MECHANISM DESIGN FOR THE OPTIMAL ALLOCATION OF QUOTAS AND THE DETERMINATION OF THE TOTAL ALLOWABLE CATCH FOR EU FISHERIES UNDER AN AGE-STRUCTURED MODEL

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ABSTRACT

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In this study, we consider the mechanism design problem for the optimal allocation of fishing quotas at different total allowable catch (TAC) levels. An age-structured fish population model is employed. Fishing technologies are embedded in the economic model as a key determinant. As a result, we showed that the quota allocation mechanism is important to minimize the impact of fishing on total fish biomass or achieve maximum sustainable yield (MSY). Moreover, we indicated technology-based optimality conditions for allocation of quotas at different TAC levels, which minimize the impact of fishing on total fish biomass or enable us to achieve MSY. Under the consideration that the fishermen fulfill their remaining quotas through capturing untargeted (less revenue-generating) fish after the targeted fish population is fully caught, the fix ratio of the catch of targeted fish to untargeted fish is not valid anymore. Concordantly, we indicated technology-based optimal quota levels, including the interior solutions. In the EU, TACs are distributed among states according to the principle of 'relative stability' which prescribes that the fishing quotas should be allocated based on historical catches of the EU states. In this context, rather than allocating the quotas based on historical catches, our main suggestion is that the structure of the fishing industry should be considered for allocation of quotas to provide the sustainability of EU fisheries and achieve responsible and effective management of the fishing industry in the EU.

Keywords: Allocation of quotas, Total allowable catch, Maximum sustainable yield, Fishing technology, Age-structured model.

ÖZ

YAŞA DAYALI MODEL KAPSAMINDA AVRUPA BİRLİĞİ BALIKÇILIĞINDA KOTALARIN OPTİMUM DAĞITIMI VE İZİN VERİLEN TOPLAM AV MİKTARININ BELİRLENMESİ İÇİN MEKANİZMA TASARIMI

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Bu çalışmada, yaşa dayalı balık popülasyonu modeli kullanılarak, farklı seviyelerde belirlenen izin verilen toplam av miktarlarında geçerli olan optimum kota dağıtım mekanizmasının tasarımı ele alınmıştır. Avlanma teknolojileri, kullanılan ekonomik modelde temel belirleyici olarak yer almıştır. Sonuç olarak, balıkçılığın toplam biyokütle üzerindeki etkisinde ve sürdürülebilir en yüksek ürün seviyesine ulaşılmasında kota dağıtım mekanizmalarının önemli olduğu gösterilmiştir. Buna ek olarak, farklı seviyelerde belirlenen izin verilen toplam av miktarlarında, balıkçılığın biyokütle üzerindeki etkisini en aza indirgeyen veya sürdürülebilir en yüksek ürün seviyesine ulaşılmayı sağlayan, teknolojiye dayalı optimum kota miktarları belirlenmiştir. Hedeflenen yaş grubuna ait balık popülasyonunun tamamı avlandıktan sonra, balıkçıların kotalarının tamamını kullanabilmek için hedeflenmeyen yaş grubuna ait, daha düşük miktarda gelir sağlayan balıkları avladıkları durumda; hedeflenen yaş grubuna ait toplam av ve hedeflenmeyen yaş grubuna ait toplam av miktarları arasındaki sabit oran gözlemlenmeyecektir. Bu durumda, iç çözümleri de içeren, teknolojiye dayalı optimum kota miktarları belirlenmiştir. Avrupa Birliği'nde, izin verilen toplam av miktarları, 'bağıl değişmezlik' ilkesine göre dağıtılmaktadır. Bağıl değişmezlik ilkesi, kotaların ülkelerin geçmiş yıllardaki avlanma miktarları temel alınarak dağıtılması gerektiğini bildirir. Bu bağlamda, Avrupa Birliği'ndeki balıkçılık endüstrisinin etkili ve güvenilir bir şekilde yönetilebilmesi ve sürdürülebilir balıkçılık koşullarının sağlanabilmesi için, kotaların ülkelerin geçmiş yıllardaki avlanma miktarları temel alınarak dağıtılması yerine, kotaların dağıtımında balıkçılık endüstrisinin yapısının göz önünde bulundurulması gerektiği önerilmiştir.

