine Policy, 13(2), 137-154.

Jentoft, S., McCay, B. (1995). User participation in fisheries management: lessons drawn from international experiences. Marine Policy, 19(3), 227-246.

King, D.M., Sutinen, J.G. (2010). Rational noncompliance and the liquidation of Northeast groundfish resources. Marine Policy, 34(1), 7-21.

Klee, E., Kornhauser, L.A. (2007). Comparisons of the incentive for insolvency under different legal regimes. Journal of Legal Studies, 36(1), 141-170.

Kornhauser, L.A., Revesz, R.L. (1994). Multidefendant settlements: The impact of joint and several liability. Journal of Legal Studies, 23(1), 41-76.

Kronbak, L.G., Lindroos, M. (2006). An enforcement-coalition model: fishermen and authorities forming coalitions. Environmental and Resource Economics, 35(3), 169-194.

Kuperan, K., Sutinen, J.G. (1998). Blue water crime: deterrence, legitimacy, and compliance in fisheries. Law and Society Review, 32(2), 309-338.

McKiernan, K., Tomolonis, A. (2016). Fishing mogul Carlos Rafael arrested on federal conspiracy charges. SouthCoastToday [internet] February 26, 2016 [accessed March 10, 2016]. Available from: http://www.southcoasttoday.com/article/20160226/NEWS/160229553.

NAO. (2003). Fisheries enforcement in England. Report by the Comptroller and Auditor General; HC 563 Session 2002-2003. National Audit Office, London: The Stationary Office.

Nielsen, J.R. (1994). Participation in fishery management policy making: National and EC regulation of Danish fishermen. Marine Policy, 18(1), 29-40.

Nielsen, J.R., Vedsmand, T. (1997). Fishermen's organisations in fisheries management. Perspectives for fisheries co-management based on Danish fisheries. Marine Policy, 21(3), 277-288.

Nielsen, J.R., Mathiesen, C. (2003). Important factors influencing rule compliance in fisheries lessons from Denmark. Marine Policy, 27(5), 409-416.

Ostrom, E. (1990). Governing the commons: The evolution of institutions for collective action. Cambridge university press.

Ostrom, E. (1995). Designing complexity to govern complexity. In: Hanna, S., Munasinghe, M. (Eds) Property rights and the environment: Social and ecological issues. Washington, DC.

Ostrom, E. (2014). Collective action and the evolution of social norms. Journal of Natural Resources Policy Research, 6(4), 235-252.

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

Pinkerton, E. (2011). Co-operative management of local fisheries: new directions for improved management and community development. UBC Press.

Pitcher, T.J., Watson, R., Forrest, R., Valtýsson, H.Þ., Guénette, S. (2002). Estimating illegal and unreported catches from marine ecosystems: a basis for change. Fish and Fisheries, 3(4), 317-339.

Polinsky, A.M., Shavell, S. (1979). The optimal tradeoff between the probability and magnitude of fines. American Economic Review, 69(5), 880-891.

Polinsky, A.M., Shavell, S. (1992). Enforcement Costs and the Optimal Magnitude and Probability of Fines. Journal of Law and Economics, 35(1), 133-148.

Shavell, S. (1993). The optimal structure of law enforcement. Journal of Law and Economics, 36(1), 255-287.

Soma, K., Van Tatenhove, J., Van Leeuwen, J. (2015). Marine Governance in a European context: regionalization, integration and cooperation for ecosystem-based management. Ocean & Coastal Management, 117, 4-13.

Sumaila, U.R., Alder, J., Keith, H. (2006). Global scope and economics of illegal fishing. Marine Policy, 30(6), 696-703.

Sutinen, J.G., Gauvin, J.R., Gordon, D.V. (1989). An econometric study of regulatory enforcement and compliance in the commercial inshore lobster fishery of Massachusetts. In: Neher, P.A., Arnason, R., Mollett, N. (Eds) Rights based fishing. Springer, Netherlands.

Sutinen, J.G., Rieser, A., Gauvin, J.R. (1990). Measuring and explaining noncompliance in federally managed fisheries. Ocean Development and International Law, 21(3), 335-372.

Sutinen, J.G., Kuperan, K. (1999). A socio-economic theory of regulatory compliance. International Journal of Social Economics, 26(1/2/3), 174-193.

Van Hoof, L. (2010). Co-management: an alternative to enforcement? ICES Journal of Marine Science, 67, 395-401.

Veiga, P., Pita, C., Rangel, M., Gonçalves, J.M., Campos, A., Fernandes, P.G., Sala, A., Virgili, M., Lucchetti, A., Brčić, J., Villasante, S., Ballesteros, M.A., Chapela, R., Santiago, J.I., Agnarsson, S., Ögmundarson, Ó., Erzini, K. (2016). The EU landing obligation and European small-scale fisheries: What are the odds for success?. Marine Policy, 64, 64-71.

Vestergaard, N. (2010). Principal-Agent Problems in Fisheries. Chap 42 in Grafton, R.Q. (Ed) Handbook of marine fisheries conservation and management. Oxford University Press.

Appendix A

A.1 Incomplete information game with one-way uncertainty

We consider a cooperative setting as in the Joint and Several Liability & Independent Internal Penalty (JSLIIP) scenario presented in Section 2.2. Suppose the following incomplete information game:

> Let $\overline{X_i}$ and $\underline{X_i}$ be such that $\underline{X_i} < \frac{1}{2}p_rV_r < \overline{X_i} < \frac{1}{2}p_rV_r + p_cV_c$. Nature's choice sets $X_i = \overline{X_i}$ with probability q and $X_i = \underline{X_i}$ with probability $1-q$.
>
> Player i is informed of the choice of Nature.
>
> Player j is not sure whether X_i equals $\overline{X_i}$ or $\underline{X_i}$, but he knows $\Pr\left(X_i = \overline{X_i}\right) = q$.

We also consider $X_j < \frac{1}{2}p_rV_r$ and $\alpha < p_cV_c$.

Player i has two types and Player j has only one type. Because $X_j < \frac{1}{2}p_rV_r$, Player j never violates and Player i never watches. Therefore each player has only 2 strategies: Player i can violate or not, whereas Player j can watch or not. The game that is being played corresponds to either Matrix I or Matrix II according to the choice of Nature.

Matrix I: probability q

		Player j	
		(0,0)	(0,1)
Player i	(0,0)	$\begin{cases}\pi_i = 0\\ \pi_j = 0\end{cases}$	$\begin{cases}\pi_i = 0\\ \pi_j = -\alpha\end{cases}$
	(1,0)	$\begin{cases}\pi_i = \overline{X_i} - \frac{1}{2}p_rV_r\\ \pi_j = -\frac{1}{2}p_rV_r\end{cases}$	$\begin{cases}\pi_i = \overline{X_i} - \frac{1}{2}p_rV_r - p_cV_c\\ \pi_j = -\frac{1}{2}p_rV_r + p_cV_c - \alpha\end{cases}$

Matrix II: probability $1-q$

		Player j	
		(0,0)	(0,1)
Player i	(0,0)	$\begin{cases}\pi_i = 0\\ \pi_j = 0\end{cases}$	$\begin{cases}\pi_i = 0\\ \pi_j = -\alpha\end{cases}$
	(1,0)	$\begin{cases}\pi_i = \underline{X_i} - \frac{1}{2}p_rV_r\\ \pi_j = -\frac{1}{2}p_rV_r\end{cases}$	$\begin{cases}\pi_i = \underline{X_i} - \frac{1}{2}p_rV_r - p_cV_c\\ \pi_j = -\frac{1}{2}p_rV_r + p_cV_c - \alpha\end{cases}$

In order to obtain the Bayesian Nash Equilibria, we need to look at each player's best responses. Suppose:

- Player j chooses strategy $j(0,0)$ with probability y and $j(0,1)$ with probability $1-y$
- Player i of Type I chooses strategy $i(0,0)$ with probability z and $i(1,0)$ with probability $1-z$
- Player i of Type II chooses strategy $i(0,0)$ with probability x and $i(1,0)$ with probability $1-x$

Player i's best response in Matrix II is $i(0,0)$. Therefore $x=1$.

In Matrix I, player's mutual best responses contain necessarily mixed strategies since there is no pure strategy equilibrium. Player j assigns a probability of q to Matrix I, and $1-q$ to Matrix II. Thus Player j is indifferent between $j(0,0)$ and $j(0,1)$ when:

$$\left[-\tfrac{1}{2}p_rV_r \times (1-z)\right] \times q + \left[-\tfrac{1}{2}p_rV_r \times (1-x)\right] \times (1-q)$$
$$= \left[-\alpha \times z + \left(-\tfrac{1}{2}p_rV_r + p_cV_c - \alpha\right) \times (1-z)\right] \times q + \left[-\alpha \times x + \left(-\tfrac{1}{2}p_rV_r + p_cV_c - \alpha\right) \times (1-x)\right] \times (1-q)$$
$$\Leftrightarrow z = \frac{1}{q} \times \left(1 - \frac{\alpha}{p_cV_c} + x \times (q-1)\right)$$

And since $x=1$, we have:

$$z = 1 - \frac{\alpha}{q\,p_cV_c}$$

To find y we shall use the conditional probabilities (as in Bayes' theorem). Let s_j denote the strategy played by Player j, $s_j \in \{j(0,0), j(0,1)\}$. Then we have:

$$y = \Pr\left(s_j = j(0,0)\right)$$
$$= \Pr\left(s_j = j(0,0) | X_i = \overline{X_i}\right) \times \Pr\left(X_i = \overline{X_i}\right) + \Pr\left(s_j = j(0,0) | X_i = \underline{X_i}\right) \times \Pr\left(X_i = \underline{X_i}\right)$$
$$\Leftrightarrow y = \Pr\left(s_j = j(0,0) | X_i = \overline{X_i}\right) \times q + 1 \times (1-q)$$

In Matrix I, Player i is indifferent between $i(0,0)$ and $i(1,0)$ when:

$$\Pr\left(s_j = j(0,0) | X_i = \overline{X_i}\right) \times \left(\overline{X_i} - \tfrac{1}{2}p_rV_r\right) + \left(1 - \Pr\left(s_j = j(0,0) | X_i = \overline{X_i}\right)\right) \times \left(\overline{X_i} - \tfrac{1}{2}p_rV_r - p_cV_c\right) = 0$$

$$\Leftrightarrow \Pr\left(s_j = j(0,0) | X_i = \overline{X_i}\right) = \frac{\tfrac{1}{2}p_rV_r + p_cV_c - \overline{X_i}}{p_cV_c}.$$

It follows that:

$$y = (1-q) + q \times \frac{\frac{1}{2}p_rV_r + p_cV_c - \overline{X_i}}{p_cV_c}$$
$$\Leftrightarrow 1 - y = q \times \frac{\overline{X_i} - \frac{1}{2}p_rV_r}{p_cV_c}$$

Hence the players' mutual best responses are

- Player i of Type I chooses strategy $i(0,0)$ with probability $z = 1 - \frac{\alpha}{q\, p_cV_c}$ and $i(1,0)$ with probability $1 - z = \frac{\alpha}{q\, p_cV_c}$
- Player i of Type II chooses strategy $i(0,0)$ with probability 1
- Player j chooses strategy $j(0,0)$ with probability $y = (1-q) + q \times \frac{\frac{1}{2}p_rV_r + p_cV_c - \overline{X_i}}{p_cV_c}$ and $j(0,1)$ with probability $1 - y = q \times \frac{\overline{X_i} - \frac{1}{2}p_rV_r}{p_cV_c}$

This is actually the unique Bayesian Nash Equilibrium of the game.

<u>Note</u>: $\alpha > q\, p_cV_c \implies z = 0$ and $y = 1$ (because $j(0,0)$ is then the dominant strategy for Player 2 in the Bayesian game). Intuitively, we reach a corner solution because the cost of watching is greater than the probability of having $X_i = \overline{X_i}$ times the expected gains from the penalty p_cV_c.

<u>Comments</u>: if Player i has Type I (*i.e.* $X_i = \overline{X_i}$) then Player j's uncertainty about $X_i$allows Player i to play strategy $i(1,0)$ more often than in the complete information game. The probability of violation by Player i in the incomplete information game is $q \times \frac{\alpha}{q\, p_cV_c} = \frac{\alpha}{p_cV_c}$. This is actually equal to the probability of violation by Player i in the complete information game where $\frac{1}{2}p_rV_r < X_i < \frac{1}{2}p_rV_r + p_cV_c$. Hence the uncertainty raises the probability of violation by $\frac{1}{q}$ as compared to the complete information game. If q is small enough (*i.e.* q is such that $q\, p_cV_c < \alpha$), then uncertainty results in Player i being better off by violating every time Nature's choice sets $X_i = \overline{X_i}$; but of course this may be not so significant since q is small.

A.2 Incomplete information game with two-way uncertainty

Here we consider a game similar to the one presented in Section A.1, with the difference that Player j is now informed of the choice of Nature with probability s. Each player has now 2 types:

- Player i of Type I (probability q) is such that $X_i = \overline{X_i}$
- Player i of Type II (probability $1-q$) is such that $X_i = \underline{X_i}$

- Player j of Type A (probability s) knows X_i
- Player j of Type B (probability $1-s$) is uncertain about X_i but knows $\Pr(X_i = \overline{X_i}) = q$

Player i is uncertain about the type of Player j but knows the probability s (resp. $1-s$) associated with Type A (resp. Type B). Let t_i denote the type of Player i, $t_i \in \{\text{Type I}, \text{Type II}\}$, and $t_j \in \{\text{Type A}, \text{Type B}\}$.

This game has a unique Bayesian Nash Equilibrium:

- Player i of Type I chooses strategy $i(0,0)$ with probability $1 - \frac{\alpha}{p_c V_c} \times \frac{1-s+sq}{q}$ and $i(1,0)$ with probability $\frac{\alpha}{p_c V_c} \times \frac{1-s+sq}{q}$. Indeed, for Player i of Type I we have:

$$\Pr(s_i = i(0,0)) = \Pr(s_i = i(0,0)|t_j = \text{Type A}) \times \Pr(t_j = \text{Type A}) + \Pr(s_i = i(0,0)|t_j = \text{Type B}) \times \Pr(t_j = \text{Type B})$$

$$\Leftrightarrow \Pr(s_i = i(0,0)) = \left(1 - \frac{\alpha}{p_c V_c}\right) \times s + \left(1 - \frac{\alpha}{q\, p_c V_c}\right) \times (1-s)$$

$$\Leftrightarrow \Pr(s_i = i(0,0)) = 1 - \frac{\alpha}{p_c V_c} \times \frac{1-s+sq}{q}$$

- Player i of Type II chooses strategy $i(0,0)$ with probability 1
- Player j of Type A's strategy depends on t_i. If $t_i = \text{Type I}$, Player j of Type A chooses $j(0,0)$ with probability $1 - \frac{q}{1-s+qs} \times \frac{\overline{X_i} - \frac{1}{2} p_r V_r}{p_c V_c}$ and $j(0,1)$ with probability $\frac{q}{1-s+qs} \times \frac{\overline{X_i} - \frac{1}{2} p_r V_r}{p_c V_c}$. If $t_i = \text{Type II}$, Player j of Type A chooses $j(0,0)$ with probability 1. Combining these 2 possibilities and the fact that $\Pr(t_i = \text{Type I}) = q$, Player j of Type A chooses strategy $j(0,0)$ with probability $1 - \frac{q^2}{1-s+qs} \times \frac{\overline{X_i} - \frac{1}{2} p_r V_r}{p_c V_c}$ and $j(0,1)$ with probability $\frac{q^2}{1-s+qs} \times \frac{\overline{X_i} - \frac{1}{2} p_r V_r}{p_c V_c}$.
- Player j of Type B chooses strategy $j(0,0)$ with probability $1 - \frac{q}{1-s+qs} \times \frac{\overline{X_i} - \frac{1}{2} p_r V_r}{p_c V_c}$ and $j(0,1)$ with probability $\frac{q}{1-s+qs} \times \frac{\overline{X_i} - \frac{1}{2} p_r V_r}{p_c V_c}$.

Comments: the probability of violation in this game is somewhere in between the ones in the complete information game and the incomplete information game presented in Section A.1:

$$\frac{\alpha}{p_c V_c} < \frac{1-s+sq}{q} \times \frac{\alpha}{p_c V_c} < \frac{\alpha}{q p_c V_c}$$

Also, one may argue that only Player i's beliefs about s (rather than the real value of s) has an influence on the probability of violation. That is, if Player j (or the cooperative manager) can make Player i believe that s is high, the level of compliance will tend to be the same as the one expected in the complete information game.

Chapter 3. A new approach to determine the distributional effects of quota management in fisheries

Published in *Fisheries Research*

Bellanger, M., Macher, C., Guyader, O. (2016). A new approach to determine the distributional effects of quota management in fisheries. Fisheries Research, 181, 116-126.

Abstract

Quota allocation mechanisms have distributional effects that are highly relevant to the economic organization of fisheries. In France, where fishing allocations are non-transferable, quotas are shared among Producer Organizations (POs) based on the historical landings of their members. Each PO is then responsible for implementing their own internal rules that provide individual or collective allocations to their members. This study investigates the distributional effects of the various quota management systems adopted by POs on quotas and production for the Bay of Biscay sole fishery. A comparison between initial allocations by vessel based on historical landings and actual observed landings is presented. Inequality metrics are used to quantify distributional effects, and a new method that is based on the decomposability property of the Theil index is introduced. Results show that the French management system successfully avoided concentration of production while reducing the fishing capacity through decommissioning schemes. The non-transferability of fishing allocations is a critical element that favored this outcome by allowing POs to control the distribution of catch shares in the fishery. Besides, it appears that the allocation strategies developed by POs were notably influenced by their local roots and their fishing fleet profiles. The various quota allocation systems among POs had contrasting effects on vessels' production, including greater equity within particular subfleets, benefits to vessels most dependent on sole in most POs, and benefits to the small-scale fisheries in a few POs.

Keywords: distribution; inequality; producer organizations; catch shares; common-pool resources; fishery management.

3.1 Introduction

In Europe, the management of fisheries mainly relies on Total Allowable Catches (TACs) set by fish stock and distributed to member states according to historical allocation keys (Holden, 1994). Each member state is then responsible for managing its own quotas, and different countries allocate their quotas among producers using various systems (Le Floc'h et al., 2015). In its Green Paper on European Union Common Fisheries Policy (CFP) reform, the European Commission (2009a) suggested that individual Transferable Fishing Concessions (TFCs) – a right-based management system similar to the well-known Individual Transferable Quotas (ITQs) – should be considered, at the European level, as a potential solution to tackle the deep-rooted problem of overcapacity seen as the main structural failing of the CFP. Some EU countries (The Netherlands, Denmark, Spain and the United Kingdom) have actually implemented ITQs systems in the past decades (González Laxe, 2006; Marchal et al., 2009; Aranda and Murillas, 2015). However, the French administration, following the position of fishermen's representatives, took position against the generalization of ITQs (Gouvernement Français 2009, p.29) in a memorandum arguing that ITQs would eventually result in fishing rights concentration and destabilization of local fishing communities. In order to maintain economic and social equilibriums in French territory, the French administration supported the current quota co-management system implemented by Producer Organizations (POs) (Larabi et al., 2013).

Quota allocations in catch share programs deal with important issues because of their biological (Branch, 2009), economic (Squires et al., 1995; Grafton, 1996; Asche et al., 2008) and social (Pálsson and Petursdottir, 1997; Soliman, 2014) implications. Issues of wealth redistribution and heterogeneity may disrupt the performance of quota management systems (Karpoff, 1987; Grainger and Costello, 2015) and distributional effects of quota allocation on production and economic returns are critical towards addressing issues of fairness and acceptability (Copes, 1986). Yet these distributional effects are rarely studied and many authors have argued that they should be given more attention (e.g., Bromley and Bishop, 1977; Copes, 1986; Matthíasson, 1992; Wilen and Casey, 1997; Guyader and Thébaud, 2001; Copes and Charles, 2004; Thébaud et al., 2012). These issues are particularly significant in the French context where large-scale and small-scale fisheries coexist (Daurès et al., 2009; Guyader et al., 2013) and equity in rights of access to fisheries resources is at stake (Le Gallic et al., 2005; see also Gray et al. 2011 for an English case study). Quota distribution also relates to environmental concerns about the usage of active (e.g., trawls) *vs*. passive (e.g., gillnets) fishing gear for the harvest of demersal species (Branch, 2009). Besides, the French quota management system is based on POs that have strong territorial roots and as such their strategies in terms of membership dynamics (e.g., POs are not required to accept any membership requests from fishermen) and quota distribution may also influence the rights of access to resources of local fishing communities. This study therefore addresses the questions of quantifying the distributional effects of the French quota governance system and whether the quota management by POs limits inequalities and concentration of production.

The debate that occurred in France – and in other EU countries – during the Common Fisheries Policy reform raised the question of which quota management system should be adopted (European Commission, 2010). Two main options were Individual Transferable Quotas (ITQs) markets and co-management systems where allocations are granted to groups of harvesters. Extensive literature exists on their respective potential to provide solutions as sustainable fishery management systems (e.g., Jentoft, 1989; Ostrom, 1990; Copes and Charles, 2004; Grafton et al., 2006; Costello et al., 2008; Gutiérrez et al., 2011; Deacon, 2012), but little is known about their influence on wealth distribution in terms of winners / losers within a fishery. There are two main approaches used to study distributional effect in the fisheries economics literature. The first uses theoretical models to investigate outcomes of alternative management regimes (Dupont and Phipps, 1991; Salvanes and Squires, 1996; Armstrong and Clark, 1997; Sumaila and Armstrong, 2006). The second is the application of inequality metrics to empirical data to quantify the changes in harvest distributions, often related to a change in management such as the introduction of ITQs (Connor, 2000; Hamon et al., 2009). Our paper falls into this later type of approach and addresses the case of PO-based co-management, as implemented in some EU countries, and which has not yet been empirically addressed in a quantitative way.

Quantifying distributional effects first necessitates a clear understanding of the initial situation or initial quota allocation from which redistribution occurs. Then it requires selecting appropriate metrics. The inequality metrics that are most commonly found in the fisheries economics literature typically measure inequality in the population as a whole (Gauvin et al., 1994; Adelaja et al., 1998; Hamon et al., 2009), and not much attention is paid to the inequality *within* and *between* subgroups of vessels (Armstrong and Clark, 1997). In particular, consideration of different scales offers insight for the analysis of distributional changes to the primary and secondary contributors to the fishery, which is essential in the context where large-scale and small-scale fisheries operate alongside one another using various fishing gears. Our paper discusses the relevance of different inequality metrics for the exploration of distributional effects of quota management and introduces a new method which uses the decomposability property of the Theil index (Theil, 1967; Bourguignon, 1979) to decompose the inequality into subgroups of vessels and determine the *between* and *within* components.

The Bay of Biscay common sole (*Solea solea*) fishery was the first fishery where individual vessel quotas (IVQs) were used in France in 2006, and this management innovation tends to be generalized to many of the most important French fisheries (Le Floc'h et al., 2015). This paper therefore uses this influential fishery to investigate the distributional effects of the quota management systems adopted by POs on sole landings based on the 2011 reference year. Actual landings observed were compared to a simulated initial situation based on historical landings by vessel that corresponds to the current rule defined by the French administration for allocating collective sub-quotas to POs and could virtually be used as an individual initial allocation in an ITQ system. Decompositions by fishing gear used, length class and maritime district were employed to analyze the differences between the initial and the final situations.

3.1.1 Structure and evolution of the Bay of Biscay sole fishery

The demersal fisheries of the Bay of Biscay – i.e. operating in ICES divisions VIIIa-b – are commonly referred to as mixed fisheries, because the catches of vessels operating in this area are usually composed of a mix of various species. The common sole fishery has a long history of being one of the main fisheries in the Bay of Biscay as sole has been the first species in value for the last several decades. These fisheries are mainly composed of French vessels that catch about 92% of the TAC, and trawl and gillnet are the main fishing gears used.

In 2011, the French Bay of Biscay sole fishery was composed of 472 vessels that landed more than one ton of sole (Table 3.1). The number of vessels operating in the sole fishery (Figure 3.1a) has been decreasing between 2000 and 2011 (-21%), due mainly to decommissioning schemes (Quillérou and Guyader, 2012).

Table 3.1: Number of vessels and average vessel characteristics by fleet segment of the Bay of Biscay sole fishery in 2011 (vessels with annual landings > 1 metric ton)

Fleet segment	Number of vessels	Vessel length (m)	Crewsize	Days at sea	Gross revenue (k€)	Sole Gross revenue (k€)	Sole Landings (Tons)	Sole dependency (% Gross revenue)
Sole gillnetters	138	13.6	3.7	197	469	269	22.6	57.4
Mixed gillnetters	28	9.8	1.9	141	134	20	1.4	14.7
Specialized Nephrops trawlers	85	14.4	3.2	211	454	42	3.6	9.2
Non specialized Nephrops trawlers	53	15.6	3.5	225	628	75	6.9	11.9
Inshore mixed bottom trawlers	75	10.6	1.9	152	193	37	3.2	19.4
Offshore mixed bottom trawlers	30	17.5	3.8	227	682	59	5.5	8.6
Others	63	12.2	2.7	196	353	37	3.0	10.6
Average	**-**	**13.3**	**3.1**	**194**	**419**	**110**	**9.4**	**25.7**

Total landings of sole in 2011 were 4,259 tons (Figure 3.1b) and generated gross revenue of 54 million euros. The sole gillnetters were the greatest sole producers (22.6 t per vessel in average) as well as the most dependent on this species (57.4% of their gross revenue in average). Their contributions to the fishing mortality of sole were about 68%. The mixed gillnetters (that catch a mix of species) constituted a smaller fleet less dependent on sole, with smaller vessels and smaller crew sizes than the sole gillnetters. The trawlers – for which the sole could either be a target species or a bycatch – accounted for more than half of the vessels participating in the fishery. The Nephrops trawlers can be differentiated by their degree of specialization – i.e. the share of their gross revenue depending on nephrops (Nephrops norvegicus) – which also corresponds to diverse fishing strategies along the course of the year (Macher et al., 2011; Raveau et al., 2012). Although their dependence on sole was quite low, their contribution to sole fishing mortality was significant (respectively 8% for the non-specialized nephrops trawlers and 7% for the specialized nephrops trawlers). The mixed bottom trawlers catch a mix of species, including hake (Merluccius merluccius), nephrops and sole. The inshore mixed bottom trawlers had an average dependency to sole of 19.4% and average sole landings of 3.2 t whereas offshore mixed bottom trawler were less dependent on sole (8.6%) and had greater landings (5.5 t).

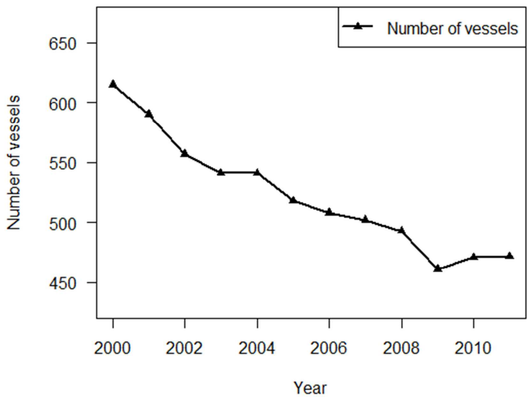


Figure 3.1a: Evolution of the number of vessels participating in the Bay of Biscay common sole fishery (vessels with annual landings > 1T) between 2000 and 2011.

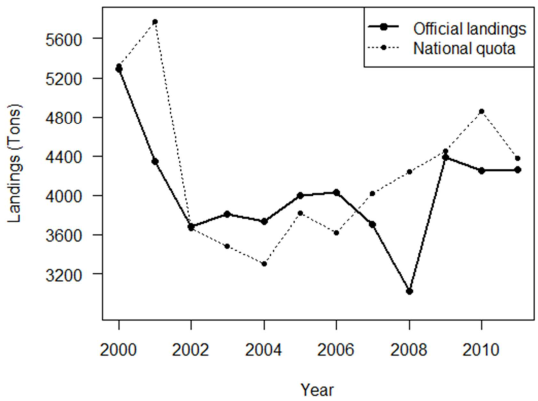


Figure 3.1b: Evolution of the Bay of Biscay common sole official landings in weight and the national quota (France) between 2000 and 2011.

3.1.2 Quota co-management

Common sole in the Bay of Biscay has been subject to an EU TAC since 1984 that is divided into Member State quotas according to fixed historical keys (Holden, 1994), and the French share accounts for more than 90%. According to the French quota co-management system, the national quota is shared out into sub-quotas per PO as defined by legal statutes dating from 2006 (JORF, 2006). The POs are groups of harvesters that manage collectively-granted fishing allocations. They are geographically-relevant – typically, a PO has its headquarters in a fishing harbor city and most of its members are from the same area, although it is not a rule and there are no area restrictions. They were not established on target species criteria and they usually participate in more than one fishery. The distribution of the national quota between POs is based on the *historical landings track records* of member producers over the period 2001-2003 (Larabi et al., 2013). PO membership is voluntary and non PO vessels are collectively managed by the administration. In 2011, there were nine POs involved in the Bay of Biscay sole fishery. Since 2008, these POs account for more than 93% of the total number of vessels operating in the fishery. The main reason why fishermen massively joined POs was that those who remained outside of POs were operating in a race-for-fish where fishery closures could happen early in the season.

The national quota of Bay of Biscay sole was systematically exceeded during 2002-2006[10] (Figure 3.1b). Because quota overruns yield in penalties through the EU common fishery policy regulations (European Commission, 2009b), POs were brought to make their quota management system evolve and started implementing non-tradeable IVQs systems. This was initiated in 2006 by the largest French PO to optimize the exploitation of their allocated sub-quota and avoid over-consumption. Indeed, well-defined individual limits were considered easier to enforce than collective limits by PO managers as individual limits allowed for threats of individual penalty to become more meaningful. In 2011, with the increasing sub-quotas constraints, many POs have generalized a limitation system on individual landings for sole at least for the most important producers of sole, which are sole gillnetters. That year, 65% of the TAC that was managed by non-tradeable IVQs. For the POs that have effectively implemented IVQs systems, quota exchanges or swaps between producers were not allowed, not even within POs. From the authorities' point of view, the law prohibits marketed exchanges of fishing allocations. Whether quota swaps occur between fishers of the same PO is the responsibility of the PO managers. To this day, all French POs have forbidden internal quota swaps between fishers after distribution, although this could be a legally acceptable management option as long as monetary transactions are not involved. The rules for the allocation of IVQs among members of the same PO vary according to POs. They were documented in an exhaustive survey of all Bay of Biscay POs whose results are reproduced in Appendix B. The introduction of IVQs is considered as a key element in the limitation of quota overruns and coincides with the official landings not exceeding the national quota during 2007-2011 (Figure 3.1b). In the meantime, publicly funded decommissioning schemes were implemented to reduce fleet capacity (Quillerou and Guyader, 2012). Under these programs, historical landings track records attached to the scrapped PO-affiliated vessels were equally reallocated to the so-called *PO reserve* and *national reserve*. This mechanism

[10] Until 2006, there was no measure regulating the access to the Bay of Biscay sole fishery. Under the sole management plan (European Commission, 2006), a vessel fishing permit system was put in place in 2006 to regulate the entry to the fishery.

provided the POs with some flexibility in the collective management of their fishing allocations (Larabi et al., 2013). It is worth noting that quota swaps between POs are allowed and such transactions are regulated and recorded by the fisheries authorities. In the institutional context of French fisheries, quota swap refers to a bartering system (without monetary transaction) where a PO can temporarily give away x tons of a quota species to another PO in exchange for y tons of some other quota species. However, swaps between POs have been of limited for the Bay of Biscay sole quota in 2011 and mainly involved non-Bay of Biscay POs that were willing to barter their sole quota they did not need for some other quota that they actually needed.

Out of the 472 vessels that participated in the sole fishery in 2011, 443 were member of one of the nine POs that spread all along the Bay of Biscay coastline (Figure 3.2). The size of the POs ranged from 35 to 490 vessels. Because the constraints and the fleet composition of POs were diverse, their needs in terms of quota management were heterogeneous. Interestingly the three POs that did not implement individual limits (OPPAN, OP Ile d'Yeu and OP Vendée) welcomed sole gillnetters for which more than 40% of the total gross revenue depended on sole. More generally, the two POs operating in the north of the Bay of Biscay (PMA and OPOB) were mainly composed of trawlers that caught sole as part of a mix of species whereas sole was a more important target species for all other POs. The fleet characteristics by length class and by maritime district are available in Appendix B.

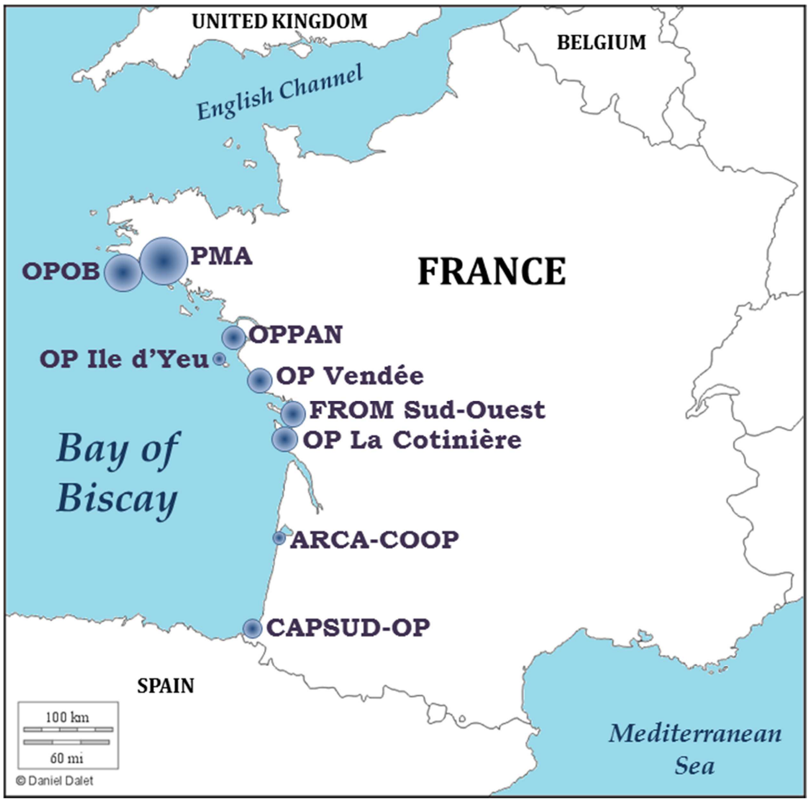


Figure 3.2: Map of the Producer Organizations in the Bay of Biscay in 2011. Circle size is scaled to the number of vessels operating in the Producer Organization (min=35, max=490).

3.2 Material and methods

The study of distributional effects of the sole quota management by POs consists in the comparison between how historical landing records are distributed in the fishery with how landings are distributed in the fishery for a given year, considering that the difference is the consequence of the management by POs and their impacts on the strategies of producers. The analysis focused on the year 2011 because it corresponds to the year when IVQ systems were generalized to most POs in the fishery. Besides the actual historical landings records database that was used by the regulator that year was available which was essential for establishing the initial situation.

3.2.1 Data and population of reference

The population of reference is the union (in the mathematical sense of set operation) of all vessels with non-zero Bay of Biscay sole landings in 2011 and all vessels with non-zero historical landings records (including inactive vessels). It is important for the investigation of distributional effects that the population of reference is composed not only of vessels that landed sole in 2011, but also of the vessels that did not land sole but have non-zero historical landings records as they contributed to the collective historical landings of POs and non-PO sector. This population of reference is referred to as "total population" and it is composed of 1,535 vessels that account for 100% of the 2011 landings and 89% of the historical landings records – the remaining 11% having been placed in the national reserve (2%) and PO reserves (9%) after vessel decommissioning.

The data that were used for the analysis included landings, historical landings track records, a fishing activity calendar specifying the types of gear used, vessel length, maritime district and PO membership status for all commercial fishing vessels that operated in the Bay of Biscay (ICES areas VIIIa-b) in 2011. Landings, fishing activity and characteristics of French vessels are compiled in IFREMER's Harmonie database (Leblond et al., 2008). The analysis also used a typology of *subfleets* based on vessel's fishing activity and landings that has been specifically implemented to study the Bay of Biscay mixed fisheries (Macher et al., 2011). Individual historical landings track records – the basis used by the administration to distribute the French quota among POs – were compiled into a database that contains all vessels with non-zero historical landings records and their PO membership status as of 2011. The vessels with landings greater than 1 t in 2011 accounted for 97% of the sole production in 2011 and 64% of the historical landings track records (see Appendix B). This difference is actually the first result showing that the system has created flexibility and that there is indeed redistribution between the historical landings track records and the landings observed. The vessels with landings between 0 and 1 t accounted for 3% of the production and 6% the historical landings. The total population also included 496 vessels – of which 255 were actually inactive – that had non-zero historical landings records but no sole landings in 2011. These vessels that did not participate in the sole fishery in 2011 were still affiliated to a PO for the most part and contributed to the redistribution towards the 2011 sole fishery vessels.

The historical landings track records database allowed for the computation of the PO sub-quotas (i.e., the PO shares of the national quota). It also allowed for the simulation of initial vessel allocations based on strict historical landings (SHL vessel limits) that were obtained by multiplying the share of each vessel in the historical landings records by the 2011 TAC. Although they were simulated since the administration does not actually grant individual limits to vessel owners, the SHL vessel limits are relevant because they represent the contribution of each vessel to its PO sub-quota. Therefore SHL vessel limits were considered as the initial distribution and the difference with the landings observed was interpreted as the distributional effects of the quota management by POs. As such, the analysis merged the direct consequences of the way POs administered quotas and their incidental impacts on producers' behavior. Intuitively, the assumption that all changes in distribution could be traced back to management strategies of the POs was straightforward considering the institutional context where POs were exclusively responsible for implementing their own internal allocation rules. Marginally, the fact that the authorities' distribution policy of the national reserve could also have contributed to the distributional effects was overlooked since the national reserve only accounted for 2% of the historical landings records and was therefore considered as not particularly significant.

3.2.2 Inequality metrics and decomposability property of the Theil index

There are many inequality metrics that are used in social sciences and we considered some of the most well-known ones for the further comparison of the distributions of initial allocations based on historical landings records and the landings observed. A review of pros and cons of the main inequality metrics is proposed in Table 3.2.

The *Gini index* is the most commonly used measure of inequality (Gini, 1921) and is a core component of many distributional effects analyses. However there are issues associated with Gini index: the same value may arise from different distribution curves; it is not easily decomposable into subgroups – i.e., it cannot provide relative contributions of subgroups to the inequality in the population.

The review of the various inequality metrics allowed us to identify an index that proved to be particularly useful for the analysis: the Theil index (Theil, 1967). Despite not being as intuitive as the Gini, the Theil index has an interesting decomposability property: it is a weighted average of inequality within subgroups, plus inequality among those subgroups (Bourguignon, 1979). If the population is divided into m subgroups and s_j is the income share of subgroup j, T_j is the Theil index for that subgroup, and $\overline{x_j}$ is the average income in subgroup j, then the Theil index can be rewritten as:

$$T = \sum_{j=1}^{m} s_j \times T_j + \sum_{j=1}^{m} s_j \times \ln \frac{\overline{x_j}}{\bar{x}}. \quad (3.1)$$

The contribution of the subgroup j to the total inequality T, sometimes referred to as the *within* subgroup j component, is $s_j \times T_j$. The contribution of the inequality among subgroups to the total inequality, also known as the *between* component, is $\sum_{j=1}^{m} s_j \times \ln \frac{\overline{x_j}}{\bar{x}}$.

Table 3.2: inequality metrics and their characteristics. x is the income (or the production); N is the size of the population; α is the order of entropy parameter; ε is the inequality-aversion parameter.

	Formula	**Pros**	**Cons**
Gini index	$G = \frac{\sum_{i=1}^{N}\sum_{j=1}^{N}\lvert x_i - x_j \rvert}{2N^2\bar{x}}$	▪ Intuitive	▪ Not easily decomposable
Hoover index	$H = \frac{1}{2N}\sum_{i=1}^{N}\left\lvert \frac{x_i}{\bar{x}} - 1 \right\rvert$	▪ Intuitive	▪ Non decomposable
Theil index	$T = \frac{1}{N}\sum_{i=1}^{N}\left(\frac{x_i}{\bar{x}} \times \ln \frac{x_i}{\bar{x}}\right)$	▪ Decomposable	▪ Non intuitive
Generalized entropy index	$GE(\alpha) = \frac{1}{N\alpha(\alpha-1)}\sum_{i=1}^{N}\left[\left(\frac{x_i}{\bar{x}}\right)^{\alpha} - 1\right]$	▪ Decomposable	▪ Non intuitive ▪ Parameter to be set
Atkinson index	$A(\varepsilon) = 1 - \frac{1}{\bar{x}}\left(\frac{1}{N}\sum_{i=1}^{N} {x_i}^{1-\varepsilon}\right)^{\frac{1}{1-\varepsilon}}$	▪ Sensitivity to upper/lower end	▪ Parameter to be set
Herfindahl-Hirschman index (HHI)	$HHI = \sum_{i=1}^{N}\left(\frac{x_i}{\sum_{j=1}^{N} x_j}\right)^2$	▪ Applicable in a variety of contexts	▪ Correlated with number of firms

3.2.3 Quantifying distributional effects

The Theil index measures an entropic distance between the observed distribution and the perfect equality distribution. Its decomposition uses the notion of within- and between-groups components that relates to similar concepts often encountered in statistical analysis. For instance, ANOVA models use the variation within and between groups to provide a statistical test to determine if the observed differences in means can be attributed to the natural variations in the population. Likewise, intra-cluster variance and inter-cluster distance are the core concepts behind cluster analysis techniques such as *k*-means clustering and hierarchical clustering. In the study of distributional effects, the decomposition of the Theil index appears as a well-suited quantitative tool to identify which groups contribute most to the total inequality. When comparing two situations, changes in the within and between group components indicate that distributional effects have happened. However, it does not provide direct information about the mean of a specific group relative to the other groups or to the overall mean. Similarly, if the contribution of one specific group to the Theil index is found to have decreased between two situations, it indicates that the distribution of what is being measured has become more homogeneous (thus distributional effects have happened), but it does not convey any information about a potential change in mean. Only the *between groups* component is linked to the differences in means between the different groups. A similar argument could be made about the other inequality metrics presented in Table 3.2: they essentially measure variability, but do not quantify trends. Hence it is important that an analysis of distributional effects not only rely on inequality metrics, but also include some measurement of changes in mean or sum per group. When the composition of the different groups remains unchanged between the two situations that are being compared, both the mean and the sum provide some information about the trend. The sum provides a global overview of where in the fishery cumulative differences are the most important. However it can overlook potentially interesting changes in mean that may occur in small groups. Conversely, the mean may focus attention on small groups containing an outlier while obscuring more interesting aggregate trends in larger groups. Hence the quantification of distributional effects may include both the mean and sum per group as complementary measurements of trends. Visual representations based on the sum and capturing group size aspects (such as the ones proposed in this paper) can also be convenient to apprehend these different scales simultaneously.

3.2.4 Methods for the study of distributional effects in the Bay of Biscay sole fishery

The analysis involved the comparison between an initial situation and a final situation at different scales. The initial situation is the SHL vessel limits, i.e. the simulated individual allocations computed as the share of each vessel in the historical landings records (2001-2003) multiplied by the 2011 TAC. The final situation is the landings that were observed by vessel in 2011. The first hypothesis to be tested is whether the quota management by POs has contributed to greater equity in some dimension. All inequality metrics presented in the Table 3.2 were computed at the total population level on both distributions. It was undetermined what to expect at this scale because the concentration of production that might have occurred following the decommissioning schemes and the reduction of the number of vessels in the fishery might have been balanced or overweighed by the POs' apparent disposition to maintain access to the resource of local fishing communities. Then fleet segmentations were used to bring the analysis to a more disaggregated level. The analysis covered 3 dimensions:

- Fishing gear, which was related to the fact that some POs had recourse to separated quota management according to the fishing gear used to manage conflicts arising from different quota consumption behaviors
- Vessel length, which was related to the contrasting attitudes POs have had towards the membership of small-scale vessels in the past and the issue of equity of access to the resource in a context where small-scale vessels claimed their historical landings records were underestimated by the fisheries administration
- Maritime district, which related to the strong local roots of POs and access to the resource of local fishing communities.