Anahtar kelimeler: Kotaların dağıtımı, İzin verilen toplam av miktarı, Sürdürülebilir en yüksek ürün, Avlanma teknolojisi, Yaşa dayalı model.

Dedicated to my parents and wife.

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LIST OF ABBREVIATIONS

CFP	Common Fisheries Policy
AT	Austria
BE	Belgium
BG	Bulgaria
CAP	Common Agricultural Policy
CCRF	Code of Contact for Responsible Fisheries
CQ	Community Catch Quotas
CY	Cyprus
CZ	Czech Republic
DE	Germany
DK	Denmark
EE	Estonia
EL	Greece
ES	Spain
EU	European Union
FAO	Food and Agriculture Organization
FI	Finland
FR	France
HU	Hungary
ICCAT	International Commission for Conservation of Atlantic Tunas
IE	Ireland
IQ	Individual Non-Transferable Quotas
IT	Italy
ITE	Individual Transferable Effort Quotas
ITQ	Individual Transferable Quotas
IUU	Unreported and Unregulated Fishing
KW	Kilowatt

LL	Limited Non-Transferable Licensing
LT	Lithuania
LTL	Limited Transferable Licensing
LV	Latvia
MEY	Maximum Economic Yield
MSY	Maximum Sustainable Yield
MT	Malta
NEAFC	North East Atlantic Fisheries Commission
NL	Netherlands
OECD	Organization for Economic Co-operation and Development
PL	Poland
PT	Portugal
RBM	Rights-Based Management
RO	Romania
SE	Sweden
SI	Slovenia
SK	Slovakia
TAC	Total Allowable Catch
TURF	Territorial Use Rights in Fisheries
UK	United Kingdom of Great Britain and Northern Ireland
VC	Vessel Catch Limits

CHAPTER 1

INTRODUCTION

1.1 Overview

Since ancient times, fishing has been one of the primary economic activities for human beings. In the course of time, demand for fish has increased, supply of fish has diminished, vessels have become larger and fishing has become a complex activity not only for fishermen but also for governments. Due to the increasing demand for fish and fish products, the number of fishing fleets has increased, which led to a highly competitive fishing industry. In the past, private ownership or intervention of government was not at issue when stocks were large enough and fishing fleets were small. For instance, private ownership of fisheries was banned in England in the 13th century and fishing was free in English waters till 19th century (Scott, 2000). The situation was similar in the other European countries where both inshore waters and high seas were regarded as 'common property'. The only limitation agreed upon by the European countries was that the foreign fishermen were excluded from fishing activities of a country to protect local markets and local fishermen (Scott, 2000). Lack of necessary limitations resulted in threatening levels of increases in fishing activities and decreases in fish stocks in 19th century. Since then, oceans have started to be invaded by human beings due to the lack of necessary regulations.

As a result of these developments, fisheries became an issue of resource economics which deals with optimum management strategies for natural resources. Changes in environmental conditions, uncertainty in fisheries and growing competition in the fishing industry made researchers' minds clear about the need for 'property rights' for the management of fisheries. Scott summarizes the evolution of the competition in the early 20th century in the Atlantic fisheries. He stated that initially, as fishermen started to compete with each other, hours spent for fishing rose, vessels became larger and fishing efforts increased. In such a competitive environment, catching levels decreased, fishing costs rose and fishermen started to put pressure on governments for the regulation of fisheries (Scott, 2000). The regulations were also required to prevent the fishing industry from non-competitive environment such as monopolistic actions. As a result, regulations and legislations in fisheries took the place of free fishing in 20th century.

Over the last decades, sustainability of natural resources became more of an issue. For a long time, natural resources have been threatened by deteriorated environmental conditions and human being's interruptions. Fisheries have also been exposed to the effects of climate change. Rising sea levels and acid oceans cause changes in recruitment and natural mortality of fish. Hence, regulations should also be made so as to protect oceans from the effects of climate change and human being's interruptions and provide sustainability of fisheries besides their usage in the context of the improvement of market efficiency. In the circumstances, future of fisheries depends on the effective management tools which will provide regeneration of the life in the oceans.

1.2 Conceptual Framework

Overfishing and overcapitalization (overcapacity) come to the forefront as the major problems in fisheries. In order to eliminate overfishing and overcapitalization, various measures are taken worldwide. Governments deal with management issues such as control systems, financial aids and allocation of property rights to overcome these problems. In this sense, the European Union (EU) has created a common policy and proceeded to effective management of the fishing industry via the Common Fisheries Policy (CFP) and rights-based management (RBM) systems. The CFP aims to preserve fish stocks and provide conditions of economic efficiency both for producers and consumers. The CFP is on a reform process, and reforming the CFP takes place in cooperation of governments with scientists. Hence, scientific suggestions take an active role in the reform of the CFP. Due to the growing markets for fisheries, it is necessary that the problems of overfishing and overcapacity be analyzed intensely and reflected in the next CFP. In order to find the roots of both problems, several topics from structure of the fishing industry to biological properties of fish should be investigated in detail.

In the near future, a common management system for fisheries is nearly impossible to be implemented in all regions of the EU. Fisheries in the EU are managed through different types of management systems. In order to overcome major problems in the fishing industry, different types of management systems are offered. The most preferred options among these systems are RBMs. RBM systems are formed in various types such as input rights, output rights or limited entry. In the EU, LL (limited licensing), TURF (territorial used rights in fisheries), IQ (individual non-transferable quotas) and ITQ (individual transferable quota) systems are the most popular types of RBM systems. LL and TURF are examples for limited entry form of RBM. On the other hand, IQ and ITQ are examples for output rights form of RBM. Input rights systems generally aim to control inputs used for fishing such as effort, vessel size or fishing gear controls. Besides, output rights systems such as ITQs are widely accepted as efficient ways to ease problems of overfishing, overcapacity and ‘race to fish’. However, according to a measurement method used by Arnason, while ITQ systems are measured as medium-high quality rights, sole ownership and TURFs are measured as high quality rights in terms of characteristics of property rights (Arnason, 2007a). Is ITQ a medium-quality system in terms of economic efficiency and which properties of ITQ make it such a desired management system in many countries? In spite of advantages of ITQ, there are some debatable parts of these systems such as bycatch problems or increasing levels of discards. Bycatch refers to unintended catches while fishermen intended to catch other type of fish. Besides, the other importantly debatable issue of ITQ systems is the transfer of quotas because these systems may become useless if markets do not perform well. In a real-life situation, markets for transferable quotas may be very thin.

Above all, efficiency of an output control system depends on well-designed quota allocation mechanism and truly determined total allowable catch (TAC) levels. A well functioning quota allocation mechanism and truly determined TAC levels will enable us to provide sustainability conditions and achieve maximum sustainable yield (MSY) level. MSY is the optimal catch level while protecting fish capacity by sustaining regeneration in the future.

MSY is one of the prominent subjects of the next CFP reform. EU has started to seek the ways to achieve MSY in all fishing areas in the EU. Since MSY will lead to larger stocks in the future, problems such as discards or return on investment will be mostly eliminated. However, EU fisheries have been mostly exploited over MSY, recently. There are different types of biological models used for estimation of MSY. As one of the bioeconomic models, age-structured fish population model has become popular among scientists over the last decades. These models are more complex than simple biomass models. They are perceived as more realistic models because they take the biological conditions such as recruitment, natural mortality or fecundity characteristics into account. Simple biomass models are based on an approach ‘fish is a fish’. ‘Fish is a fish’ means to ignore the stochastic variations and environment while measuring the effect of a unit catch of fish on the fishery (Inarra and Skonhoft, 2008). However, an age-structured bioeconomic model has a different approach as it does not ignore stochastic variations and environment. Thus, age-structured models enable scientists to achieve more realistic estimations for optimality conditions.