The Theil index was used to determine the *within* and *between* components for each of these dimensions. It was expected that the quota management by POs may have contributed to greater equity within some subgroups of vessels as some of the allocation criteria used by POs were based on the fishing gear, the vessel length or territorial aspects.

Next, for each PO k and fleet segment j, the cumulative difference CD_{kj} between landings observed and SHL vessel limits was also computed as:

$$CD_{kj} = \sum_{i \in (k \cap j)} (\text{Landings}_i - \text{SHL vessel limits}_i) \tag{3.2}$$

where the subscript i represents the individual vessels. The cumulative difference by subgroup is complementary to the decomposition of the Theil index as it may reveal distributional changes such as differences in means between the different groups that are unrelated to concentration of production. As such, the cumulative differences were intended to determine which subgroups of vessels actually benefited from the flexibility that the system created and it was expected that the subgroup trends (increase or decrease) would vary according to the PO since POs had contrasting quota management strategies. Lastly, Kruskal-Wallis non-parametric tests (Kruskal and Wallis, 1952) were applied to measure the statistical significance of the differences among the subgroup mean differences computed as $\mu_{kj} = \frac{CD_{kj}}{N_{kj}}$ where N_{kj} is the number of vessels in the PO k and fleet segment j.

3.3 Results

3.3.1 Application of inequality metrics at the total population level

The various metrics that were applied to the SHL vessel limits and the observed landings distributions at the total population level as well as some baseline index values are presented in Table 3.3. These indices clearly indicated that both distributions were intrinsically very concentrated. This result was not a surprise since the population of reference contained many vessels with very few historical landings or few landings observed. All metrics showed the same tendency, namely that the landings observed were slightly less concentrated than the SHL vessel limits. This result was consistent across all indices as there was no outstanding value. However, for each index, the difference between the index values for the historical landings records and the landings observed distributions was rather small. Therefore it was concluded that there was no clear sign of distributional effects at this scale, i.e., the quota management by POs did not clearly reduce concentration at the total population level (nor did it increase it).

Table 3.3: Application of inequality metrics to the distributions of Strict Historical Landings (SHL) vessel limits and Landings observed. Perfect equality distribution is the baseline value when all individuals have the same landings. Two-levels 75-25 distribution is a simulated distribution where one half of the population equally shares 75% of all landings and the other half of the population equally shares the remaining 25%. Maximal inequality distribution is when one individual has all landings, and all others have none.

	SHL vessel limits (based on historical landings)	**Landings observed**	**Perfect equality distribution**	**Two-levels 75-25 distribution**	**Maximal inequality distribution**
Gini index	0.87	0.86	0	0.25	1
Hoover index	0.73	0.72	0	0.25	1
Theil index	1.77	1.76	0	0.13	7.33
Generalized entropy index (α=2)	4.82	4.72	0	0.12	767
Atkinson index (ε=0.75)	0.93	0.93	0	0.10	1
Herfindahl-Hirschman index (HHI)	0.0069	0.0068	0.00065	0.00081	1

3.3.2 Decomposition of the inequality by groups of vessels

The decomposability property of the Theil index was used to compute the contributions of different fleet segments to the inequality in the distributions of SHL vessel limits and Landings observed (Figures 3.3a-c). A small contribution of a subgroup indicates that the distribution within the subgroup is homogeneous, and conversely. The *between groups* component indicates the importance of the contribution of the differences between subgroup means in the total inequality.

The inequalities within subfleets[11] contributed less to the total inequality in the case of landings observed than for SHL vessel limits (Figure 3.3a). Indeed, the between groups component (in black) was more important in the landings than in the SHL limits. This means that the quota management by POs implied landings within subfleets being more homogeneous than the historical landings.

The decomposition of the inequality by length class (Figure 3.3b) allowed an assessment of whether the quota management system impacted distribution towards the small scales fisheries. The inequality between groups was found less important than in the case of decomposition by fleets, which means that historical landings and the landings observed were both not very homogeneous within length classes. Besides, the inequalities among the >20 m vessels as well as among the <10 m vessels were slightly greater for the landings than for SHL vessel limits, which was compensated – in the sense that the total inequality in both distributions were about the same – by the between groups component being slightly greater for the SHL vessel limits than for the landings.

The decomposition of the inequality by maritime district (Figure 3.3c) allowed an investigation whether regional equilibriums were preserved in the fishery. One notable outcome was that vessels operating in the north of the Bay of Biscay, i.e. from Morlaix to Vannes, contributed for only a small part of the total inequality in both the landings and the SHL vessel limits distributions, whereas vessels operating in the south contributed for the most part of the inequality. Comparing the landings to the SHL limits, inequalities marginally increased in L’Ile d’Yeu, Les Sables d’Olonne and La Rochelle, and decreased in Saint-Nazaire, Noirmoutier and Marennes.

[11] The typology of subfleets used was specifically implemented to study the Bay of Biscay mixed fisheries (Macher et al., 2011).

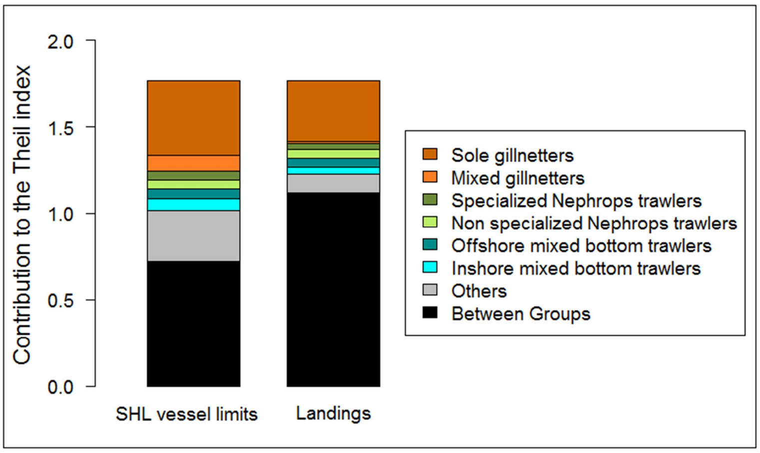


Figure 3.3a: Decomposition of inequality in the distributions of Strict Historical Landings (SHL) vessel limits and Landings observed: contributions to the Theil index by subfleet

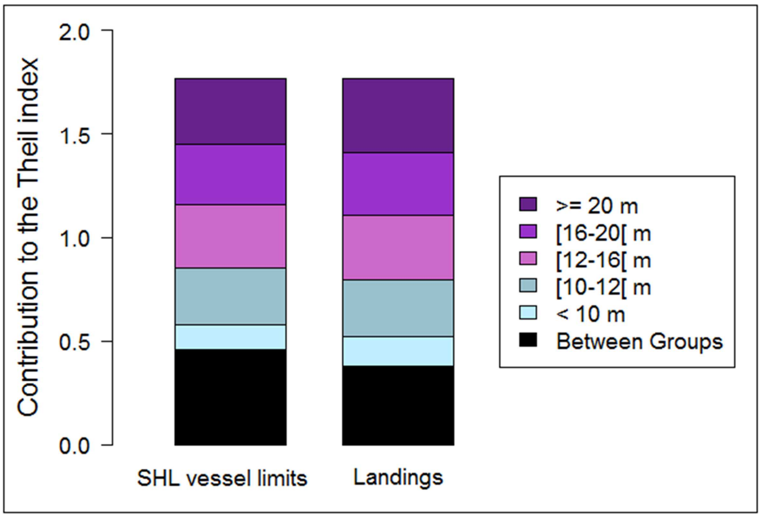


Figure 3.3b: Decomposition of inequality in the distributions of Strict Historical Landings (SHL) vessel limits and Landings observed: contributions to the Theil index by length class

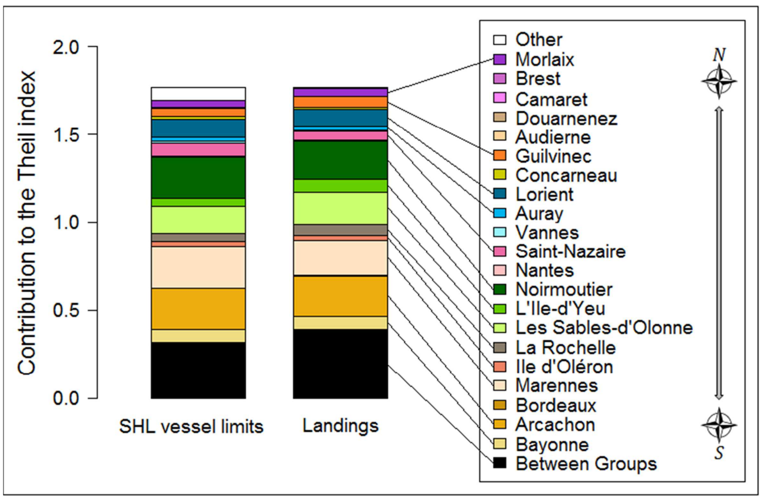


Figure 3.3c: Decomposition of inequality in the distributions of Strict Historical Landings (SHL) vessel limits and Landings observed: contributions to the Theil index by maritime district

3.3.3 Cumulative difference by groups of vessels

In 2011, the sum of landings exceeded the sum of SHL limits in the total population because SHL limits do not account for the national and PO reserves of historical landings track records. Consequently the graphs of the cumulative difference between landings and SHL vessel limits (Figures 3.4a-c) were dominated by positive differences in favor of landings. The red circles indicate that the sum of the landings observed for the vessels belonging to the corresponding fleet segment and PO was more important than the sum of their SHL vessel limits. In other words, the red circles indicate the “winning” subgroups in a PO and the blue circles indicate the opposite, and the size of the circles corresponds to the number of vessels belonging to the corresponding PO subgroup.

The landings by sole gillnetters and by non-specialized nephrops trawlers – i.e. the fleets with the greatest sole landings per vessel and for which the gross revenue was most dependent on sole – were greater than their SHL limits, at least at an aggregated scale (Figure 3.4a). Conversely, the sole landings by mixed gillnetters and by the fleet “Others” were less than their SHL limits. This means that the quota management system either incentivized them to change their fishing strategies, e.g. through PO fishing plans, or restrained their possibility to catch sole while potentially offering alternative fishing opportunities on other target species thanks to the PO track records pooling mechanism.

There were some POs in which the vessels smaller than 12 m benefited from the sole quota management system (Figure 3.4b). These are POs that are dominated by small-scale vessels. While the decomposition of the Theil index by vessel length class indicated that landings were slightly less homogeneous than SHL vessel limits among the >20m vessels, the cumulative difference suggests that this is due to a sensible increase in landings for the bigger vessels in a few POs.

With POs being geographically-relevant entities, it was not surprising that for most POs the greatest positive cumulative difference was observed in their main maritime district in terms of number of vessels (Figure 3.4c). Notably the maritime districts that were previously identified for their marginal inequality increases and decreases actually corresponded to maritime districts where essentially only one PO operates. As for the *non-Bay of Biscay PO* vessels that were part of the total population and appeared as having negative cumulative difference, they were vessels that used to operate in the Bay of Biscay during the historical landings period but had moved outside of the Bay of Biscay as of 2011.

The statistical significance of the differences among the subgroup mean differences between landings observed and SHL vessel limits was tested with the Kruskal-Wallis one-way test along the subfleet, vessel length class, and maritime district dimensions. Each of these factors taken independently were found statistically significant (p-value $< 10^{-3}$), i.e. for each dimension the test rejected the null hypothesis of the factor having no effect on the subgroup mean differences between landings observed and SHL vessel limits. The outcomes of these tests were therefore in line with the expectation that the quota management by POs contributed to significant distributional changes in the above-mentioned dimensions.

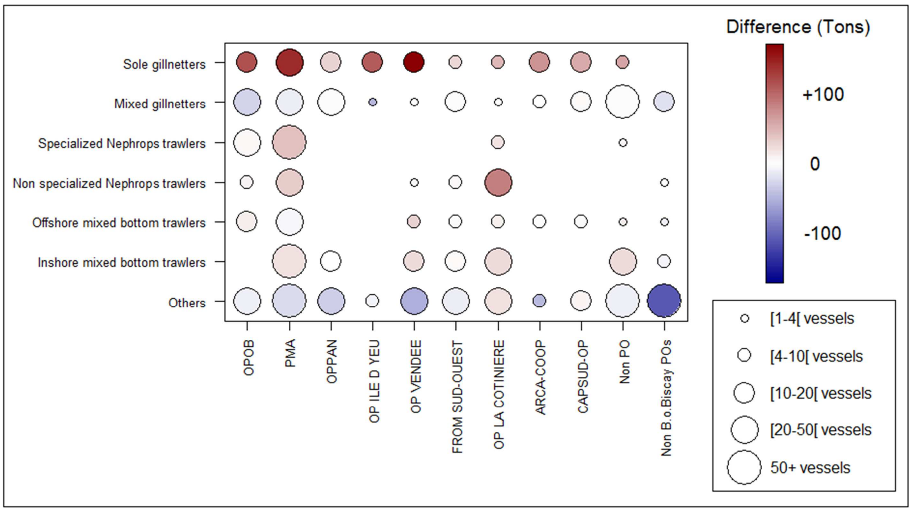


Figure 3.4a: Cumulative difference between Landings observed and Strict Historical Landings (SHL) vessel limits in 2011 by subfleet (in row) and Producer Organization (in column). Red circles (resp. Blue circles) indicate that the sum of the landings observed (resp. SHL limits) by vessels belonging to the corresponding subfleet and PO was more important than the sum of their SHL limits (resp. landings observed). Color is scaled to the maximum absolute value. Circle size corresponds to the number of vessels belonging to the corresponding fleet and PO.

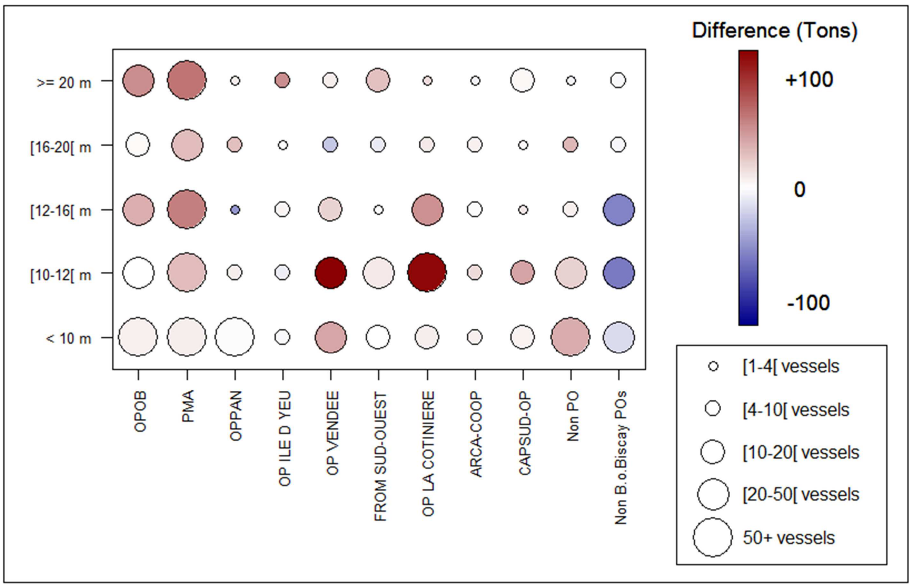


Figure 3.4b: Cumulative difference between Landings observed and Strict Historical Landings (SHL) vessel limits in 2011 by length class (in row) and Producer Organization (in column). Red circles (resp. Blue circles) indicate that the sum of the landings observed (resp. SHL limits) by vessels belonging to the corresponding length class and PO was more important than the sum of their SHL limits (resp. landings observed). Color is scaled to the maximum absolute value. Circle size corresponds to the number of vessels belonging to the corresponding length class and PO.

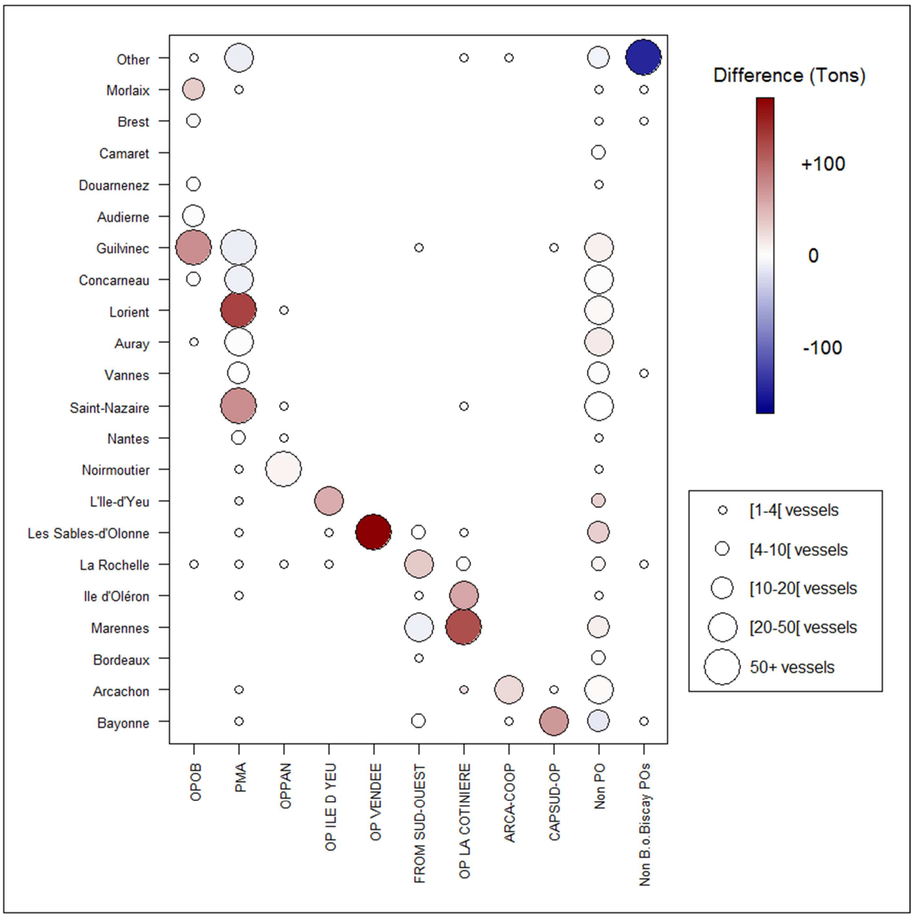


Figure 3.4c: Cumulative difference between Landings observed and Strict Historical Landings (SHL) vessel limits in 2011 by Maritime District (in row) and Producer Organization (in column). Red circles (resp. Blue circles) indicate that the sum of the landings observed (resp. SHL limits) by vessels belonging to the corresponding length class and PO was more important than the sum of their SHL limits (resp. landings observed). Color is scaled to the maximum absolute value. Circle size corresponds to the number of vessels belonging to the corresponding maritime district and PO.

3.4. Discussion

3.4.1 Preventing concentration of production while reducing fleet capacity

A typical ITQ system generally induces a rationalization of the fishing fleet capacity to increase economic yield. The switch from a “derby” fishery to an ITQ generates a decrease of the number of vessels that operate in the fishery, and quota sellers or leasers behave rationally according to economic objectives that can be contradictory to maintaining social values. Direct consequences are the concentration of the production and the reduction of employment in the harvesting sector (Squires et al., 1995). Ultimately, the benefits of higher economic efficiency tend to flow to owners who may not be fishermen themselves (Pálsson and Helgason, 1995; Pinkerton and Edwards, 2009) and territorial socio-economic equilibriums may be threatened if quotas can be transferred from one region to another. Although safeguard clauses may be adopted to prevent some of the negative social impacts of an ITQ (Kroetz and Sanchirico, 2010), it appears that concentration of production does occur in most ITQ systems (Hamon et al., 2009; Abayomi and Yandle, 2012; Clay et al., 2014; Matthíasson et al., 2015).

The originality of the French case study is that an input control policy (EU funded decommissioning schemes) was combined with an output management system (allocations by POs) and resulted in an adjustment of the fishing capacity without aggravating the problems of wealth concentration. Decommissioning schemes indeed allowed the number of vessels in the Bay of Biscay sole fishery to decrease by 20% over 10 years. At the same time, the quota allocation system, based on several POs spread along the coastline with specificities in terms of quota management strategies that they can adapt to their fleet composition, aimed at maintaining economic and social equilibriums. The results showed that concentration did not occur. To this regard, the French management system, that combines a track records pooling mechanism to provide collective allocations to POs and redistribution between members and unique controls on tradeability of catch shares, successfully managed to avoid some of the social issues that tend to happen in an ITQ while reducing the fishing capacity through decommissioning schemes.

3.4.2 Room for maneuver in a context of non-transferability

There are several reasons that can explain how distributional effects have occurred in the Bay of Biscay sole fishery even though quota trades between individuals are prohibited. One of the main sources of flexibility in the quota management system comes from the PO reserves of historical landings track records that were introduced alongside decommissioning schemes. These reserves, which are directly managed by the POs, add to the collective historical landings each member brings to the POs and are meant to support new entrants to the fishery and established PO members. Likewise, the national reserve gives the administration room to maneuver in the management of the non PO vessels. Furthermore, it used to be considered that POs that exceeded their allocation would not face sanctions unless the national quota was exceeded too, thus the national reserve could also give flexibility to the PO that were careless with their sub-quota consumption. Further flexibility originated from the non-Bay of Biscay PO vessels. Having conserved their historical landings track records while being outside of the fishery in 2011, these vessels effectively contributed to quota reallocation in the fishery. Indeed, quota swaps between POs are allowed and POs that have some quota they do not need are usually willing to exchange it for some quota that they actually need. Thus it is not uncommon to observe quota swaps between POs that happen on a regular basis.

3.4.3 Allocation systems and equity

In a catch share program, the initial allocation plays a major part in determining how wealth is distributed among individuals. The French quota management system mainly relies on grandfathering as catch shares that are allocated to POs are based on historical landings of their members. However, each PO developed their own internal rules for providing individual or collective allocations to their members which sometimes involve alternatives to grandfathering methods such as gear-based or equal-sharing rules (see Appendix B for the details of the allocation criteria used by POs). As the French system does not allow for quota trades between individuals, not even within POs, the design of PO internal allocation rules has a direct influence on individual strategies and economic performances of PO members. The rules that have been adopted by POs are heterogeneous and exhibit the variety of the fishing fleet profiles across POs. The results showed that the redistribution of the sole quota significantly benefited the fleets that were the most economically dependent on this species. Thus, in a context of non-transferability of fishing allocations, the POs played the role of quota fine-tuning to adjust for the subfleets needs. This was essentially achieved through three distinct (but non-exclusive) mechanisms: setting allocation rules based on reference years that are more recent than the historical landings track records period (used in three POs); securing distinct collective catch shares for one or more specific subfleets determined by gear-based, vessel length and/or geographical criteria (respectively in three, one and three POs); and differentiating allocation rules for one or more specific subfleets (in five POs). This later type of allocation methods includes equal-sharing rules (in two POs) that presumably contributed to reduce inequalities within subfleets (Figure 3.3a).

In certain POs, management policies were also favorable to small-scale fisheries (<12m) and local fishing communities. At first sight, it appears that this is not directly linked to some internal allocation rule specifically designed to favor small-scales. Rather, this can be explained by the fact that, in the past, the landings of small-scale vessels were not systematically recorded as the compliance with landings declarations requirements could be deficient and the use of logbooks was mandatory for large-scale vessels only. This consequently led the administration to underestimate their historical landings in the years 2001-2003. Their cumulated landings thus exceeded their cumulated SHL vessel limits. However, this is still relevant to the distributional effects of the management by POs as it is a consequence of POs strategies regarding the membership of small-scale vessels that did not have historical landings track records and allowing them to stay in the fishery by granting them a share of the PO sub-quota. This is actually critical as addressing participants who may not have catch history records but have historically caught fish in the fishery is considered as one of the main concerns about fairness when allocations are based on historical catch (Lynham, 2014).

The territorial dimension also appears to have influenced the allocation strategies chosen by POs. Results established that the redistribution of the sole quota primarily benefited the vessels operating in the maritime district where POs have their headquarters (Figure 3.4c) and constituting the subfleets that are historically linked to the POs "identity". Thus, the participatory decision-making process that determines the allocation rules seems to be influenced by PO's local roots and predominant subfleets. Concretely, local differentiations can be directly established in the design of allocation rules through geographically-based criteria or indirectly by using gear-based criteria that designate specific subfleets that essentially operate in a particular area. The results also indicated that distributional effects among non-PO vessels were minor. In fact, the non-PO vessels remained in a common pool supervised by the administration where a race-for-fish is still happening. This explains why most historical landings records holders were incentivized to join POs.

Although the system in place prevented the concentration of production and contributed to greater equity in some dimensions, inequalities between subfleets, both within and across POs, are still important. As a matter of fact, the question of equity between POs is still being asked by many stakeholders. Some small-scale POs consider that the larger-scale POs benefited from having vessels eligible to the decommissioning schemes. These small-scale POs further denounced the strict membership policy adopted by the larger-scale POs that denied membership to participants without track records, which they claim was not fair to the small-scale participants (although it was efficient in making the larger-scale PO members benefit from the possibilities they acquired thanks to the decommissioning schemes). Some POs invariably complain about the use of historical landings as the basis for sub-quota assignments and a potential contradiction with antitrust laws (Autorité de la concurrence, 2015).

Some stakeholders also expressed their concerns about inter-generational equity. To address this issue, a "tax system" on track record transfers associated with vessel transactions has recently been implemented (Code rural et de la pêche maritime, 2014). The taxed track records are first assigned to the national and PO reserves and are then meant to be reallocated to young fishermen who do not currently have track records to support the rejuvenation of the fishery participants. In practice, the system is quite new and as of now the taxed track records mainly benefit already established PO members by increasing the POs' collective allocations. Although this new measure demonstrates a real effort towards improving inter-generational equity, the access to the fishery remains very restrained.

In conclusion, even if the system has prevented an increased concentration of production that could have resulted from the reduction of the fleet size, inequalities are still important and many stakeholders call for an evolution of the allocation system towards greater equality and transparency. To this regard, the co-management approach in place, where fishermen actively participate to the decision-making process, appears as a means of implementing the rules that can lead to such further changes.

3.4.4 Limits and perspectives

Further developments in the analysis of the Bay of Biscay sole fishery case study could be considered due to the following limitations:

- the analysis focused on the sole quota distribution could be integrated into a multispecies analysis as most vessels actually operate in more than one fishery. In addition to the distribution of the sole historical landings track records and landings, a multispecific analysis would highlight which groups of vessels were globally advantaged and disadvantaged by taking into account potential compensations among species. Such analysis is reserved for future work.
- the analysis was carried out at the vessel level while distributional effects are usually considered at the firm level. Since most firms operating in the Bay of Biscay actually own only one vessel, this approximation is in fact likely to have only minor implications on the outcomes.
- inequality metrics were applied to production while it is more common to apply them to income.

The perspectives in this case study also include a comparison with the individual quotas vessels were allocated by their PO: the difference between the SHL vessel limits and the individual quotas should highlight the effects of the quota management by POs on the initial distribution, and the difference between the individual quotas and the landings observed should provide information on how well-balanced individual quotas and landings are. An analysis of the performance in terms of equity of the alternative allocation rules used in distinct POs would certainly be valuable to make more explicit which allocation rule is best to favor equity for a particular subfleet profile. However, comparisons between POs are not straightforward as each PO uses a different fleet segmentation to differentiate allocation rules for one or more specific subfleets (Appendix B). Therefore, it appears that more data such as historical landings and allocation rules for other species or for different years is needed to develop this type of analysis.

3.5 Conclusion

This paper includes for the first time the use of the decomposability property of an inequality metric in an empirical study of distributional effects of fishing quota management systems. The analysis showed how the decomposition of the inequality by subgroups can provide useful insights for the description and interpretation of the dynamics of the fishery. This approach appears to be particularly relevant in cases where the distributional effects cannot be observed at the global scale and where distributional issues are concerned with multiple dimensions such as social and territorial issues. This approach, coupled with some measurement of subgroup trends, appears as an effective framework for the analysis of distributional effects and could for example be utilized to improve the understanding of the impacts of the allocation method used in a new catch share program.

The analysis that was carried out in this paper was primarily concerned with equity and the results showed that the current French fishing allocation system tends to maintain pre-existing territorial and socio-economic equilibriums due to the management operated at the PO level. Beyond issues of equity, the economic efficiency of the allocation system must also be assessed. Tradeoffs between economic efficiency and social issues are one of the largest challenges of fisheries management. In France, fishermen who want to acquire more quota than they have are currently constrained by the non-transferability rule. Besides, the institutional context is evolving with the last CFP reform introducing a discard ban. This reform may challenge the efficiency of the current quota management system and increase the need for quota tradeability, so that the quota management objectives and means may be brought to evolve further in the near future.

References

Abayomi, K., Yandle, T. (2012). Using conditional Lorenz curves to examine consolidation in New Zealand commercial fishing. Marine Resource Economics 27(4), 303-321.

Adelaja, A., Menzo, J., McCay, B. (1998). Market power, industrial organization and tradable quotas. Review of Industrial Organization 13(5), 589-601.

Aranda, M., Murillas, A. (2015). Allocation of fishing possibilities, incentives and outcomes: Insights from Basque fishermen's organisations in Spain. Marine Policy 61, 171-178.

Armstrong, C.W., Clark, D.J. (1997). Just fishing? Equity and efficiency in fisheries management regimes. Marine Resource Economics 12(3), 203-220.

Asche, F., Eggert, H., Gudmundsson, E., Hoff, A., Pascoe, S. (2008). Fisher's behaviour with individual vessel quotas—Over-capacity and potential rent: Five case studies. Marine Policy 32(6), 920-927.

Autorité de la concurrence. (2015). Avis n°15-A-19 du 16 décembre 2015 relatif aux effets sur la concurrence du mécanisme de répartition des quotas de pêche en France. Autorité de la concurrence, République Française, available online at http://www.autoritedelaconcurrence.fr/pdf/avis/15a19.pdf

Bourguignon, F. (1979). Decomposable income inequality measures. Econometrica, 901-920.

Branch, T.A. (2009). How do individual transferable quotas affect marine ecosystems? Fish and Fisheries 10(1), 39-57.

Bromley, D.W., Bishop, R.C. (1977). From Economic Theory to Fisheries Policy: Conceptual Problems and Management Prescriptions. In Anderson, L.G. (ed.) Economic Impacts of Extended Fisheries Jurisdiction. Ann Arbor MI: Ann Arbor Science Publishers.

Clay, P.M., Kitts, A., Pinto da Silva, P. (2014). Measuring the social and economic performance of catch share programs: Definition of metrics and application to the U.S. Northeast Region groundfish fishery. Marine Policy 44, 27-36.

Code rural et de la pêche maritime. (2014). Article R921-45, décret n°2014-1608 du 26 décembre 2014. Available online at https://www.legifrance.gouv.fr/ affichCode.do?cidTexte=LEGITEXT000006071367

Connor, R. (2000). Trends in fishing capacity and aggregation of fishing rights in New Zealand under individual transferable quotas. FAO Fisheries Technical Paper, (2), 267-278.

Copes, P. (1986). A critical review of the individual quota as a device in fisheries management. Land Economics 62(3), 278-291.

Copes, P., Charles, A. (2004). Socioeconomics of Individual Transferable Quotas and Community-Based Fishery Management. Agricultural & Resource Economics Review 33, 171-181.

Costello, C., Gaines, S.D., Lynham J. (2008). Can catch shares prevent fisheries collapse? Science, 321(5896), 1678-1681.

Daurès, F., Rochet, M.J., Van Iseghem, S., Trenkel, V.M. (2009). Fishing fleet typology, economic dependence, and species landing profiles of the French fleets in the Bay of Biscay, 2000-2006. Aquatic Living Resources 22(04), 535-547.

Deacon, R.T. (2012). Fishery management by harvester cooperatives. Review of Environmental Economics and Policy 6(2), 258-277.

Dupont, D.P., Phipps, S.A. (1991). Distributional consequences of fisheries regulations. Canadian Journal of Economics, 206-220.

European Commission. (2006). Council regulation No 388/2006 of 23 February 2006 establishing a multiannual plan for the sustainable exploitation of the stock of sole in the Bay of Biscay. Official journal of the European Union L 65/1 7.3.2006

European Commission. (2009a). Green Paper: Reform of the Common Fisheries Policy. COM (2009) 163 final, 28 pp.

European Commission. (2009b). Council regulation No 1224/2009 of 20 November 2009 establishing a Community control system for ensuring compliance with the rules of the common fisheries policy. Official journal of the European Union L 343/3 22.12.2009

European Commission. (2010). Synthesis of the Consultation on the Reform of the Common Fisheries Policy. Commission Staff Working document. SEC(2010)408 final. Available online at http://ec.europa.eu/fisheries/reform/sec(2010)0428_en.pdf

Gauvin, J.R., Ward, J.M., Burgess, E.E. (1994). Description and evaluation of the wreckfish (Polyprion americanus) fishery under individual transferable quotas. Marine Resource Economics 9, 99-118.

Gini, C. (1921). Measurement of Inequality and Incomes. The Economic Journal 31, 124-126.

González Laxe, F. (2006). Transferability of fishing rights: The Spanish case. Marine Policy 30(4), 379-388.

Gouvernement Français. (2009). Mémorandum français relatif à la réforme de la politique commune de la pêche. Paris. Available online at http://ec.europa.eu/fisheries/reform/docs/france_memo_fr.pdf

Grafton, R.Q. (1996). Individual transferable quotas: theory and practice. Reviews in Fish Biology and Fisheries 6(1), 5-20.

Grafton, R.Q., Arnason, R., Bjørndal, T., Campbell, D., Campbell, H.F., Clark, C.W., Connor, R., Dupont, D.P., Hannesson, R., Hilborn, R., Kirkley, J.E., Kompas, T., Lane, D.E., Munro, G.R., Pascoe, S., Squires, D., Steinshamn, S.I., Turris, B.R., Weninger, Q. (2006). Incentive-based approaches to sustainable fisheries. Canadian Journal of Fisheries and Aquatic Sciences 63(3), 699-710.

Grainger, C.A., Costello, C. (2015). Distributional Effects of the Transition to Property Rights for a Common-Pool Resource. Marine Resource Economics 31(1), 1-26.

Gray, T., Korda, R., Stead, S., Jones, E. (2011). Quota discarding and distributive justice: The case of the under-10m fishing fleet in Sussex, England. Marine Policy 35(2), 122-129.

Gutiérrez, N.L., Hilborn, R., Defeo, O. (2011). Leadership, social capital and incentives promote successful fisheries. Nature 470(7334), 386-389.

Guyader, O., Thébaud, O. (2001). Distributional issues in the operation of rights-based fisheries management systems. Marine Policy 25(2), 103-112.

Guyader, O., Berthou, P., Koutsikopoulos, C., Alban, F., Demaneche, S., Gaspar, M.B., Eschbaum, R., Fahy, E., Reynal, L., Curtil, O., Frangoudes, K., Maynou, F. (2013). Small scale fisheries in Europe: A comparative analysis based on a selection of case studies. Fisheries Research 140, 1-13.

Hamon, K.G., Thébaud, O., Frusher, S., Little, L.R. (2009). A retrospective analysis of the effects of adopting individual transferable quotas in the Tasmanian red rock lobster, Jasusedwardsii, fishery. Aquatic Living Resources 22(04), 549-558.

Holden, M. (1994). The Common Fisheries Policy: Origin, Evaluation and Future. Fishing News Books, Oxford, England.

Jentoft, S. (1989). Fisheries co-management: delegating government responsibility to fishermen's organizations. Marine Policy 13(2), 137-154.

Journal Officiel de la République Française (JORF). (2006). n°301 du 29 décembre 2006 page 19953 texte n°104: Arrêté du 26 décembre 2006 établissant les modalités de répartition et de gestion collective des possibilités de pêche (quotas de captures et quotas d'effort de pêche) des navires français immatriculés dans la Communauté européenne. NOR: AGRM0602585A.

Karpoff, J.M. (1987). Suboptimal Controls in Common Resource Management: The case of the Fishery. Journal of Political Economy 95(1), p.179-194.

Kroetz, K., Sanchirico, J. N. (2010). Economic insights into the costs of design restrictions in ITQ programs. RFF Report, Resources for the Future, 46p.

Kruskal, W.H., Wallis, W.A. (1952). Use of ranks in one-criterion variance analysis. Journal of the American Statistical Association 47(260), 583-621.

Lagière, R., Macher, C., Guyader, O. (2012). Bilan et évolution des mesures de gestion mises en œuvre dans le golfe de Gascogne : Focus sur les mesures impactant directement ou indirectement la pêcherie de sole. Publications électroniques Amure, Série Rapports R-25-2012, 88 pp.

Larabi, Z., Guyader, O., Macher, C., Daurès, F. (2013). Quota management in a context of non-transferability of fishing rights: The French case study. Ocean and Coastal Management 84, 13-22.

Leblond, E., Daurès, F., Berthou, P., Dintheer, C. (2008). The Fisheries Information System of Ifremer: a multidisciplinary monitoring network and an integrated approach for the assessment of French fisheries, including small-scale fisheries. ICES 2008 Annual Science Conference, 22-26 september 2008, Halifax, Canada.

Le Floc'h, P., Murillas, A., Aranda, M., Daurès, F., Fitzpatrick, M., Guyader, O., Hatcher, A., Macher, C., Marchal, P. (2015). The regional management of fisheries in European Western Waters. Marine Policy 51, 375-384.

Le Gallic, B., Mardle, S., Boncoeur, J. (2005). Les objectifs d'une politique publique vus par les acteurs: une analyse multicritères de la politique commune de la pêche. Public Economics 16.

Lynham, J. (2014). How have catch shares been allocated? Marine Policy 44, 42-48.

Macher, C., Merzéréaud, M., Le Grand, C., Frésard, M., Bertignac, M., Fifas, S., Guyader, O., Biais, G., Lissardy, M., Jadaud, A., Le Corre, G., Frangoudes, K., Daurès, F., Van Iseghem, S., Raveau, A. (2011). Groupe de travail partenarial pour la construction d'outils bio-économiques d'aide à la décision pour l'aménagement des pêcheries. Publications électroniques Amure, Série Rapports R-21-2011, 44.

Marchal, P., Lallemand, P., Stokes, K., Thébaud, O. (2009). A comparative review of the fisheries resource management systems in New Zealand and in the European Union. Aquatic Living Resources 22(04), 463-481.

Matthíasson, T. (1992). Principles for Distribution of Rent from a 'Commons'. Marine Policy 16(3), 210-231.

Matthíasson, T., Giry, F., Agnarsson, S. (2015). Individual Transferable Quotas Allocation in Icelandic Fisheries: a Community-Oriented Inequality Analysis. Rannsóknir í félagsvísindum XVI.

Ostrom, E. (1990). Governing the commons: The evolution of institutions for collective action. Cambridge university press.

Pálsson, G., Helgason, A. (1995). Figuring Fish and Measuring Men: The Individual Transferable Quota System in the Icelandic Cod Fishery. Ocean and Coastal Management 28(1), 117-146.

Pálsson, G., Pétursdóttir, G. (1997). Social impacts of quota systems in fisheries. Copenhagen: TemaNord, Nordic Council of Ministers. 353 p.

Pinkerton, E., Edwards, D.N. (2009). The elephant in the room: the hidden costs of leasing individual transferable fishing quotas. Marine Policy 33(4), 707-713.

Quillérou, E., Guyader, O. (2012). What is behind fleet evolution: a framework for flow analysis and application to the French Atlantic fleet. ICES Journal of Marine Science 69, 1069-1077.

Raveau, A., Macher, C., Méhault, S., Merzereaud, M., Le Grand, C., Guyader, O., Bertignac, M., Fifas, S., Guillen, J. (2012). A bio-economic analysis of experimental selective devices in the Norway lobster (Nephrops norvegicus) fishery in the Bay of Biscay. Aquatic Living Resources 25(03), 215-229.

Salvanes, K.G., Squires, D. (1996). Markets for Production Rights: Efficiency-Equity Trade-Offs. Discussion paper 22/96. Norwegian School of Economics and Business Administration, Institute of Economics, Bergen, Norway.

Soliman, A. (2014). Using individual transferable quotas (ITQs) to achieve social policy objectives: A proposed intervention. Marine Policy 45, 76-81.

Squires, D., Kirkley, J., Tisdell, C.A. (1995). Individual transferable quotas as a fisheries management tool. Reviews in Fisheries Science 3(2), 141-169.

Sumaila, U.R., Armstrong, C.W. (2006). Distributional and efficiency effects of marine protected areas: A study of the Northeast Atlantic cod fishery. Land Economics 82(3), 321-332.

Thébaud, O., Innes, J., Ellis, N. (2012). From anecdotes to scientific evidence? A review of recent literature on catch share systems in marine fisheries. Frontiers in Ecology and the Environment 10(8), 433-437.

Theil, H. (1967). Economics and Information Theory. Chicago: Rand McNally and Company.

Wilen, J.E., Casey, K. (1997). Impacts of ITQs on labor: Employment and remuneration effects. In Pálsson G., Petursdottir, G. (eds.) Social Implications of Quota Systems in Fisheries, pp. 315-333. Copenhagen, Denmark: Nordic Council of Ministers.