1.3 Aim and Scope of the Thesis

In this study, we investigated the EU fishing industry, one of the largest fishing industries in the world. We analyzed the recent situation of the European fisheries and problems in the European fishing industry. A literature review about EU fisheries, the CFP, RBM systems, ITQ systems, age-structured fish population models and quota allocation mechanisms are given briefly. Recent situation of fisheries in the EU is summarized in the light of production, consumption, employment, trade and input data. Afterwards, the CFP and ways of improving the CFP are discussed and RBM systems are handled in detail. RBM systems and ITQ system, the most well-known type of RBM systems, are explained and evaluated according to their advantages and disadvantages.

Following the analyses of the CFP and RBM systems, economic modeling is used for further analyses on quota allocation mechanism, which is one of the most debatable issues of RBM systems. In the light of the dynamics of fisheries and recent scientific advances in fisheries researches, we used an age-structured fish population model. An age-structured fish population model developed by Skonhoft et al. (2012) is employed. The main aim of this study is investigating the importance of allocation of quotas for minimizing the impact of fishing on total biomass or achieving MSY. As a result of the analyses, we showed that quota allocation mechanisms are important to minimize the impact of fishing on total biomass and achieve MSY. Furthermore, for the stated purposes, technology-based optimality conditions for allocation of quotas at different TAC levels are indicated.

Fishing mortality rates at MSY are calculated using the method suggested by Skonhoft et al. (2012). We investigated the implementation of MSY under an individual quota system. Different than the existing literature, we indicated fishing technology-based optimal quota levels under the consideration that the fishermen fulfill their remaining quotas through capturing untargeted (less revenue-generating) fish after the targeted fish population is fully caught. As a result, we described an effective design for quota allocation mechanism that provides sustainability of resources and increases market efficiency under an output quota regime.

CHAPTER 2

LITERATURE REVIEW

2.1 EU Fisheries and the Common Fisheries Policy

The Common Fisheries Policy, A User's Guide (CFP, 2009) [1] is an official document supplied by the European Commission. Information about management of fisheries in the EU and long-term goals for EU fisheries are given in this guide. Furthermore, international fishing, industry-fisheries relations and aquaculture are discussed in this guide as the other major topics of the CFP. In addition to the CFP, the Facts and Figures on the CFP (FAF, 2010) [2] and similar reports are published by the European Commission. These publications provide data about catches, production, consumption and employment in the EU fishing industry.

Besides, various scientific articles are enlightening us about the CFP and fisheries in the EU waters. *Reflections on the Common Fisheries Policy* (Sissenwine and Symes, 2007) was submitted to the General Directorate for Fisheries and Maritime Affairs of the European Commission to reflect the situation with respect to the 2002 reform of the CFP. In that report, improvements of the CFP and sustainability of EU fisheries are discussed in the light of the recent situation of EU fisheries. Lindebo, Frost and Lokkegaard (2002) evaluate the CFP reform, fleet capacities and applications of the capacity analyses. Reforming the CFP is argued in various studies. Gray and

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[1] The Common Fisheries Policy, A User's Guide, European Communities, 2009. Hereafter (CFP, 2009).

[2] Facts and figures on the Common Fisheries Policy, ISBN 978-92-79-14127-0, European Commission Maritime Affairs and Fisheries, 2010. Hereafter (FAF, 2010).

Hatchard (2003) explain the 2002 CFP reform's system of governance. The authors concluded that the reform has failed in terms of system of governance. Daw and Gray (2004) conducted a research about the relations between politics and fisheries science and the failure of the CFP. Jensen (1999) gives information about the history of the CFP, European fisheries and policy tools of the CFP such as conservation policy, structural policy and the control policy. Symes (1997) investigates the evaluation of the CFP and proposed scientific advice about the future of the CFP. Frost and Andersen (2006) evaluate the extent to which the CFP corresponds with the basis of bioeconomics.

On the other hand, the Green Paper on the reform of the CFP includes critiques about the current CFP. It presents ideas about course of actions to be applied in the future, which will improve management of EU fisheries. It is stated in the Green Paper that the current CFP is not effectual to solve major problems in fisheries such as overcapacity and overfishing. These two major problems are common worldwide. Hence, there are a number of studies on these issues for enlightening the roots of these problems and overcoming the recent situation through scientific advices. Food and Agriculture Organization (FAO) of the United Nations supplies reports, technical papers and documents on fisheries on the purpose of strengthening the global governance and sustainable use of fisheries and aquaculture worldwide. *FAO Technical Guidelines for Responsible Fisheries* is one of the publication series about fisheries management. Moreover, *Code of Conduct for Responsible Fisheries* was published in 1995. After its first publication, relevant documents have been published by FAO. *Code of Conduct for Responsible Fisheries* includes advice for countries and provides a framework to ensure sustainability of fisheries at national and international levels.

2.2 Fisheries Economics

In earlier times, Jens Warming (1911, 1931) investigated the failure of open-access fisheries and the overcapacity problem in his articles. Theoretically, modern researches on bioeconomics were initially done by Gordon (1954) and Scott (1955). Gordon (1954) propounds the optimum utilization theories for fisheries and refers to property rights and the importance of age distribution of catches. Scott (1955) discusses the role of property rights under the sole-ownership of fisheries.

Modern fisheries economics was shaped by Gordon and Scott in the mid 20^{th} century. In regard to scientific developments, incentives to seek optimum management strategies for fisheries have increased. Through time, environmental conditions, restrictions and legislations on fishing activities have been applied by governments and different biological properties of fish have been involved in economic theories.

After early times of modern fisheries economics, Clark and Munro (1975, 1979), Munro (1992, 1999), Clark (1980, 1990) and Arnason (1993) investigate optimum management strategies for fisheries in more detailed ways. Scott (1988) indicated major characteristics of rights, and his characterization is in use for classification of property rights.

Arnason (2002) stated that the earliest paper he could find on the scientific foundations of the individual quotas was written by Christy in 1973. In that paper, Christy was suggesting individual quotas as a solution to fisheries problem. Similar thoughts are belonged to Quirk and Smith (1970), yet they were not expressed in details. Arnason (1977) discussed transferable individual quotas in his study. A clear expression of use of individual quotas was given by Moloney and Pearse (1979).

Iceland, The Netherlands and New Zealand started implementing ITQ systems in the late 1970s and 1980s. However, systematic explanation for ITQs was scientifically discussed after their initial implementations. ITQ systems were analyzed systematically by Arnason (1993), Gauvin et al. (1994), Buck (1995), Geen and Nayar (1988) in late 1980s and 1990s. These studies promoted the efficiency of ITQs by showing the reductions in overcapacity and elimination of 'race to fish' under ITQ systems. There are also researches which introduced counter arguments to efficiency of ITQ systems. Anderson (1991) mentioned that the total cost would not be minimized under non-perfectly competitive market conditions. Newell et al. (2005) stated that the ITQs could be a solution for the long-run since unstable quota prices are observed in the short-run. Vestergaard (2005) points out that achieving the efficiency for fishing fleets would be delayed due to sunk costs. Additionally, Grafton and Mcllgorm (2009) performed cost-benefit analyses of ITQ systems to evaluate whether ITQs should be introduced in Australian fisheries. Bjorndal et al. (2007) prepared the book of *Advances in Fisheries Economics* in honor of Munro. In this book, ITQs are discussed in the light of property rights and RBM systems. Furthermore, Higashida and Takarada (2009) and Higashida and Managi (2010) discuss the efficiency of ITQ systems under different market conditions. Tietenberg (2002) and Yandle and Dewees (2008) explain the importance of tradable permits. Ledyard (2009) conducted a research on allocation mechanisms and showed that the initial quota allocation was not important under an ITQ management system since fishermen would reach to their targeted quota levels after quota trade was finalized. Besides, the European Commission and FAO supplied several documents on RBM systems and ITQs.