Appendix B

B.1 Allocation criteria used by POs

Table B1: Quota management system by PO for the sole in the Bay of Biscay and allocation criteria in 2011 (adapted from Lagière et al., 2012)

PO	Sub-group	Quota management	Allocation method and criteria
PMA	Vessels with production > 2 tons	Individual limits	Mean production by vessel 2004-2006
	Vessels with production < 2 tons	Individual limits	Package of 2 tons per vessel
OPOB	Large gillnetters > 18 m	Individual limits	Package of 26 tons per vessel
	Large gillnetters < 18 m	Individual limits	Package of 18 tons per vessel
	Inshore trawlers	Collective quota	
	Small-scale fishery	Collective quota	
OPPAN	All vessels	Collective quota	
OP YEU	All vessels	Collective quota	
OP VENDEE	Trawlers Sables d'Olonne	Collective quota	
	Gillnetters Sables d'Olonne	Collective quota	
	Trawlers Saint Gilles Croix de Vie	Collective quota	
	Gillnetters Saint Gilles Croix de Vie	Collective quota	
FROM SUD OUEST	Gillnetters Royan	Individual limits	Historical landings records (2001-2003)
	Binational French-Spanish fleet	Collective quota	
	Seafaring fleet	Collective quota	
	Coureauleur fleet	Collective quota	
LA COTINIERE	All vessels	Individual limits	Historical landings records (2001-2003) + Production by vessel 2008-2010
ARCA-COOP	Offshore (extra-bassin) vessels	Individual limits	Maximum production of the last 10 years
	Inshore (intra-bassin) vessels	Collective quota	
CAPSUD-OP	Sole-targeting vessels	Individual limits	Historical landings records (2001-2003)
	Others	Collective quota	

B2. Fleet composition and characteristics by length class and maritime regions

Table B2: Number of vessels and average vessel characteristics by length class of the Bay of Biscay sole fishery in 2011 (vessels with landings > 1 metric ton)

Length Class	Number of vessels	Vessel length (m)	Crewsize	Days at sea	Gross revenue (k€)	Sole Gross revenue (k€)	Sole Landings (Tons)	Sole dependency (% Gross revenue)
>= 20 m	34	21.4	5.2	250	944	276	23.8	29.3
[16-20[m	69	17.5	4.5	234	736	170	14.8	23.1
[12-16[m	120	14.2	3.4	211	502	123	10.7	24.4
[10-12[m	163	11.5	2.5	180	265	76	6.3	28.7
< 10 m	86	9.1	1.6	143	129	44	3.4	34.2
Average	**-**	**13.3**	**3.1**	**194**	**419**	**110**	**9.4**	**25.7**

Table B3: Number of vessels and average vessel characteristics by maritime district (ordered North to South) of the Bay of Biscay sole fishery in 2011 (vessels with landings > 1 metric ton)

Maritime district	Number of vessels	Vessel length (m)	Crewsize	Days at sea	Gross revenue (k€)	Sole Gross revenue (k€)	Sole Landings (Tons)	Sole dependency (% Gross revenue)
Morlaix	6	17.0	4.2	210	739	214	19.0	29.0
Guilvinec	71	13.9	2.6	204	383	38	2.9	9.9
Concarneau	17	13.0	3.0	203	347	19	1.6	5.6
Lorient	50	14.3	3.8	216	533	98	8.1	18.3
Auray	18	10.9	2.7	158	201	46	3.7	23.1
Vannes	6	9.6	1.5	133	117	36	2.4	30.7
Saint-Nazaire	49	13.8	3.3	206	540	58	4.6	10.8
Noirmoutier	27	12.6	3.1	176	413	235	19.5	57.0
L'Ile-d'Yeu	22	14.3	3.7	195	435	190	16.6	43.7
Les Sables-d'Olonne	50	12.2	2.6	177	332	141	12.1	42.4
La Rochelle	24	13.8	2.7	182	328	81	6.9	24.8
Ile d'Oléron	25	12.5	2.6	203	402	91	7.9	22.6
Marennes	48	13.0	2.8	186	427	136	11.9	32.0
Arcachon	27	14.8	4.0	217	587	296	26.0	50.4
Bayonne	25	13.0	3.4	180	362	96	8.3	26.5
Others	7	12.0	2.6	168	279	34	2.8	12.2
Average	**-**	**13.3**	**3.1**	**194**	**419**	**110**	**9.4**	**25.7**

Table B4: Number of vessels and average vessel characteristics by Producer Organization in the Bay of Biscay sole fishery in 2011 (vessels with landings > 1 metric ton)

Producer Organization	Number of vessels	Share of the total number of vessels of the PO (%)	Main fleet segments	Sole Landings (Tons)	Sole dependency (% Gross revenue)
PMA	163	33.9	Mixed bottom trawlers Nephrops trawlers	4.8	13.0
OPOB	50	14.9	Nephrops trawlers Sole gillnetters	5.3	15.2
OPPAN	27	27.0	Sole gillnetters	21.8	59.2
OP ILE D YEU	18	54.5	Sole gillnetters	19.3	48.7
OP VENDEE	44	40.2	Mixed bottom trawlers Sole gillnetters	12.4	42.6
FROM SUD-OUEST	28	26.7	Sole gillnetters Mixed bottom trawlers	14.8	39.5
OP LA COTINIERE	67	65.0	Mixed bottom trawlers	7.6	21.9
ARCA-COOP	24	68.5	Sole gillnetters	24.3	49.0
CAPSUD-OP	22	31.3	Sole gillnetters	10.9	33.6
Non PO	29		Sole gillnetters	5.2	26.8

B.3 Distribution of landings and historical landings in the total population

Table B5: Composition of the population of all Bay of Biscay vessels with non-zero sole landings in 2011 or non-zero historical landings records, and relative contributions of sub-populations to landings and historical landings records (SHL = strict historical landings)

	Number of vessels	Landings 2011 (Tons)	% Landings 2011	SHL vessel limits[A] (Tons)	% Historical landings records[B]
Total population	**1535**	**4259**	**100**	**3906**	**89**
Inactive vessels with Historical landings records > 0	255	0	0	493	11
Vessels with Historical landings records > 0 & 2011 landings = 0	241	0	0	345	8
Vessels with 2011 landings in]0,1000kg[	567	132	3	270	6
Vessels with 2011 landings > 1000kg	**472**	**4127**	**97**	**2798**	**64**

[A] based on the final French sole quota of 4380 Tons for ICES areas VIIIa-b in 2011.

[B] about 11% of the historical landings records were placed in the national and PO reserves, so that the total population accounted for 89% of historical landings records.

Chapter 4. Investigating trade-offs in alternative catch share systems: an individual-based bio-economic model applied to the Bay of Biscay sole fishery

Submitted to the *Canadian Journal of Fisheries and Aquatic Sciences*

Bellanger, M., Macher, C., Merzéréaud, M., Guyader, O., Le Grand, C.

Abstract

An individual-based bio-economic model (IAM) is presented and applied to the Bay of Biscay sole fishery to investigate alternative quota management systems from a multi-criteria perspective. Notably, the model integrates several institutional arrangements related to catch share management. The current French co-management system with non-transferability of quota is compared to an alternative ITQ system in a context of transition to maximum sustainable yield (MSY). Trade-offs between ecological and socio-economic impacts are highlighted and the effectiveness of governance scenarios is discussed in regard to the challenge of capacity adjustment. Results emphasize that the introduction of ITQ is expected to reduce by 40% the number of vessels in the fishery. While effectively mitigating the economic impacts of the transition phase to MSY, ITQs are also expected to significantly increase the trawling effort, which may cause ecological concerns. The scenarios tested also include the simulation of a decommissioning scheme where subsequent decommissioned vessels are notably different from the vessels that would lease out their quotas in an ITQ system, resulting in differentiated ecological and socio-economic impacts between scenarios.

Keywords. Bio-economic model; quota management systems; catch share; institutional design; fisheries governance.

4.1 Introduction

Fishery management tools put in place at the European level to regulate the fishing sector are mainly based on conservation measures, in particular total allowable catches (TACs). Regulation of access to resources is managed by each Member State with an important heterogeneity in access regulation among Member States and between fisheries within a given member state as illustrated by MRAG (2009), Le Floc'h et al. (2015), and Marchal et al. (2016). Following the failures of the Common Fisheries Policy (CFP) to tackle overcapacity and overexploitation in European fisheries, the use of rights-based approaches and the implementation of individual transferable rights, intended to counter incentives for race to fish, have been proposed as a solution to be explored (CEC, 2009). Many countries have already adopted individual transferable quotas (ITQs) (Grafton, 1996; Arnason, 2002; Newel et al., 2005; Asche et al., 2008; Grafton and McIlgorm, 2009). In the European Union, formal quota markets also already exist in the Netherlands, Denmark, Spain and the United Kingdom (Gonzalez Láxe, 2006; Marchal et al., 2009a; Aranda and Murillas, 2015). Quota co-management systems where collective allocations are granted to groups of harvesters have also been identified as being a potential successful management option for fisheries (Jentoft, 1989; Smit, 1997; Ostrom, 2009; Gutierrez et al., 2011; Deacon, 2012; Le Floc'h et al., 2015). Combining the ability of a regulator to implement regulations and self-organization of users to manage their resources, co-management systems can be qualified as hybrid systems of governance of common-pool resources (German and Keeler, 2009). Advantages or disadvantages of a national fishing quota market based on ITQs compared to alternative hybrid quota governance systems have thus been debated in the context of the reform of the CFP (Coelho et al., 2011; Van Hoof, 2013).

In France, the regulator has gradually transferred competencies in quota management to Producer Organizations (POs) and fishing possibilities are managed within a PO-based catch share system where individual fishing allocations are non-transferable (Larabi et al., 2013). POs were initially created by the European Community for fish market management (Hatcher, 1997) but their role in fisheries management has continued to grow over the last decade to become essential. The French catch share system is now administered through collective allocations to POs based on the pooled fishing rights (also known as *track records*) of their members, and POs establish their own rules for individual or collective redistribution to their members. In the context of non-transferability of fishing rights, POs have put in place different quota management methods influenced by constraints of collective quotas, fish markets and abundance of resources (Larabi et al., 2013). Quota management is effectively very heterogeneous across POs and influences producers' fishing strategies and thus fleets' performances (Le Floc'h et al., 2015; Bellanger et al., 2016a). In the meantime, these quota policies were supplemented by policies for adjusting fleet capacity that relied on limited entry and public-aided decommissioning schemes (Quillerou and Guyader, 2012). The introduction of ITQs has been mostly rejected by French stakeholders during the discussions over the last reform of the CFP (Frangoudes and Bellanger, 2017). France eventually took position against the generalization of ITQs (Gouvernement Français, 2009; p.29) and supported a PO-based co-management system. However, a recent report by the national competition authority (Autorité de la concurrence, 2015) proposing ITQs as a potential solution to identified failures of the current system reopened the debate.

In this context, the assessment of the effectiveness of catch share systems balancing pros and cons of ITQs versus PO-based co-management systems from a multi-criteria perspective is critical. There is therefore a need to develop modelling frameworks that integrate interactions between resources, uses and governance mechanisms for the simulation analysis of policy issues (Hopkins et al., 2012; Mongruel et al., 2013). According to EU guidelines, impact assessment (IA) is a process that prepares evidence for political decision-makers on the advantages and the drawbacks of potential policy options by evaluating their likely short-term and long-term effects (EC, 2009). The key analytical steps include the identification of the problem, the development of policy options, the analysis of the impacts of the options, and the follow-up evaluation. The analysis should highlight trade-offs between management objectives and compare options against one another and against the baseline. However, ranking the different option and selecting the best one is more a matter devolved to political decision-makers (Malvarosa et al., 2015; Murillas-Maza and Andres, 2016). Evaluations of management measures are traditionally based on simulations provided by bio-economic models that support decision making at the EU level (Prellezo et al., 2012). These models are used to forecast and compare the implications at aggregated fleet level of different options such as transition to the maximum sustainable yield (MSY), maximum economic yield (MEY) (Guillen et al., 2013; Merino et al., 2014; STECF, 2015), or analyse trade-offs between management objectives (Mardle et al., 2002). Management options consider impacts of selective devices (Macher et al., 2008; Raveau et al., 2012), management plans (STECF, 2015) and introduction of ITQs (Marchal et al., 2011). Traditional bio-economic modelling tools as reviewed by Prellezo et al. (2012) and updated by STECF (2012) based on Cobb-Douglas production functions do not account for interactions between agents. The context of the new CFP (European Union, 2013) and the necessity of having multi-objective assessments (European Commission, 2010) thus raised the issues of (1) developing improved modelling tools for fisheries socio-ecosystems that can integrate several institutional arrangements to better account for the influence of governance in the impact assessment of management options (2) developing individual-based modelling tools able to represent the constraints and strategies of producers at the vessel level and their interactions through markets and resources.

Impact assessments based on bio-economic models have also included for several years the management strategy evaluation (MSE) approach (e.g. Holland, 2010; Bunnefeld et al. 2011; Ives et al., 2013; Fulton et al., 2014; Punt et al., 2014) where uncertainty associated with observation and implementation of TAC is traditionally well represented. However, MSEs generally do not explicitly take into account catch share management systems and disaggregated constraints at the individual producer level despite their influence on producers' strategies. While POs effectively play a major role in quota governance in many EU member states (Aranda and Murillas, 2015), existing models of EU fisheries do not incorporate quota management mechanisms as instigated at the PO level. As a result, they do not model the impacts such governance modes have on producer behaviours and bio-economic performances while considering multiple (and potentially conflicting) management objectives. As such, they fail in providing a good understanding of the complexities in PO-based co-management systems that is required for an adequate comparison with other governance systems based on market mechanisms. A means of overcoming this drawback is to develop innovative bio-economic tools that include the core processes of catch share management so as to augment the *management model* and the *harvest control rule (HCR) implementation* components of the typical MSE loop (Holland, 2010; Bunnefeld et al. 2011; Punt et al., 2014).

This paper presents an individual-based bio-economic simulation model that was developed to explore the impacts of catch share management systems from a multi-criteria perspective including the economic, social and ecological dimensions. It is applied to the Bay of Biscay common sole (*Solea solea*) fishery which is a high-value commercial fishery and one of the first fisheries where individual quotas were implemented by French POs. The model explicitly represents quota management mechanisms according to existing institutional arrangements and a potential alternative ITQ system. Vessels are individually modelled which allows to analyze outcomes in terms of heterogeneity and intra-fleet variability. Interactions among individual vessels are taken into account via stock externalities through the Baranov catch equation. The paper first describes the current catch share system and the role of POs in the Bay of Biscay sole fishery. A bio-economic methodology based on an augmented version of the IAM model (Merzéréaud et al., 2011; Raveau et al., 2012; Guillen et al., 2013, 2015) that integrates several institutional arrangements is then proposed for the impact assessment of different governance options for the management of Bay of Biscay sole quotas. Simulations of the bio-economic impacts of the current PO-based quota co-management system, with and without decommissioning scheme, are compared to an alternative ITQ system under the common hypothesis of target stock being exploited so as to achieve MSY. The analysis of the ability of these different management options to address key issues related to quota governance is presented from a multi-criteria perspective.

4.2 The common sole fishery in the Bay of Biscay

The Bay of Biscay common sole fishery (ICES divisions VIIIab) is one of the most important fisheries in France. In 2014, it represented more than 360 vessels, 1200 fishermen and total gross revenue of 157 million euros. The fishery is managed by a Total Allowable Catch (TAC) decided at the European level, of which 91% is allocated to French fleets and 9% is allocated to Belgium beam trawlers. According to a typology that was specifically developed to study the Bay of Biscay demersal fisheries (Macher et al., 2011), the French sole fishery is mainly composed of the following fleet segments: specialized Nephrops trawlers, non-specialized Nephrops trawlers, mixed bottom trawlers, pelagic trawlers, mixed netters and sole netters (Table 4.1). In addition to the TAC, the management of the fishery also includes a total gross tonnage limit and a special fishing permit regulation so that aggregate capacity cannot increase and must decrease along with vessels' State-aided permanent cessation of activity (EC, 2006). Consequently, decommissioning schemes implemented over the last decade on so-called sensitive fisheries, including sole, have largely contributed to decreasing the number of vessels (-26% of vessels landing more than 1 ton of sole between 2006 and 2014).

Following high fishing mortalities on sole and risks of collapse in the 2000's, a CFP management plan was decided in 2002. The first step of the plan was to recover the fish stock to precautionary biomass limit (B_{pa} = 13000 tons). This objective was achieved in 2008. The second step was to define multiannual management objectives based on the Johannesburg international objective of achieving MSY by 2015 (UN, 2002), and at the latest by 2020. In accordance with the CFP reform, management plans should be implemented within a multispecies context where multiple stocks are jointly exploited (Article 24 of Regulation (EU) No 1380/2013), which is still to be enacted for the Bay of Biscay sole management plan. The spawning stock biomass (SBB) peaked in 2009 (15,919 t.) and decreased afterwards (12,700 t. in 2014) due to the combination of poor recruitment of juveniles and increased fishing mortality (ICES, 2015). The current level of SSB is therefore well below the level of biomass B_{MSY} needed to produce the maximum sustainable yield, B_{MSY} = 28,800 t.

Management of quotas in France is operated by the administration (regulator) and the producer organizations (POs) with an increasing role of the POs in the last decade. The POs are groups of harvesters that collectively manage their fishing possibilities. PO membership is voluntary and a PO as an entity is somewhat geographically-relevant. In the current French catch share system, national quotas are divided into sub-quotas per PO according to the historical rights of the PO members. In 2006, a decree established that the reference years for the calculation of the share each PO is granted were the years 2001-2003 (JORF, 2006). The historical rights of non-PO vessels remain in a common-pool managed by the administration, effectively generating a race-for-fish among non-PO

Table 4.1: Description of French fleet-length segments involved in the Bay of Biscay sole fishery in 2014

Fleet	Length category	Number of vessels	Mean crew per vessel	Mean number of days at sea per vessel	Mean number of days at sea on métier sole per vessel	Total landings of sole (tons)	Mean gross value of landings per vessel (k€)
Specialized Nephrops trawlers	0-12 m	14	2.2	174.8	14.1	28.2	260.9
	12-24 m	40	3.4	168.5	10.0	243.3	601.5
Non-specialized Nephrops trawlers	0-12 m	3	2.0	147.7	52.0	11.7	235.2
	12-18 m	18	3.6	99.3	37.1	187.5	624.4
	18-24 m	8	4.7	104.8	31.8	92.4	869.0
Mixed bottom trawlers	0-10 m	20	1.4	128.2	62.5	54.3	120.5
	10-12 m	60	2.2	151.1	48.8	206.2	249.3
	12-18 m	22	3.3	90.4	28.4	147.1	502.8
	18-24 m	5	4.8	70.0	30.6	41.5	655.3
Pelagic trawlers	0-10 m	4	2.7	175.8	24.2	10.6	390.1
	10-18 m	6	4.3	162.3	20.3	17.2	670.4
	18-24 m	8	5.3	113.2	3.5	17.1	1025.5
Mixed netters	0-10 m	16	1.6	133.9	63.1	22.2	91.1
	10-18 m	7	2.1	139.9	48.9	10.6	121.9
Sole netters	0-10 m	14	2.2	178.4	104.9	61.2	205.6
	10-12 m	47	3.2	153.8	104.9	614.1	313.8
	12-18 m	39	4.5	112.9	61.7	1031.4	642.0
	18-24 m	21	6.1	52.2	26.5	773.6	841.0

Source: DPMA-Ifremer Fisheries Information System (2015)

vessels. In 2014, there were six POs involved in the Bay of Biscay sole fishery (Figure 4.1) that accounted for 95% of the landings. Notably, number of vessels and fleet composition are very uneven across POs (see Table C4 in Appendix C).

Following increasing constraints on their Bay of Biscay sole sub-quotas compared to resource availability, POs have developed various management systems including individual quotas, each PO being free to determine their own rules for quota allocation (Bellanger et al., 2016a). Management rules are decided at the board of directors in each PO and can vary from year to year according to stock abundance and thus to risks of quota overruns or of unbalanced distribution of catch among seasons or among fleets. POs generally decide of the allocation rules with two objectives: optimizing the use of the quota by PO members (catch-quota balancing, avoidance of in-season market congestion) and minimizing the monitoring costs and the risks of quota overruns. These allocation rules are based on criteria that vary among POs (*e.g.* historical landings, gear-based or equal-sharing rules). In 2014, more than 70% of the sole landings were effectively subject to individual quotas (Guyader et al., 2014). Besides, POs typically require their members to detail their fishing activity plan before the start of each year so that each PO can internally use some reallocation arrangements as part of a collective management of fishing possibilities. Catch-quota balancing arrangements may also be operated by POs during the fishing season to ensure that quotas of target species are fully exploited.

In France, marketed transfers of historical rights or quota trades between producers are not allowed (JORF, 1997), not even within POs. However, there exists a certain degree of flexibility in the management of historical rights (Larabi et al., 2013). Along the years, reserves of rights were constituted in POs and at the State level alongside decommissioning schemes, fishery exits and vessel sells from one PO to another. These reserves of rights are redistributed according to decisions made within POs or to decisions of a national commission on quotas. POs thus have a critical role in the governance of French quotas, and the French catch share system can be qualified as a co-management system as the regulator has given POs important prerogatives and decision-making responsibilities in terms of managing their sub-quotas.

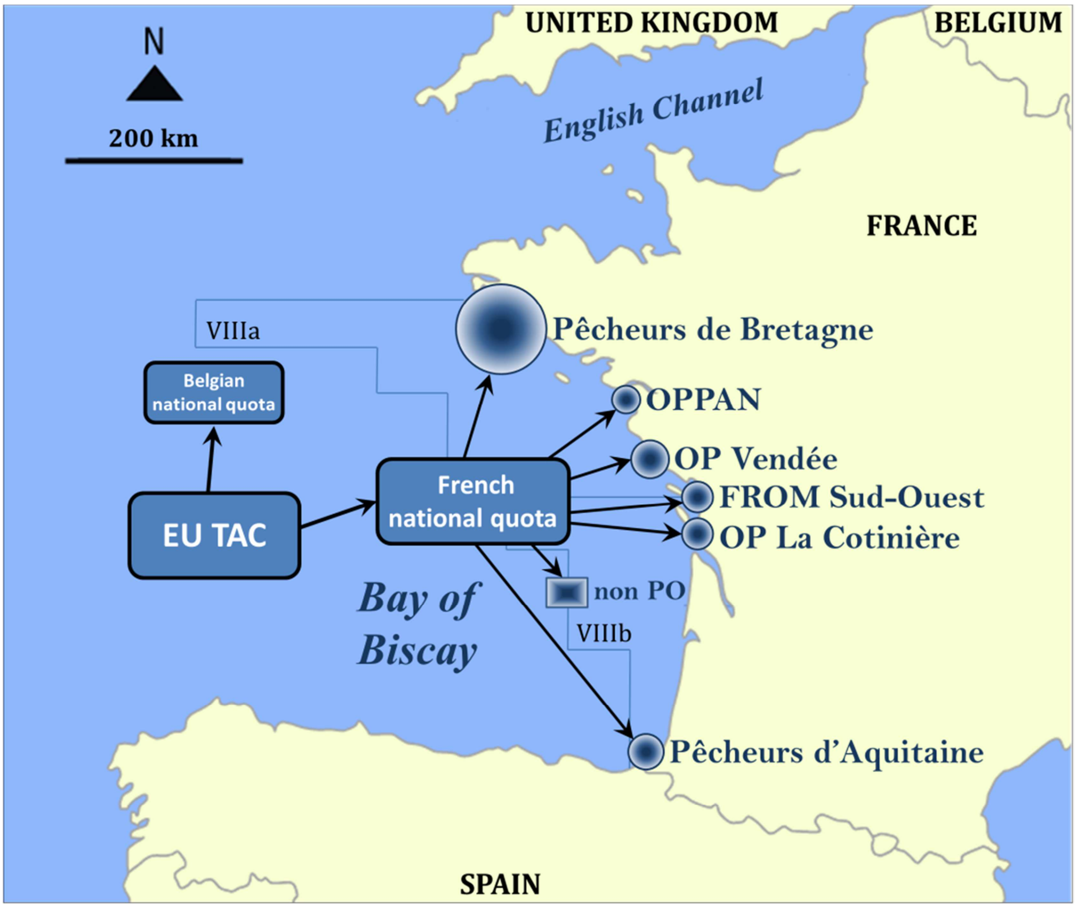


Figure 4.1: Map of the Producer Organizations (POs) in the Bay of Biscay in 2014 and distribution of the common sole total allowable catch and national quota between POs/non-PO common-pool. Circle size is scaled to the number of vessels operating in the PO (min=93, max=795).

4.3 Bio-economic modelling for governance scenarios comparison

The bio-economic model IAM (Impact Assessment Model for fisheries management) (Macher et al., 2008; Raveau et al., 2012; Guillen et al., 2013, 2015) is used to perform individual-based simulations with an annual time step. The model consists of the coupling of an *operating model* with a *management procedure* (Figure 4.2). The operating model classically represents the biological dynamics of fish stocks and the harvest dynamics at the vessel level. It is aged-structured to best apprehend the impacts of heterogeneous fleet selectivity on stock dynamics. It also distinguishes multiple *metiers*[12] to account for the heterogeneity of the fishing practices among fleets (Ulrich et al., 2012) and even at the vessel level. A short-term behavior module dictates individual efforts and catches that feed the biological and economic modules. A long-term behavior module then determines the adjustment of fleet capacity based on the outputs of the economic module. The management procedure integrates several institutional arrangements related to catch share management. Remarkably, the management procedure is not limited to a simple harvest control rule. It includes individual quota allocations following the quota pooling and reallocation mechanism operated by POs. It also integrates a module that mimics the management of historical rights related to fishery exits. Additionally, the simulation of a decommissioning scheme and the simulation an ITQ lease market can be activated as scenario in the management procedure.

The combination of the operating model with the management procedure enables to simulate the constraints and behaviour of fishermen at the individual level and their interactions through quota market and fish stocks. The model can be used to evaluate the impacts of various management options and investigate the trade-offs between ecological, economic and social objectives. The model considers the following dimensions:

s: species
a: age group
f: fleet
m: metier
i: vessel
t: year

While Sections 4.3.1, 4.3.2 and 4.3.3 summarize the essential features of the model relevant to the current study, detailed equations are fully reproduced in Merzéréaud et al. (2011).

[12] metier is "a group of fishing operations targeting a similar (assemblage of) species, using similar gear, during the same period of the year and/or within the same area and which are characterized by a similar exploitation pattern" (European Commission Decision 2010/93/EU, Appendix I Chapter 1, p.9).

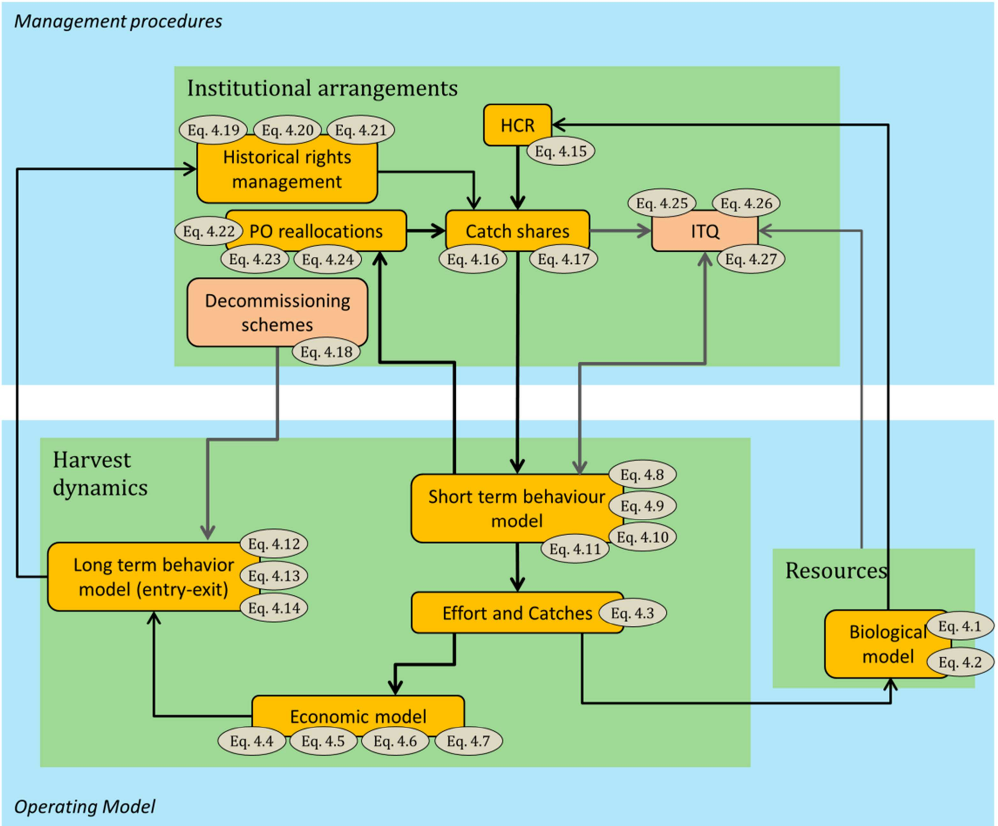


Figure 4.2: Flowchart of the main processes run at each step of the model. Decommissioning schemes and ITQ can be (dis)activated as scenario.

4.3.1 Resources

4.3.1.1 Biological model

The stock dynamics of species s is age structured to account for a variety of exploitation patterns by age and by vessel. It follows the Beverton and Holt (1957) equations:

$$N_{s,a+1,t+1} = N_{s,a,t} \cdot e^{-Z_{s,a,t}} \tag{4.1}$$

with:

$N_{s,a,t}$: the number of individuals of species s of age a in year t

$Z_{s,a,t}$: the total mortality, equal to the sum of natural mortality $M_{s,a,t}$ and fishing mortality $F_{s,a,t}$.

The spawning stock biomass (SSB) is given by:

$$SSB_{s,t} = \sum_a Mat_{s,a} \cdot N_{s,a,t} \cdot w_{s,a} \tag{4.2}$$

with:

$w_{s,a}$: the mean weight at age a in the stock, assumed to be constant over the simulation period

$Mat_{s,a}$: the proportion of mature individuals at age a.

4.3.2 Harvest dynamics

4.3.2.1 Effort and catches

Landings of species s, by vessel i and metier m, $L_{i,s,m,t}$, are calculated using the Baranov equation:

$$L_{i,s,m,t} = \sum_{a} \frac{F_{i,s,a,m,t}}{Z_{s,a,t}} \cdot N_{s,a,t} \cdot (1 - e^{-Z_{s,a,t}}) \tag{4.3}$$

where the fishing mortality $F_{i,s,a,m,t}$ of species s by age, vessel, and metier is calculated as the product of a catchability coefficient $q_{i,s,a,m,t}$ and the effort $E_{i,m,t}$, the catchability coefficients being computed according to the initial effort and catch per metier of each vessel and the initial fishing mortality per age to account for particular selectivity profiles at the vessel level (Macher et al., 2008). Notably, $F_{i,s,a,m,t}$ can be corrected by a discard factor and $Z_{s,a,t}$ accounts for discard survival rates. We see from eq. 4.3 that $L_{i,s,m,t}$ depends not only on the individual fishing mortality but also on the total mortality so that agents effectively interact through stock externalities.

4.3.2.2 Economic model

The gross value of landings by vessel and metier is calculated from the landings by species and metier, the ex-vessel price $p_{s,f,m}$ of species s (assumed to be constant by fleet*metier), and a gross revenue of other "non-modeled" species by metier assumed to be constant by unit of effort ($GVL_{other,m}$) as in Raveau et al. (2012) and Gourguet et al. (2013). The total gross value of landings of i_f (the vessel i belonging to the fleet f) is thus the sum of the gross value of landings by metier:

$$GVL_{i_f,t} = \sum_{m} \left(\sum_{s} p_{s,f,m} . L_{i_f,m,s,t} + GVL_{other,m} \right) \tag{4.4}$$

Denoting $cshr_{i_f}$ the crew share of the gross revenue after deduction of variable costs, the crew costs ($Ccrew_{i_f,t}$) and the vessel gross operating surplus ($\pi_{i_f,t}$) are then calculated as follows:

$$Ccrew_{i_f,t} = cshr_{i_f} . \left(GVL_{i_f,t} - \sum_{m} CvarUE_{i_f,m} . E_{i_f,m,t} \right) \tag{4.5}$$

$$\pi_{i_f,t} = \left(1 - cshr_{i_f}\right) . \left(GVL_{i_f,t} - \sum_{m} CvarUE_{i_f,m} . E_{i_f,m,t} \right) - Cfix_{i_f,t} \tag{4.6}$$

with $CvarUE_{i_f,m}$ the variable costs (including fuel costs) per unit of effort by metier and $Cfix_{i_f,t}$ the fixed costs. Notably, the variable costs are considered linearly dependent on the fishing effort[13].

[13] Data analyses of the variable costs have been conducted on different samples to estimate variable costs as quadratic functions of the effort as suggested by Clark (2006) and used in Péreau et al. (2012). However, variable costs were found to be linear of the effort in most cases.

The net present value of the net profit at time horizon T, considering a discount rate r, is then computed as the sum of discounted net profits over the discounting period:

$$NPV_{i_f,t_0}^{(T)} = \sum_{t=t_0}^{T} \frac{1}{(1+r)^{(t-t_0)}} . \left(\pi_{i_f,t} - Ccap_{i_f,t}\right) \tag{4.7}$$

with $Ccap_{i_f,t}$ the cost of capital depreciation.

4.3.2.3 Short-term behaviour model

The model simulates the short-term dynamics of fishing activity in terms of individual effort per metier. The modelling of fishermen' behaviour often considers the choice of metier as driven by a combination of tradition and economic factors (Soulier and Thébaud, 2006; Marchal et al., 2009b, 2011). Besides, quota availability of target species $Q_{i,s,t+1}$ and individual maximum effort $E_{i,max}$ constrain the choice of fishermen. The short-term behaviour model that we developed combines an *effort allocation* module and an *effort determination* module that are built in endogenously. The effort allocation module distributes the individual efforts per metier according to the short-term anticipated marginal profits and to the efforts observed during the previous year. The effort determination module adjusts individual efforts with the production function (eq. 4.3) with constraints on landings ($L_{i,s,t+1} \leq Q_{i,s,t+1}$) and on maximum effort.

In order to keep the description of the model simple, let us consider the case where there are two metiers ($Met1$ and $Met2$), and one species (s) subject to binding quotas. We further suppose that s is a target species for $Met2$ (so that individual landings constraints apply) whereas it is a bycatch for $Met1$. Let α and $1-\alpha$ be the relative weight given to anticipated profit and traditions respectively. We also define $\hat{E}_{i,m,t+1}^{MAX}$ the anticipated effort on metier m if 100% of the individual allocation $Q_{i,s,t+1}$ is used on metier m:

$$\hat{E}_{i,m,t+1}^{MAX} = Q_{i,s,t+1} \cdot \frac{E_{i,m,t}}{L_{i,s,m,t}} \tag{4.8}$$

For each vessel i:

- if $\hat{E}_{i,m=Met1,t+1}^{MAX} \cdot \frac{\pi_{i,m=Met1,t}}{E_{i,m=Met1,t}} \leq \hat{E}_{i,m=Met2,t+1}^{MAX} \cdot \frac{\pi_{i,m=Met2,t}}{E_{i,m=Met2,t}}$, then

$$E_{i,m=Met1,t+1} \coloneqq (1-\alpha). E_{i,m=Met1,t} \tag{4.9}$$

- if $\hat{E}_{i,m=Met1,t+1}^{MAX} \cdot \frac{\pi_{i,m=Met1,t}}{E_{i,m=Met1,t}} > \hat{E}_{i,m=MET2,t+1}^{MAX} \cdot \frac{\pi_{i,m=Met2,t}}{E_{i,m=Met2,t}}$, then

$$E_{i,m=Met1,t+1} \coloneqq E_{i,m=Met1,t} + \alpha. E_{i,m=Met2,t} \tag{4.10}$$

If $\alpha = 1$, fishing behaviour is entirely driven by the short-term anticipated marginal profit and the effort on $Met1$ is set to 0 if $Met2$ is more profitable (eq. 4.9) or set equal to the total effort observed during the previous year if the $Met1$ is more profitable (eq. 4.10). If $\alpha = 0$, the effort on the $Met1$ remains constant throughout the simulation.

Effort allocation on $Met1$ imposes a constraint of available effort for $Met2$ ($E_{i,m=Met2,t+1} \leq E_{i,max} - E_{i,m=Met1,t+1}$). The determination of individual effort for $Met2$ thus depends on the profit-traditions weighting (eq. 4.9-10) via the maximum effort constraint but also on a landings constraint because $Met2$ targets a species that is subject to binding quota. $E_{i,m=Met2,t+1}$ is therefore such that:

$$\begin{cases} L_{i,s,m=Met2,t+1} = Q_{i,s,t+1} - L_{i,s,m=Met1,t+1} & \text{if } E_{i,m=Met2,t+1} \leq E_{i,max} - E_{i,m=Met1,t+1} \\ E_{i,m=Met2,t+1} \coloneqq E_{i,max} - E_{i,m=Met1,t+1} & \text{otherwise} \end{cases} \quad (4.11)$$

where $L_{i,s,m,t+1}$ is determined according to the Baranov production function (eq. 4.3). Eq. 4.11 is a constrained optimization problem and the solution $E_{i,m=Met2,t+1}$ (that depends on the total mortality $Z_{s,a,t+1}$) is simultaneously found for all i with a convergent iterative process similar to the method of Lagrange multiplier.

4.3.2.4 Long-term behaviour model

The long-term fleet dynamics relate to investment and disinvestment decisions that affect the capacity of the fleets. In the model, we consider that vessel entry/exit decisions depend on profitability and potential imperfect malleability of capital as suggested by the theory (Clark et al., 1979). Investment decisions are considered at the fleet level (with new vessels assumed to have average fleet characteristics as in Garcia et al., 2012) while disinvestment decisions are considered at the vessel level. Previous revenues are used as proxy of potential earnings.

For each fleet f, the ratio between profit and landings value ($I_{f,t}^{max}$) is given by:

$$I_{f,t}^{max} = \frac{\sum_{i_f}\left(GVL_{i_f,t} - \sum_m CvarUE_{i_f,m} \, . E_{i_f,m,t} - Cfix_{i_f,t} - Ccrew_{i_f,t}\right)}{\sum_{i_f} GVL_{i_f,t}} \quad (4.12)$$

This ratio is an indication of the maximum share of the profits that can be invested in the fleet (Garcia et al., 2012). However, not all profits are used to increase the fleet. Let $\eta_{f,t} \in [0,1]$ be the proportion of the profits that is actually invested to buy new vessels in fleet f. Denoting $N_{f,t}$ the number of vessel in fleet f and provided that regulations allow for increasing capacity, the number of new vessels is determined by:

$$N_{f,t+1}^{new} = \max\left(\lfloor N_{f,t} . \eta_{f,t} . I_{f,t}^{max} \rfloor, 0\right) \quad (4.13)$$

where $\lfloor x \rfloor$ is the *integer part* of x.

For fishery exits, we distinguish fishery exits without public aids from fishery exits supported by public aids as part of a decommissioning scheme (see Section 4.3.3.3). Without public aids, i_f exits the fishery before the start of step $t+1$ if:

$$\frac{GVL_{i_f,t} - Cfix_{i_f,t} - \sum_m CvarUE_{i_f,m} \,.\, E_{i_f,m,t} - Ccrew_{i_f,t}}{GVL_{i_f,t}} < -\omega_{i_f} \quad (4.14)$$

where $\omega_i \in [0,1]$ is a parameter that represents capital malleability for the vessel i, i.e. whether investment is reversible in terms of vessel resale value for capital when exiting the fishery (with $\omega_i = 0$ corresponding to perfect malleability).

4.3.3 Institutional arrangements

4.3.3.1 Harvest control rule

The TAC can be either exogenously given, or dynamically modified based on the output data generated by the biological model as part of the management procedure. One such decision rule that we modelled is the determination of a TAC such that the expected fishing mortality is consistent with achieving MSY (i.e. stock exploitation at F_{MSY}) as assumed in the ICES advice procedure. Using the same variable notations as in eq. 4.1-3, the TAC_{MSY} is computed as follows:

$$TAC_{s,t} = \sum_a \frac{F_{s,a,t-1} \times \frac{F_{MSY}}{F_{s,t-1}}}{F_{s,a,t-1} \times \frac{F_{MSY}}{F_{s,t-1}} + M_{s,a,t}} \cdot N_{s,a,t} \cdot \left(1 - e^{-\left(F_{s,a,t-1} \times \frac{F_{MSY}}{F_{s,t-1}} + M_{s,a,t}\right)}\right) \quad (4.15)$$

where $F_{s,t-1} = \sum_a F_{s,a,t-1}$.

4.3.3.2 Catch shares

The governance sub-model makes explicit the distribution of the TAC among member states, the allocation of collective sub-quotas to POs and individual allocations to producers. Let $FLEET$ be the entire fleet, i.e. the set of all vessels i. For a given Total Allowable Catch in year t ($TAC_{s,t}$), the sub-quota $Q_{j,s,t}$ allocated to the producer organization j, is given by:

$$Q_{j,s,t} = \frac{\sum_{i \in j} \sum_{\tau=2001}^{\tau=2003} L_{i,s,\tau}}{\sum_{i \in FLEET} \sum_{\tau=2001}^{\tau=2003} L_{i,s,\tau}} \times TAC_{s,t} \quad (4.16)$$

with $L_{i,s,\tau}$ the historical landings of vessel i in year τ.

Initial allocation of catch share to producers is then:

$$Q_{i,s,t} = \phi_{i,s,t}^{j} \times Q_{j,s,t} \,, \forall i \in j, \forall j \in FLEET \quad (4.17)$$

where $\phi_{i,s,t}^{j}$ is the allocation key used by the producer organization j, $\sum_{i \in j} \phi_{i,s,t}^{j} = 1$.

4.3.3.3 Decommissioning schemes

The simulation of a decommissioning scheme can be considered as part of the management procedure. In that case, the decision rule implemented is similar to the one presented in Guyader et al. (2004). Suppose a vessel i is eligible to a decommissioning premium $Prem_{i,t}$. It is assumed that the decision at the individual level depends on the net present value of the gross operating surplus at year horizon T and the discounted replacement value of the vessel. Thus, on condition of eligibility to a decommissioning scheme, i_f exits the fishery before the start of step $t+1$ if:

$$Prem_{i_f,t} > NPV_{i_f,t}^{(T)} + \frac{Repv_{i_f,T}}{(1+r)^{(T-t)}} \tag{4.18}$$

with $Repv_{i_f,T}$ the replacement value of vessel i_f that can be estimated according to the PIM method (IREPA Onlus coordinator, 2006).

4.3.3.4 Historical rights management

In France, although historical rights are non-tradeable among producers, the historical landings track records attached to scrapped vessels can be transferred to some *reserves* of historical rights that were created at the national and PO levels alongside decommissioning schemes. These reserves are critical for quota management as they increase the POs' collective quotas, and the benefits of decommissioning schemes can be heterogeneous if the proportion of eligible vessels varies across POs. The details of these arrangements (*e.g.* the shares of historical rights attached to the scrapped vessels transferred to the national and the PO reserves according to whether decommissioning is associated with premiums) are quite complex and have evolved over years (JORF, 2014; see *décret n° 2014-1608 du 26 décembre 2014*, articles R921-44 and R921-45 for current regulation). The mechanism describing the transfer of historical rights to reserves associated with the decommissioning of vessel i, member of the PO j, can be formalized in a generic manner as follows:

$$\begin{bmatrix} Rsv_{j,s}^{update} \coloneqq Rsv_{j,s} + POshr_i.\left(\sum_{\tau=2001}^{\tau=2003} L_{i,s,\tau}\right) \\ Rsv_{nat,s}^{update} \coloneqq Rsv_{nat,s} + NATshr_i.\left(\sum_{\tau=2001}^{\tau=2003} L_{i,s,\tau}\right) \end{bmatrix} \tag{4.19}$$

with

$Rsv_{j,s}$: the reserve of PO j

$Rsv_{nat,s}$: the national reserve

$POshr_i$: the share of historical rights transferred to the PO reserve

$NATshr_i$: the share of historical rights transferred to the national reserve

$POshr_i + NATshr_i = 1, \forall i$

and where $Rsv_{j,s}^{update}$ (resp. $Rsv_{nat,s}^{update}$) is the new value of $Rsv_{j,s}$ (resp. $Rsv_{nat,s}$) after transfer.

Then the historical landings of vessel i are set to 0 and the vessel is considered as definitively decommissioned (i.e. it exits the fleet and the PO):

$$\left[\begin{array}{c} L_{i,s,\tau} \coloneqq 0, \tau \in 2001, 2002, 2003 \\ FLEET_{t+1} \coloneqq FLEET_t \backslash \{i\} \\ j_{t+1} \coloneqq j_t \backslash \{i\} \end{array}\right. \tag{4.20}$$

where j_t is the set of vessels that are member of the PO j at time t. The sub-quota $Q_{j_t,s,t}$ defined in eq. 4.16 then becomes:

$$Q_{j,s,t+1} = \frac{\sum_{i \in j_{t+1}} \sum_{\tau=2001}^{\tau=2003} L_{i,s,\tau} + Rsv_{j,s}}{\sum_{i \in FLEET_{t+1}} \sum_{\tau=2001}^{\tau=2003} L_{i,s,\tau} + \sum_j Rsv_{j,s} + Rsv_{nat,s}} \times TAC_{s,t+1} \tag{4.21}$$

4.3.3.5 PO reallocations

To ensure that quotas of target species are fully exploited, a reallocation mechanism within POs can be considered when the anticipated individual quota consumption is less than 100%. We denote by $m = target$ the metier that targets the species s managed with individual quotas ($E_{i,m=target,t}$ is thus the control variable that the model adjusts to try to obtain $L_{i,s,t} = Q_{i,s,t}$).

Defining the landings per unit of effort $LPUE_{i,s,m,t}$ as

$$LPUE_{i,s,m,t} = \frac{L_{i,s,m,t}}{E_{i,m,t}} \tag{4.22}$$

and the anticipated individual quota surplus $Q^{\Delta}_{i,s,t+1}$ as

$$\begin{aligned} Q^{\Delta}_{i,s,t+1} = Q_{i,s,t+1} - \sum_{m \neq target} E_{i,m,t+1} . LPUE_{i,s,m,t} \\ - \left(E_i^{MAX} - \sum_{m \neq target} E_{i,m,t+1} \right) . LPUE_{i,s,m=target,t} \end{aligned} \tag{4.23}$$

the reallocation mechanism operates as follows. For each vessel i of the PO j, if $Q^{\Delta}_{i,s,t+1} > 0$ then

$$\left[\begin{array}{c} \forall \tilde{\imath} \in j_{t+1} \text{ such that } Q^{\Delta}_{\tilde{\imath},s,t+1} \leq 0,\ \ Q^{update}_{\tilde{\imath},s,t+1} \coloneqq Q_{\tilde{\imath},s,t+1} + Q^{\Delta}_{i,s,t+1} . \frac{Q_{\tilde{\imath},s,t+1}}{\sum_{\tilde{\imath}} Q_{\tilde{\imath},s,t+1}} \\ Q^{update}_{i,s,t+1} \coloneqq Q_{i,s,t+1} - Q^{\Delta}_{i,s,t+1} \end{array}\right. \tag{4.24}$$

where $Q^{update}_{i,t+1}$ is the new value of $Q_{i,t+1}$ after reallocation. Note that the variable $Q^{\Delta}_{i,s,t+1}$ is fixed by eq. 4.23 and is not updated by the procedure defined with eq. 4.24 so that $\{i \in j_{t+1} | Q^{\Delta}_{i,s,t+1} > 0\}$ and $\{\tilde{\imath} \in j_{t+1} | Q^{\Delta}_{\tilde{\imath},s,t+1} \leq 0\}$ are two distinct sets of vessels. This reallocation can be run after the adjustment of effort by vessel per metier (eq. 4.9-10) to ensure full exploitation of target species quotas.

4.3.3.6 Individual transferable quotas

The simulation of the ITQ lease market integrates the Baranov catch equation of the bio-economic model so that interactions among individual agents are taken into account via stock externalities. Let $Q_{i,s,t}$ be the initial quota of species s allocated to vessel i. The quota lease market is described by the following constrained optimization problem:

$\forall i$ determine $E^*_{i,m,t}$ such that

$$\pi^{ITQ}_{i_f,t}\left(E^*_{i,m,t}\right) = \max_E \pi^{ITQ}_{i_f,t}\left(E_{i,m,t}\right)$$
$$\text{subject to } \sum_i \sum_m L_{i,s,m,t} = \sum_i Q_{i,s,t} \qquad (4.25)$$

with

$$\pi^{ITQ}_{i_f,t}\left(E_{i,m,t}\right) = \left(1 - cshr_{i_f}\right).\sum_m \left(\sum_s p_{s,f,m,t}.L_{i,s,m,t} - CvarUE_{i_f,m}\,.\,E_{i,m,t}\right)$$
$$- p^{quota}_{s,t}.\left(\sum_m L_{i,s,m,t} - Q_{i,s,t}\right) - Cfix_{i_f,t} \qquad (4.26)$$

where the price of one unit of quota $p^{quota}_{s,t}$ is unknown and must be adjusted such that supply and demand coincide in a context of individual profit maximization. Since for each vessel the individual effort needed to reach a given objective in terms of landings depends on the efforts of all the other vessels (eq. 4.3), it is in fact a multi-dimensional problem whose complexity increases with the number of vessels. To avoid the difficulties related to multi-dimensional solving, the problem can be transformed into an iterative process involving successive one-dimensional optimizations and convergent key factors correction. This transformation allows using standard linear programming routines to efficiently find a solution. The convergence procedure used to determine $p^{quota}_{s,t}$ under constraints is:

$$p^{(0)} = p_0$$
$$\forall k > 0,$$
$$p^{(k)} = p^{(k-1)} + \lambda.\left(\sum_i \sum_m \left(L_{i,s,m,t}(k) - Q_{i,s,t}(k)\right)\right) \qquad (4.27)$$
$$p^{quota}_{s,t} = p^{(k)}, k \text{ s.t. } p^{(k)} - p^{(k-1)} < \varepsilon_1 \;\&\; \sum_i \sum_m \left(L_{i,s,m,t}(k) - Q_{i,s,t}(k)\right) < \varepsilon_2$$

where $\lambda, \varepsilon_1, \varepsilon_2 > 0$ are set to ensure a balance between quick convergence and precision of estimation. The price of quota and the individual efforts can then be derived simultaneously with a nested iterative procedure aimed at achieving double convergence. As the costs and the production function are assumed linear, solutions are corner solutions for each individual vessel that will either lease in quota to be able to fish until its maximum effort or will lease out its own quota.

4.3.4 Scenarios for the impact assessment of alternative catch share systems

Three distinct management scenarios for the Bay of Biscay sole fishery were considered and analyzed according to a set of multi-criteria indicators using simulations performed with the bio-economic model integrating the governance sub-model. These scenarios were determined so as to reflect some of the potential options supported by different stakeholders. To make a meaningful comparison, the initial individual catch share allocations operated by POs are consistent across the three scenarios and are proportional to landings of reference. Common hypotheses across scenarios also include:

- Bay of Biscay sole TACs are set such that the stock is exploited at F_{MSY}
- full exploitation of Bay of Biscay sole quotas (supported by the fact that landings have systematically reached the TAC in recent years)
- no restriction on landings of other species (no choke species preventing the exploitation of sole quotas)
- short term fleet dynamics defined by eq. 4.8-11 that represents potential seasonal activity intensification
- long term fleet dynamics relating to disinvestment decisions defined by eq. 4.14 and the mechanisms replicating the transfer of historical rights of scrapped vessels to reserves (eq. 4.19-21)
- impossibility of investment in new vessels, which relates to the CFP management plan for the Bay of Biscay sole fishery that prevents increasing capacity (i.e. the process associated with eq. 4.12-13 is deactivated).

Quota co-management Baseline (BA) scenario

This first scenario corresponds to the current co-management system of sole quota where each PO operates the redistribution of its collective sub-quota among its members according to its own rules and individual allocations are assumed non-transferable. With this scenario, the aim is that almost all vessels remain active as fishery exit is only considered for vessels that are non-profitable (eq. 4.14). Reallocation mechanisms (eq. 4.23-24) are included to simulate the collective management of quotas operated by POs.

Quota co-management Decommissioning Scheme (DS) scenario

In this second scenario, we consider a co-management catch-share system similar to the BA scenario (including the non-transferability of individual allocation and the quota reallocation mechanism) with the additional postulate that the State operates in year $t = t^{DS}$ a publicly funded decommissioning scheme (with virtually unlimited funding) to reduce the fleet capacity. We assume that the decision of staying or decommissioning is instantaneous at the start of the year t^{DS} (eq. 4.18). The transfer of historical rights associated to vessels decommissioning (eq. 4.19-21), typical of the French co-management system, is of particular importance in this scenario since it determines how the quotas of decommissioned vessels are redistributed among the remaining vessels.

Individual Transferable Quotas (ITQ) scenario

In this scenario, each individual vessel is granted a share of the TAC that can then be traded on a quota lease market (eq. 4.25-27). We make the assumption that the Bay of Biscay sole is the only species that can be traded. The aim of this management option is to address issues of excessive fleet capacity with market instruments (as opposed to using public money like in the DS scenario) and maximize the fleets' profitability in a context of transition to MSY.

4.3.5 Parameters and model initialization

The reference year used for parameterization is 2014 and the simulations were run over the period 2015-2025 for a selection of 359 individual vessels that have caught more than 1 ton of sole in the Bay of Biscay in 2014. TACs were determined as follows:

- Real TACs for 2015 and 2016
- Simulated TACs between 2017 and 2025 such that the fishing mortality is equal to $F_{MSY} = 0.26$

Bay of Biscay sole (*Solea solea*) and Nephrops (*Nephrops norvegicus*) biological dynamics were explicitly included in the model. Inputs for short term predictions performed by ICES (ICES, 2015) were used to parameterize fishing and natural mortality, stock numbers and weight at age in the biological sub-model (see Table C1 in Appendix C for parameter values). In line with ICES methodology, the recruitment was assumed to be constant over the simulation periods and equal to the geometric mean on years 1993-2012.

Effort and productions data in tonnage and value by vessel and metier were calculated from the SACROIS data source which is an algorithm crossing multiple existing data sources (auction halls, logbooks, dealer reports) to provide the best possible estimation of effort and production by vessel at the trip level (source: IFREMER/Fisheries Information System/DPMA). Economic data on variable cost per unit of effort and fixed cost structure were available for a sample of vessels in 2013 (see Table C2 in Appendix C for average cost structures by sub-fleet and length class) and were then estimated by vessel for 2014 according to their sub-fleet and length class (the sub-fleet and length class segmentation is identical to the one used in Table 4.1). Ex-vessel prices of sole and Nephrops by commercial grade were assumed to be constant and were calculated on year 2014 for each intersection of sub-fleet and length class.

As a simplifying assumption we consider that each vessel plans its fishing activities by choosing among two metiers:

- *"sole metier"*, corresponding to the fishing activity that targets sole
- *"other metier"*, corresponding to the fishing activity where sole is not targeted and considered a bycatch.

Fishing mortality by metier is parameterized at the vessel-trip level using a criterion that was specifically determined for the Bay of Biscay dermersal fisheries, defining a fishing trip as targeting sole when sole represents more than 6% of the trip landings in weight and Nephrops represents less than 10% (ICES, 2015). Individual efforts on *sole metier* are control variables of the bio-economic model that can be endogenously determined to achieve a given fishing mortality. Individual efforts on *other metier* are exogenously given and initialized based on the reference year.

PO affiliations (membership) and historical landings were obtained with the actual database that was used for the French administration to determine the allocation of catch shares to POs. The distribution keys used by POs for the initial allocation of individual quotas to vessels are assumed proportional to the landings of reference $L_{i,s=sole,t=2014}$. Regarding the transfer of historical rights associated with fishery exits, we assume that the share transferred to the PO reserve is $POshr_i = 1$ for all vessel i that have PO membership whereas non-PO vessels are such that $NATshr_i = 1$.

A number of empirical studies have estimated that traditions tend to prevail upon economic drivers in fishermen individual choices related to their fishing activity (Holland and Sutinen, 1999; Marchal et al., 2009b, 2013). In keeping with the empirical estimations that can be found in Marchal et al. (2013), we set the relative weights given to balance anticipated profit and traditions to $\alpha = 0.2$ and $1 - \alpha = 0.8$ respectively, i.e. the individual effort on *other metier* can vary up to $\pm 20\%$ at each step t. The capital malleability parameter ω_i is assumed equal to 0.05 for all i. As recommended by Lebègue et al. (2005) for the evaluation of public projects in France, a discount rate of $r = 0.04$ is assumed for the computation of the net present value (eq. 4.7) and disinvestment decisions (eq. 4.18).

For the parameters that are relevant to the DS scenario, we set $t^{DS} = 2017$ and $Prem_{i,t}$ is calculated using the same method as in decommissioning schemes that have been implemented in various fisheries in France over the last decade[14]. The premium scale is reproduced in Table C3 (Appendix C). The time horizon considered in eq. 4.18 is $T = 20$ years.

[14] e.g. see https://www.legifrance.gouv.fr/affichSarde.do?idSarde=SARDOBJT000007105189

4.3.6 Multi-criteria indicators for impact assessment

The impact assessment multi-criteria analysis aims at rating the different management options proposed in terms of ecological, economic and social sustainability. The analysis that we carried out follows the general prescriptions of the EU guidelines (EC, 2009). For each of the ecological, economic and social sustainability dimensions, the assessment procedure consisted of the following steps:

- selection of a small set of relevant indicators
- description of the evolution of the situation under the baseline scenario
- quantitative measure and comparison of the relative effectiveness of alternative management scenarios using the baseline as reference point.

Long-term impacts were evaluated using the end year of the simulation period (2025) and transition phase impacts were measured on the first year where the simulated TAC was based on F_{MSY} (2017). Most of the selected indicators can be straightforwardly calculated from the output of the model. Additionally, the evolution of revenue inequality in the fishery was considered by means of the decomposability property of the Theil index that can be used to compute the contributions of different fleet segments to the total revenue inequality. A small contribution of a subgroup indicates that the distribution of revenue within the subgroup is homogeneous, and conversely. In addition, the between groups component indicates the importance of the contribution of the differences between subgroup averages in the total inequality. The formulas used to calculate each component of the Theil index are identical to those presented in Bellanger et al. (2016a).

4.4 Results

4.4.1 Fleet evolution

The BA scenario, characterized by the co-management by POs, results in a limited decrease of the number of vessels (-4% on the simulation period; see Figure 4.3) and thus in the conservation of the fleet structure in general. In this case, fishery exits are disinvestment decisions due to negative profits and vessels that leave are decommissioned without premium.

In the DS scenario, the simulated decommissioning scheme results in the exit (with premium) of 61 vessels that are notably constituted of 12-18 m trawlers for the most part (Figure 4.4a). As the discounted replacement value of vessels at the end of the discounting period is virtually not very significant for most vessels, the main drivers of the individual decision to stay or leave are the net present value of the expected gross operating surplus and the decommissioning premium. Noticeably, only few sole netters are expected to leave the fishery within the decommissioning scheme.

In the ITQ scenario, supplier or buyer vessels depend on the marginal profit per kg of sole compared to the equilibrium price of the quota (see Figures C6 and C7 in Appendix C). Depending on the year, between 39% and 46% of vessels lease out their individual quota of sole. The main suppliers are the sole netters and the specialized Nephrops trawlers, whereas the main buyers are the mixed netters and mixed bottom trawlers (Figure 4.4b). Therefore, it appears that highly specialized fleets have a lower willingness to pay than mixed fleets for which acquiring more quotas of sole increases the possibilities to catch a mix of species that includes sole.

Interestingly, 70% of the vessels decommissioned with premium in the DS scenario are vessels that actually lease in quota in the ITQ scenario (see Table C5 in Appendix C). This result shows that the introduction of ITQs would provide new possibilities to some vessels that would otherwise seize the opportunity of a decommissioning premium in a system without transferability. Thus, the simulated evolutions of the fleet structure under the DS and ITQ scenarios are quite differentiated, as are the evolutions of effort by fleet segment and metier according to each scenario (Figure C1 in Appendix C).

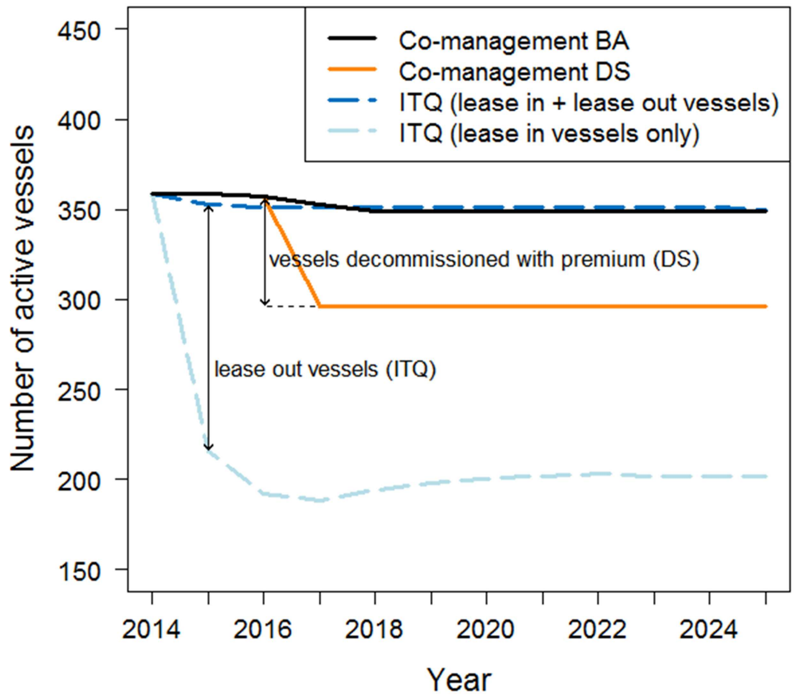


Figure 4.3: Evolution of the fleet size.

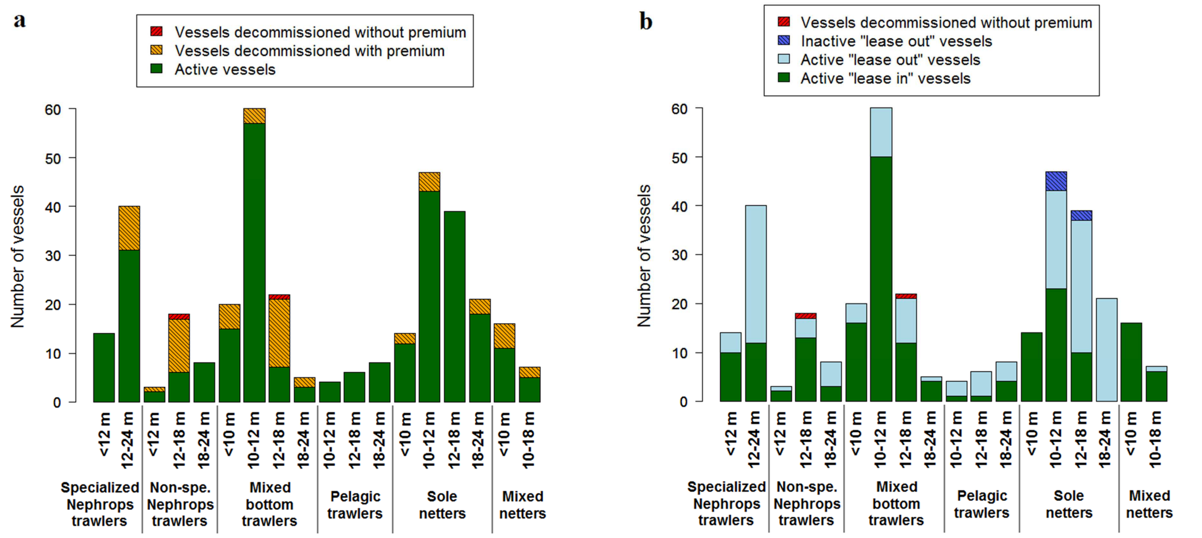


Figure 4.4: Simulated fleet structure in 2025 after (a) decommissioning scheme (DS scenario), (b) the introduction of individual transferable quotas (ITQ scenario).

4.4.2 Ecological impacts

Evolution under BA scenario

From a stock status perspective, the hypothesis of exploitation at F_{MSY} that is considered results in the progressive rebuilding of the SSB of sole as expected (+149% over the simulation period; Figure C2 in Appendix C). In the first year of exploitation at F_{MSY} (2017), sole landings drop to -22% of those of the initialization year (2014). By the end of the simulation (2025), sole landings have increased by +27% in comparison to those of 2014 and +63% in comparison to those of 2017. In the meantime, SSB of Nephrops also increases (+90% over the simulation period) as a consequence, at least partly, of constraining individual sole quotas limiting Nephrops exploitation for trawlers that catch a mix of species.

The total fishing effort, used as a proxy for impacts on habitats, first decreases by 31% between 2014 and 2017 due to decreasing TACs, and then is approximately constant until 2025 while the TACs are in fact increasing, which means that SSB recovery induces higher landings per unit of effort (Figure 4.5a). The total trawling "energy effort", measured as the engine power in kW multiplied by the fishing time of trawlers, decreases by 33% between 2014 and 2017, and then only slightly increases between 2017 and 2025 (+7%) (Figure 4.5b). Not surprisingly, the global trawling effort in hours and total fuel consumption, also used as proxies for impacts on habitats and carbon footprint, follows an analogous path (Figure C5 in Appendix C).

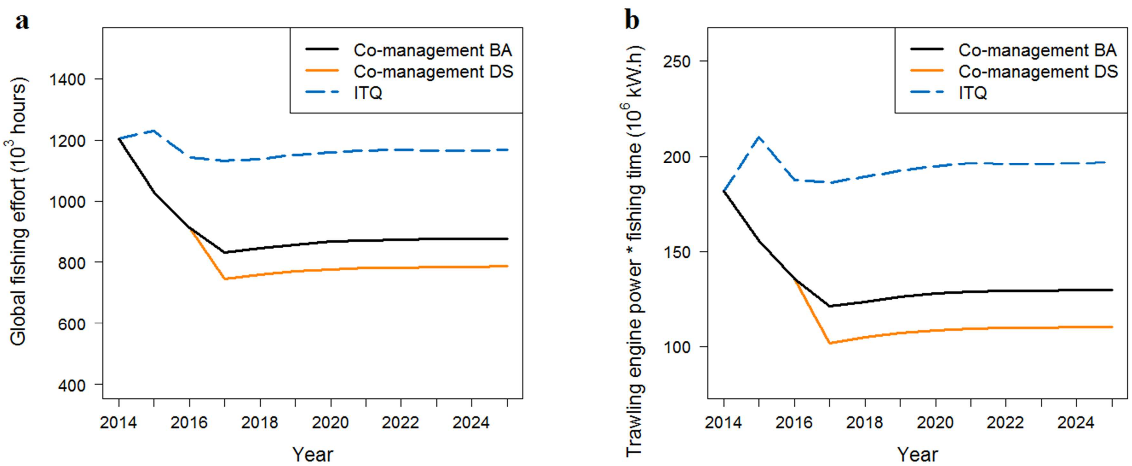


Figure 4.5: Impacts on habitats: evolution of (a) fishing effort, (b) trawling "energy effort".

Evaluation of the effectiveness of DS and ITQ scenarios

The respective performance on ecological indicators of the DS and ITQ options evaluated against the baseline (DS/BA and ITQ/BA) are summarized in Table 4.2. The differences on stock status observed between options are explained by changes in the global fishing pattern (mortality at age) and thus in the biomass at age due to variations in the distribution of the TAC among vessels that have different exploitation pattern (see Figure C4 in Appendix C for exploitation patterns). The co-management BA and DS options provide higher sole SSB than the ITQ option. As the final distribution of quota according to the ITQ option is essentially shifted from sole netters fleet to the trawlers fleets that have an exploitation pattern less selective of smaller individuals, the sole SSB recovers less quickly than in the co-management options. Overall, the DS option performs better than the BA option on ecological indicators. Particularly, the total fishing effort and trawling energy effort are decreased (-10% and -16% in 2017, respectively). To the contrary, the ITQ option induces greater impacts on habitats and increase significantly fuel consumption.

Table 4.2: Assessment of ecological impacts of alternative management options

	Indicator	Transition phase (2017)		Long-term impacts (2025)	
		DS *vs* BA	ITQ *vs* BA	DS *vs* BA	ITQ *vs* BA
Stock status	SSB sole (t)	+0%	+0%	+0%	-8%
	SSB Nephrops (t)	+0%	-3%	+5 %	-9%
	Landings sole (t)	+0%	+11%	+0%	+2%
Impacts on habitats proxies	Fishing effort (h/year)	-10%	+36%	-10%	+33%
	Trawling energy effort (kWh)	-16%	+53%	-15%	+52%
Carbon footprint	Fuel consumption (L/year)	-11%	+41%	-11%	+38%

4.4.3 Economic impacts

Evolution under BA scenario

The total gross operating surplus of the fishery first decreases by 27% between 2014 and 2017 due to decreasing TACs (Figure 4.6a). The economic viability of the fleet hits its lowest point in 2017 with 7% of vessels having a negative gross operating surplus that year (Figure 4.6b). The fleetwide gross operating surplus then increases between 2017 and 2025 together with SSB recovery and increasing TACs. By 2019 the gross operating surplus is higher than the initial value, and overall it increases by 42% over the simulation period (Figure 4.6a). The rate of increase appears to tend to zero toward the end of the simulation as the bio-economic system tends to reach equilibrium. The cumulative net present value of fleetwide net profits throughout the simulation period is 202 million €.

The total economic inequality between vessels, measured with the Theil index applied to the gross value of landings, is slightly increasing between 2014 and 2017 and is constant after (Figure 4.7; see Figure C8 in Appendix C for a similar result obtained with the Gini index). The decomposition of the inequality by fleet (Figure 4.7a) reveals that the main contributors to the increase between 2014 and 2017 are the Nephrops trawlers. The decomposition by length class (Figure 4.7b) shows that inequalities among the < 10 m and > 20 m vessels are small. The between groups component was found more important between than in the case of decomposition by fleets, which means that revenues within fleets are more homogeneous than within length class.

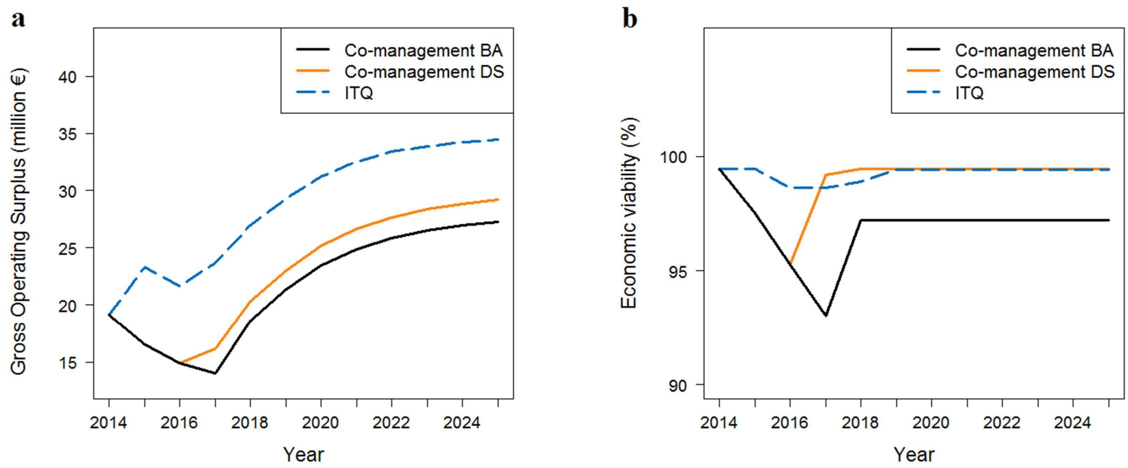


Figure 4.6: Evolution of (a) the total gross operating surplus, (b) economic viability index: % vessels with gross operating surplus > 0.

Evaluation of the effectiveness of DS and ITQ scenarios

Out of the three scenarios tested, the management of quotas through ITQs appears to be the most economically efficient option both in the short and long terms (Figure 4.6a). As compared to the baseline, the ITQ scenario increases the gross operating surplus of the fishery by 69% during the phase of transition to MSY and by 33% the net present value of profits over the whole simulation period (Table 4.3). To a lesser extent, the DS scenario also achieves better economic efficiency than the baseline. Both the DS and ITQ scenarios allow improving the economic viability of the fleet, particularly during the transition phase (+7% and +6% in 2017, respectively).

Economic impacts also include the evolution of inequality associated with profitability changes induced by alternative management options. Inequality between vessels is globally expected to increase after the introduction of ITQs (+25% in 2025). According to the decomposition by fleet, it appears that this is mainly due to an increase in inequality within the sole netters and, to a lesser extent, within the mixed bottom trawlers (Figure 4.7e). This result relates to the fact that these two fleets constitute most of the sole quota demand in the simulated quota market (Figure C7 in Appendix C) so that some (but not all) vessels of these groups increase their revenue, hence the increased inequality within these groups. It is also notable that inequality increases within all length classes (Figure 4.7f), which suggests that small-scale and large-scale vessels are all concerned with this issue in the ITQ scenario. Conversely, inequality appears to be decreasing in the DS scenario (-7% compared to the BA scenario in the year after the application of the decommissioning scheme), this reduction being mostly associated to distributional changes in the trawler fleets (Figure 4.7c). This result can be explained by the fact that the vessels that exited the fishery with a decommissioning premium are essentially vessels with poor economic performances, so that the vessels that remained in the fleet are somewhat more homogenous in terms of revenue.

Table 4.3: Assessment of economic impacts of alternative management options

Indicator		Transition phase (2017)		Long-term impacts (2025)	
		DS *vs* BA	ITQ *vs* BA	DS *vs* BA	ITQ *vs* BA
Profits	Gross Operating Surplus (€)	+15%	+69%	+7%	+27%
Economic efficiency	Cumulative net present value of Net Profit (€)			+6%	+33%
Economic viability	Gross Operating Surplus > 0 (% vessels)	+7%	+6%	+2%	+2%
Economic inequality	Theil index applied to gross value of landings (entropic distance from perfect equality)	-7%	+23%	-5%	+25%

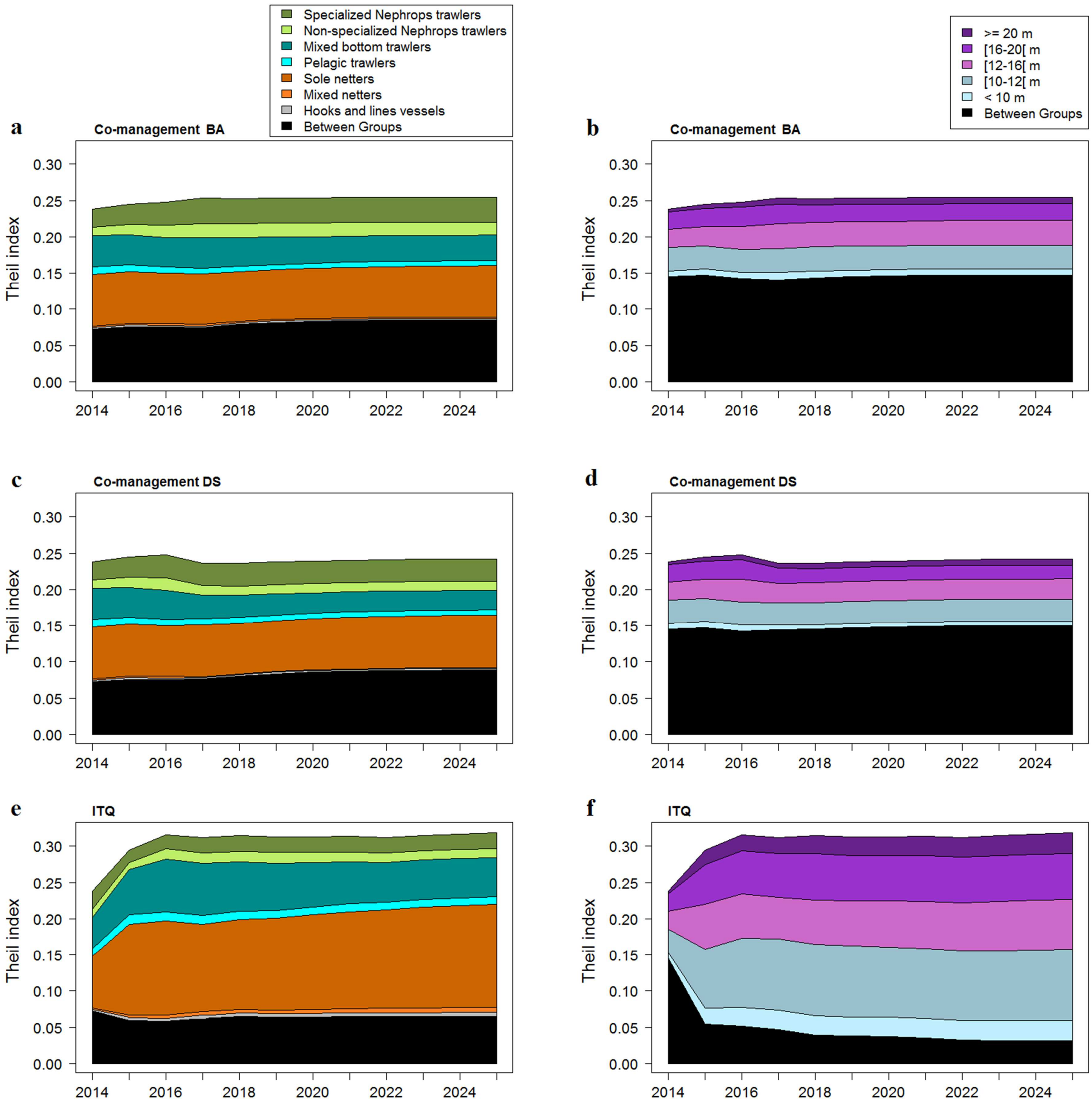


Figure 4.7: Evolution of inequality between vessels: Theil index applied to gross value of landings (a) BA scenario – decomposition by fleet, (b) BA scenario – decomposition by length class, (c) DS scenario – decomposition by fleet, (d) DS scenario – decomposition by length class, (e) ITQ scenario – decomposition by fleet, (f) ITQ scenario – decomposition by length class.

4.4.4 Social impacts

Evolution under BA scenario

For the purpose of the analysis, employment hours are measured as the sum over all vessels in the fishery of the yearly number of hours at sea per metier and multiplied by average crew per metier (Figure 4.8a). Notably, variations in employment hours are identical to variations in full time equivalent (FTE) employment as those two proxies only differ by a scalar. Under the BA scenario, employment hours first decrease by 32% between 2014 and 2017 and then slightly increase between

2017 and 2025 (+5%) but remains significantly lower than their initial level. The average time at sea, used as a proxy for drudgery of work, follows a similar trajectory (Figure 4.8c). Contrastingly, the average hourly wage per crew increases from 18 €/h to 28 €/h over the simulation period (Figure 4.8d) so that the average yearly wage per crew in 2025 is greater than its 2014 level (+20%) despite the reduction of the time at sea. Therefore, these results suggest that the socio-economic benefits expected from MSY exploitation are mostly directed to enhance wages rather than the number of jobs in the fishery. Additionally, the salary increases appear to be accompanied by a moderate augmentation of the total inequality among yearly wage per crew (Figure C9 in Appendix C). The decomposition of this inequality by segments indicates that this is due to increased inequality between fleets and more heterogeneous wages within the larger-scale vessels length classes (see Figure C10 in Appendix C). Since most vessels remain active in this scenario, changes in fleet composition and territorial impacts are minimal.

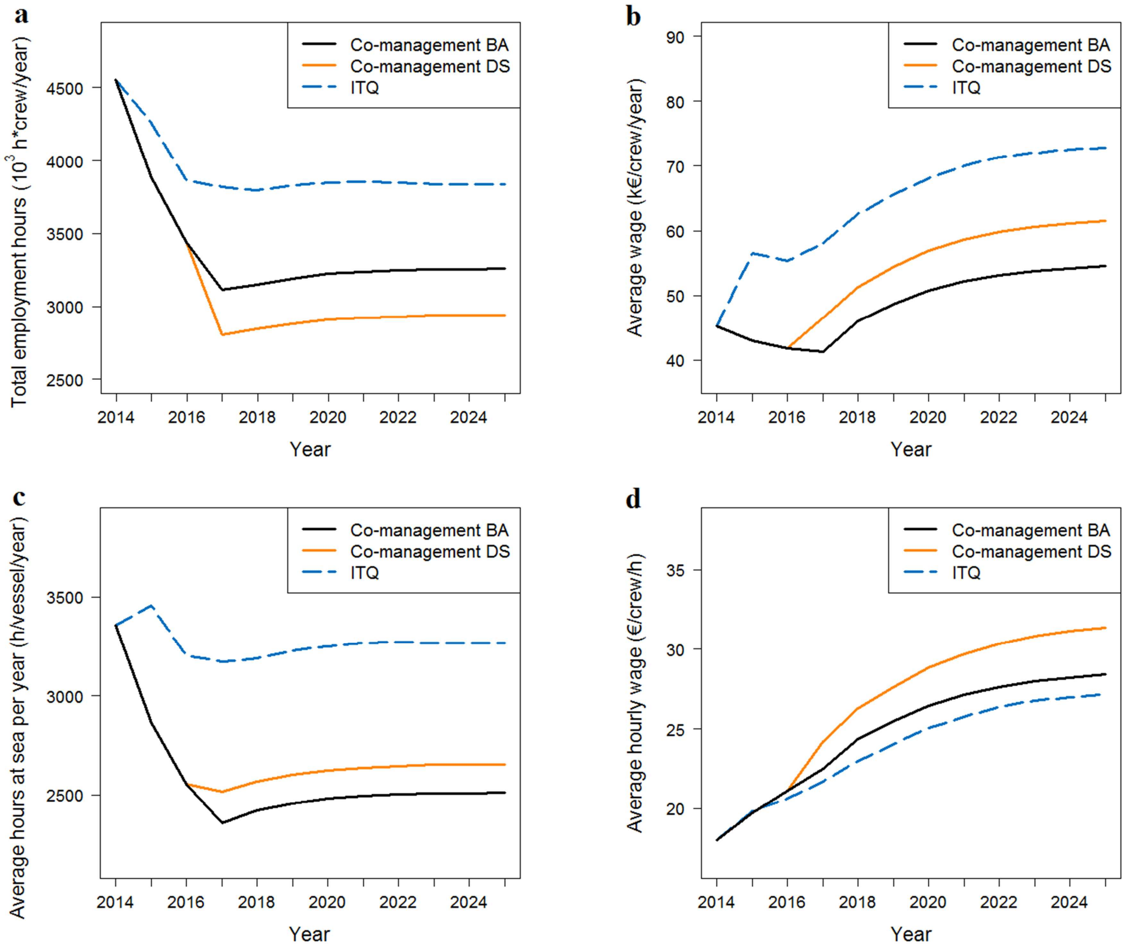


*Figure 4.8: Social impacts: evolution of (a) total employment hours in the fishery (hours at sea * crew), (b) average crew remuneration per year, (c) average time at sea, (d) average hourly wage.*

Evaluation of the effectiveness of DS and ITQ scenarios

Social impacts of the DS scenario notably include lower employment hours in the fishery than in the BA scenario (-10%) but higher average yearly wage (+13%) (Table 4.4). Wage inequality is also marginally decreased, particularly within the mixed bottom trawlers fleet (Figure C10c in Appendix C), as a result of the decommissioning scheme. Therefore, the effectiveness of the DS scenario in the social dimension is contrasted between lower employment hours and improved wage conditions. In addition, changes in fleet composition in this scenario mainly concern the decommissioning of 12-18 m trawlers that essentially operate in the north of the Bay of Biscay.

Oppositely, the ITQ scenario leads to higher employment hours and average yearly wage, but this is mostly related to a higher time at sea per year (Figure 4.8; Table 4.4). In fact, average hourly wage is lower than in the other scenarios. In addition, wage inequality greatly increase due to distributional changes in the sole netters and mixed bottom trawlers fleets (see Figure C10e in Appendix C). As such, the social acceptability performance indicators of the ITQ scenario are essentially inferior to those of the BA and DS scenarios, although this may be offset to some extent by increased yearly wages. In terms of territorial impacts, the larger-scale sole netters (> 10 m), which essentially operate in the south of the Bay of Biscay, are the predominant fleet segments leasing out their quotas to Nephrops trawlers and mixed bottom trawlers. Therefore, the introduction of ITQs could potentially induce a shift of activity in the fishery from the south to the north of the Bay of Biscay as well as a change in the nature of the work itself since operating on a trawler is quite different to operating on a netter.

Table 4.4: Assessment of social impacts of alternative management options

	Indicator	Transition phase (2017)		Long-term impacts (2025)	
		DS *vs* BA	ITQ *vs* BA	DS *vs* BA	ITQ *vs* BA
Employment hours	Crew * hours at sea (h/year)	-10%	+23%	-10%	+18%
Acceptability	Average yearly wage per crew (€/year)	+13%	+41%	+13%	+34%
	Average hourly wage (€/year)	+8%	-4%	+10%	-4%
	Time at sea (h/year)	+7%	+35%	+6%	+30%
	Wage inequality: Theil index applied to yearly wage per crew	-12%	+94%	-5%	+97%

4.4.5 Summary of trade-offs

The results of the simulations show differentiated impacts between the three governance options for the Bay of Biscay sole quotas and reveal the trade-offs between ecological, economic and social performances for each option (see Tables 4.2-4). The baseline co-management scenario toward MSY achieves satisfactory ecological objectives in general including the rebuilding of the sole and Nephrops stocks and the reduction of impact on habitats and carbon footprint. However, under this management option, which is linked to an objective of maintaining the fishing activity of almost all vessels, the evolution of the socio-economic situation is a major issue in a context of overcapacity and transition to MSY. In the short term, the primary concern is the economic viability of the fleet. In the longer term, employment hours are also expected to decrease despite management objectives directed to maintaining the fleet structure.

According to the second scenario that combines the current co-management arrangements with a decommissioning scheme, the capacity reduction achieved by the decommissioning scheme would mostly be associated to the exit of trawlers. This would benefit to the stock by improving the exploitation pattern and providing more quotas for sole netters that are more selective fleets. This would also significantly improve the profitability and economic viability of the fleet as compared to the baseline. In terms of social impacts, this option offers an increased hourly wage but lower employment hours than the baseline.

According to the quota market simulation, the ITQ option would change the distribution of the quota among fleets and would lead sole netters to lease out their quota to other fleets that are not specialized on sole. Results show that ITQs would generate higher profits than the other options, ensuring high economic viability and improving the economic efficiency of the fishery in the long term. However, this favourable economic situation comes at a price: increased inequalities in the fishery as well as greater carbon footprint and impacts on habitats due to increased trawling effort. As such, social and ecological concerns may impede the acceptability of this ITQ option. If ITQs were to be implemented in reality, safeguards on tradability (e.g. to limit quota concentration and transfers from netters to trawlers) may be necessary to gain support from the industry and public opinion.

4.5 Discussion and concluding remarks

4.5.1 Subsidies and cost of public policies

The Green Paper (CEC, 2009) identifies heavy subsidies as one of the main problems of the CFP and thus tends to promote the use of ITQs rather than public-aided decommissioning schemes to achieve necessary reduction of fleet capacity. The choice of a decommissioning scheme is clearly a matter related to the costs of public policies. However, the industry also benefits from the overall exemption from fuel taxes, considered as indirect subsidies (Borrello et al., 2013). This also relates to the push to integrate ecological concerns into fisheries management, as illustrated by the following quote from the Green Paper: "Some of the most fuel-intensive fishing practices are increasingly harder to justify given the need to reduce greenhouse gas emissions" (CEC, 2009). Therefore, it may be relevant not to overlook the issue of indirect subsidies through fuel taxes exemption in the assessment of the cost of public policies (OECD, 2006). As such, it is interesting for the purpose of our analysis to compare the cost of the decommissioning scheme (DS scenario) with the expected level of fuel taxes exemptions, especially since results indicates that fuel consumption is greatest in the ITQ scenario. According to the estimates generated with our simulations, the total cost of the decommissioning scheme is 15.2 million euros whereas annual average fuel tax exemptions in the ITQ and DS scenarios are 26.1 and 17.5 million euros, respectively (see Table C6 in Appendix C). Put differently, the cost of the decommissioning scheme is less than the difference between the ITQ and DS scenarios in fuel tax exemptions for two years. This somewhat mitigates the widely-acknowledged affirmation that ITQs are more cost-effective than public-aided decommissioning schemes for achieving capacity reduction and also raises the question as to whether public financial support should be directed to promote ecological sustainability, which could be one way to justify the funding of a decommissioning scheme in this context. Not investigated in this analysis, including fuel taxes in the ITQ scenario would presumably induce a shift of the quota demand toward less energy-consuming fleets, thereby improving the ecological performance of this option while reducing the level of indirect subsidies. Alternatively, introducing a limitation on quota transfers from netters to trawlers in the design of the ITQ program would likely generate a similar effect.

4.5.2 Added value of including institutional arrangements into bio-economic modelling frameworks, current limitations and perspectives

The paper illustrates the complexity of the co-management of quota implemented by French POs in the Bay of Biscay sole fishery. Including institutional arrangement involving POs, such as the management of catch shares, historical landings track records and internal reallocations, into the model allowed to improve the comparability of PO-based co-management systems with market-based systems. Besides, simulating the constraints and strategies of producers at the vessel level is also critical to better assess the impacts of alternative management options. Thus, the present model constitutes a step forward to inform institutional design of catch share programs and help focusing the decision-making framework on achieving sustainability objectives.

Despite this outline of practical elements that makes this contribution relevant to help improve the bio-economic methodologies used for impact assessment, further developments could be considered as there is a number of assumptions and limitations that can potentially impede the realism of the model and scenarios as it stands. First, the parameterization of the initial allocation of catch shares was assumed proportional to the landings of reference, which could significantly differ from allocation keys used by POs in reality (Guyader et al., 2014). The model could easily incorporate allocation rules that vary depending on the PO. The difficulty lies in the fact that these rules are not necessarily made public by POs and that they may change from one year to another depending on quota availability, which makes it challenging to include as input of the model. With the push to make quota allocation decisions more objective and transparent under Article 17 of the CFP (EU, 2013), publicly available documentation on the methods and criteria used by POs for quota allocation may be demanded by authorities, thereby clarifying the quota management of POs. This information could be highly beneficial to the parameterization of the model and to the exploration of additional management scenarios.

There are also multiple assumptions made for the modelling of the ITQ market that directly influences the results of this scenario. The quota market was assumed to be a quota lease market whereas most ITQ programs also allow for permanent transfer of quota shares (Holland, 2016). In turn, fleets' dynamics related to long-term behaviour of fishermen, i.e. changes in the level of capital investment, in a quota market situation were very limited and thus expected consequences of capacity adjustment were not fully assessed. Nevertheless, quota concentration phenomenon, which is one of the expected effects of implementation of an ITQ market as described in the literature (Squires et al., 1998; Arnason, 2002) and underlined as a potential undesirable shift by a number of stakeholders fighting against implementation of ITQs, still occurs in a quota lease market (Pinkerton and Edwards, 2009; Van Putten and Gardner, 2010). Our simulations suggest that we could expect about 40% of vessels leasing out their quota, a result somewhat comparable to empirical evidence found in the literature (e.g., Hamon et al. (2009) and Abbott et al. (2010) observed -35% of vessels in the Tasmanian rock lobster fishery and -58% of vessels in the Bering Sea crab fisheries a few years after the introduction of ITQs, respectively). However, quota distribution adjustment after introduction of ITQ was considered instantaneous and fully efficient in the model, i.e. with minimal transaction costs (Squires et al., 1998). In reality, ITQ markets generally mature slowly and there may be a number of elements that could limit their efficiency (Holland, 2016). Some factors influencing fishers leasing decisions such as imperfect information (e.g. uncertainty on future catch rates or a lack of publicly available information on quota price) are not captured by the marginal profit equation used in the model while they have been found to impact the efficiency of quota markets in reality. In addition, the changes observed in the distribution of the quota among fleets are an inherent consequence of considering the implementation of a quota market for only one species in a mixed fishery context. Compared to fleets that are most dependent on sole, non-specialized fleets have a higher willingness to pay for additional sole quota in order to be able to catch their by-product that represent a large part of their gross revenue (in reality, considering possible legal or illegal discarding practices may mitigate this result and alter the final distribution of the ITQ). To the contrary, sole netters that are very selective and dependent on sole have strong incentive to lease out their quota in our ITQ simulation. These results are highly dependent on the level of aggregation considered to model the joint production function and the single-species quota market represented in the model. As such, the assumptions on the possible effort reallocation by vessel and the possibility to consider a multispecies ITQ market would need to be further explored to consolidate our analysis.

Aside from these ITQ modelling issues, the landings obligation featured in the last CFP and progressively implemented in EU fisheries was not included in the present analysis although it may effectively challenge the efficiency of the current quota management system and increase the need for quota transferability. Indeed, in a multispecies fishery context, individual fishermen may have a limited ability to control the species composition of their catch and avoid specific stocks (Macher et al., 2008; Holland, 2016; Scheld and Anderson, 2017). Another consideration that was not integrated in the model is the potential dynamics and structural changes of crew remuneration systems (Guillen et al., 2015). Most fisheries worldwide traditionally use a share system to remunerate crew and the analyses that we carried out were performed assuming a fixed share rate. In reality, crew remuneration systems can be altered in response to new management measures (Guyader and Thébaud, 2001). For example, it has been theorized and observed that the introduction of ITQs can induce a reduction of crew share rates or a transfer of lease fees to crews in order to cover the cost of quota purchases (McCay, 1995; Wilen and Casey, 1997; Guyader, 2002; Abbott et al., 2010). In any case, labor contracts between vessel owners and crew are complex arrangements and available information on these is scarce, making it challenging to incorporate possible dynamics of remuneration systems into bio-economic modelling frameworks. Finally, the fishery management costs were not taken into account in our analyses and should be taken into consideration in a full cost-effectiveness analysis of alternative options (OECD, 2003). Regardless of whether individual quotas are transferable, the institutional design of PO-based catch share systems has important implications for management costs (Van Hoof, 2010). For example, the fishery authorities may be able to promote compliance while reducing their own monitoring expenditure by taking advantage of a joint liability mechanism and ensuring POs have well designed internal compliance systems (Bellanger et al., 2016b). Besides, some imposition of fees on resource rents to contribute to management costs is more likely in ITQ fisheries as they are capable of generating substantial economic profits. According to Arnason et al. (2002), such mechanisms (known as cost recovery or catch fees) have been effectively implemented in most ITQ fisheries, albeit the fees actually collected are substantially less than the total management costs incurred by the fishery authorities.

Although informative in terms of quantifying the trade-offs between management objectives, the analysis did not reveal any win-win-win scenario among those tested. This suggests that neither the current institutions nor the introduction of an ITQ market are likely to make such solutions emerge. As suggested by Burgess et al. (2017), the focus should be on the design of institutions, which should be goal-oriented to maximize the chances of finding solutions that improve outcomes in all three sustainability dimensions simultaneously. This underscores the relevance of integrating institutional arrangements into bio-economic modelling frameworks to better understand the potential impacts of management options and inform institutional design, although this does not ensure finding win-win-win management options. To this end, the (co-)viability approach, aimed at identifying feasible paths toward desirable objectives within a set of ecological, economic and social constraints, offers interesting insights (Martinet et al., 2007; Péreau et al., 2012; Thébaud et al., 2014; Gourguet et al., 2016). However, bio-economic viability simulation modelling approaches have not fully integrated the impacts of management systems on fishermen individual constraints yet, which could be an interesting subject of research considering the push to develop integrated multi-objective tools.

Acknowledgement

This work was funded by the Région Bretagne and by EU FP7 SOCIOEC project (Grant no. 289192). This financial support is gratefully acknowledged. Economic data provision was supported by a public grant overseen by the French National Research Agency (ANR) as part of the "Investissements d'Avenir" program (reference: ANR-10-EQPX-17 - Centre d'accès sécurisé aux données – CASD).

References

Abbott, J.K., Garber-Yonts, B., Wilen, J.E. (2010). Employment and remuneration effects of IFQs in the Bering Sea/Aleutian Islands crab fisheries. Marine Resource Economics 25(4), 333-354.

Aranda, M., Murillas, A. (2015). Allocation of fishing possibilities, incentives and outcomes: Insights from Basque fishermen's organisations in Spain. Marine Policy 61, 171-178.

Arnason, R. (2002). A review of international experiences with ITQs. Annex to Future Options for UK Fishing Management, Report to the Department for the Environment, Food and Rural Affairs, CEMARE, University of Portsmouth, UK.

Asche, F., Eggert, H., Gudmundsson, E., Hoff, A., Pascoe, S. (2008). Fisher's behaviour with individual vessel quotas--Over-capacity and potential rent: Five case studies. Marine Policy 32, 920-927.

Autorité de la concurrence. (2015). Avis n°15-A-19 du 16 décembre 2015 relatif aux effets sur la concurrence du mécanisme de répartition des quotas de pêche en France. Autorité de la concurrence, République Française, available online at http://www.autoritedelaconcurrence.fr/pdf/avis/15a19.pdf.

Bellanger, M., Macher, C., Guyader, O. (2016a). A new approach to determine the distributional effects of quota management in fisheries. Fisheries Research 181, 116-126.

Bellanger M., Holland D., Anderson C.M., Guyader O., Macher C. (2016b). A game-theoretic model of monitoring and compliance in fishery cooperatives. 18th Biennial Conference of the International Institute for Fisheries Economics and Trade, Aberdeen, Scotland July 2016.

Beverton, R.J.H., Holt, S.J. (1957). On the dynamics of exploited fish populations. Fishery Investigations, 2 (19), HMSO, Londres: 533 p.

Borrello, A., Motova, A., Dentes de Carvalho, N. (2013). Fuel subsidies in the EU fisheries sector. In: Policy Department B: Structural and Cohesion Policies. European Parliament, Italy.

Bunnefeld, N., Hoshino, E., Milner-Gulland, E.J. (2011). Management strategy evaluation: a powerful tool for conservation?. Trends in Ecology & Evolution 26(9), 441-447.

Burgess, M.G., Clemence, M., McDermott, G.R., Costello, C., Gaines, S.D. (2017). Five rules for pragmatic blue growth. Marine Policy (in press).

CEC. (2009). Commission of the European Communities. Green paper: reform of the Common Fisheries Policy. COM (2009)163 final CEC, Brussels.

Clark, C.W., Clarke, F.H., Munro, G.R. (1979). The optimal exploitation of renewable resource stocks: problems of irreversible investment. Econometrica, 25-47.

Clark, C.W. (2006). The worldwide crisis in fisheries: economic models and human behavior. Cambridge University Press.

Coelho, M.F., Filipe, J.A., Ferreira, M.A.M. (2011). Rights based management and the reform of the common fisheries policy: the debate. International Journal of Latest Trends in Finance and Economic Sciences, 1(1).

Deacon, R.T. (2012). Fishery management by harvester cooperatives. Review of Environmental Economics and Policy 6(2), 258-277.

European Commission. (2006). Council regulation No 388/2006 of 23 February 2006 establishing a multiannual plan for the sustainable exploitation of the stock of sole in the Bay of Biscay. Official journal of the European Union L 65/1 7.3.2006.

European Commission. (2010). Development of Protocols for Multi-annual Plan Impact Assessments. Scientific, Technical and Economic Committee for Fisheries (STECF) SGMOS-10-0.

European Union. (2013). Regulation (EU) 138/2013 of the European Parliament and the Council of the 11 of December 2013 on the Common Fisheries Policy. Official Journal of European Union, L354/22, 28.11.2013.

Frangoudes, K., Bellanger, M. (2017). Fishers' opinions on marketization of property rights and the quota system in France. Marine Policy 80, 107-112.

Fulton, E.A., Smith, A.D., Smith, D.C., Johnson, P. (2014). An integrated approach is needed for ecosystem based fisheries management: insights from ecosystem-level management strategy evaluation. PLoS One 9(1), e84242.

Garcia, D., Prellezo, R., Sanchez, S., Andres, M., Santurtun, M. (2012). FLBEIA: A toolbox to conduct bio-economic impact assessment of fisheries management strategies. In: ICES ASC, Bergen.

German, L., Keeler, A. (2009). "Hybrid institutions": Applications of common property theory beyond discrete tenure regimes. International Journal of the Commons, 4(1).

González Laxe, F. (2006). Transferability of fishing rights: The Spanish case. Marine Policy 30, 379-388.

Gourguet, S., Thébaud, O., Jennings, S., Little, L.R., Dichmont, C.M., Pascoe, S., Deng, R.A., Doyen, L. (2016). The cost of co-viability in the Australian northern prawn fishery. Environmental Modeling & Assessment 21(3), 371-389.

Gourguet, S., Macher, C., Doyen, L., Thébaud, O., Bertignac, M., Guyader, O. (2013). Managing mixed fisheries for bio-economic viability. Fisheries Research 140, 46-62.

Gouvernement Français. (2009). Mémorandum français relatif à la réforme de la politique commune de la pêche. Paris. Available online at http://ec.europa.eu/ fisheries/reform/docs/france memo fr.pdf.

Grafton, R.Q. (1996). Individual transferable quotas: theory and practice. Reviews in Fish Biology and Fisheries 6(1), 5-20.

Grafton, R.Q., McIlgorm, A. (2009). Ex ante evaluation of the costs and benefits of individual transferable quotas: A case-study of seven Australian commonwealth fisheries. Marine Policy 33, 714-719.

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, 64-74.

Guillen, J., Macher, C., Merzéréaud, M., Boncoeur, J., Guyader, O. (2015). Effects of the Share Remuneration

System on Fisheries Management Targets and Rent Distribution. Marine Resource Economics 30(2), 123-138.

Gutierrez, N.L., Hilborn, R., Defeo, O. (2011). Leadership, Social capital and incentives promote successful fisheries. Nature 470, 386-389.

Guyader, O., Metz, S., Macher, C., Merzereaud, M., Daures, F., Le Floc'h, P., Bellanger, M. (2014). Self-imposed catch shares by French producers organizations. IIFET 2014, International Institute of Fisheries Economics & Trade. 7-11 July 2014, Brisbane, Australia.

Guyader, O., Thébaud, O. (2001). Distributional issues in the operation of rights-based fisheries management systems. Marine Policy 25(2), 103-112.

Guyader, O. (2002). Simulating the effect of regulatory systems in a fishery, an application to the French driftnet Albacore fleet. Environmental and Resource Economics 23(1), 1-28.

Hamon, K., Thébaud, O., Frusher, S., Little, L.R. (2009). A retrospective analysis of the effects of adopting individual transferable quotas in the Tasmanian red rock lobster, Jasus edwardsii, fishery. Aquatic Living Resources 22(4), 549-558.

Hatcher, A. (1997). Producers' organizations and devolved fisheries management in the United Kingdom: collective and individual quota systems. Marine Policy 21 (6), 519-533.

Holland, D.S., Sutinen, J.G. (1999). An empirical model of fleet dynamics in New England trawl fisheries. Canadian Journal of Fisheries and Aquatic Sciences 56(2), 253-264.

Holland, D.S. (2010). Management Strategy Evaluation and Management Procedures: Tools for Rebuilding and Sustaining Fisheries, OECD Food, Agriculture and Fisheries Working Papers, No. 25, OECD Publishing. http://dx.doi.org/10.1787/ 5kmd77jhvkjf-en.

Holland, D.S. (2016). Development of the Pacific Groundfish Trawl IFQ Market. Marine Resource Economics 31(4), 453-464.

Hopkins, T., Bailly, D., Elmgren, R., Glegg, G., Sandberg, A., Støttrup, J. (2012). A systems approach framework for the transition to sustainable development: potential value based on coastal experiments. Ecology and Society 17(3).

ICES. (2015). Report of the Working Group for the Bay of Biscay and the Iberian waters Ecoregion (WBGIE), 4-10 May 2015 Copenhagen, Denmark. Ref ICES CM/ACOM:11. 503 pp.

IREPA Onlus (Coordinator). (2006). Evaluation of the capital value, investments and capital costs in the fisheries sector. N° FISH/2005/03, 203p.

Ives, M.C., Scandol, J.P., Greenville, J. (2013). A bio-economic management strategy evaluation for a multi-species, multi-fleet fishery facing a world of uncertainty. Ecological Modelling 256, 69-84.

Jentoft, S. (1989). Fisheries co-management: Delegating government responsibility to fishermen's organizations. Marine Policy 13, 137-154.

Journal Officiel de la République Française (JORF). (1997). Loi n° 97-1051 du 18 novembre 1997 d'orientation sur la pêche maritime et les cultures marines. NOR: AGRX9600072L

Journal Officiel de la République Française (JORF). (2006). N°301 du 29 décembre 2006 page 19953 texte n°104: Arrêté du 26 décembre 2006 établissant les modalités de répartition et de gestion collective des possibilités de pêche (quotas de captures et quotas d'effort de pêche) des navires français immatriculés dans la Communauté européenne. NOR: AGRM0602585A.

Larabi, Z., Guyader, O., Macher, C., Daurès, F. (2013). Quota management in a context of non-transferability of fishing rights: the French case study. Ocean and Coastal Management 84, 13-22.

Lebègue, D., Baumstark, L., Hirztman, P. (2005). Révision du taux d'actualisation des investissements publics. Commissariat Général au Plan, France, 112 pp.

Le Floc'h, P., Murillas, A., Aranda, M., Daurès, F., Fitzpatrick, M., Guyader, O., Hatcher, A., Macher, C., Marchal, P. (2015). The regional management of fisheries in European Western Waters. Marine Policy 51, 375-384.

Macher, C., Guyader, O., Talidec, C., Bertignac, M. (2008). A cost-benefit analysis of improving trawl selectivity in the case of discards: The Nephrops norvegicus fishery in the Bay of Biscay. Fisheries Research 92(1), 76-89.

Macher, C., Merzéréaud, M., Le Grand, C., Frésard, M., Bertignac, M., Fifas, S., Guyader, O., Biais, G., Lissardy, M., Jadaud, A., Le Corre, G., Frangoudes, K., Daurès, F., Van Iseghem, S., Raveau, A. (2011). Groupe de travail partenarial pourla construction d'outils bio-économiques d'aide à la décision pour l'aménagement des pêcheries. Publications électroniques Amure, Série Rapports R-21-2011, 44.

Malvarosa, L., Motova, A., Doering, R., Murillas, A., Gothi, Macher, C., L., Lehuta, S., Nielsen, R., Araldson, G., Accadia, P. (2015). Improvements in Impact Assessment for Fisheries Management: The Socioec Experience. XXII conference of the European Association of Fisheries Economist, April 28-30 2015, Salerno, Italy.

Marchal, P., Lallemand, P., Stokes, K., Thébaud, O. (2009a). A comparative review of the fisheries resource management systems in New Zealand and in the European Union. Aquatic Living Resources 22(4), 463-481.

Marchal, P., Lallemand, P., Stokes, K. (2009b). The relative weight of traditions, economics, and catch plans in New Zealand fleet dynamics. Canadian Journal of Fisheries and Aquatic Sciences 66(2), 291-311.

Marchal, P., Little, L.R., Thébaud, O. (2011). Quota allocation in mixed fisheries: a bioeconomic modelling approach applied to the Channel flatfish fisheries. ICES Journal of Marine Science 68(7):1580-1591.

Marchal, P., De Oliveira, J.A., Lorance, P., Baulier, L., Pawlowski, L. (2013). What is the added value of including fleet dynamics processes in fisheries models?. Canadian Journal of Fisheries and Aquatic Sciences 70(7), 992-1010.

Marchal, P., Andersen, J.L., Aranda, M., Fitzpatrick, M., Goti, L., Guyader, O., Haraldsson, G., Hatcher, A., Hegland, T.J., Le Floc'h, P., Macher, C., Malvarosa, L., Maravelias, C., Mardle, S., Murillas, A., Nielsen, J.R., Sabatella, R., Smith, A.D.M., Stokes, K., Thoegersen, T., Ulrich, C. (2016). A comparative review of fisheries management experiences in the European Union and in other countries worldwide: Iceland, Australia, and New Zealand. Fish and Fisheries 17, 803-824.

Mardle, S., Pascoe, S., Boncoeur, J., Le Gallic, B., García-Hoyo, J.J., Herrero, I., Jimenez-Toribioc, R., Cortesc, C., Padillac, N., Nielsen, J.R., Mathiesen, C. (2002). Objectives of fisheries management: case studies from the UK, France, Spain and Denmark. Marine Policy 26(6), 415-428.

McCay, B.J. (1995). Social and ecological implications of ITQs: an overview. Ocean and Coastal Management 28(1), 3-22.

Merino, G., Barange, M., Fernandes, J.A., Mullon, C., Cheung, W., Trenkel, V., Lam, V. (2014). Estimating the economic loss of recent North Atlantic fisheries management. Progress in Oceanography 129, 314-323.

Merzéréaud, M., Macher, C., Bertignac, C., Frésard, M., Le Grand, C., Guyader, O., Daurès, F., Fifas, S. (2011). Description of the Impact Assessment bio-economic Model for fisheries management (IAM), Amure Electronic Publications, Working Papers Series D-29-2011, 19 pp. Available at: http://www.umr-amure.fr/electro_doc_amure/D_29_2011.pdf.

Mongruel, R., Vanhoutte-Brunier, A., Fiandrino, A., Valette, F., Ballé-Béganton, J., Pérez Agúndez, J.A., Gallai, N., Derolez, V., Rousel, S., Lample, M., Laugier, T. (2013). Why, how, and how far should microbiological contamination in a coastal zone be mitigated? An application of the systems approach to the Thau lagoon (France). Journal of Environmental Management 118, 55-71.

MRAG, IFM, CEFAS, AZTI Tecnatio, PolEM. (2009). An analysis of existing rights based management (RBM) instruments in Member States and on setting up best practices in the EU, Final Report. London.

Murillas-Maza, A., Andrés, M. (2016). Providing incentives for fishermen through rights-based co-management systems. An impact-assessment on Basque fisheries. Marine Policy 70, 128-136.

Newell, R.G, Sanchirico, J.N., Kerr, S. (2005). Fishing quota markets. Journal of Environmental Economics and Management 49, 437-462.

OECD. (2003). The costs of managing fisheries. OECD Publications, Paris, 2003.

OECD. (2006). Financial support to fisheries: implications for sustainable development. OECD Publications, Paris, 2006.

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

Péreau, J.C., Doyen, L., Little, L.R., Thébaud, O. (2012). The triple bottom line: Meeting ecological, economic and social goals with individual transferable quotas. Journal of Environmental Economics and

Management 63(3), 419-434.

Pinkerton, E., Edwards, D.N. (2009). The elephant in the room: the hidden costs of leasing individual transferable quotas. Marine Policy 33, 707-713.

Prellezo, R., Accadia, P., Andersen, J., Andersen, B., Buisman, E., Little, A., Nielsen, J., Poos, J.,Powell, J., Röckmann, C. (2012). A review of EU bio-economic models for fisheries: The value of a diversity of models. Marine Policy 36(2), 423-431.

Punt, A.E., Butterworth, D. S., Moor, C.L., De Oliveira, J.A., Haddon, M. (2014). Management strategy evaluation: best practices. Fish and Fisheries 17, 303-334.

Raveau, A., Macher, C., Mehault, S., Merzereaud, M., Le Grand, C., Guyader, O., Bertignac, M., Fifas, S., Guillen, J. (2012). A bio-economic analysis of experimental selective devices in the Norway lobster (Nephrops norvegicus) fishery in the Bay of Biscay. Aquatic Living Resources 25(3), 215-229.

Scheld, A.M., Anderson, C.M. (2017). Selective fishing and shifting production in multispecies fisheries. Canadian Journal of Fisheries and Aquatic Sciences 74(3), 388-395.

Smit, W. (1997). Common fishery policy and national fisheries management. Marine Resource Economics 12, 355-360.

Squires, D., Campbell, H., Cunningham, S., Dewees, C., Grafton, R.Q., Herrick, S.F., Kirkley, J., Pascoe, S., Salvanes, K., Shallard, B., Turris, B., Vestergaard, N. (1998). Individual transferable quotas in multispecies fisheries. Marine Policy 22(2), 135-159.

STECF. (2012). Simmonds, J., Jardim, E. (Eds). 2012. Management plans part 2 - developing area based management plans (STECF-12-14). Publications Office of the European Union, Luxembourg, JRC 73150, EUR 25448, 75pp.

STECF. (2015). Jardim, E., Mosqueira, I. (Eds). 2015. Multiannual management plans SWW and NWW (STECF-15-04 & 09). Publications Office of the European Union, Luxembourg, JRC Scientific and Policy reports. 84pp.

Thébaud, O., Ellis, N., Little, L.R., Doyen, L., Marriott, R.J. (2014). Viability trade-offs in the evaluation of strategies to manage recreational fishing in a marine park. Ecological Indicators 46, 59-69.

UN. (2002). Report of the World Summit on Sustainable Development, Johannesburg, South Africa, 26 August–4 September. Chapter I. Resolutions adopted by the Summit. 2. Plan of Johannesburg Plan of Implementation of the World Summit on Sustainable Development, IV. Protecting and managing the natural resource base of economic and social development, Paragraph 31.

Van Hoof, L. (2010). Co-management: an alternative to enforcement?. ICES Journal of Marine Science 67(2), 395-401.

Van Hoof, L. (2013). Design or pragmatic evolution: applying ITQs in EU fisheries management. ICES Journal of Marine Science 70(2), 462-470.

Van Putten, I., Gardner, C. (2010). Lease quota fishing in a changing rock lobster industry. Marine Policy 34(5), 859-867.

Wilen, J.E., Casey, K. (1997). Employment and remuneration effects. In: Pálsson, G., Pétursdóttir, G. (Eds). Social implications of quota systems in fisheries. Copenhagen: TemaNord, Nordic Council of Ministers.

Appendix C

C.1 Model parameters

Table C1: biological parameters

	Age a	2	3	4	5	6	7	8+
Sole parameters	Initial abundundance N_{s,a,t_0} ($\times 10^6$)	25.77	8.86	5.40	7.05	3.46	2.62	1.64
	Natural mortality rate $M_{s,a}$	0.10	0.10	0.10	0.10	0.10	0.10	0.10
	Weight at age $w_{s,a}$ (kg)	0.19	0.26	0.30	0.32	0.37	0.41	0.58
	% of mature individuals $Mat_{s,a}$	0.32	0.83	0.97	1.00	1.00	1.00	1.00
	Mean recruitment ($\times 10^6$)	25.77						

	Age a	1	2	3	4	5	6	7	8	9+
Nephrops parameters	Initial abundundance N_{s,a,t_0}($\times 10^6$)	658.76	529.15	206.38	138.13	65.86	30.06	12.61	4.53	4.26
	Natural mortality rate $M_{s,a}$	0.30	0.30	0.25	0.25	0.25	0.25	0.25	0.25	0.25
	Weight at age $w_{s,a}$ ($\times 10^{-3}$kg)	3.53	9.17	16.53	26.57	36.37	45.00	56.83	67.57	85.43
	% of mature individuals $Mat_{s,a}$	0	0	0.75	1.00	1.00	1.00	1.00	1.00	1.00
	Mean recruitment ($\times 10^6$)	658.76								

Source: ICES. (2015). Report of the Working Group for the Bay of Biscay and the Iberian waters Ecoregion (WBGIE), 4–10 May 2015 Copenhagen, Denmark. Ref ICES CM/ACOM:11. 503 pp.

Table C2: average revenue and cost structures by sub-fleet and length class in 2014

Sub-fleet	Vessel length (m)	Gross value of landings (k€/trip)	Fuel cost (k€/trip)	Other var. costs (k€/trip)	Crew cost (k€/trip)	Repair cost (k€/trip)	Fixed costs (k€/year)
Specialized Nephrops trawlers	[0-12[	1.49	0.32	0.18	0.52	0.11	22.14
	[12-24[	3.57	0.96	0.45	1.28	0.35	52.08
Non-specialized Nephrops trawlers	[0-12[	1.59	0.27	0.22	0.60	0.11	26.51
	[12-18[	6.29	1.68	0.79	2.25	0.62	54.07
	[18-24[	8.30	2.19	1.13	2.69	0.69	61.18
Mixed bottom trawlers	[0-10[	0.94	0.16	0.13	0.36	0.06	13.58
	[10-12[	1.65	0.35	0.20	0.58	0.12	21.15
	[12-18[	5.56	1.49	0.70	1.99	0.55	43.54
	[18-24[	9.36	2.47	1.28	3.04	0.78	46.14
Pelagic trawlers	[0-12[	2.22	0.27	0.10	0.97	0.12	21.48
	[12-18[	4.13	1.04	0.53	1.40	0.38	39.69
	[18-24[	9.05	2.40	0.69	1.62	0.70	57.23
Sole netters	[0-10[	1.15	0.09	0.12	0.49	0.06	33.19
	[10-12[	2.04	0.17	0.24	0.88	0.15	41.66
	[12-18[	5.68	0.45	0.77	2.48	0.35	81.77
	[18-24[	16.11	1.62	2.09	6.63	1.25	108.99
Mixed netters	[0-12[	0.68	0.05	0.07	0.29	0.04	14.70
	[12-18[	0.87	0.07	0.10	0.38	0.06	16.19

Source: DPMA-Ifremer Fisheries Information System (2015)

Table C3: premium scale

Gross tonnage of vessels (GT)	Premium[a]	
	Variable part	Fixed part
[0-5[	0 €/GT	57,000 €
[5-20[	11,007 €/GT	1,965 €
[20-300[	2,930 €/GT	163,505 €
[300-800[	1,770 €/GT	511,505 €
[800-1000[	850 €/GT	1,247,505 €
≥ 1000	0 €/GT	2,097,505 €

[a] a discount factor function of vessel age is applied:

[0-15] years old vessels: no discount factor applied

[16-29] years old vessels: discount factor of 1.5 % per year above 15

≥ 30 years old vessels: discount factor of 22.5 %

Source: reproduced from JORF n°0289 du 12 décembre 2012 (accessible online: https://www.legifrance.gouv.fr/eli/arrete/2012/11/29/DEVM1241341A/jo/texte)

C.2 Fleet composition and characteristics by Producer Organization

Table C4: Number of vessels and average characteristics by Producer Organization in the Bay of Biscay sole fishery in 2014 (vessels with landings > 1 metric ton)

Producer Organization	Nb vessels	Share of the total number of vessels of the PO (%)	Main fleet segments	Sole Landings (Tons)	Sole dependency (% GR)
Pêcheurs de Bretagne	145	18.2	Mixed bottom trawlers Nephrops trawlers	6.1	14.2
OPPAN	25	26.9	Sole netters	18.5	43.1
OP VENDEE	56	40.6	Mixed bottom trawlers Sole netters	12.9	33.7
FROM SUD-OUEST	23	23.5	Sole netters Mixed bottom trawlers	17.1	42.0
OP LA COTINIERE	56	54.9	Mixed bottom trawlers	6.7	20.4
Pêcheurs d'Aquitaine	45	37.5	Sole netters	16.5	38.9
Non PO	9		Sole netters	2.0	23.1

C.3 Evolution of fleet structure

Table C5. Contingency table of fleet structure evolution in DS and ITQ: simulated fleet structure in 2025

		Mixed bottom trawlers				Non specialized Nephrops trawlers			Specialized Nephrops trawlers		Pelagic trawlers			Sole netters				Mixed netters		Hooks and lines vessels		
Status under DS scenario	Status under ITQ scenario	[0-10[m	[10-12[m	[12-18[m	[18-24[m	[0-12[m	[12-18[m	[18-24[m	[0-12[m	[12-24[m	[10-12[m	[12-18[m	[18-24[m	[0-10[m	[10-12[m	[12-18[m	[18-24[m	[0-10[m	[10-18[m	[0-10[m	[10-12[m	Total
Active	Active "lease in"	13	49	1	2	1	4	3	10	7	1	1	4	12	20	10	0	11	4	4	1	158
Active	Active "lease out"	2	8	6	1	1	2	5	4	24	3	5	4	0	20	27	18	0	1	0	2	133
Active	Inactive "lease out"	0	0	0	0	0	0	0	0	0	0	0	0	0	3	2	0	0	0	0	0	5
Active	Decommissioned without premium	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Decommissioned with premium	Active "lease in"	3	1	11	2	1	9	0	0	5	0	0	0	2	3	0	0	5	2	0	0	44
Decommissioned with premium	Active "lease out"	2	2	3	0	0	2	0	0	4	0	0	0	0	0	0	3	0	0	0	0	16
Decommissioned with premium	Inactive "lease out"	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1
Decommissioned with premium	Decommissioned without premium	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Decommissioned without premium	Active "lease in"	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Decommissioned without premium	Active "lease out"	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Decommissioned without premium	Inactive "lease out"	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Decommissioned without premium	Decommissioned without premium	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
Total		20	60	22	5	3	18	8	14	40	4	6	8	14	47	39	21	16	7	4	3	359

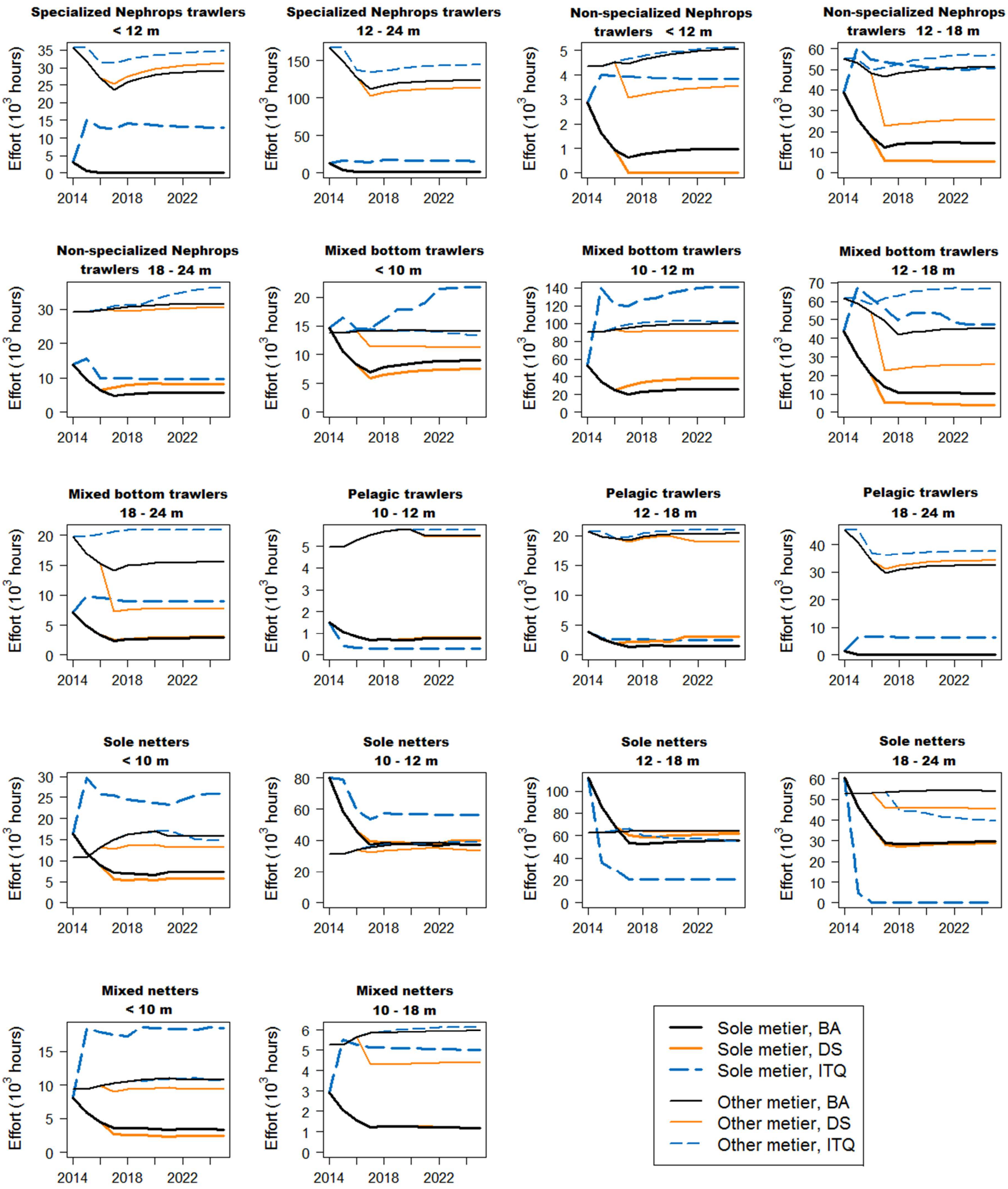


Figure C1: Evolution of effort per fleet and per metier.

C.4 Indicators related to the ecological dimension

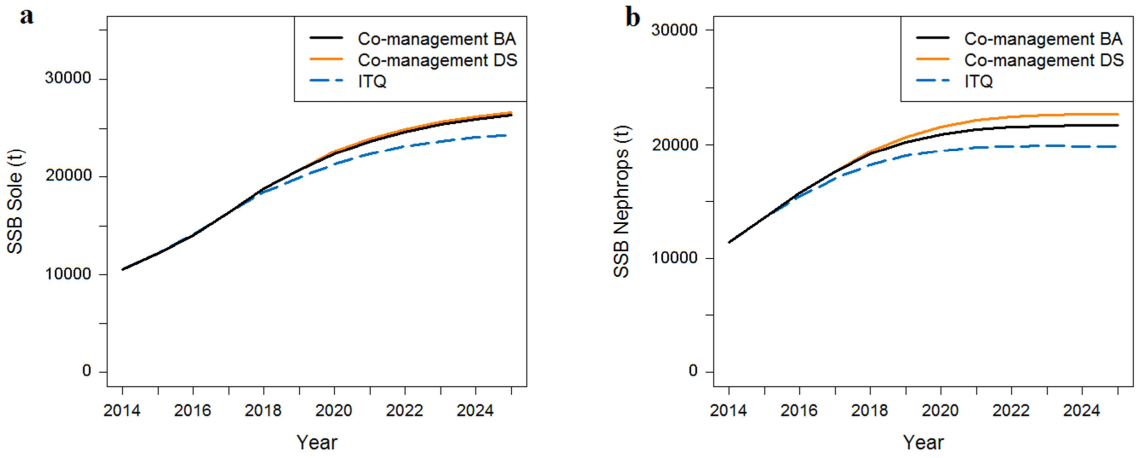


Figure C2: Evolution of the spawning stock biomass (SSB) of (a) sole, (b) Nephrops.

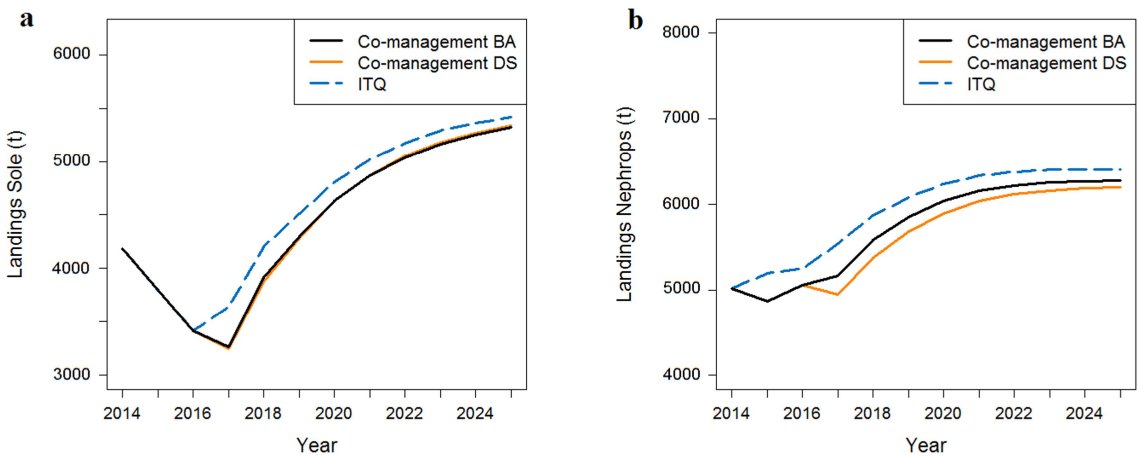


Figure C3: Evolution of landings of (a) sole, (b) Nephrops.

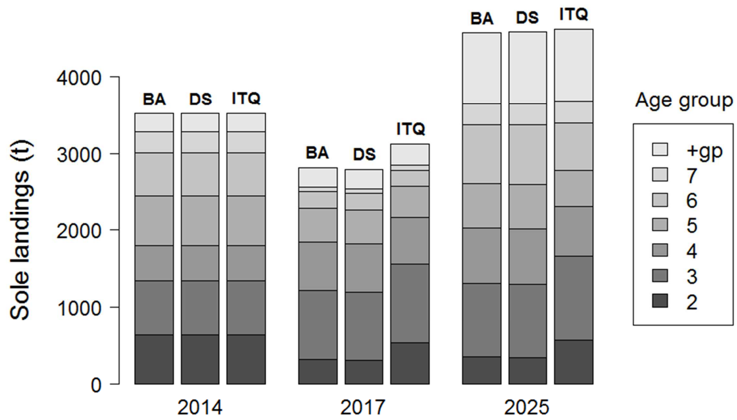


Figure C4: Evolution of sole exploitation patterns per age group.

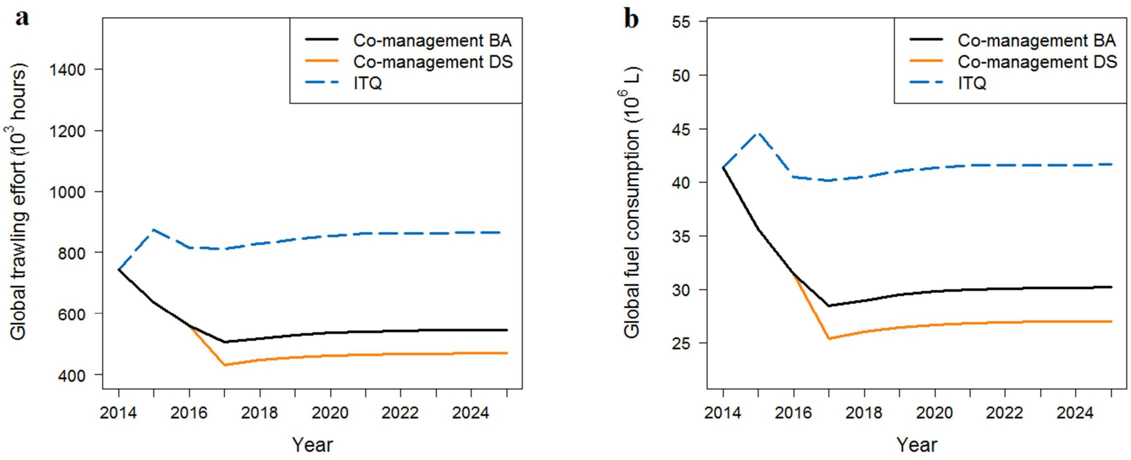


Figure C5: Impact on habitats and carbon footprint: evolution of (a) trawling effort, (b) fuel consumption.

C.5 Indicators related to the economic dimension

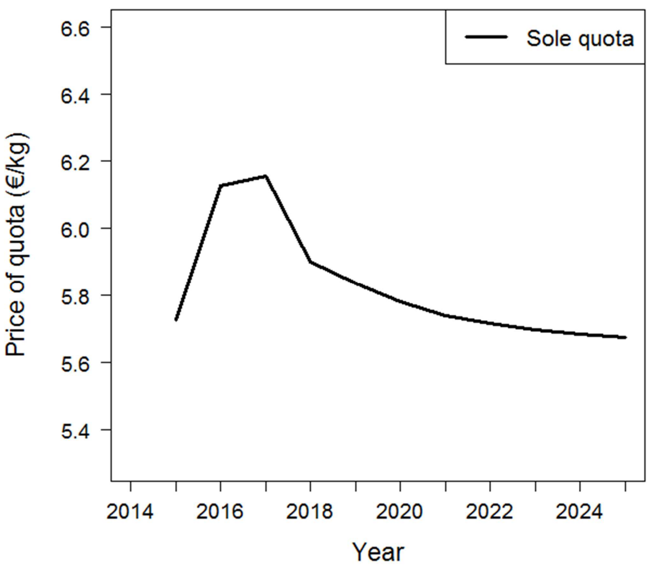


Figure C6: Evolution of the price of the sole quota.

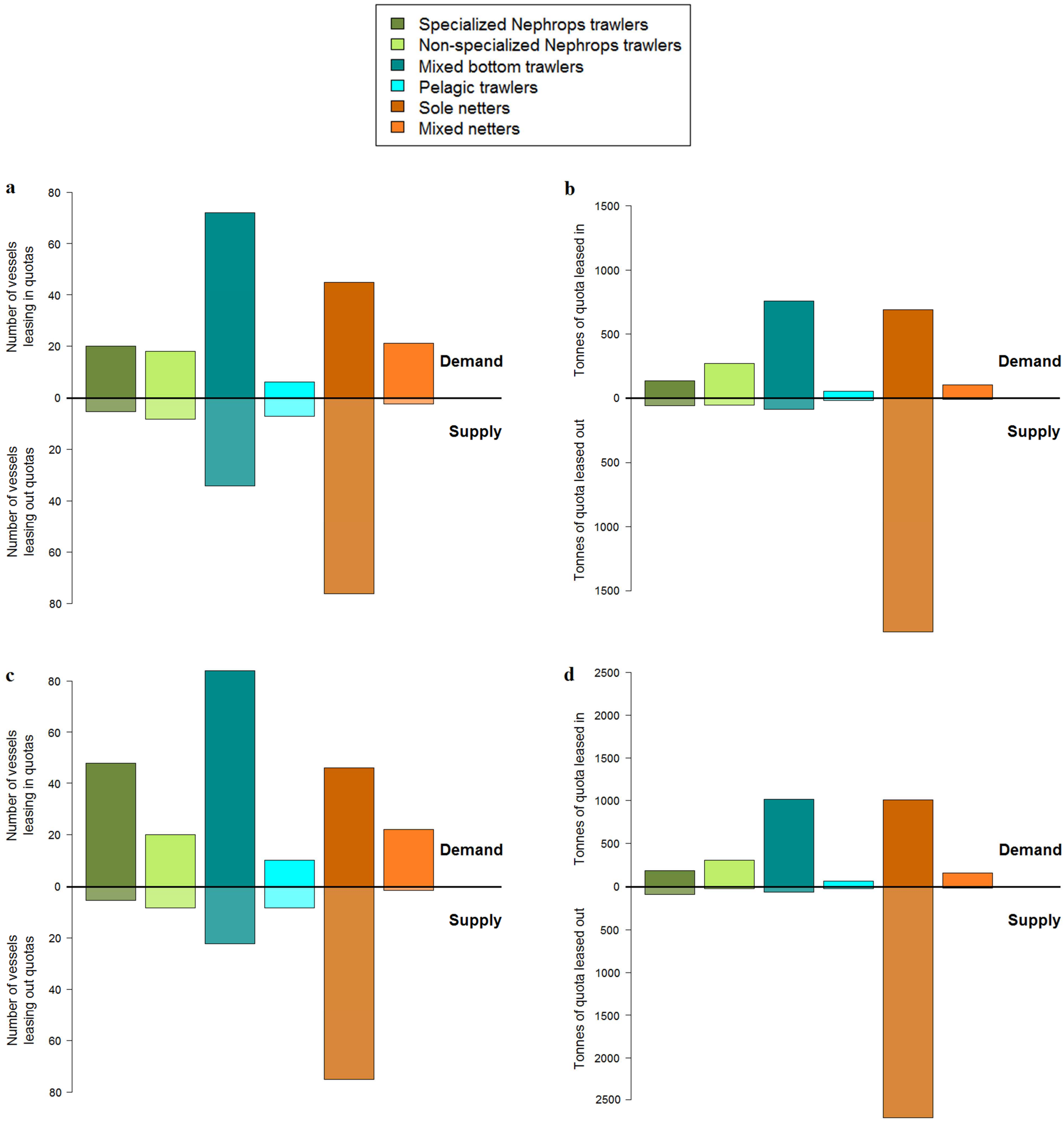


Figure C7: Demand/supply of sole quota by fleet (a) number of vessels, year=2017, (b) tonnes of quota, year=2017, (c) number of vessels, year=2025, (d) tonnes of quota, year=2025

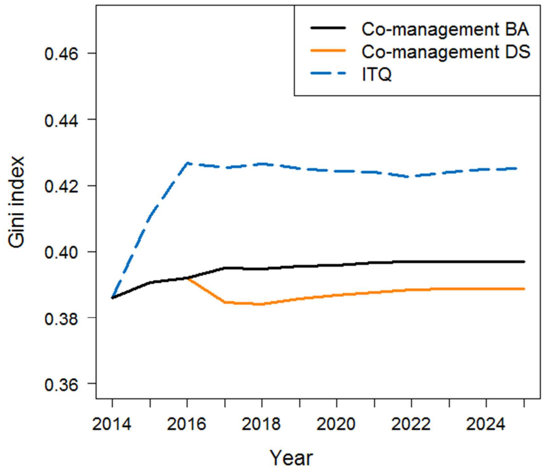


Figure C8: Evolution of economic inequality between vessels: Gini index applied to gross value of landings.

Table C6: Estimation of subsidies: cost of public-aided decommissioning scheme and fuel tax exemptions

	Public-aided decommissioning scheme[A] (million €)	**Fuel tax exemptions[B]: annual average 2015-2025 (million €)**
BA scenario	-	19.1
DS scenario	15.2	17.5
ITQ scenario	-	26.1

[A] based on the premium scale presented in Table C3

[B] considering a fuel tax concession rate of 0.63 €/l (Source: JRC estimate for France in 2013, OECD data)

C.6 Indicators related to the social dimension

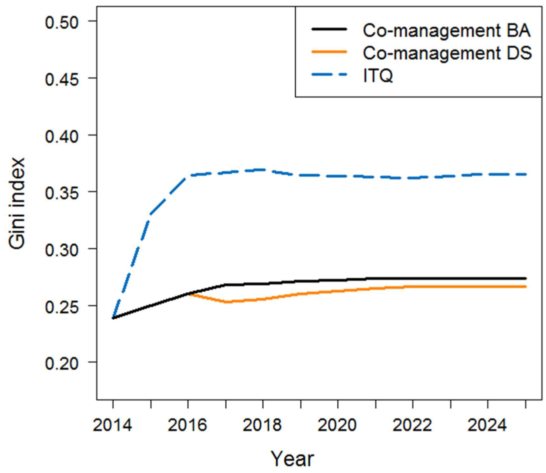


Figure C9: Evolution of wage inequality in the fishery: Gini index applied to the yearly wage per crew.

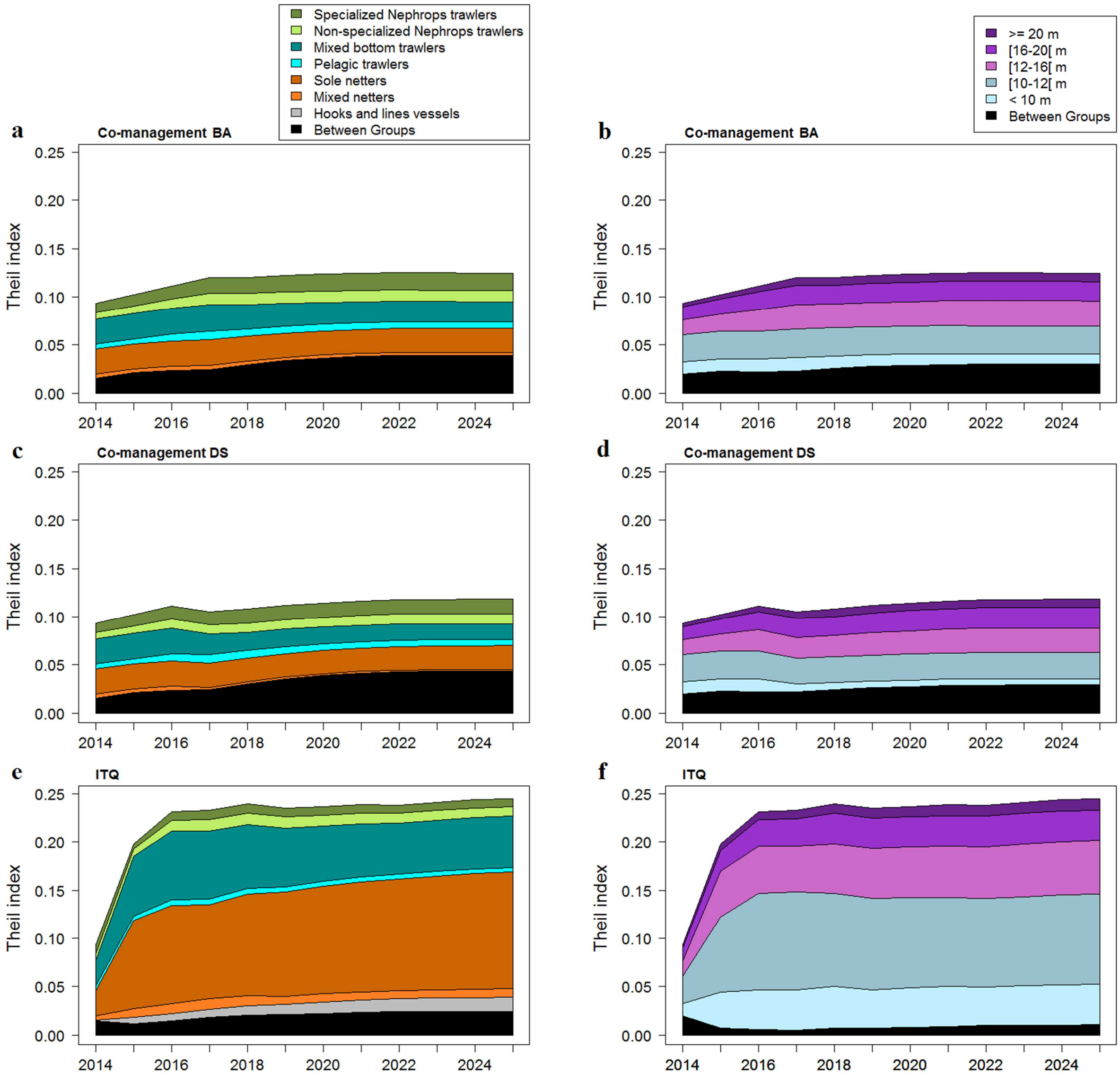


Figure C10: Evolution of wage inequality in the fishery: Theil index applied to the yearly wage per crew (a) BA scenario – decomposition by fleet, (b) BA scenario – decomposition by length class, (c) DS scenario – decomposition by fleet, (d) DS scenario – decomposition by length class, (e) ITQ scenario – decomposition by fleet, (f) ITQ scenario – decomposition by length class.

Chapter 5. General conclusion

5.1 Main findings and policy recommendations

This dissertation examined the effects of having producer organizations (POs) between the regulator and the fishermen, and the potential of institutional design to influence outcomes in PO-based catch share systems in terms of compliance, distribution, and ecological-socioeconomic trade-offs achieved by alternative options. In France, a PO-based catch share system was effectively implemented in 2006 in a context of global overcapacity of fishing fleets and increasing constraints on fishing opportunities. Notably, this system is characterized by a historical rights pooling mechanism organized at the PO level and by the fact that individual quota allocations are non-transferable by law. Therefore, the influence of POs that are responsible for allocating quotas among their members is critical. The Bay of Biscay sole fishery, the main case study used in this thesis, presents many challenging characteristics as large-scale and small-scale fisheries operate alongside one another using various fishing gears in a multispecies situation. In this complex socio-ecological environment, the evolving institutional context under the recent CFP revision raises numerous issues related to access regulation, regionalization, and long-term management plans that were addressed in this thesis.

In Chapter 2, it was shown that joint and several liability is a critical component of PO-based catch share systems that has important policy implications for regulatory compliance. The capability of the regulator to revoke catch privileges from the entire PO may generate a deterrent effect more effective than the threat of an individual fine in a system without POs. The joint and several liability mechanism can thus increase compliance for a given enforcement expenditure. However, the regulator cannot only rely on having the POs ensure regulatory compliance and must make sure that the incentives of the POs coincide with implementing and enforcing effective internal compliance regimes. To this end, the regulator may want to require and review internal compliance programs as a condition of allocating quota to a PO. The analyses established that internal agreements of POs should include penalties for breaching internal rules regardless of whether a violation was detected by the regulator. The regulator may also be able to make these internal compliance systems more effective and desirable to POs by reducing the POs costs of observing non-compliance, e.g. by sharing information from observers or electronic observation equipment. Additional elements that can significantly benefit compliance in PO-based catch share systems include the increased legitimacy of rules and the emergence of behavioral norms related to co-management groups. In France, where POs are self-forming and have the ability to exclude undesirable members, most POs have several decades of experience working together, which is an important component of social capital and suggests that the joint and several liability for quota overages is able to generate positive results on compliance. Although it is currently not clear how the landing obligation introduced with the new CFP will be monitored and enforced, our analysis suggests that the regulator could potentially benefit from making illegal discarding a joint and several liability offense (similar to the New England groundfish cooperative program[15]), which would incentivize PO to internally promote compliance with the rules. More generally, in a situation where small-scale fisheries account for around 80% of EU fishing vessels (Guyader et al., 2013) and compliance with the landing obligation appears difficult to achieve without high economic costs, regulators should consider how institutional design may help improve the overall cost-effectiveness of the compliance system in EU fisheries.

In Chapter 3, the distributional effects of PO-based catch share system in the context of non-transferability of fishing allocations were assessed by investigating the case of the Bay of Biscay sole fishery. While a traditional ITQ system generally induces a rationalization of the fishing fleet capacity and concentration of production on fewer fishing vessels, the French system successfully avoided some of the social issues that tend to occur in an ITQ while effectively reducing the fishing capacity through decommissioning schemes. The non-transferability of fishing allocations appeared as a critical element that favored this outcome by allowing POs to control the distribution of catch shares in the fishery. In keeping with the objective of maintaining territorial and socio-economic equilibriums, POs were able to adapt their quota management strategies to their fishing fleet profiles. For instance, greater equity within particular subfleets has been observed. However, even if the system has prevented an increased concentration of production, inequalities that existed before the implementation of the catch share system remain significant and many stakeholders are currently calling for an evolution of the allocation system toward more transparency and increased equality in quota access. As reported by the Competition Authority (Autorité de la concurrence, 2015), complaints have been made that some PO decisions were negatively influenced by internal politics and favoritism toward fishermen that possess the largest historical rights, which undermines inter-generational equity. According to Article 17 of the CFP (EU, 2013), Member States are required to ensure that methods and criteria for allocating fishing opportunities among fishermen are objective and transparent. To that end, the regulator could, for example, require that outcomes of allocation decisions within POs be made available in a quota register detailing the recipients of allocations (Carpenter and Kleinjans, 2017). Additionally, since primary allocations made to POs based on historical participation tend to give more bargaining power within POs to the largest historical rights holders, the regulator could decide to allocate a (small) share of the national quota among POs using an alternative criterion in order to offset negative impacts of grandfathering practices. Accordingly,

[15] See Articles 50 CFR 648.87(b)(iii-iv) that stipulate what violations are subject to joint and several liability in the groundfish New England sectors (available at https://www.law.cornell.edu/cfr/text/50/648.87).

Blomeyer et al. (2015) assessed many criteria, including social and environmental aspects, that can be used to promote compliance with Article 17 of the CFP (Carpenter and Kleinjans, 2017).

In Chapter 4, different quota management options for the transition to MSY in the Bay of Biscay sole fishery were assessed according to their ecological, economic, and social performances. The simulations of the impacts of the current PO-based quota co-management arrangements without transferability were compared to those of an ITQ system, and for each option, trade-offs among multiple management objectives were quantified. The analysis showed that the baseline scenario toward MSY, featuring the current co-management arrangements where each PO operates the redistribution of its collective sub-quota among its members, is expected to cause financial hardship and threaten the economic viability of the fleet in a context of overcapacity and transition to MSY. Alternatively, the combination of the current co-management arrangements with a decommissioning scheme would likely result in the exit of many trawlers, which would reduce impacts on habitat, reduce the carbon footprint, as well as ease the transition to MSY in terms of economic viability as compared to the baseline option. Although costly in terms of public money, the decommissioning scheme option could possibly be justified in the particular case of the Bay of Biscay sole fishery by a desirable shift toward more energy-efficient fleets. On the other hand, ITQs are expected to effectively mitigate the economic impacts of the transition phase to MSY and improve profitability in the long term, but would ultimately lead to significant increases in the trawling effort and augment economic inequalities in the fishery. These results suggest that if ITQs were to be implemented in reality, safeguards on tradability (e.g. to limit quota concentration and transfers from netters to trawlers) would be helpful to ensure this management option is consistent with ecological and social objectives. These findings also underscore the necessity to readdress the question of fuel tax exemptions that appear to be in contradiction with the need to reduce greenhouse gas emissions while having a direct influence on the effectiveness of future potential management measures. As shown by Guyader (1999), direct or indirect subsidies may distort the relative profitability of vessels, which could have substantial effects on realized ITQ prices and fleet adjustment.

Since 2006, French POs tend to operationalize their quota management duties by means of individual allocation rules. However, the French PO-based catch share system remains quite singular because of the non-transferability of individual allocation, which is a characteristic most POs consider essential to achieve the multiple management objectives. Whether this co-management system is a sustainable governance mode as it is, or merely a transitory system before an inevitable ITQ system, is an interesting subject that deserves attention. Despite being opposed by many stakeholders in France (Frangoudes and Bellanger, 2017), some consider that transferability is a practical necessity that should normally follow from the individualization of quotas. In fact, there is anecdotal evidence that the shadow price of historical rights attached to a vessel are somewhat internalized in the selling price of the vessel, which could be viewed as the premises of a quota market (Guyader et al., 2006;

Larabi et al., 2013). In general, while a system of non-transferable individual allocations operated by POs can be appropriate to manage one particular species (e.g. common sole in the Bay of Biscay), some uncertainty remains regarding its manageability in a multi-species situation with reduced fishing possibilities on multiple key target species. In addition, the implementation of the landing obligation can potentially increase the need for transferability because of the augmented risk of choke species problems (Baudron and Fernandes, 2015). On the one hand, the transferability of individual allocations could provide some flexibility in a multi-species context with high heterogeneity of fishing profiles among fishermen and restrictive quota constraints. On the other hand, the co-management arrangements involving non-transferability appear to be relevant to prevent some of the negative territorial and social impacts that are usually associated with ITQs. Should transferability be authorized at some point, the question of whether and how ITQs could be embedded within a PO-based co-management system in order to combine the advantages and limit the drawbacks of both systems would then need to be addressed. In terms of institutional design, this could potentially take the form of regional quota markets where individual transactions would be supervised by POs under the overarching control of a public agency. In light of the results established in this thesis, it appears that such a hybrid system could be relevant in the perspective of integrating the French quota management system within the regionalization and ecosystem approach promoted by the CFP.

5.2 Methodological contributions

This thesis work, multidisciplinary in nature, has necessitated a suite of complementary approaches to address the variety of questions related to the effect of POs. In Chapter 2, a game-theoretic approach was developed to investigate the incentive effect of joint and several liability on compliance in the context of fishery cooperatives. Game theory is a tool for examining problems of strategic interaction where decision makers intend to maximize their outcome in a given situation. Game theory is particularly applicable to the study of common-pool resources such as fisheries (Bailey et al., 2010; Sumaila, 2013) and can be applied to examine regulatory compliance issues (Kronbak and Lindroos, 2006). The model that we developed contributes to the existing literature by integrating an institutional analysis of the effects of liability regimes on compliance into a principal-agent problem framework. The model included traditional economic incentives as well as social factors that are often overlooked in analytical models of regulatory compliance, and the analysis produced policy insights informing the institutional design of PO-based catch share systems.

In Chapter 3, a statistical framework was developed to improve the study of distribution and equity issues in fisheries. The analysis identified relevant metrics and showed how the decomposition of the inequality by subgroups can provide interpretive elements to investigate the dynamics of the fishery, especially when the distributional effects cannot be observed at the global scale. As distributional issues may be associated with multiple dimensions including social and territorial issues, the decomposition of the Theil index appeared to be a useful tool to identify which groups contributed most to the total inequality of landings (or incomes). This decomposition uses the notions of within- and between-groups components, which allow the determination of whether distributional changes have happened within particular subfleets and whether inequality between certain groups of vessels has increased. However, inequality decomposition essentially measures changes in variability among vessels but does not provide direct information about global trends (e.g. whether average landings or incomes increased or decreased). As such, it is necessary that an analysis of distributional effects also include some measurement of trends per group in order to assess how potential redistributions have affected each component of the fleet.

The individual-based bio-economic approach based on the IAM model (Merzéréaud et al., 2011) and presented in Chapter 4 constitutes a step forward in the integrated modelling of interactions between resources, uses, and governance mechanisms for the simulation analysis of policy options. This contribution includes the modelling of several institutional arrangements to better account for the influence of governance systems in the impact assessment of management options. Notably, the role played by POs, including the management of catch shares, historical landings track records, and internal reallocations, was explicitly endogenized in a bio-economic model for the first time. This allowed us to enhance the comparability of PO-based co-management systems with alternative market-based systems by considering their impacts on the individual constraints of fishermen in the impact assessment of alternative management options. The behavior of fishermen regarding effort allocation and disinvestment decisions were endogenously incorporated within a short-term and a long-term dynamics models, respectively. While these developments only represent a preliminary step toward integrating the complexity and diversity of possible co-management arrangements into bio-economic modelling frameworks, the analysis that was focused on the Bay of Biscay sole fishery showed how this approach could help inform the design of institutions through the investigation of trade-offs in different catch share systems.

5.3 Perspectives for future research

The role played by POs in improving the economic, social and ecological outcomes from fishery management is complex and not fully comprehended. While this dissertation addressed a number of issues related to the effects of having POs in catch share systems, this work could be extended in a number of ways.

One aspect worthy of further investigation concerns the influence of the size of a PO, for example in terms of regulatory compliance. On the one hand, a larger PO can presumably augment its pool of fishing opportunities (and thus the size of the penalty that can be recovered from the PO) and limit the risks of overrunning its collective quotas. On the other hand, oversized groups of resource users may also undermine social capital (Ostrom, 1990), which is linked to voluntary compliance and social control that play an important role in regulatory compliance overall (Holland et al., 2013). Therefore, it is not clear what the dynamics of compliance are when addressing the question of the ideal size of POs. In the French system, there may be a contradiction between the push to have bigger and less numerous POs, creating larger pools of fishing rights that are often necessary to avoid choke species, and the loss of social capital that could impede the legitimacy of rules and deter compliance, which could ultimately provoke quota overruns and create a choke species phenomenon. Such issues could be explored theoretically through analytical modelling, but it could also be relevant to obtain empirical validation as well. As compliance issues are difficult to address empirically by nature (Hatcher et al., 2000), this might involve some experimental economics approaches that use lab experiments intended to reproduce real-world incentives in order to test the validity of economic conjectures (Falk and Heckman, 2009; Charness and Kuhn, 2011). These have been successfully applied to examine some coordination and social preferences issues (Fehr and Gächter, 2000, 2002; Cooper and Kagel, 2016) and could be valuable to explore the questions related to POs and their potential benefits to promote compliance.

The economic analysis of liability regimes in PO-based catch share systems developed in Chapter 2 focused on two potential monitoring-penalty mechanisms that POs could implement and have actually applied in some cases. However, there is a global lack of knowledge and experience in the application of joint and several liability in fisheries. For example, in cases where the regulator can either impose a penalty on a violator or on a PO as a whole, it is not clear what drives the regulator's decision between the two options. In addition, there are many possible different specifications of a regime of joint and several liability (Kornhauser and Revesz, 1994; Kornhauser, 2013). These include potential settlement arrangements and claim reduction, right and duty holders clauses, the determination of the share of the liability (whether it should be proportional to the cause or to the result of the harm) and the allocation of insolvent share. All of these legal details may affect the incentive effects of liability regimes and should be examined in a particular regulatory context in order to inform institutional design. These refinements clearly necessitate collaborating with legal scholars for the application of microeconomic analysis to legal problems in order to go one step further and make policy recommendations based on the economic consequences of various legal rules. These should include a reflection on how to build incentives so that the motivations of POs are aligned with those of the regulator to prevent the POs from developing inside strategies to evade regulations. In general, a comparison of the way liability regimes are structured in a variety of fishery cooperative programs worldwide would be useful to improve our understanding of their relevance and practicality.

An early ambition of this thesis work was to include allocations according to the actual PO rules in the comparison with historical landings and landings observed in the Bay of Biscay sole fishery (Bellanger et al., 2014). In terms of examining the distributional effects of quota management by POs (Chapter 3), this comparison would more explicitly outline which allocation rule is best to favor equity for a particular subfleet profile. However, the lack of knowledge and data on PO strategies limited the applicability of this comparison. Interviews that were conducted with PO managers revealed that quota management by POs is constantly adapting to internal and external factors, including real time management (e.g. in-season reallocation). Additionally, the rapidly-changing institutional and socio-economic contexts make it difficult to unravel the drivers of PO strategies and draw general conclusion on their behavior. Then again, PO allocation rules are not fully transparent and, until a hypothetical and hopeful quota registry is made mandatory by the fisheries authority, additional interviews would be necessary to collect information and improve our understanding on these. Once this is achieved, another interesting extension to the model presented in Chapter 4 would be to consider POs as agents making decisions that influence fishermen strategies. This could involve some discrete-choice modelling (Guyader et al., 2014; Girardin et al., 2016) to try to simulate the behavior of POs in terms of internal rules used for quota management and distribution among their members, quota swapping with other POs, membership management, and PO merger. This is definitely challenging, but would represent significant progress for the integration of governance mechanisms into bio-economic modelling. Perhaps one aspect that needs to be considered is the balance between modelling institutional details that are relevant to one particular case study and the usefulness of these developments when applying the model in other contexts. In any case, science-stakeholder partnership approaches, where stakeholders are involved in the development of decision-support tools, could also be highly beneficial to gain a better understanding of the objectives and behavior of POs and determine prospective scenarios collaboratively to address particular management issues (Macher et al., 2016).

According to Punt et al. (2014), MSE is “widely considered to be the most appropriate way to evaluate the trade-offs achieved by alternative management procedures and to assess the consequences of uncertainty for achieving management goals". Nevertheless, MSE approaches have not fully considered the impacts of management systems on fishermen individual constraints yet. Considering the push to develop integrated multi-objective tools, incorporating the bio-economic model presented in Chapter 4 in a comprehensive MSE approach would be an interesting development of this thesis work. This would involve including some stochasticity in the model to represent the uncertainty associated with observation and implementation of the decision rules in order to assess the ability of management option to achieve a predefined set of sustainability objectives. The uncertainty related to the unexpected behavior of fishermen when implementing a new management measure is in fact critical as it may lead to the failure of fisheries policy (Fulton et al., 2011; Kraak et al., 2013). Ultimately, bringing together game-theoretic and bio-economic simulation frameworks in order to enhance the behavioral components of socio-ecological modelling approaches (e.g. Haynie et al., 2009; Doyen and Péreau, 2012) constitutes a stimulating subject of research to further increase the realism of models used as decision-support tools.

References

Autorité de la concurrence. (2015). Avis n°15-A-19 du 16 décembre 2015 relatif aux effets sur la concurrence du mécanisme de répartition des quotas de pêche en France. Autorité de la concurrence, République Française, available online at http://www.autoritedelaconcurrence.fr/pdf/avis/15a19.pdf.

Bailey, M., Sumaila, U. R., Lindroos, M. (2010). Application of game theory to fisheries over three decades. Fisheries Research, 102(1), 1-8.

Baudron, A.R., Fernandes, P.G. (2015). Adverse consequences of stock recovery: European hake, a new "choke" species under a discard ban?. Fish and Fisheries, 16(4), 563-575.

Bellanger M., Macher C., Merzéréaud M., Guyader O. (2014) Exploring fisheries dynamics according to different quota governance mechanisms: application to the Bay of Biscay common sole fishery. 17th Biennial Conference of the International Institute for Fisheries Economics and Trade, Brisbane, Australia.

Blomeyer, R., Nieto, F., Sanz, A., Stobberup, K., Erzini, K. (2015). Criteria for allocating access in the EU. Directorate-general for Internal Policies. Policy Department B: Structural and Cohesion Policies, European Parliament, Brussels.

Carpenter, G., Kleinjans, R. (2017). Who gets to fish? The allocation of fishing opportunities in EU Member States. New Economics Foundation, London.

Charness, G., Kuhn, P. (2011). Lab labor: What can labor economists learn from the lab?. Handbook of labor economics, 4, 229-330.

Cooper, D., Kagel, J. (2016) Other regarding preferences: a selective survey of experimental results. In: Kagel, J., Roth, A. (Eds.) The Handbook of Experimental Economics, vol. 2, Princeton University Press, Princeton.

Doyen, L., Péreau, J., 2012. Sustainable coalitions in the commons. Mathematical Social Sciences, 63(1), 57-64.

EU. (2013). Regulation (EU) 1380/2013 of the European Parliament and the Council of the 11 of December 2013 on the Common Fisheries Policy. Official Journal of European Union, L354/22, 28.12.2013.

Falk, A., Heckman, J. J. (2009). Lab experiments are a major source of knowledge in the social sciences. Science, 326(5952), 535-538.

Fehr, E., Gächter, S. (2000). Fairness and retaliation: The economics of reciprocity. The journal of economic perspectives, 14(3), 159-181.

Fehr, E., Gächter, S. (2002). Altruistic punishment in humans. Nature, 415(6868), 137-140.

Frangoudes, K., Bellanger, M. (2017). Fishers' opinions on marketization of property rights and the quota system in France. Marine Policy, 80, 107-112.

Fulton, E.A., Smith, A.D., Smith, D.C., and Van Putten, I.E. (2011). Human behaviour: The key source of uncertainty in fisheries management. Fish and Fisheries, 12(1), 2-17.

Girardin, R., Hamon, K.G., Pinnegar, J., Poos, J.J., Thébaud, O., Tidd, A., Vermard, Y., Marchal, P. (2016). Thirty years of fleet dynamics modelling using discrete-choice models: What have we learned?. Fish and Fisheries (in press).

Guyader, O. (1999). Transition from open access to a regulatory system with subsidies: the case of the French driftnet fleet. In Hatcher, A., Robinson, K. (Eds.) Overcapacity, overcapitalisation and subsidies in European fisheries, Portsmouth, Proceedings of the first Concerted Action workshop on Economics and the Common Fisheries Policy: UK, 28-30 October, 1998. CEMARE Miscellaneous Publication no. 44 1999: 109-124.

Guyader, O., Berthou, P., Daures, F., Jezequel M., Thebaud O., (2006). Marché des navires d'occasion et coût d'accès à la ressource : application à la Bretagne. Amure Electronic Publications, Working Papers Series D-17-2006, 14pp. Available at: http://archimer.ifremer.fr/doc/00243/35408.

Guyader, O., Berthou, P., Koutsikopoulos, C., Alban, F., Demaneche, S., Gaspar, M.B., Eschbaum, R., Fahy, E., Tully, O., Reynal, L., Curtil, O., Frangoudes, K., Maynou, F. (2013). Small scale fisheries in Europe: A comparative analysis based on a selection of case studies. Fisheries Research, 140, 1-13.

Guyader, O., Metz, S., Macher, C., Merzereaud, M., Daures, F., Le Floc'h, P., Bellanger, M. (2014). Self-imposed catch shares by French producers organizations. IIFET 2014, International Institute of Fisheries Economics & Trade. 7-11 July 2014, Brisbane, Australia.

Hatcher, A., Jaffry, S., Thebaud, O., Bennett, E. (2000). Normative and social influences affecting compliance with fisheries regulations, Land Economics, 76(3), 448-461.

Haynie, A.C., Hicks, R.L., Schnier, K.E. (2009). Common property, information, and cooperation: commercial fishing in the Bering Sea. Ecological Economics, 69(2), 406-413.

Holland, D.S., Kitts, A.W., Da Silva, P.P., Wiersma, J. (2013). Social capital and the success of harvest cooperatives in the New England groundfish fishery. Marine Resource Economics, 28(2), 133-153.

Kornhauser, L. A., Revesz, R. L. (1994). Multidefendant settlements: The impact of joint and several liability. The Journal of Legal Studies, 41-76.

Kornhauser, L.A. (2013). Economic analysis of joint and several liability. In Arlen, J.H (Ed.) Research Handbook on the Economics of Torts, 199-233.

Kraak, S.B.M., Bailey, N., Cardinale, M., Darby, C., De Oliveira, J.A., Eero, M., Graham, N., Holmes, S., Jakobsen, T., Kempf, A., Kirkegaard, E., Powell, J., Scott, R.D., Simmonds, E.J., Ulrich, C., Vanhee, W., Vinther, M. (2013). Lessons for fisheries management from the EU cod recovery plan. Marine Policy, 37, 200-213.

Kronbak, L. G., Lindroos, M. (2006). An enforcement-coalition model: fishermen and authorities forming coalitions. Environmental and Resource Economics, 35(3), 169-194.

Larabi, Z., Guyader, O., Macher, C., Daurès, F. (2013). Quota management in a context of non-transferability of fishing rights: the French case study. Ocean and Coastal Management, 84, 13–22.

Macher, C., Guyader, O., Le Grand, C., Merzéréaud, M., Bertignac, M. (2016). Developing operational bio-economic decision-support tools with stakeholders: Challenges and opportunities from the experience of the bio-economic partnership working group project. MSEAS 2016 - Understanding marine socio-ecological systems: including the human dimension in Integrated Ecosystem Assessments. 30 May - 3 June 2016, Brest, France.

Merzéréaud, M., Macher, C., Bertignac, C., Frésard, M., Le Grand, C., Guyader, O., Daurès, F., Fifas, S. (2011). Description of the Impact Assessment bio-economic Model for fisheries management (IAM), Amure Electronic Publications, Working Papers Series D-29-2011, 19 pp. Available at: http://www.umr-amure.fr/electro_doc_amure/D_29_2011.pdf.

Ostrom, E. (1990). Governing the Commons: The Evolution of Institutions for Collective Action. Cambridge University press.

Punt, A.E., Butterworth, D. S., Moor, C.L., De Oliveira, J.A., Haddon, M. (2014). Management strategy evaluation: best practices. Fish and Fisheries, 17, 303-334.

Sumaila, U. R. (2013). Game theory and fisheries: Essays on the tragedy of free for all fishing. Routledge, London.

Appendix D

Fishers' opinions on marketization of property rights and the quota system in France

Published in *Marine Policy*

Frangoudes, K., Bellanger, M. (2017). Fishers' opinions on marketization of property rights and the quota system in France. Marine Policy, 80, 107-112.

Abstract

After many years of Common Fisheries Policies in the European Union, 88% of stocks are still being fished beyond their Maximum Sustainable Yield. While several Member States and the European Commission are moving toward Individual Transferable Quotas as a solution, France has declared its opposition to such marketization of fishing access rights and a national law has classified fisheries resources as a collective heritage. This paper discusses the evolution of the French system, principally its distribution of access rights. Of particular interest is the way in which Producer Organizations, which are more linked to the industrial fleet organizations, have or have not modified their sharing formulae to include small-scale fisheries, and the way in which some small-scale fisheries still operate outside these sharing formulas, based on a share set aside for them.

Keywords: co-management, ITQs, quota allocation, small-scale fisheries

D.1 Introduction: Common Fisheries Policy in Europe

The European Union (EU) treaties establish marine fisheries management as one of the exclusive competencies of the European Community. This competency seems to find its root in the past and it is related to the fact that fish can run across national jurisdictions and fishers have to move to catch the fish. Before the introduction of Exclusive Economic Zones (EEZ's) and the Common Fisheries Policy (CFP) fishers moved from place to place. To guarantee equal access to the fish resources for fishers of all Member States an exclusive competency in this domain was given to the EU. The first CFP was set up in the 1970's and has since been revised several times. The latest revision is dated December 2013 and came into force in January 2014.

France, like all other members of the EU, has to implement the objectives and rules defined by the CFP. National decisions related to fisheries management take into consideration the objectives defined by the CFP. The main policy areas covered by the CFP are fisheries management, international policy, market and trade policy and finally funding policy. While the CFP gives equal access to EU waters and resources, National States still have the competency to manage fishing activities within their 12 nautical miles territorial seas and vessels of other Member States having historical activity in this space cannot be excluded.

To conserve the resource, the CFP aims to manage fishing effort through limitation of fleet capacity, restricted days at sea, and technical measures regulating fishing areas, gear and catch. The management of European fish stocks is based on total allowable catch (TAC) or fishing opportunities set up for a great number of commercial species. The European Commission (EC) prepares a proposal, based on scientific advice on the stock status from the International Council of Exploration of the Sea (ICES), Scientific Technical and Economic Committee for Fisheries (STECF) and the decision is made by the council of Ministers and the Parliament which are often accused of making decisions without following formulated recommendations (Carpenter et al., 2016a, 2016b). TACs are shared among the different Member States based on a historical rights criterion (Holden, 1994). For each stock a different percentage allocation of the quota is assigned to each Member States. This fixed percentage is known as the relative stability key. The CFP authorizes the exchange of quota between Member States (EU, 2013).

Within this complex context, the CFP recommends that national authorities use transparent and objective criteria including the sharing of fishing opportunities among fishers to ensure that quotas are not overfished. When the national quota is reached the country must close the fishery. In the past, the CFP did not mention the quota distribution to small-scale fisheries (SSFs). During the last revision of the CFP some advances were made with the introduction of Article 17. This article calls on Member States to “use transparent and objective criteria including those of an environmental, social and economic nature” (EU, 2013).

According to the Green Paper (GP) the reform of Common Fisheries Policy the Europen, the CFP based on TAC and quota systems seems to have failed to achieve its objectives, as shown in the following quotation: “… 88% of Community stocks are being fished beyond MSY and 30% of these stocks are outside safe biological limits, which mean that they may not be able to rebound” (CEC, 2009). To remedy these negative results, the GP suggests the introduction of more neoliberal policies including the creation of transferable fishing rights because the “use of market instruments such as transferable rights to fishing” (CEC, 2009) will reduce overcapacity as the industry will adapt its fishing rights in order to achieve economic efficiency. To “avoid excessive concentration of ownership or negative effects on smaller-scale fisheries and coastal communities” the GP suggested using safeguard clauses (CEC, 2009). During the public consultation on the proposals of the GP the French fishing industry reacted strongly against the recommendations about Individual Transferable Quotas (ITQs, referred to in the GP as Individual Transferable Concessions) in Europe and more particularly in France.

This paper aims to present the main arguments expressed during the public consultation in France on ITQs and how these discourses influenced the National Fisheries law, how the quota system evolved and how these changes are viewed by SSFs and Environmental Non Governmental Organizations (ENGOs) as well as power relations within the Producer Organizations (POs). This article is based on various written sources: EU regulations and documents, academic literature and the minutes of all public consultation meetings, newspapers and reports published by the French Parliament and Senate. Face-to-face interviews with 10 small-scale fishers, originated from different coastal areas, were also employed.

D.2 Debate around the last CFP revision in France

After the publication of the GP, French authorities undertook a substantial consultation with the French fishing industry and other stakeholders. Regional meetings in 2009 brought together fishers, territorial authorities, representatives of national authorities at regional levels, scientists and ENGO’s. Participants were asked to address the following four issues: governance, management tools for EU fisheries, market regulation and how fishing products can best have added value. In the regional meetings the different visions of ITQs promoted by the GP were discussed.

For Brittany fishers the implementation of ITQs represented high capitalistic risks which may end with “uncontrollable quota uptake”. They feared speculation in quota prices and believed that the use of such a tool would not impact positively on resource conservation. For them, Member States should be free to manage national quota “in a more adaptive manner” and they called for a more “collective management” at the local level with fishers as active players (CNPMEM, 2009).

Lower Normandy fishers underlined their attachment to the “relative stability principle” and called for the application of the subsidiary principle in the matter of the management of “fishing opportunities”. They were not fully against the idea of Individual Quotas in fisheries but did not agree with adding the “transferability” aspect. For them, liberalization of the European market for fisheries quota would mean “abandoning relative stability” and concentration of quota in the hands of few big fisheries enterprises (CNPMEM, 2009).

Fishers of Upper Normandy were in favor of the implementation of non-transferable Individual Quotas (IQs) that would increase predictability for fisheries enterprises. However, they considered that quotas, even individual ones, must be managed by Producer Organizations (POs). Fishers from the South Atlantic regions reacted to the proposed implementation of ITQs. Pays de la Loire fishers said that they “completely mistrust the term transferable rights” which for them is synonymous with the privatization of fishing resources. Poitou-Charentes fishers thought that ITQ would lead to “an excessive concentration of quota without any attachment to territories”. For Aquitaine fishers it was impossible to introduce the ITQ system because “fishing resources are a public good”. All agreed that the collective management of quotas, within POs, is the best system to achieve resources conservation (CNPMEM, 2009).

French authorities conveyed to the European Commission (EC) the ideas expressed by fishers during these public consultations. So France could accept the principle of individual quotas if they were collectively managed, for example by POs, but “… remains against the compulsory introduction of ITQs to monetize a system [which would be] … conducive to speculation and to excessive concentration of quota through the establishment of a free market” (DPMA, 2011). During the public debates it appeared that French fishers viewed IQs as a good tool if it was managed collectively within the POs framework. But they were vehemently against the concept of privatization and transferability of resource access. Transferability of quota was seen as a way to jeopardize the relative stability and concentrate quota in the hands of a few fishers. Concentration of fishing opportunities would impact negatively on employment and other social aspects within fishing communities.

ENGOs participated in the public consultation and also expressed their disagreement with the implementation of ITQs in France. The French branch of Greenpeace, for example, had the same position as French fishers: that such a system would concentrate fishing rights without reaching the main objective of the CFP: the “reduction of fishing pressure on the resources” (GreenPeace France, 2009).

During the 2009 public debate only a few comments were expressed about the protection of SSFs. One of these was formulated during the meeting in Boulogne-sur-Mer and it concerned the distinction between small-scale and industrial fisheries made by the EC. Participants could not understand why the EC divided fisheries into two categories, because in France there is no such distinction, as all are members of the same organizations. Participants wondered if this distinction would impact on the distribution of the fisheries structure fund (CNPMEM, 2009). This second concern was expressed by Greenpeace which noted that "… the CFP didn't pronounce any specific measures for SSFs, which constitute 80% of the total employment in fisheries and 20% of the landings in the EU" (GreenPeace France, 2009). In their opinion, the CFP should promote access to resources for vessels having less impact on the ecosystem. The following section examines the French quota system in which SSFs operate and SSFs opinion of that system.

D.3 The French quota system

Despite the introduction of Total Allowable Catches (TACs) at the European Union level in 1983, France did not implement this system at a national level until 1990. The first sharing of national TACs concerned only six species: cod, pollock, hake, mackerel, plaice and sole. The national TACs were divided among the different coastal regions of the EU except the Mediterranean Sea where the TACs are not applied. The division of TACs or quotas among regions was monitored by the national committee of quota management established for that region. The main concern of the French authorities was the way the quota becomes a sub-quota for each region, itself divided by harbors and vessels. A national committee was established to monitor the quota allocation per region and advise the national administration. Aside from the national fisheries administration, the other members of the committees were the POs which were in charge of the organization of fisheries markets and the National Committee of Maritime Fisheries (CNPMEM) which has been responsible for resource management within national territorial waters since 1993 through its regional committees (CRPMEM).

The first distribution of the national quota was redefined by the Fisheries law in 1997 which asserts the role of the State in the allocation of fisheries licenses and quota and declares the non-individual and non-transferable character of the quota. The 1997 Fisheries Law states that national quota should be shared among vessels operating under the French flag and having economic links with the country. But EU rules on freedom of establishment allow fishing companies from one EU member country to be established in another country's fishing waters and therefore under its quotas. To preserve the EU member state quotas, there should be some real connection between the fishers in question, their boats and the flag of the country they decide to fish under. For France the following criteria apply: hire a French skipper or sell fish at a French auction. The role of POs was also strengthened by the Fisheries law in 2010 fisheries law since POs are also responsible for sub-quota management. POs involvement in quota management is not really new because, before this, they prepared fisheries plans to adapt to the demand of fish markets which in turn helped to stabilize the price of the fish (Morin, 2016).

From the beginning of the 1990’s until 2005 -the date when the State decided to freeze the historical rights of the vessels at a three years reference point (2001-2003)- only a few small-scale vessels joined POs. POs membership is voluntary and only fishers wishing to benefit from the minimum price mechanism managed by POs joined these organizations. The services offered by POs, at that period, were not considered sufficient to warrant membership by SSFs and most decided not to join these organizations. Nor did they join later when the State gave the POs authority to manage sub-quotas. So, SSF continued their activities outside of these organizations and fished under the quotas held by national fisheries administration and only the large vessels such as trawlers and purse seines joined POs at those times. This situation did not change until the beginning of 2000 when quota allocation and division into sub-quotas between regions and POs were introduced. But the main change in the French quota system was produced in 2006 by the ministerial order which introduced for the first time the principle of IQs. It clarified the rules of quota allocation by reaffirming the principle of historical rights and also imposed the historical rights track records as a “method for calculating how quota may be divided up into sub-quota among POs” (JORF, 2006). Since historical rights became the main principle for quota allocation to POs, vessel-owner couples and the average landings of 2001-2003 constituted historical rights for vessels (Larabi et al., 2013). Consequently, vessels that entered the fishery after 2003 have no historical rights.

One of the first species to fall under the system of IQs per vessel, after a decision of national authorities, was bluefin tuna in the Mediterranean Sea, a place which is not subject to the EU quota system. The introduction of bluefin tuna quota was done by the International Commission for Conservation of Atlantic Tuna (ICCAT) in 2008 and the French national authorities allocated this quota on an individual vessel level. The irony is that this IQs system was introduced in France for a regional sea not concerned with the EU quota system for other species. It appears that this first experience of IQs contributed to the expansion of the system into others regions of France. In 2009, following a negotiation between the French Fisheries Directorate and the different POs, it was decided to test IQs for some species in regions where the EU TAC system was applied. In 2011, the administration encouraged POs to use individual catch limitations for all species but many POs did not implement this system during the first years (Larabi et al., 2013).

In brief, it can be said that the French quota system evolved rapidly and the discussions held in France during the public debates made it easy to introduce IQs. The system moved from national quotas open to all vessels to the division of the national quotas into (1) sub-quotas managed by POs and (2) those managed by the Directorate for Maritime Fisheries and Aquaculture (DPMA) open to non-PO members (Larabi et al., 2013).

In 2010, the French fisheries law legalized different changes to the quota system. In 2014, some other changes were made, thanks to the establishment of a national working group called “reform of production rights” which studied the issue of the management of historical rights through a system of reserves. Previously, 100% of the historical rights of retiring boat owners were reverted to the POs in which they were members. Now a retiring boat owner must return 30% of his historical rights to the national reserve and 70% to the PO. Additionally, a part of the national reserve may be reallocated to the PO reserves (JORF, 2010, 2014). The same principle is also available when the owner of the vessel changes but in this case only 20% of historical rights is returned to the national and POs reserves. These changes were aimed at supporting new entrants. The quota in the national reserve managed by Fisheries authorities was supposed to support small-scale fisheries in accordance with Article 17 of the CFP which recommended Member States to take into account environmental, economic and social criteria for quota allocation (EU, 2013). These were the official objectives; the next section examines what happened in practice.

D.4 Where do SSFs stand within this complex system?

In 1995, 4,889 vessels out of a national fleet of 6,646 vessels were less than 12 meters long. In 2015, 3,539 vessels out of a national fleet of 4,400 vessels were less than 12 meters long (INSEE, 2016). In the past, the majority of SSF vessels was found in the Mediterranean Sea but this is no longer the case. According to the data collected by the French Institute for the Exploitation of the Sea (IFREMER) in 2012, the SSF fleet is constituted as follow: 1,658 on the Atlantic coast, 1,486 on the Mediterranean Sea and 1,422 on the North Sea and English Channel. These numbers show the importance of SSFs to the entire French coast.

During the 1990’s, none of the SSF vessels on the Atlantic and North Sea-English Channel joined a PO. The first reason mentioned by fishers in the interviews was that “they were skeptical about the implementation of this system in practice”. They considered that this system introduced by Brussels could not be applied in France because it restricted the operational capacity of the vessels. For many SSFs this system could be applied to larger vessels but not to themselves, who operated in coastal waters with more environmentally friendly gear and with small landings. For those reasons the SSF vessels did not join the POs. In addition, the SSFs did not need the support of POs to add value to their production which was of higher quality than that provided by trawlers, for example.

In 2000, 50% of the French small-scale fleet were members of POs and this increased to 60% by 2010 (Larabi et al., 2013). Some authors explained this change in the attitude of SSFs towards POs as their wish to avoid the "race of fish" affecting all fishers operating under the quota managed by the national fisheries administration which was fast exhausted. Vessels using the quota managed by the fisheries administration do not benefit from historical rights and the principle of first come first served is applied. Therefore, some small-scale fishers decided to secure their catches by joining POs, in an attempt to organize their work throughout the year (Larabi et al., 2013; Bellanger et al., 2016).

However, the lack of historical rights was the reason why POs were reluctant to integrate SSFs into their ranks. POs and their members did not wish to discuss the reallocation of their fishing opportunities. The lack of historical rights of SSF can mostly be explained by the misreporting their catches for many years as only vessels over 12 meters length are required to report their catches. Eventually the integration was facilitated thanks to external changes such as the decommissioning policy applied by the EU from which many larger vessels benefited. With the departure of many larger vessels, there were fewer members in POs and subsequently available quota. So POs decided to facilitate the entrance of SSFs into their organizations. The new policy undertaken by POs was supported by the Fisheries Authorities which allocated historical rights on a few species to some SSF vessels. Unfortunately, it was impossible to learn what criteria were used to allocate historical rights to SSF vessels. This new role of POs coincided with their objective to "obtain EU recognition" and a larger membership required a greater budget to run the POs. But despite all these efforts, many SSFs remained outside of POs.

In France, vessels without quota (i.e. historical rights) do not obtain the same price as those with quota when they are sold (Quillérou and Guyader, 2012). In a vessel transaction, an agreement between buyer and vendor must be approved by the POs and is then submitted to the national advisory committee of quota for its approval. But in general such an agreement is approved. Although fish resources are classified by the Fisheries Law (JORF, 2010) as a common heritage in order to avoid their privatization, the quota of vessels can be passed on to the next owner and the value of the quota is included in the price of vessels. As such the quota becomes an individual right with a shadow or hidden price (Pinkerton and Edwards, 2009). In interviews with small-scale fishers this idea of giving a value to the vessel through the possession of quota appeared several times. The price of vessels can be higher if they have quota of some valuable species, for example, sole. In other words, IQs became ITQs attached to vessels, but limited by the need for PO approval of any sale.

One interviewee, a small-scale fisher member of a PO allowed to fish 12 tons of sole, said that his boat can be sold for several thousand euros more than other vessels that do not have the equivalent sole historical rights. The same fisher admits that quota allocation by POs can lead to the specialization of fishers because in his case, he was able to obtain his large quota as soon he joined the PO because he concentrates on sole fishing. But this quota of sole is not enough to live on and he would like to find 4 tons more. This is impossible because he cannot buy more quota as it is prohibited by law. Neither can he buy another boat because very few of them have historical rights equivalent to more than 12 tons of sole. So for him the only hope is that the PO may have spare quota every year to share among members.

Another fisher interviewee said that he is doing more multi-species fishing since he joined the PO. But for him the practice of this type of fishing is an obstacle to obtaining new quota since the IQ was introduced. That is because his historical catches were low during the three qualifying years and its quota was dispersed across many species. The same argument was made by other fishers who could not access enough quotas, especially when species fetched good commercial prices. Some of them think that fishers targeting mainly one species could obtain a larger amount of quota and earn enough money to live on. Small-scale fishers consider that nowadays it is difficult to become sole fishers as there is no more available sole quota and the vessels having high quota are old and nobody can buy them as they are expensive.

Other small-scale fishers mentioned that POs fix the quota of each vessel and as soon as the quota of each species is taken, they should "stay in the harbor". Fishers need to organize their activity differently than in the past so as not to exhaust their quota at the beginning of the season but also to be sure that they will find the allocated quantities when they want. For example, fishers from the harbor of Audierne, Brittany, harvest pollock between January and March and then shift to monkfish, red sea bream, etc. But a few years ago they could not follow this calendar because one big boat fished all the available quota of red sea bream and 15 vessels in the harbor who had very little quota for this species could not fish it at all. So all of them had to turn to other species and the equilibrium which they had established over the years was disrupted. Since then the local PO has opened the season of this species first to the small vessels and as soon their individual quotas are reached the PO opens the fishery to trawlers.

But the situation of small-scale vessels that are not in a PO is different. They fish under the part of the quota managed by the DPMA and they are often out of quota especially for species which have good value. So they shift to non-quota species. They can become members of POs but without access to quota because, as one fisher explained, "the PO quotas are entirely used up by the members so it is impossible to share them with newcomers". This quotation highlights the main difficulty faced by vessels not yet members of POs. Current members, mainly larger vessels, will not agree to share the available quota with newcomers. The current system of quota allocation is closed to newcomers and unlucky fishers who do not have historical rights and were not able to join a PO to secure their access to quota in time no longer have access to them. Newcomers can access IQs only if they buy a vessel with quota, but the price of such a vessel is high, higher than in the past (Symes and Phillipson, 2009). For those who cannot access IQ, the only solution is to fish quota species under the quota managed collectively by the Directorate at the national level or to fish species that are not subject to quota. Few valuable species are not subject of European quota, so SSFs without IQ can work but in a limited fashion.

But for SSFs having little IQ or, even more, for those fishing under the national collective quota, the main difficulty is the implementation of the Landing Obligation (LO), which requires that all harvested quota species be landed, not discarded (Gray et al., 2011). Implementing LO can be done only in two ways: make fishers stop fishing or allocate them new quotas in such a way so as to prevent discards. If implemented at the EU level, such changes would affect the relative stability principle, which would be an unexpected consequence of the LO.

Most SSF members of POs have little understanding of the governance of POs and particularly of the criteria for allocating quota among members. Some of them have the feeling that fishers with greater lobbying capacity are better served than others by the PO. The challenge for them is to understand how the board makes decisions and to learn whether these are influenced by groups of fishers with high lobbying capacity. This is not easy to discover because internal rules and minutes of board meetings are not made public.

The composition of the board of the largest French PO illustrates what appears to be a typical power imbalance: with 759 vessels of which 59% are less than 12 meters, only 16.3% of the seats within its board are occupied by SSFs. The low representation of SSFs within this PO board may explain the weak position of SSFs in the quota allocation process.

D.5 Different visions of the CFP and quota system

French small-scale fishers did not have their own organizations because by law, from 1945, when the first fisheries organizations were established, all fishers were members of the same organizations: the fisheries committees. The fisheries committees are the only organization allowed representing fishers' interests and rights at the French level (Larabi et al., 2013). In 2012, small-scale fishers from the Mediterranean Sea appealed to their colleagues from other coastal areas of France to join their initiative and establish together a national organization representing the interests of SSFs. Thus was born the Plateforme de la Petite Pêche Artisanale (PPPA), the small-scale and artisanal fisheries platform. This initiative was supported by ENGOs who saw in this initiative the opportunity to fight against the use of non-environmentally friendly gear. Small-scale fishers have viewed this support positively, as the ENGO's have more political weight than they do. Both were beginning to question national authorities, representative fisher organizations and POs about the equity in sub-quota allocation. Traditional fishers' organizations and POs tried to marginalize this new organization which dared to rally to the traditional enemy of fisheries industry: the environmentalists! According to the PPPA leaders, fisheries committees of the POs did not hesitate to exercise their power on SSFs wishing to join the new organization by explaining that, if they joined, they would lose the fishing rights allocated by the committees such as the licenses by gear or species. So only a few fishers from the Atlantic coast joined the PPPA. The PPPA gained more visibility at the EU level by joining the newly established organization called Low Impact Fisheries in Europe (LIFE) which also acts for the recognition of SSFs at the EU level and their inclusion in the CFP.

A short overview of the vision of the PPPA and ENGOs for EU policy and the quota system is presented here. Since its creation, the PPPA has acted against the implementation of the fisheries transferable concessions because for them this tool regulates fishing effort through the market, promotes access to the resource to the most economically powerful fishers, and engenders resource concentration. In opposition to this system proposed by the EU, PPPA members suggested the implementation of a new regime of access to the resource based on environmental, social and territorial criteria. These criteria are found in Article 17 of the CFP, so PPPA calls for the full implementation of Article 17, especially in quota allocation that they consider unfair for them. As discussed above, quota allocation is based on historical rights obtained during the period when SSFs were not members of POs. So they contest the current quota system and claim “fair share destinies for SSFs” (PPPA, 2016). In 2016 the co-chairs of the PPPA ironically stated that “quota is a formidable tool to small-scale fishers. It operates on a deeply unfair mechanism, the catch record. It rewards larger vessels and abandons those practicing reasonable fisheries”. They call for a new system which offers more benefits to SSFs, but for the moment nothing has changed. Another article on their website critiques the unfair SSF share of bluefin tuna quota in the Basque country, as the local PO allocated 88 tons of tuna to pelagic trawlers while two SSF vessels using hook and line got 500 kilos per year and seven others only 100 kilos per year (PPPA, 2016). This example shows that productive gears which negatively impacted tuna stocks in the past still have more rights than gear which have less impact on the resource. The transparency of quota allocation by POs is also denounced.

Another member of PPPA considers it discriminatory that fishing activity must stop as soon the quota of one species is reached. In his view, larger vessels are responsible for overfishing so the same rules should not be applied to both fleets. This is actually the practice in the pollock fishery, a major hook and line fishery in which the local PO closed the fishery for larger vessels and allowed the SSFs to finish their season.

ENGOs developed the same arguments as the PPPA in public debate and especially in places where they meet decision makers. One example is the public hearing organized in the senate about the future of fisheries following the CFP. The Greenpeace representative at this public hearing explained that they found Individual Quota a good tool but that they are opposed to the trade of these quotas. They argued that the only criteria on which the allocation of sub-quota is based are historical rights and they called for the implementation of a new system based on the criteria found in Article 17 of the CFP. For them the new system should be transparent in contrast to the current situation in which nobody knows on what criteria IQ allocation is based. The lack of transparency of the current system limits the development of a new system. The World Wildlife Fund and Bloom NGO used more or less the same argument vis à vis the current system and also called for transparency (Cléach, 2014). PPPA members and ENGOs are on the same page regarding the current system and constitute a stronger voice together.

D.6 Conclusion

French fishers, ENGOs, and territorial authorities expressed their opposition to Transferable Concessions as they were proposed by the European Commission in the Green Paper, thus rejecting a full neoliberalization of French fisheries. Transferable concessions or transferable quotas are against of the principle that fisheries resources are a public good and cannot be privatized. Fishing is an activity with significant territorial roots and the concentration of quotas in the hands of few companies may well deprive coastal communities of their identity and jobs. This link between fishing rights and territory was also an objective that the Dutch authorities wished to accomplish in the implementation of their ITQ system (Hoefnagel and de Vos, 2017). POs are responsible for keeping fishing rights within the geographic area where they operate as a way to preserve the economic link with the local community. This is possible through the collective management of the quotas within the POs and French fishers believe that collective management is a better tool for achieving resource conservation than ITQs which are freely transferable to any area. But there is growing skepticism about recent developments in which some POs have significantly increased their membership and extended their geographical area of responsibility as a consequence of multiple PO mergers. Many fishers view this as a potential watering down of the economic link of the resource to a local area.

The first allocation of quotas in France was viewed by some SSFs as “inequitable” and the non transparency of sub-quotas allocation within the POs has further reduced their confidence in the system. The new organization established by some SSFs, the PPPA, hopes for a revision of the current law regarding quotas allocation by insisting on the implementation of Article 17 of CFP. A full implementation of this article by Member States would require the introduction of new criteria of sub-quota allocation, for example, the use of more selective gear and the requirement for a smaller ecological footprint. The imposition of these new criteria can be done only by national authorities. Small-scale fishers and ENGOs need to convince policymakers about the unfairness of the current system and demand they act. This objective will be difficult to achieve in a country where decision-makers see larger vessels as successes but have little regard for their impact on the environment and where historically POs viewed ENGOs as the enemy.

Acknowledgement

We acknowledge the financial support of the project Discardless REP-633680-1, supported by HH2020 program of EU, and thank all interviewed fishers.

References

Bellanger, M., Macher, C., Guyader, O. (2016). A new approach to determine the distributional effects of quota management in fisheries. Fisheries Research, 181, 116-126.

Carpenter, G., Villasante, S., O'Leary, B.C. (2016a). Europe: Keep allowable fish catches sustainable. Nature, 531(7595), 448-448.

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

CEC. (2009). Commission of the European Communities. Green paper: reform of the Common Fisheries Policy. COM (2009)163 final CEC, Brussels.

Cléach, M.P. (2014). Pêches Maritimes : comment concilier exploitation et conservation des ressources halieutiques ?. Office Parlementaire d’évaluation des choix scientifiques et Techniques, Assemblée Nationale, Sénat, Paris.

CNPMEM. (2009). Contribution des professionnels de la pêche maritime, Réponse au Livre Vert, Réforme de la politique commune de pêches, 23 novembre 2009.

DPMA. (2011). Réforme de la Politique Commune de pêches, Présentation du Paquet Réforme PCP, Positions Françaises. Available online: www.peche.gouv.fr

Gray, T., Korda, R.C., Stead, S., Jones, E. (2011). Quota discarding and distributive justice: The case of the under-10 m fishing fleet in Sussex, England. Marine Policy, 35, 122-129.

GreenPeace France. (2009) Réforme de la politique Commune des Pêches (PCP) : notes sur le livre vert de la Commission Européenne, avril 2009, Paris.

Hoefnagel, E., de Vos, B. (2017). Social and economic consequences of 40 years of Dutch quota management. Marine Policy, 80, 81-87.

Holden, M. (1994). The Common Fisheries Policy. Origin, Evaluation and Future. Fishing News Books. Blackwell Scientific Publications Ltd., Oxford. 274 p.

INSEE. (2016). Tableaux de l’économie française, édition 2016, Paris.

JORF. (2006). Journal Officiel de la République Française N°301 du 29 décembre 2006 page 19953 texte n°104: Arrêté du 26 décembre 2006 établissant les modalités de répartition et de gestion collective des possibilités de pêche (quotas de captures et quotas d’effort de pêche) des navires français immatriculés dans la Communauté européenne. NOR: AGRM0602585A.

JORF. (2010). Journal Officiel de la République Française N°0106 du 7 mai 2010 page 8304 texte n°49: Ordonnance n° 2010-462 du 6 mai 2010 créant un livre IX du code rural relatif à la pêche maritime et à l'aquaculture marine. NOR: AGRS1007353R.

JORF. (2014). Journal Officiel de la République Française N°0299 du 27 décembre 2014 page 22407: Décret n° 2014-1608 du 26 décembre 2014 relatif à la codification de la partie réglementaire du livre IX du code rural et de la pêche maritime, Article R921-45. NOR: DEVM1411755D.

Larabi, Z., Guyader, O., Macher, C., Daurès, F. (2013). Quota management in a context of non-transferability of fishing rights: the French case study. Ocean and Coastal Management, 84, 13-22.

Mesnil, B. (2008). Public-aided crises in the French fishing sector. Ocean & Coastal Management, 51, 689-700.

Morin, M. (2016). L’avis de l’Autorité de la Concurrence sur le mécanisme de repartition des quotas de pêche en France. Neptunus e.revue, Vol. 22, Centre du Droit Maritime et Océanique, Université de Nantes, www.cdmo.univ-nantes.fr

Pinkerton, E., Edwards, D.N. (2009). The elephant in the room: the hidden costs of leasing individual transferable fishing quotas. Marine Policy 33(4), 707-713.

PPPA. (2016). Déclaration de la Plateforme de Petite Pêche Artisanale Française, available online: http://www.plateforme-petite-peche.fr/

Quillérou, E., Guyader, O. (2012). What is behind fleet evolution: a framework for flow analysis and application to the French Atlantic fleet. ICES Journal of Marine Science, 69, 1069-1077.

Symes, D., Phillipson, J. (2009). Whatever became of social objectives in Fisheries Policy? Fisheries Research, 95, 1-5.

Appendix E. Résumé long

En France, où les droits de pêches ne sont pas transférables, la gestion des quotas de pêche est essentiellement déléguée aux organisations de producteurs (OP), lesquelles se voient attribuer des allocations collectives et sont responsables de la gestion des possibilités de pêche de leurs adhérents. On peut ainsi s'interroger sur la manière dont la présence des OP au sein des institutions peut permettre d'améliorer les performances écologiques, économiques et sociales de la gestion des pêches en comparaison avec d'autres formes institutionnelles telles que les systèmes de quotas individuels transférables (QIT). Les recherches de thèse, comprenant une partie théorique et s'appuyant sur le cas de la pêcherie de sole du golfe de Gascogne pour les applications empiriques, sont organisées autour des questions suivantes : (1) Par quels mécanismes les OP peuvent-elles permettre d'améliorer le respect des réglementations et influencer l'émergence de normes sociales ? (2) Quels sont les effets redistributifs de la gestion des quotas par les OP ? (3) Comment les mécanismes de gestion des quotas par les OP peuvent-ils être intégrés dans la modélisation bio-économique pour l'évaluation d'impact de scénarios de gestion ? Les analyses développées établissent l'intérêt de prendre en compte des contraintes induites par différents arrangements institutionnels et les résultats sont notamment examinés au regard des trois dimensions (écologique, économique et sociale) nécessaires à la gestion durable des pêches. Les compromis entre ces différentes dimensions sont mis en évidence dans le cadre de scénarios prospectifs visant une meilleure compréhension des enjeux liés à la gestion des pêches.

E.1 Introduction générale

E.1.1 Tragédie des communs et nécessité de gérer les pêcheries

Les ressources halieutiques font partie de la catégorie des ressources communes, caractérisées par leur nature *rivale* et *non-exclusive*. Si ces ressources sont laissées en accès libre, les incitations économiques individuelles qui conduisent à pêcher le plus possible pour maximiser les profits de court terme sont généralement opposées à l'intérêt collectif. Initialement, il est rationnel pour un pêcheur d'augmenter son effort et/ou sa capacité de pêche pour capturer une quantité maximum de poissons en un temps minimum, un comportement connu sous le nom de 'course aux poissons'. De plus, dans une situation d'accès libre, l'existence d'une rente économique attire de nouveaux pêcheurs. Cependant, le caractère rival de la ressource implique que les captures extraites par un pêcheur d'un stock commun réduisent la disponibilité de la ressource aux autres pêcheurs, ce qui provoque l'augmentation du coût de l'effort de pêche. Progressivement, la différence entre la valeur des débarquements et le coût de l'effort de pêche diminue. D'autre part, il est très difficile et coûteux d’exclure d’autres pêcheurs de l’exploitation d’une ressource halieutique à cause de sa mobilité et de l’incertitude quant aux dynamiques des populations constituant les stocks de pêche. En termes économiques, plusieurs entreprises exploitant une ressource rivale et non-exclusive génèrent des externalités négatives mutuelles. Ainsi, ce décalage entre rationalités individuelle et collective induit la surcapacité, c’est-à-dire à une situation où il y a trop de navires par rapport à la quantité de ressources disponibles. En outre, la surcapacité provoque aisément la surexploitation, c’est-à-dire un taux de capture en excès du taux de renouvellement naturel de la ressource. En résumé, les externalités négatives mutuelles mènent à la surcapacité et à la surexploitation, les deux induisant une dissipation de la rente économique. Cette situation est une illustration de la ‘tragédie des communs’ décrite par Hardin en 1968.

Pour endiguer ce processus pernicieux, des mesures de gestion doivent être mises en place. On distingue deux principaux types de mesures de gestion des pêches : les mesures techniques, dédiées à la préservation des capacités productives et reproductives des stocks, et les mesures de régulation de l’accès, destinées à sélectionner qui peut pêcher et dans quelle quantité. Les mesures techniques, comprenant les totaux admissibles de captures (TAC), les fermetures géographiques et/ou saisonnières, ainsi que les restrictions sur la sélectivité des engins de pêche et sur les tailles minimales de débarquement, sont traditionnellement mis en œuvre par des méthodes dites "administratives". Ces mesures, si elles sont convenablement appliquées, peuvent permettre de contraindre l’exploitation des stocks de manière efficace. Cependant, elles n’éliminent pas le phénomène de ‘course aux poissons’ qui est lié au caractère commun de la ressource et qui peut affecter négativement l’efficacité de ces mesures.

La régulation de l’accès peut se faire par un contrôle sur l’effort de pêche via un système de licences de pêche, ou par un contrôle sur les débarquements avec la mise en place de ‘droits de pêche’ individuels. Ces droits de pêche, que l’on désigne habituellement par ‘quotas’ (ou également par ‘catch shares’ en anglais), correspondent le plus souvent à des pourcentages fixes d’un TAC qui est lui-même établi par une administration publique. Contrairement aux méthodes administratives, les approches à base de droits incitent les usagers de la ressource à adopter certains comportements et sont classées parmi les méthodes dites "économiques".

E.1.2 Echecs de la Politique Commune de la Pêche

En Europe, les activités de pêche sont gouvernées par la Politique Commune de la Pêche (PCP) qui était historiquement focalisée sur les politiques de conservation basées sur des mesures techniques mises en œuvre par des méthodes administratives. A ses débuts en 1983, la réglementation introduit des TAC pour les principales espèces commerciales et le concept de stabilité relative par lequel chaque Etat Membre se voit attribuer des possibilités de pêche selon ses activités historiques pour chaque stock. Dans les premiers temps de la PCP, la politique structurelle aidait financièrement le secteur de la pêche à se moderniser et à augmenter la compétitivité des flottilles. En 1992, étant donné le besoin d'un meilleur équilibre entre les ressources halieutiques disponibles et la capacité de la flotte communautaire, la PCP a été réformée pour y intégrer la mise en place progressive de système de licences à accès limité (*numerus clausus*) et la nécessité de contrôler l'effort de pêche. En 2002, la politique structurelle a été réorientée pour corriger les apparentes contradictions entre les aides à la construction de nouveaux navires et les objectifs de conservation de la ressource.

La réglementation a ainsi évolué vers des considérations de long terme avec des objectifs de durabilité écologique, économique et sociale. Les programmes successifs mis en place pour réduire la surcapacité ont permis de réduire progressivement la capacité totale de la flotte communautaire. Cependant, la surcapacité reste à l'heure actuelle un problème majeur. Bien que les aides publiques pour la construction de nouveaux navires aient cessé depuis 2004, le niveau de subvention des pêcheries de l'Union Européenne demeure élevé. Ceci est bien illustré par la citation suivante du Livre Vert sur la réforme de la PCP : « Les citoyens européens payent presque deux fois pour leur poisson : une première fois à l'étal, et une nouvelle fois avec leurs impôts ».

Malgré un consensus général entre scientifiques, politiciens et gestionnaires sur les objectifs de durabilité, la PCP a échoué à maintenir les stocks de pêche dans un bon état. Les tendances historiques montrent que les débarquements totaux ont atteint un pic au milieu des années 1970 et ont globalement décliné depuis. Le Livre Vert liste ainsi les problèmes que la PCP n'a pas su prévenir : surpêche, surcapacité, subventions considérables, faible résilience économique, déclin des quantités pêchées, et faible respect des réglementations par l'industrie. Bien que certaines études scientifiques récentes rapportent l'amélioration de l'état de certains stocks importants au cours de la dernière décennie, de nombreux stocks de pêche en Europe continuent d'être exploités au-delà des niveaux qui seraient appropriés pour atteindre les objectifs de durabilité. Ainsi, les TAC sont constamment fixés au-dessus des recommandations scientifiques, les autorités publiques devant faire face à la pression politique pour accroître les possibilités de pêche à court terme aux dépens de considérations de long terme. Devant les limites d'une gestion basée essentiellement sur des mesures de conservation, la Commission Européenne encourage clairement l'utilisation d'approches à base de droits afin de pouvoir atteindre les objectifs de la PCP.

E.1.3 Dernière réforme de la Politique Commune de la Pêche

Le nouvelle PCP, effective depuis le 1er Janvier 2014, est l'aboutissement d'une réforme initiée avec la publication du Livre Vert sur la réforme de la PCP en 2009. L'une des mesures phares introduites par la nouvelle PCP est l'obligation de débarquement qui a pour objectif d'éliminer les rejets de poissons non désirés et d'améliorer la mise en œuvre des TAC. Cependant, la mise en place d'une telle mesure soulève la question du contrôle et du respect des réglementations qui sont considérés déficients dans les pêcheries de l'UE. Selon la Commission Européenne, les inspections ne sont pas assez fréquentes et les pénalités encourues ne sont pas suffisamment dissuasives pour assurer le respect des réglementations. Sans aucun doute, l'obligation de débarquement, progressivement mise en place entre 2015 et 2019, sera difficile à faire respecter. Alors que les captures non déclarées ont des effets écologiques négatifs impactant les évaluations de stocks, l'obligation de débarquement souligne une nouvelle fois la nécessité d'identifier des mécanismes de contrôle capables d'assurer des niveaux élevés de respect des réglementations.

Un autre aspect important de la dernière réforme de la PCP concerne la régulation de l'accès et l'utilisation de méthodes à base de droits. La proposition du Livre Vert de mettre en place au niveau européen des concessions de pêche transférables, un concept similaire aux quotas individuels transférables (QIT), a provoqué un intense débat sur la pertinence de la généralisation des instruments de marché dans les pêcheries de l'UE. La France s'est fermement opposée à ce projet et a réaffirmé son attachement à des systèmes de gestion collectifs décentralisés et au principe de non transférabilité des allocations de pêche inscrit dans sa législation nationale. Après consultation et prise en compte des points de vue des Etats Membres, la Commission Européenne a abandonné le projet de généralisation de droits de pêche marchands et a laissé le choix de mettre en place ou non de tels systèmes à des échelles nationales à la discrétion des Etats Membres. Néanmoins, ces considérations concernant les mécanismes de régulation de l'accès ont mis en lumière le besoin d'évaluations des effets de la mise en place de systèmes à base de droits.

La nouvelle PCP a également établi la nécessité d'évoluer vers des perspectives de long terme et a confirmé l'engagement d'adapter les taux d'exploitation des ressources halieutiques à des niveaux pouvant restaurer et maintenir les populations de poissons au-dessus des seuils permettant de produire le *rendement maximum durable* (également connu sous l'acronyme anglais MSY pour maximum sustainable yield) pour toutes les pêcheries de l'UE. En pratique, les outils mis en place pour atteindre les objectifs de MSY sont des plans de gestion multi-annuels recouvrant plusieurs stocks dans les pêcheries multi-spécifiques. Un élément important de ces plans est l'évaluation régulière de leurs objectifs et l'évaluation d'impacts de nouvelles mesures de gestion. Ces évaluations nécessitent des outils bio-économiques qui intègrent les multiples dimensions qui peuvent influencer l'efficacité des mesures de gestion. Ainsi, il y a une forte demande de la part des gestionnaires et décideurs pour avoir de tels outils à disposition afin d'analyser les divers compromis possibles entre objectifs écologiques, économiques et sociaux.

En outre, la nouvelle PCP intègre une évolution de la gouvernance vers une plus grande *régionalisation*, donnant à l'industrie et aux institutions locales plus de responsabilité pour améliorer le système de prise de décision. L'idée sous-jacente est qu'atteindre simultanément plusieurs objectifs de gestion à une large échelle géographique constitue souvent un défi insurmontable et que les chances de succès peuvent être plus grandes si l'on considère les problèmes de gestion à des échelles régionales ou locales.

E.1.4 Intégration des politiques de la pêche dans une approche écosystémique

Alors que les premiers développements autour de la question de la gestion des ressources halieutiques étaient généralement concentrés sur des problèmes concernant une seule espèce, il est maintenant largement accepté que la gestion des pêches doit être intégrée dans une approche plus holistique considérant toutes les composantes de l'écosystème et leurs interactions. Ce nouveau paradigme a engendré un certain nombre de concepts tels que l'*ecosystem-based fishery management* (EBFM) et l'*ecosystem approach to fisheries* (EAF) qui, s'ils se distinguent d'un point de vue opérationnel, promeuvent tous une approche multi-spécifique et intégrée de la gestion des pêches.

Au niveau international, les principaux instruments législatifs pour la régulation des mers et des océans sont la Convention des Nations unies sur le droit de la mer (UNCLOS) et la Convention sur la diversité biologique (CBD). En Europe, la Directive-cadre Stratégie pour le milieu marin (DCSMM) définit également des objectifs généraux de conservation et de gestion. La DCSMM fixe pour objectif l'atteinte du 'bon état écologique' de toutes les eaux européennes d'ici 2020 et la protection des stocks de pêche dont les activités socio-économiques dépendent. Les politiques mises en place dans le cadre de la PCP doivent ainsi être compatibles avec les multiples régulations internationales liées à la conservation de la faune marine, ce qui souligne la nécessité de développer des approches intégrées au niveau scientifique.

E.1.5 Importance des régimes de gouvernance et des institutions

La mise en œuvre de mesures de régulation de l'accès est dépendante du système de gouvernance qui détermine les règles, les mécanismes et les structures institutionnelles. L'inefficacité de la gouvernance a été identifiée comme étant l'une des causes principales de la mauvaise gestion des pêches, menant à la surpêche et à des pertes économiques considérables à l'échelle mondiale. Il est désormais largement reconnu que les approches à base de droits sont souhaitables pour conférer aux utilisateurs de la ressource les incitations appropriées pour une pêche durable. Cependant, l'utilisation de ces approches n'est pas une condition suffisante pour assurer une bonne gestion si celles-ci ne sont pas adaptées au 'système à gouverner'. En effet, il existe une certaine incertitude quant à la capacité des systèmes de gouvernance à produire les résultats espérés, ce qui amène à considérer des approches alternatives ou complémentaires basées sur l'action collective et des arrangements de cogestion.

Les quotas individuels transférables (QIT) sont les systèmes à base de droits qui ont le plus attiré l'attention dans les sphères académiques et politiques durant les dernières décennies. Le premier avantage des QIT est la fin attendue de la 'course aux poissons' de par la mise en place de droits exclusifs. Des allocations individuelles sécurisées permettent en effet aux pêcheurs de se concentrer sur la minimisation de leurs coûts et la maximisation de la valeur de leurs quotas. La transférabilité des quotas permet également d'augmenter l'efficacité économique du système. D'un point de vue théorique, le consentement à payer pour l'acquisition de quotas dépend du profit marginal, de sorte que les pêcheurs les moins efficaces (ayant les coûts marginaux les plus élevés) vont rationnellement vendre leurs quotas aux pêcheurs les plus efficaces. Avec l'accumulation des expériences de mise en place de QIT à travers le monde, les preuves empiriques que ces systèmes peuvent permettre d'augmenter considérablement la profitabilité des pêcheries sont de plus en plus nombreuses.

Il existe cependant un certain nombre de problèmes associés aux QIT. La rationalisation économique des activités de pêche induit généralement une concentration des droits de pêche. Les plus grosses entreprises qui ont plus de liquidités sont plus susceptibles d'être en mesure d'acheter des quotas que les petites entreprises. Cela peut notamment faire diminuer le nombre d'emplois dans le secteur de la pêche, avec des conséquences sociales pour la petite pêche (i.e. la pêche artisanale) et les économies locales si les activités sont transférées dans d'autres régions. Des garde-fous sur la transférabilité des quotas peuvent ainsi être nécessaires pour limiter ces effets sociaux. L'acceptabilité des QIT par les pêcheurs peut donc dépendre de ces garde-fous et de l'allocation initiale qui doit être considérée équitable pour qu'un tel système soit légitime aux yeux de la profession. L'acceptabilité des QIT dans l'opinion publique peut aussi poser problème si les droits de pêche sont attribués gratuitement alors que la ressource est supposée être une propriété publique. En théorie, des mécanismes d'enchères ou de taxes pourraient rendre au public une partie de la rente générée à partir d'une ressource commune. En pratique, afin d'obtenir le soutien des professionnels, les régulateurs utilisent principalement des allocations gratuites qui produisent des effets d'aubaine pour la première génération de pêcheurs bénéficiaires.

Dans son célèbre livre datant de 1990, Elinor Ostrom a commencé à développer son influente théorie sur les ressources communes (connues sous l'acronyme CPRs pour *common-pool resources* en anglais) et l'action collective. Son approche décrit comment les règles qui opèrent à différents niveaux d'organisation sociale pèsent sur les résultats de l'utilisation d'une ressource naturelle par des individus. Ostrom a notamment montré que la gestion par une autorité centrale ou par des instruments de marché ne sont pas les seules réponses institutionnelles à la tragédie des communs. Les utilisateurs d'une ressource commune peuvent, en dehors de tout cadre législatif, s'accorder sur des règles au bénéfice de tous et ainsi prévenir la surexploitation. Sa conception des institutions, considérées comme un moyen de réduire les incertitudes dans un environnement complexe, permet de comprendre les conditions nécessaires à l'établissement de la confiance et de normes de réciprocité pour encourager l'action collective. Les facteurs qui affectent la vraisemblance d'une auto-organisation et d'une gestion durable d'une ressource commune incluent : l'importance de la ressource pour les utilisateurs, la connaissance du système socio-écologique, la prédictibilité de ses dynamiques, l'autonomie pour mettre en place et contrôler des règles décidées collectivement, la taille et l'homogénéité du groupe, le leadership, et le capital social.

A la suite du travail d'Ostrom, de nombreux auteurs ont soutenu l'idée que la cogestion basée sur des communautés d'utilisateurs peut favoriser une gestion durable des pêches. La cogestion est un système de gouvernance collective de la ressource dans lequel les responsabilités de gestion sont partagées entre agences gouvernementales, utilisateurs de la ressource et autres parties prenantes du secteur. Les utilisateurs de la ressource sont donc impliqués dans le processus de gestion et participent aux prises de décision concernant la réglementation et son contrôle. Contrairement aux approches centralisées, la cogestion délègue la gestion à des groupes d'utilisateurs organisés aux niveaux national, régional et local et promeut l'autonomie des utilisateurs à l'intérieur d'un cadre institutionnel général. En outre, conférer des droits d'usage à des groupes d'utilisateurs plutôt qu'à des individus peut permettre de faciliter la coordination et l'action collective. Il est généralement considéré que les approches de cogestion sont plus avantageuses que de simples mesures techniques appliquées par une autorité centrale lorsque la capacité du régulateur à assurer le suivi et le contrôle des règles est déficiente, ou lorsque la mise en place d'instruments de marché est inenvisageable.

La cogestion et les systèmes de QIT sont souvent opposés notamment parce qu'ils sont fondés sur des idéologies profondément différentes. Cependant, les systèmes de QIT et de cogestion sont théoriquement non-exclusifs. Par exemple, le système de gestion des pêches néerlandais présente un cas où les QIT ont été incorporés dans des arrangements de cogestion. Ainsi, la distinction entre QIT et cogestion peut être ambiguë.

E.1.6 Coopératives de pêche / Organisations de Producteurs

Les coopératives de pêche, également appelées organisations de producteurs (OP) en Europe, sont des acteurs majeurs de la gouvernance dans de nombreuses pêcheries à travers le monde. Les coopératives de pêche sont des groupes de pêcheurs qui gèrent collectivement leurs activités. Les compétences réglementaires déléguées par une administration aux coopératives de pêche peuvent inclurent la gestion des droits de pêche, le suivi et le contrôle des activités, la commercialisation et un rôle de représentation dans des instances consultatives et décisionnaires. En pratique, les coopératives peuvent être responsables de la distribution des quotas parmi leurs membres, influençant ainsi l'efficacité économique d'une pêcherie et produisant des *effets redistributifs*. Un certain nombre de mécanismes par lesquels les coopératives peuvent améliorer la gestion des pêches sont détaillés ci-dessous.

Facilitation de l'exploitation des quotas

Il existe des exemples d'utilisation partielle de TAC dans des pêcheries sous QIT, comme cela a pu être observé sur la côte ouest des Etats-Unis et en Nouvelle-Zélande. Le marché peut se révéler inefficace pour allouer les quotas en raison de coûts de transaction élevés qui résultent de phénomènes d'information imparfaite et asymétrique, de rationalité limitée, et d'externalités. Si les coûts de transaction sont élevés et que la valeur du quota est faible, les pêcheurs peuvent renoncer à prendre part au marché. En pratique, un certain nombre de comportements expliquant pourquoi des pêcheurs ne mettent pas leur quota à disposition sur le marché peuvent être identifiés. Premièrement, les pêcheurs peuvent penser qu'ils auront besoin du quota pour eux-mêmes plus tard dans la saison, ou ils peuvent ne pas vouloir que leur quota soit utilisé gratuitement parce que cela peut réduire la productivité du stock pour le futur. Dans des pêcheries multi-spécifiques sous QIT, les pêcheurs peuvent sous-exploiter leurs quotas pour certaines espèces en raison de quotas insuffisants sur d'autres espèces et de la difficulté d'estimer ce qu'ils devraient payer pour une espèce en particulier afin d'équilibrer captures et quotas dans leur portefeuille d'espèces. Une coopérative n'est pas forcément en mesure de modifier ces comportements, mais la gestion collective des possibilités de pêche peut se matérialiser sous la forme de décisions collectives sur des taux d'exploitation pour équilibrer captures et quotas au niveau de la coopérative, avec la possibilité d'opérer des réallocations de quota en cours de saison et de réduire les coûts de transaction.

Résolution des externalités résiduelles dans un système de QIT traditionnel

La capacité qu'ont les coopératives à mettre en œuvre une gestion en temps réel peut également aider à réduire les externalités de congestion temporelle dues à des variations de capturabilité d'une espèce et les externalités spatiales liées à l'épuisement local d'une ressource. En effet, un système de QIT ne permet pas en général la coordination nécessaire à l'optimisation du déploiement spatio-temporel de l'effort de pêche à l'échelle de la flotte entière. Il a été montré qu'une coopérative peut permettre de résoudre les externalités spatiales et temporelles en coordonnant les activités de leurs membres.

Partage d'information

Les coopératives de pêche peuvent faciliter le partage d'information sur la productivité de différents lieux de pêche et la présence de 'captures indésirables'. Par exemple, des augmentations de taux de capture ont été observées au sein de groupes spontanément organisés dans les pêcheries crevettières japonaises. Dans le Mer de Béring, des pêcheurs coopèrent pour éviter les captures accessoires de flétan, ce qui leur permet d'allonger la saison de pêche pour les espèces de poissons blancs ciblées. D'un point de vue théorique, il a été démontré que le partage d'information était sous-optimal dans un système de QIT et qu'une coopérative permet de résoudre ceci partiellement, mais pas complètement à cause de phénomènes de 'passager clandestin' (chaque membre de la coopérative souhaite que les coûts liés à la recherche d'information soient supportés par les autres membres).

Réduction des coûts de suivi et amélioration du respect de la réglementation

Les suivis et contrôles internes opérés par les coopératives peuvent permettre au régulateur de réduire substantiellement ses coûts de mise en vigueur des réglementations. En outre, la cogestion basée sur des coopératives peut augmenter la légitimé des règles et favoriser le développement de normes sociales, améliorant ainsi le respect des réglementations de manière générale. Les coopératives peuvent également promouvoir la soutenabilité écologique en participant aux prises de décisions et en encourageant les professionnels à prendre part à la collecte de données et au suivi.

En France, les premières organisations de producteurs (OP) ont été créées dans les années 1970 et se sont depuis imposées comme des acteurs socio-économiques incontournables du secteur. Initialement, leur rôle était fixé par la PCP et leurs missions incluaient notamment l'adaptation des plans de pêche à la demande des marchés afin de stabiliser les prix des poissons. Elles opéraient également un mécanisme de 'prix de retrait' qui consistait à retirer du marché toute production dont le prix en criée tombait en dessous d'un seuil fixé, garantissant ainsi un prix minimum pour de nombreuses espèces commerciales. Ce mécanisme de prix de retrait est désormais interdit depuis 2014. Dans les années 2000, un transfert de compétences réglementaires de l'administration française vers les OP, incluant la gestion des quotas, a été progressivement réalisé, faisant ainsi des OP un élément central du système de gestion des quotas en relation avec le système de TAC de la PCP. Chaque année, les OP se voient attribuer des sous-quotas collectifs basés sur la somme des antériorités de pêche (correspondant aux débarquements historiques des navires sur la période 2001-2003) de leurs adhérents, et chaque OP est ensuite responsable de la gestion de ses sous-quotas et de leur distribution entre ses adhérents. Par exemple, la plupart des OP ont développé des règles internes établissant des allocations de quotas individuels en dehors de toute obligation légale. Les OP ont également un rôle de représentation et siègent dans divers comités des pêches qui sont formellement impliqués dans les prises de décisions au niveau national et ont autorité sur certains aspects de la gestion régionale. Par conséquent, le rôle des OP et leur influence socio-économique dans le système de gestion des pêches en France sont très importants.

E.1.7 Objectifs de la thèse et questions de recherche

Dans le contexte des discussions sur les avantages et inconvénients de différents systèmes de gouvernance et de leur capacité respective à surmonter les problèmes identifiés pendant la dernière réforme de la PCP, cette thèse explore plusieurs sujets en lien avec les systèmes de gestion des quotas basés sur des OP. Le but de ce travail est de déterminer comment les effets écologiques et socio-économiques de la gestion sont modifiés si le régulateur choisit un système basé sur des OP par rapport à un système sans OP. Ainsi, le point de vue adopté est volontairement plus positif que normatif : au lieu d'essayer d'expliquer pourquoi un système de gestion de quotas basé sur des OP est le meilleur système possible pour gérer les pêcheries, nous constatons qu'il s'agit d'une option qui a été adoptée dans de nombreuses pêcheries dans le monde et nous nous interrogeons sur les effets de la présence des OP dans le système. À cette fin, cette thèse associe notamment approches bio-économiques et analyses institutionnelles pour mieux anticiper les impacts écologiques, économiques et sociaux de potentielles options de gestion. Les questions de recherche sont les suivantes :

(1) Par quels mécanismes les OP peuvent-elles permettre d'améliorer le respect des réglementations et influencer l'émergence de normes sociales ?

(2) Quels sont les effets redistributifs de la gestion des quotas par les OP ?

(3) Comment les mécanismes de gestion des quotas par les OP peuvent-ils être intégrés dans la modélisation bio-économique pour l'évaluation d'impact de scénarios de gestion ?

Ce manuscrit est structuré autour de ces trois questions de recherche, chacune ayant donné lieu à un article qui constitue respectivement les chapitres 2, 3 et 4. Le manuscrit se termine par un chapitre de conclusion qui synthétise les principaux résultats et apports méthodologiques de la thèse, souligne les limitations de ce travail et propose des perspectives pour de futurs travaux de recherche.

Les approches analytiques et empiriques mobilisées dans cette thèse sont diverses : formalisation de mécanismes institutionnels, modélisation par la théorie des jeux, analyse de distribution, modélisation bio-économique intégrée et simulations. En particulier, les développements bio-économiques s'appuient sur le modèle IAM (*Impact Assessment Model for fisheries management*) qui a été développé par l'équipe de recherche de l'UMR AMURE pour évaluer les impacts de scénarios de gestion dans le contexte de la mise en place de plans de gestion multi-annuels avec des objectifs de MSY.

E.1.8 Principal cas d'étude : la pêcherie de sole du golfe de Gascogne

La pêcherie de sole du golfe de Gascogne est le cas d'étude utilisé pour les chapitres 3 et 4 de cette thèse. Il s'agit de l'une des principales pêcheries françaises et est un exemple de pêcherie multi-spécifique où de multiples flottilles interagissent. La sole commune est une espèce de poisson plat distribuée dans l'Atlantique nord-est, du sud de la Norvège jusqu'au Sénégal, ainsi qu'en mer Méditerranée. Classée parmi les deux plus importantes espèces en termes de valeur des débarquements entre 2012 et 2016 en France, la sole commune est une espèce essentielle pour les fileyeurs et les chalutiers opérant dans le golfe de Gascogne.

La sole du golfe de Gascogne dans les zones CIEM VIIIab fait l'objet d'un plan de gestion multi-annuel depuis 2002 qui a été décidé à la suite de mortalités par pêche élevées ayant provoqué des risques d’effondrement du stock. L’état du stock s’est depuis amélioré, mais il est encore pêché au-delà du MSY en dépit de l’objectif affiché du plan de gestion d’atteindre le MSY en 2015 ou au plus tard en 2020. Ce stock est soumis à un TAC européen depuis 1984, et la part de la France est égale à 92% du TAC. Comme pour les autres espèces faisant l’objet d’un TAC, la gestion des quotas de sole est opérée en France par l’administration et par les OP. Il est intéressant de noter qu’il s’agit de l’une des toutes premières pêcheries françaises où des quotas individuels (également appelés quotas par navire) ont été mis en place en réponse à des contraintes accrues sur les quotas collectifs des OP par rapport à la disponibilité de la ressource et des menaces de sanctions pour dépassement de quota prévues par la PCP et par les réglementations nationales. Par ailleurs, alors qu’il y avait neuf OP impliquées dans la pêcherie de sole du golfe de Gascogne en 2011, trois fusions ont eu lieu entre 2011 et 2014 de sorte qu’il y a désormais six OP réparties le long de la côte du golfe de Gascogne. Celles-ci sont très hétérogènes de par leurs tailles et leurs compositions en termes de flottilles.

E.2 Chapitre 2

Les problèmes liés à la fraude peuvent compromettre la gestion durable des stocks de poissons. Il a été démontré empiriquement que les incitations économiques ‘conventionnelles’ prédominent dans les décisions individuelles concernant le respect des réglementations et des modèles de dissuasion appliqués aux pêcheries ont été développés. Les principales conclusions de ces modèles se rapportent à la probabilité de détection et de sanction, et la première recommandation est que la pénalité encourue doit être aussi élevée que possible afin d’augmenter la dissuasion. Cependant, un certain nombre d’éléments peuvent limiter le niveau de pénalité. En premier lieu, une pénalité imposée à une entreprise de pêche individuelle ne peut dépasser la valeur nette de l’entreprise. En réalité, les niveaux de pénalité sont bien moindres car les tribunaux sont peu enclins à faire appliquer des sanctions perçues comme excessives. Ainsi, dans la majorité des pêcheries, la fréquence des contrôles (et plus généralement les niveaux de suivi) et les niveaux de pénalités imposés par le régulateur sont insuffisants pour assurer une dissuasion appropriée en comparaison des gains potentiels associés au non-respect des réglementations et des quotas de pêche.

Constatant que les incitations économiques ne sont pas les seuls facteurs influençant le respect des réglementations, Sutinen et Kuperan ont proposé un modèle plus complet incluant des facteurs sociaux. Pour cela, ils ont ajouté un ensemble de variables liées aux jugements personnels normatifs et aux influences sociales telles que l’opinion des pairs concernant les comportements de fraude. Plus précisément, l’utilité retirée du bénéfice additionnel associé à la fraude est diminuée par les préférences sociales individuelles contre la fraude. Par ailleurs, de nombreux auteurs ont soutenu l’idée que les systèmes de cogestion sont un moyen d’améliorer le respect des réglementations dans la pêche. La cogestion fait référence à un processus collaboratif de prise de décision combinant les capacités et intérêts d'organisations professionnelles telles que des coopératives de pêche avec l'autorité d'une administration pouvant établir un cadre législatif et promouvoir la coordination. De tels systèmes sont effectivement utilisés dans de nombreuses pêcheries dans le monde.

Bien que les systèmes de gestion basés sur des coopératives de pêche sont très diversement structurés, beaucoup partagent le fait que les membres d'une même coopérative sont conjointement responsables pour ne pas dépasser des droits de pêche attribués collectivement à l'ensemble de la coopérative (et parfois ils sont conjointement responsables pour d'autres types de violations tels que les fausses déclarations). De manière générale, la responsabilité conjointe[16] désigne un régime de responsabilité sous lequel les membres d'un groupe sont mutuellement responsables pour les dommages causés par un ou plusieurs membres. La responsabilité conjointe a, par exemple, été appliquée dans le domaine des pollutions environnementales impliquant des sites contaminés par des déchets dangereux aux Etats-Unis ('Superfund sites') où il a été démontré que la responsabilité conjointe avait influencé les différentes parties à réduire les risques de dommages environnementaux. Dans le contexte des coopératives de pêche, les réglementations peuvent inclure un régime de responsabilité conjointe de sorte que le régulateur peut alors imposer une sanction à l'ensemble de la coopérative pour des violations causées par un ou plusieurs membres, comme c'est le cas aux Etats-Unis et en France par exemple. La littérature en économie des pêches n'a pas encore étudié le rôle que peut jouer ce mécanisme de responsabilité conjointe pour l'amélioration (ou potentiellement la détérioration) du respect des réglementations.

Lorsque la responsabilité conjointe s'applique, les coopératives de pêche généralement mettent en place leur propre système de monitoring et de pénalités défini dans leur règlement intérieur. Le schéma de dissuasion traditionnel est alors modifié puisque le problème principal-agent classique (régulateur → pêcheurs) devient un jeu imbriqué (régulateur → coopérative & coopérative → pêcheurs). Le chapitre 2 explore la manière dont les incitations économiques sont changées dans une telle situation par la formalisation de deux mécanismes de monitoring-pénalité pouvant être mis en œuvre dans une coopérative de pêche. Dans un premier temps, les incitations économiques traditionnelles sont étudiées au moyen d'un modèle de théorie des jeux. Dans un second temps, un modèle de préférences sociales basé sur les théories de l'aversion aux inégalités est introduit pour prendre en compte les effets potentiels du capital social sur les comportements individuels. Pour simplifier les choses au maximum, le modèle de théorie des jeux est limité à deux individus (ou joueurs), formant une coopérative ou non. Chaque joueur considère la possibilité de frauder pour un bénéfice additionnel non spécifié. Le régulateur a une certaine probabilité de détecter une fraude et d'imposer une pénalité. Dans le cas sans coopérative (utilisé comme point de comparaison), les

[16] On parle également de responsabilité conjointe et solidaire (ou 'joint and several liability' en anglais) lorsque chaque membre peut être tenu responsable de tous les dommages causés par le groupe. Dans les faits, la différence entre un régime de responsabilité *conjointe* et un régime de responsabilité *conjointe et solidaire* est peu évidente dans leur application aux coopératives de pêche.

incitations économiques traditionnelles conjecturent qu'un individu respecte la réglementation si et seulement si le bénéfice additionnel de la fraude est inférieur à la probabilité de détection multiplié par le montant de la pénalité imposée par le régulateur. Dans le cas où les deux individus forment une coopérative, on suppose que la responsabilité conjointe s'applique et qu'une pénalité imposée par le régulateur est alors supportée de manière égale par les deux individus. La coopérative peut mettre en place un système de monitoring interne, ce que l'on a formalisé par le fait que chaque membre de la coopérative peut *surveiller* l'autre à un certain coût non nul. Ainsi, le jeu prévoit que chaque individu a quatre stratégies possibles selon s'il fraude ou non et s'il surveille ou non. Dans le premier mécanisme de monitoring-pénalité que l'on a défini, les pénalités internes à la coopérative ne sont appliquées que lorsqu'une fraude détectée par la coopérative a également été détectée par le régulateur (il s'agit donc d'un mécanisme d'indemnisation à l'intérieur de la coopérative). Dans le second, les pénalités internes à la coopérative sont indépendantes de la détection par le régulateur. On suppose de plus que chaque individu prend ses décisions de manière indépendante (jeu non coopératif) et que chacun possède une information parfaite des stratégies possibles de l'autre individu. Les stratégies préférées sont obtenues par détermination des équilibres de Nash, et le niveau de fraude est alors la somme des probabilités associées aux stratégies où l'individu choisit de frauder. Enfin, les joueurs peuvent être symétriques (le bénéfice additionnel de la fraude est identique pour les deux individus), ou asymétriques (les bénéfices additionnels respectifs sont différents).

Les principaux résultats analytiques établis dans le chapitre 2 sont les suivants :

Proposition 1 : si les pénalités internes sont limitées à un mécanisme d'indemnisation, la responsabilité conjointe n'augmente pas les incitations économiques au respect des réglementations.

Proposition 2-a : si les pénalités internes sont indépendantes de la détection par le régulateur, des joueurs symétriques n'ont pas intérêt à la mise en place effective d'un système de monitoring au sein de la coopérative.

Proposition 2-b : si les pénalités internes sont indépendantes de la détection par le régulateur et si les joueurs sont asymétriques, le joueur pour qui le bénéfice de la fraude est le plus faible a intérêt à la mise en place effective d'un système de monitoring au sein de la coopérative.

Proposition 3 : si les pénalités internes sont indépendantes de la détection par le régulateur et si les joueurs sont asymétriques, les incitations économiques au respect des réglementations augmentent pour un large éventail de valeurs des paramètres. En outre, en considérant un modèle d'aversion aux inégalités, la fraude diminue encore davantage.

Ainsi, les résultats montrent que la responsabilité conjointe est un élément important des systèmes de gestion basés sur des coopératives de pêche ayant des implications en termes de design institutionnel. Les conclusions tirées de notre analyse soulignent que la responsabilité conjointe est généralement bénéfique pour le respect des réglementations. Elle permet au régulateur de révoquer les droits de pêche de l'ensemble de la coopérative, ce qui génère une pénalité beaucoup plus importante que ce qui pourrait être récupéré avec une sanction individuelle et peut diminuer le niveau de fraude pour une dépense de contrôle donnée. Cependant, notre analyse montre également que le régulateur ne doit pas se reposer uniquement sur les coopératives pour assurer le contrôle du respect de réglementations. En effet, si les intérêts des différents membres de la coopérative sont convergents (i.e. s'il n'y a pas d'asymétrie), alors la responsabilité conjointe n'augmente pas les incitations au respect des réglementations et le régulateur doit s'assurer que les membres de la coopérative n'ont pas intérêt à coopérer pour échapper aux contrôles.

E.3 Chapitre 3

Les questions concernant les allocations de quotas ont un enjeu fort en raison de leurs implications écologiques, économiques et sociales. Les problèmes de redistribution des richesses et d'hétérogénéité peuvent perturber les performances des systèmes de gestion des quotas. Par ailleurs, les effets redistributifs des allocations de quotas sur les rendements économiques sont au cœur des questions de justice sociale et d'acceptabilité. Pourtant, ces effets redistributifs sont peu étudiés et de nombreux auteurs soutiennent l'idée qu'une plus grande attention devrait leur être accordée. Ces questions sont particulièrement significatives dans le contexte français où la grande pêche industrielle et la petite pêche artisanale coexistent et où l'équité en termes d'accès à la ressource est en jeu. La distribution des quotas est également associée aux problématiques environnementales liées à l'utilisation d'engins actifs (chaluts) ou passifs (filets) dans les pêcheries démersales. Par ailleurs, le système de gestion des quotas français est basé sur des OP qui ont un fort enracinement local, de sorte que leurs stratégies en termes de politique d'adhésion et de distribution des quotas peuvent influencer les droits d'accès à la ressource des communautés de pêche locales. Ainsi, l'objet du chapitre 3 est d'étudier les effets redistributifs du système de gestion des quotas français et de mesurer si la gestion des quotas par les OP a permis de limiter les inégalités et la concentration des productions.

Le débat qui a eu lieu en France pendant la réforme de la PCP a notamment soulevé la question du choix du système de gestion des quotas à adopter. Les deux principales options étaient un marché de quotas individuels transférables et un système de cogestion où les allocations sont attribuées à des groupes de producteurs. Il existe une vaste littérature sur leurs mérites respectifs pour apporter des solutions aux problèmes de la pêche durable, mais on en sait peu sur leur influence sur la redistribution des richesses en termes de gagnants et perdants dans une pêcherie. On distingue deux approches possibles pour l'étude des effets redistributifs dans la littérature en économie des pêches. La première utilise des modèles théoriques pour explorer les conséquences de différents systèmes de gestion. La seconde est l'application de mesures d'inégalité sur des données empiriques pour quantifier les changements dans la distribution des captures, souvent en lien avec un changement de gestion tel que l'introduction de QIT. L'étude développée dans le chapitre 3 se rapporte à ce deuxième type d'approche et s'intéresse au cas des systèmes de cogestion basés sur des OP tels que mis en œuvre dans certains pays d'Europe et qui n'ont pas encore été abordés de manière quantitative dans la littérature.

La quantification des effets redistributifs nécessite d'abord une connaissance précise de la situation initiale à partir de laquelle la redistribution a eu lieu. Ensuite, cela requiert de sélectionner des métriques appropriées. Les mesures d'inégalité qui sont le plus souvent trouvées dans la littérature en économie des pêches quantifient généralement l'inégalité dans la population totale, et peu d'attention est portée aux inégalités *intra*- et *inter*-groupes de navires. Pourtant, la considération de plusieurs échelles offre un aperçu des effets redistributifs pour les principaux participants de la pêcherie ainsi que pour les contributeurs secondaires, ce qui est essentiel dans un contexte où grands et petits navires se côtoient en utilisant divers engins de pêches. Ce chapitre discute la pertinence de différentes mesures d'inégalité pour l'exploration des effets redistributifs de la gestion des quotas et introduit une nouvelle méthode qui utilise la propriété de décomposabilité de l'indice de Theil pour décomposer l'inégalité par sous-groupes de navires et déterminer les composantes *intra* et *inter*.

La pêcherie de sole du golfe de Gascogne a été la première pêcherie où des quotas individuels par navire ont été utilisés en France dès 2006, et cette innovation de gestion tend désormais à être généralisée dans de nombreuses pêcheries importantes en France. Le chapitre 3 utilise ce cas d'étude pour analyser les effets redistributifs des systèmes de gestion des quotas adoptés par les OP sur les productions de sole en se basant sur l'année de référence 2011. Les débarquements réels observés sont comparés à une situation initiale simulée basée sur les antériorités de pêche par navire qui, en réalité, sont utilisées par l'administration française comme clé de répartition pour les allocations de quotas collectifs attribués aux OP dans le système de gestion actuel. Des décompositions par flottille, classe de longueur, et quartier maritime ont été employées pour étudier les différences entre la situation initiale et la situation finale.

Le système de gestion des quotas français repose principalement sur des 'droits historiques' puisque les quotas collectifs attribués aux OP sont basés sur les antériorités de pêche de leurs membres (i.e. sur la période 2001-2003). Cependant, chaque OP a développé ses propres règles internes pour fournir des allocations individuelles ou collectives à ses membres, règles qui intègrent parfois des méthodes alternatives à l'utilisation des droits historiques telles que des critères basés sur les engins de pêche ou des allocations égalitaires. Comme le système français n'autorise pas les échanges de quota entre individus, y compris à l'intérieur des OP, le design de ces règles internes mis en place par les OP a une influence directe sur les stratégies individuelles et les performances économiques des membres de ces OP. Les règles qui ont été adoptées par les OP sont hétérogènes et reflètent la variété des différents profils des flottilles entre les OP. Les résultats du chapitre 3 montrent que la redistribution des quotas de sole a bénéficié significativement aux flottilles les plus dépendantes économiquement à cette espèce. Ainsi, dans un contexte de non-transférabilité des allocations, les OP ont procédé à l'ajustement des quotas aux besoins de leurs flottilles. Ceci a notamment pu être réalisé grâce à trois mécanismes distincts (mais non exclusifs) : la mise en place de règles d'allocation basées sur des années de référence plus récentes que la période des antériorités ; la garantie et mise à disposition d'une part fixée du sous-quota de l'OP pour un groupe de navires déterminé par les engins utilisés, la taille de navires et/ou un critère géographique ; la différenciation des règles d'allocation pour une ou plusieurs flottilles spécifiques. En particulier, les allocations égalitaires utilisées dans deux OP ont vraisemblablement contribué à la réduction des inégalités observées au sein de certaines flottilles.

Dans certaines OP, les politiques de gestion ont également été favorables aux petits navires (< 12 m). À première vue, il apparaît que cela n'est pas directement lié à des règles d'allocation spécifiquement conçues pour favoriser la petite pêche. Cela s'explique plutôt par le fait que, par le passé, les débarquements des plus petits navires n'étaient pas systématiquement enregistrés car ceux-ci ne respectaient pas toujours les exigences en matière déclaration des captures et que l'utilisation des logbooks était obligatoire seulement pour les navires les plus grands. Ainsi, l'administration a pu sous-estimer les droits historiques de certains petits navires sur la période 2001-2003, ce qui explique pourquoi l'on observe des débarquements cumulés supérieurs aux antériorités pour ces navires. Néanmoins, ce phénomène reste pertinent dans le cadre des effets redistributifs de la gestion par les OP car il est la conséquence des stratégies des OP concernant la politique d'adhésion vis-à-vis des petits navires qui n'ont pas d'antériorité. Certaines OP ont ainsi permis à ces navires de rester dans la pêcherie en acceptant leurs demandes d'adhésion à l'OP et en leur attribuant une part de leur sous-quota. Il s'agit d'ailleurs d'un point critique puisque la question du sort des producteurs qui n'ont pas d'antériorité mais qui ont historiquement participé dans la pêcherie est considérée comme l'un des principaux problèmes en termes de justice sociale lorsque les allocations sont basées sur des droits historiques.

La dimension territoriale apparaît aussi comme ayant influencé les stratégies d'allocation choisies par les OP. Les résultats du chapitre 3 établissent que la redistribution des quotas de sole a bénéficié en premier lieu aux navires opérant dans le quartier maritime où l'OP a implanté son siège et qui constituent les flottilles qui sont historiquement liées à l'identité de l'OP. Concrètement, les différenciations locales peuvent être directement intégrées dans les règles d'allocation au moyen de critères géographiques ou indirectement en utilisant des critères basés sur des engins qui sont plus particulièrement pratiqués par les navires d'un port donné. Les résultats indiquent enfin que les effets redistributifs parmi les navires hors OP sont mineurs. Dans les faits, les navires hors OP sont regroupés dans un ‘pot commun’ supervisé par l’administration où la course aux poissons a toujours lieu. Cela explique notamment pourquoi la majorité des détenteurs d’antériorité ont rejoint les OP.

E.4 Chapitre 4

Dans le contexte des nombreux débats qui ont eu lieu durant la dernière réforme de la PCP, il apparaît que l’évaluation de l’efficacité des systèmes de gestion du point de vue multicritère est particulièrement importante. Il y a ainsi un besoin de développer des modèles qui intègrent les interactions entre ressources, usages et mécanismes de gouvernance pour simuler les impacts de différentes options de gestion. Les évaluations d’impact doivent notamment mettre en évidence les compromis entre les multiples objectifs de gestion et permettre de comparer les différentes options entre elles.

Les approches dites MSE (*management strategy evaluations*), qui s’appuient sur des modèles bio-économiques et où les incertitudes associées à l’observation et à l’implémentation des TAC sont traditionnellement bien représentées, sont souvent considérées comme le moyen le plus approprié pour évaluer les compromis pouvant être atteints par diverses options de gestion. Cependant, les approches MSE ne prennent pas en compte de manière explicite les contraintes induites par les systèmes de gestion des quotas sur les individus en dépit de leur influence sur les stratégies des producteurs. Alors que les OP jouent un rôle majeur dans la gestion des quotas dans de nombreux pays de l’UE, les modèles actuels n’incorporent pas les mécanismes de gestion des quotas opérés par les OP. Par conséquent, ils ne permettent pas de simuler la complexité des systèmes de cogestion basés sur des OP qui est nécessaire pour une comparaison avec d’autres systèmes de gestion basés sur des mécanismes de marché. Ainsi, il est essentiel de pouvoir : (1) améliorer les outils de modélisation des socio-écosystèmes en y intégrant divers arrangements institutionnels pour mieux prendre en compte l’influence de la gouvernance dans les évaluations d’impact d’options de gestion des pêcheries ; (2) développer des outils de modélisation capables de représenter les contraintes et stratégies des producteurs à l’échelle du navire et leurs interactions via la ressource et le marché.

Le chapitre 4 présente un modèle bio-économique de simulation à l’échelle du navire qui a été développé pour explorer les impacts écologiques, économiques et sociaux des systèmes de gestion des quotas. Ce modèle est appliqué à la pêcherie de sole du golfe de Gascogne et représente de manière explicite les mécanismes de gestion des quotas selon les arrangements institutionnels existants et de potentielles alternatives incluant un système de QIT. Les navires sont modélisés à l’échelle individuelle ce qui permet d’analyser les résultats en termes d’hétérogénéité et de variabilité au sein des flottilles. Les interactions entre individus via les externalités de stock sont prises en compte grâce à la fonction de production basée sur l’équation de Baranov. La méthodologie proposée s’appuie sur une version enrichie du modèle bio-économique IAM qui intègre divers arrangements institutionnels. Les simulations des impacts bio-économiques de l'actuel système français de cogestion basé sur des OP, combiné ou non avec un plan de sorties de flotte, sont comparées à celles d'un système de QIT sous l'hypothèse commune d'exploitation du stock pour l'atteinte du MSY. L'analyse de la capacité de ces différentes options de gestion à répondre aux problèmes liés à la gouvernance des quotas est présentée d'un point de vue multicritère.

La méthodologie développée consiste à coupler un modèle opérationnel (*operating model*) avec une procédure de gestion (*management procedure*). Le modèle opérationnel, qui a un pas de temps annuel, représente classiquement les dynamiques biologiques des stocks de poissons et les dynamiques d'exploitation à l'échelle du navire. Il est 'structuré en âge' pour mieux appréhender les impacts de la sélectivité hétérogène des différentes flottilles sur les dynamiques de stock. Il permet également de distinguer plusieurs métiers pour tenir compte de la diversité des pratiques de pêche au sein des flottilles et même à l'échelle du navire. Un module de comportement de court terme dirige les efforts individuels et les captures qui sont ensuite utilisées par les modules biologique et économique. Un module de comportement de long terme détermine l'ajustement de la capacité de la flotte sur la base des outputs du module économique. La procédure de gestion intègre divers arrangements institutionnels associés à la gestion des quotas. Contrairement à la pratique la plus courante, la procédure de gestion n'est ici pas limitée à une simple règle de contrôle de l'exploitation (*harvest control rule*). Elle inclut les allocations de quotas individuels suivant les mécanismes de mise en commun des droits de pêche et réallocations opérés par les OP. Elle intègre également un module qui reproduit la gestion des antériorités dans le cadre de sorties de flotte. En outre, la simulation d'un plan de sorties de flotte et la simulation d'un marché de location de quotas peuvent être activées en tant que scénario dans la procédure de gestion.

Trois scénarios distincts correspondant à des options de gestion potentielles soutenues par différentes parties prenantes ont été analysés : un scénario de référence qui représente l'actuel système de cogestion des quotas où chaque OP opère la redistribution de son sous-quota collectif auprès de ses membres selon ses propres règles et où les allocations individuelles sont non transférables ; un scénario similaire au scénario de référence auquel est combiné un plan de sorties de flotte aidées financé par des fonds publics ; et un scénario de QIT où les allocations individuelles peuvent être échangées dans un marché de location de quotas. L'année de référence utilisée pour le paramétrage est 2014 et les simulations ont été faites sur la période 2015-2025 pour une sélection de 359 navires individuels ayant capturé plus d'une tonne de sole dans le golfe de Gascogne en 2014.

Les résultats des simulations montrent des impacts différenciés entre les trois scénarios et révèlent les compromis entre performances écologiques, économiques et sociales pour chaque option. Le scénario de référence dans le cadre d'une transition vers le MSY atteint de manière satisfaisante les objectifs écologiques avec notamment une reconstruction des stocks de sole et de langoustine ainsi qu'une réduction de l'impact sur les habitats et de l'empreinte carbone. Cependant, dans ce scénario de gestion, qui est lié à un objectif de maintien de l'activité de pêche de presque tous les navires, l'évolution de la situation socio-économique serait un problème majeur étant donné le contexte de surcapacité et de transition vers le MSY. À court terme, le problème principal serait la viabilité économique de la flotte. À long terme, l'emploi en termes de volume horaire serait diminué malgré l'objectif de maintien de la structure de la flotte.

Selon le scénario combinant le système de cogestion actuel et un plan de sorties de flotte, la réduction de capacité réalisée par le plan de sorties de flotte serait principalement associée à des sorties de chalutiers. Cela serait bénéfique pour le stock grâce à l'amélioration de la sélectivité puisque les fileyeurs sont plus sélectifs que les chalutiers. Cette option permettrait également d'augmenter la profitabilité et la viabilité économique en comparaison avec le scénario de référence. En termes d'impacts sociaux, la rémunération horaire serait améliorée mais le nombre d'heures d'emploi serait diminué.

D'après les simulations du marché de quotas, les QIT changeraient la distribution des quotas entre flottilles et amèneraient les fileyeurs à sole à mettre à disposition leur quota aux autres flottilles qui sont moins spécialisées sur la sole. Les profits générés par le système de QIT seraient supérieurs aux autres options, assurant une viabilité économique élevée et augmentant l'efficacité économique sur le long terme. Néanmoins, cette situation économique favorable aurait un coût : de plus grandes inégalités économiques au sein de la pêcherie ainsi qu'une plus grande empreinte carbone due à l'augmentation de l'effort de chalutage. Ainsi, des problèmes sociaux et écologiques pourraient entraver l'acceptabilité des QIT. À cet égard, si les QIT devaient réellement être mis en place dans cette pêcherie, des garde-fous sur la transférabilité pourraient alors être nécessaires afin d'obtenir le soutien des parties prenantes et de l'opinion publique.

E.5 Conclusion générale

E.5.1 Principaux résultats et recommandations en termes de politiques publiques

Cette thèse a examiné les effets de la présence des organisations de producteurs (OP) entre le régulateur et les pêcheurs, et la manière dont le design institutionnel peut influencer les résultats dans les systèmes de quotas basés sur les OP en termes de respect des réglementations, de distribution, et de compromis entre les dimensions écologique et socio-économique pouvant être atteints par diverses options de gestion. En France, un système de quotas basé sur les OP a été effectivement mis en œuvre en 2006 dans un contexte de surcapacité globale des flottes de pêche et de contraintes croissantes sur les possibilités de pêche. Ce système est notamment caractérisé par un mécanisme de mise en commun des antériorités au niveau de l'OP et par le fait que les allocations individuelles ne sont pas transférables de par la loi. Par conséquent, l'influence des OP qui sont responsables pour réallouer les quotas parmi leurs membres est considérable.

Dans le chapitre 2, il a été démontré que la responsabilité conjointe est un élément central des systèmes de quotas basés sur des OP qui a d'importantes implications pour le respect des réglementations. La capacité du régulateur de révoquer les droits de pêche d'une OP entière permet de générer un effet dissuasif plus efficace que la menace d'une pénalité individuelle dans un système sans OP. Le mécanisme de responsabilité conjointe peut ainsi augmenter le respect des réglementations pour une dépense de contrôle donnée. Cependant, le régulateur ne peut pas s'en remettre aux OP pour assurer les contrôles et il doit vérifier que les OP ont elles-mêmes un intérêt à mettre en place un système de monitoring interne et faire appliquer des sanctions à l'intérieur de l'OP. À cette fin, le régulateur pourrait conditionner l'attribution des quotas aux OP à la vérification ou la justification de la mise en œuvre d'un système de monitoring et pénalités internes en conformité avec exigences réglementaires. En plus de la responsabilité conjointe, un autre avantage potentiel des systèmes de quotas basés sur les OP est l'amélioration de la légitimité et l'émergence de normes comportementales associées à la cogestion. En France, où les OP sont libres de se constituer et d'exclure les membres indésirables, la plupart des OP existent depuis plusieurs décennies et leurs membres partagent une longue expérience commune, ce qui est un élément important du capital social et suggère que la responsabilité conjointe peut générer des effets positifs pour le respect des réglementations. Bien qu'à l'heure actuelle il soit difficile de savoir comment l'obligation de débarquement introduite par la nouvelle PCP sera contrôlée, notre analyse indique que le régulateur pourrait avantageusement inclure les rejets illégaux parmi les infractions sujettes à la responsabilité conjointe (comme c'est le cas pour les coopératives de la Nouvelle-Angleterre aux Etats-Unis), ce qui inciterait les OP à promouvoir en interne le respect des règles. Plus généralement, dans une situation où la petite pêche représente 80% des navires de l'UE et où le contrôle de l'obligation de débarquement apparaît difficile sans un coût de monitoring élevé, le régulateur devrait considérer comment le design institutionnel pourrait aider à améliorer le rapport coût-efficacité du système de contrôle des réglementations dans les pêcheries de l'UE.

Dans le chapitre 3, les effets redistributifs d'un système de quotas basés sur des OP dans un contexte de non transférabilité des allocations ont été étudiés dans le cas de la pêcherie de sole du golfe de Gascogne. Alors qu'un système de QIT traditionnel induit généralement une rationalisation de la capacité de la flotte et une concentration des productions sur moins de navires, le système français a permis d'éviter certains de ces problèmes sociaux qui tendent à apparaître dans un système de QIT tout en réduisant de manière significative la capacité de la flotte grâce à des plans de sorties de flotte. La non-transférabilité des allocations est un élément décisif qui a favorisé ce résultat en permettant aux OP de contrôler la distribution des quotas dans la pêcherie. En lien avec l'objectif de maintenir les équilibres territoriaux et socio-économiques, les OP ont pu adapter leurs stratégies de gestion des quotas en fonction des profils de leurs flottilles. Par exemple, une plus grande équité au sein de certaines flottilles a pu être observée. Néanmoins, un rapport de l'Autorité de la concurrence fait état de plaintes concernant un certain nombre de décisions prises par les OP qui ont favorisé les pêcheurs possédant les antériorités les plus importantes, ce qui remet en cause l'équité intergénérationnelle. Selon l'article 17 de la PCP, les Etats Membres doivent s'assurer que les méthodes et critères d'allocation des opportunités de pêche entre producteurs sont objectifs et transparents. Pour ce faire, le régulateur pourrait exiger que les décisions d'allocation de quotas par les OP soient rendues disponibles dans un registre détaillant les récipiendaires de ces allocations. Par ailleurs, puisque les allocations faites aux OP sur la base des antériorités tendent à donner un plus grand pouvoir de négociation à l'intérieur des OP aux membres ayant le plus d'antériorités, le régulateur pourrait décider d'allouer une (petite) part du quota national entre OP en utilisant un critère alternatif (social ou environnemental) pour réduire les impacts négatifs des allocations basées sur la participation historique.

Dans le chapitre 4, différentes options de gestion pour la transition vers le MSY dans la pêcherie de sole du golfe de Gascogne ont été évaluées selon leurs performances écologiques, économiques et sociales. Les simulations des impacts du système de cogestion actuel sans transférabilité ont été comparées à celles d'un système de QIT. Pour chaque option, les compromis entre les multiples objectifs de gestion ont été quantifiés. La combinaison d'un plan de sorties de flotte avec les arrangements de cogestion actuels impliquerait vraisemblablement la sortie de nombreux chalutiers, ce qui réduirait les impacts sur les habitats et l'empreinte carbone tout en améliorant la viabilité économique de la flotte. Bien que coûteux en termes d'argent public, un plan de sorties de flotte pourrait être justifié dans le cas spécifique de la pêcherie de sole du golfe de Gascogne par un changement souhaitable des pratiques de pêche au profit de flottilles moins énergivores. D'un autre côté, les QIT pourraient efficacement atténuer les impacts économiques lors de la transition vers le MSY et accroître considérablement la profitabilité sur le long terme, mais augmenteraient l'effort de chalutage global ainsi que les inégalités économiques. Ces résultats suggèrent qu'une limitation des transferts de quotas des fileyeurs vers les chalutiers pourrait être nécessaire à l'atteinte des objectifs écologiques et sociaux dans l'éventualité de la mise en place de QIT dans cette pêcherie. Ces conclusions soulignent également l'opportunité de remettre à plat les dispositions relatives à l'exemption de la taxe sur le carburant qui paraissent être en contradiction avec le besoin de réduire les émissions de gaz à effets de serre tout en ayant une influence directe sur l'efficacité de potentielles futures mesures de gestion.

Depuis 2006, les OP françaises tendent à opérationnaliser leur responsabilité de gestion des quotas au moyen de règles d'allocations individuelles. Cependant, le système de quotas français reste singulier du fait de la non-transférabilité des allocations individuelles, ce qui est une caractéristique que la plupart des OP considèrent essentielle pour l'atteinte des multiples objectifs de gestion. La question de savoir si ce système de cogestion est un mode de gouvernance pérenne tel qu'il est, ou simplement un système transitoire avant un inévitable système de QIT, est une question à laquelle il est difficile de répondre de manière péremptoire mais qui mérite tout de même d'être posée. Bien que de nombreuses parties prenantes s'y soient opposées en France, certains considèrent que la transférabilité est une nécessité pratique qui doit normalement découler de l'individualisation des quotas. En réalité, il existe des preuves que le prix virtuel (*shadow price*) des antériorités attachées à un navire est internalisé dans le prix de vente du navire, ce qui peut être vu comme les prémisses d'un marché de quotas. De manière générale, alors qu'un système de quotas non transférables opéré par les OP peut être approprié pour gérer une espèce en particulier, des incertitudes demeurent quant à la possibilité de gérer un tel système dans une situation de pêcherie multi-spécifique où les opportunités de pêche de plusieurs espèces clés seraient réduites. De surcroît, la mise en œuvre de l'obligation de débarquement peut potentiellement augmenter le besoin de transférabilité à cause d'importants risques de phénomènes de 'choke species' (lorsque le quota d'une espèce est épuisé bien avant les quotas d'autres espèces pêchées conjointement dans une pêcherie multi-spécifique). D'un côté, la transférabilité des allocations individuelles introduirait plus de flexibilité. D'un autre côté, les arrangements de cogestion impliquant la non-transférabilité apparaissent pertinents pour prévenir certains impacts sociaux négatifs qui sont traditionnellement associés aux QIT. Si la transférabilité venait à être autorisée, la question de savoir comment les QIT pourraient être incorporés dans un système de cogestion basés sur des OP afin de combiner les avantages et limiter les inconvénients de chacun de ces systèmes devra être posée. En termes de design institutionnel, cela pourrait prendre la forme de marchés de quotas régionaux où les transactions individuelles seraient supervisées par les OP sous le contrôle global de l'administration publique. À la lumière des résultats établis dans cette thèse, il apparaît qu'un tel système hybride pourrait être pertinent dans la perspective d'intégrer le système de gestion des quotas français dans les approches écosystémiques et de régionalisation qui sont promues par la PCP.

E.5.2 Perspectives de recherche

Le rôle joué par les OP pour l'amélioration des résultats économiques, sociaux, et écologiques de la gestion des pêches est complexe et globalement méconnu. Bien que cette thèse ait traité un certain nombre de questions concernant les effets de la présence des OP dans les systèmes de quotas, ce travail pourrait être poursuivi dans plusieurs directions.

Un aspect pouvant être examiné dans plus de détails concerne l'influence de la taille d'une OP, par exemple en termes de respect des réglementations. D'un côté, une plus grande OP permet d'augmenter le cumul des antériorités et des possibilités de pêche (et donc la taille de la pénalité pouvant être imposée à l’OP), et diminue vraisemblablement les risques de dépassement des quotas collectifs. D’un autre côté, un nombre trop important d’individus au sein d’un groupe d’utilisateurs de la ressource peut affaiblir le capital social, qui est lié au contrôle social et joue un rôle majeur dans le respect des règles en général. Par conséquent, les dynamiques du respect des réglementations ne sont pas triviales lorsque l’on s’intéresse à la question de la taille idéale des OP. Dans le système français, une contradiction apparaît entre la volonté d’inciter les OP à fusionner pour éviter les phénomènes de choke species et le risque d’avoir des OP trop grandes où les règles internes pourraient être perçues comme illégitimes du fait de l’éloignement entre gestionnaires et pêcheurs. Ces problèmes pourraient être étudiés avec une modélisation analytique, mais il serait également intéressant d’obtenir une validation empirique. Comme les problèmes liés à la fraude sont difficiles à aborder de manière empirique par nature, cela pourrait prendre la forme d’une approche par l’économie expérimentale qui utilise des expérimentations ‘en laboratoire’ pour reproduire des situations du monde réel et tester la validité de conjectures économiques. Celles-ci ont notamment été appliquées pour étudier des questions de coordination et de préférences sociales et pourraient être transposées pour explorer les questions liées aux OP et à leurs potentiels avantages pour le respect des réglementations.

L’analyse économique des régimes de responsabilité dans les systèmes de quotas basés sur des OP développée dans le chapitre 2 était construite autour de deux mécanismes spécifiques de monitoring et pénalités pouvant être appliqués par une OP. Cependant, il y a un manque global de connaissance et d’expérience sur la mise en œuvre de la responsabilité conjointe dans le domaine des pêcheries. Par exemple, dans les cas où le régulateur peut imposer une sanction soit à un fraudeur ou soit à l’OP, les considérations qui vont guider le choix du régulateur entre les deux possibilités restent floues. De plus, il existe de nombreuses spécifications possibles pour un régime de responsabilité conjointe qui peuvent inclure de potentiels arrangements à l’amiable, des clauses sur les détenteurs de droits et de devoirs, la détermination des parts de responsabilité (proportionnelles à la cause ou à la conséquence d’un dommage) et la répartition des dommages d’un individu insolvable. Toutes ces considérations légales peuvent influencer les effets incitatifs des régimes de responsabilité qui doivent être examinés dans un contexte réglementaire particulier pour pouvoir éclairer les questionnements relatifs au design institutionnel. Ces raffinements nécessitent de collaborer avec des juristes pour l’application d’une analyse microéconomique à des problèmes légaux et ainsi pouvoir faire des recommandations en termes de politiques publiques basées sur les conséquences économiques de diverses règles de droit. Ce travail doit également inclure une réflexion sur comment faire en sorte que les incitations et motivations des OP restent en adéquation avec celles du régulateur pour prévenir les tentations de fraude à l’échelle de l’OP. De façon générale, il serait intéressant de mener une comparaison de la manière dont sont structurés les régimes de responsabilité dans les systèmes de quotas impliquant des OP dans diverses pêcheries dans le monde pour améliorer notre compréhension de leur pertinence et de leur praticité.

Enfin, une extension intéressante du modèle présenté dans le chapitre 4 serait de considérer les OP en tant qu'agents prenant des décisions qui influencent les stratégies des pêcheurs de manière dynamique. Cela pourrait être réalisé avec un ou plusieurs modèles de choix discrets pour essayer de simuler le comportement des OP en termes de règles internes utilisées pour gérer les quotas, les échanges de quotas avec d'autres OP, la gestion des adhésions, et les fusions d'OP. Bien que difficile à mettre en œuvre, cela représenterait un progrès significatif pour l'intégration des mécanismes de gouvernance dans la modélisation bio-économique. L'un des aspects devant être considéré est l'équilibre entre la modélisation de détails institutionnels qui sont pertinents dans un cas d'étude particulier et l'utilité de tels développements pour des applications dans d'autres contextes. Par ailleurs, afin de pouvoir incorporer le modèle dans une boucle de 'management strategy evaluation' qui est l'un des outils les plus souvent recommandés pour les évaluations d'impacts de mesures de gestion, le modèle pourrait intégrer de la stochasticité pour représenter l'incertitude associée à l'observation et la mise en œuvre des règles de décision. Dans tous les cas, les partenariats entre scientifiques et professionnels du secteur, où les parties prenantes sont impliquées dans le développement d'outils d'aide à la décision, pourraient également être bénéfiques pour mieux appréhender les objectifs et comportements des OP et déterminer des scénarios prospectifs de manière collaborative pour traiter des problèmes de gestion particuliers.

Modelling institutional arrangements and bio-economic impacts of catch share management systems: application to the Bay of Biscay sole fishery.

In France, where fishing rights are non-transferable, the management of fishing quotas is essentially delegated to producer organizations (POs). POs are granted collective allocations based on the aggregate fishing rights of their members and are then responsible for managing their fishing opportunities. The goal of this research, which contains theoretical developments as well as empirical analyses applied to the Bay of Biscay sole fishery, is to determine how outcomes of fisheries management are altered by the presence of POs within institutions as compared to alternative governance systems such as individual transferable quotas (ITQs). This dissertation notably brings together bio-economic approaches and institutional analyses to better anticipate the ecological, economic and social impacts of potential governance options. The research questions are the following: (1) What mechanisms could ensure a high level of compliance and what are the potential gains of placing the POs between the regulator and the fishermen? (2) What are the distributional effects of catch share management by POs? (3) What is the added value of integrating institutional arrangements involving POs into bio-economic modelling for the impact assessment of catch share management options? The analyses that were developed establish the ability of institutional design to influence outcomes in catch share systems in terms of compliance, distribution, and ecological-socioeconomic trade-offs achieved by alternative management options.

Keywords: sustainable management of catch shares, producer organizations, co-management, institutional arrangements, regulatory compliance, distributional effects, bio-economic modelling, micro-economic model of fishermen behavior.

Modélisation de mécanismes institutionnels et impacts bio-économiques de systèmes de gestion de quotas : application à la pêcherie de sole du golfe de Gascogne.

En France, où les droits de pêches ne sont pas transférables, la gestion des quotas de pêche est essentiellement déléguée aux organisations de producteurs (OP), lesquelles se voient attribuer des allocations collectives et sont responsables de la gestion des possibilités de pêche de leurs adhérents. On peut ainsi s'interroger sur la manière dont la présence des OP au sein des institutions peut permettre d'améliorer les performances écologiques, économiques et sociales de la gestion des pêches en comparaison avec d'autres formes institutionnelles telles que les systèmes de quotas individuels transférables (QIT). Les recherches de thèse, comprenant une partie théorique et s'appuyant sur le cas de la pêcherie de sole du golfe de Gascogne pour les applications empiriques, sont organisées autour des questions suivantes : (1) Par quels mécanismes les OP peuvent-elles permettre d'améliorer le respect des réglementations et influencer l'émergence de normes sociales ? (2) Quels sont les effets redistributifs de la gestion des quotas par les OP ? (3) Comment les mécanismes de gestion des quotas par les OP peuvent-ils être intégrés dans la modélisation bio-économique pour l'évaluation d'impact de scénarios de gestion ? Les analyses développées établissent l'intérêt de prendre en compte des contraintes induites par différents arrangements institutionnels et les résultats sont notamment examinés au regard des trois dimensions (écologique, économique et sociale) nécessaires à la gestion durable des pêches. Les compromis entre ces différentes dimensions sont mis en évidence dans le cadre de scénarios prospectifs visant une meilleure compréhension des enjeux liés à la gestion des pêches.

Mots-clefs : gestion durable des quotas de pêche, organisations de producteurs, cogestion, arrangements institutionnels, respect des réglementations, effets redistributifs, modèle bio-économique, modèle micro-économique de comportement des pêcheurs.