Age-structured models came into prominence in fisheries research over the last decades. Researchers launched to search for the optimum management under the age-structured economic models. In this type of the bioeconomic models, biological conditions such as recruitment, natural mortality or fecundity characteristics are taken into consideration. The most commonly used recruitment models are Ricker model (Ricker, 1954) and Beverton-Holt model (Beverton and Holt, 1957) among which Beverton-Holt model is the most well-known. Clark (1990) applied Beverton-Holt model in his research. Hanneson (1975) also applied Beverton-Holt recruitment function in his study on the optimal harvesting of North Atlantic cod. In the last decade, Stage (2006), Tahvonen (2009a, 2009b), Quaas et al. (2010) and Skonhoft et al. (2012) employed different age-structured fish population models and contributed to the literature of age-structured modeling for fisheries.

Besides, quota allocation mechanisms are always debatable under an output control regime. Since efficient allocation of quotas depends on different factors, finding optimality conditions becomes difficult. In the book of *Case studies on the allocation of transferable quota rights in fisheries* (FAO, 2001), initial quota allocations in 23 different fishing regions were explained. This report is a guide to apprehend the country specific quota allocation mechanisms. Quota allocation mechanisms and their efficiencies are discussed in studies on ITQ systems. Furthermore, an OECD working paper (Cox, 2009) is enlightening us about the international legal frameworks on quota allocation mechanisms.

As one of the core topics of fisheries management, the estimation of MSY is described in various studies. '*Introduction to Tropical Fish Stock Assessment - Part 1: Manual'* (FAO, 1998) includes detailed information on the estimation of MSY by using surplus production models. In that book, Schaefer and Fox models are explained.

The legislation for EU fisheries management includes the goal of achieving MSY in the EU waters. This aim is worded by the European Commission as the following:

> The Commission is proposing that Community fisheries management should be based on maximum sustainable yield (MSY), a long-term management system designed to ensure the exploitation of living marine resources in sustainable economic, environmental and social conditions. [3]

In the light of these developments, we investigated the importance of quota allocation and TAC level determination to minimize the impact of fishing on total biomass change and achieve MSY. We begin our analyses with investigating fisheries in the EU and reviewing the CFP.

[3] European Union, Summaries of EU legislation, Maritime Affairs and Fisheries, Management of fisheries resources and the environment, Maximum Sustainable Yield. http://europa.eu/legislation_summaries/maritime_affairs_and_fisheries/fisheries_resources_and_environment/l66037_en.htm

CHAPTER 3

THE COMMON FISHERIES POLICY (CFP) AND EU FISHERIES

3.1 The Common Fisheries Policy (CFP)

Up to today, various types of management systems and regulations have been applied for developing optimum management strategies for fisheries. The CFP, one of the effective fisheries policies globally, has been used for providing sustainability of EU fisheries and finding long-run solutions for the EU fishing industry.

The CFP was created in 1983 to organize and develop the fishing industry in the extended territorial waters and broadened territories of the European Community. This broadened structure was in need of an effective management policy for regulation of the fishing industry. Hence, it was inevitable for the European Community to constitute a separate policy to be implemented in the fishing industry. It was resulted in the development of the CFP. The CFP has the same legal basis and objectives with the Common Agricultural Policy (CAP) such as increasing productivity, stabilizing markets and ensuring security of supply and reasonable prices for consumers (Sissenwine and Symes, 2007). The CFP has had to be open to reforms all along since management of fisheries has been dependent to environmental and political circumstances and scientific developments. In this regard, the CFP was adapted to political developments such as withdrawal of Greenland from the Community in 1985, enlargement of the Community by accession of Spain and Portugal in 1986 and the reunification of Germany in 1990.[4] 1983 regulations, 1992 regulations and 2002 reforms were the developmental milestones of the CFP. In 1992, the general objective of the CFP was worded as below:

> As concerns the exploitation activities the general objectives of the common fisheries policy shall be to protect and conserve available and accessible living marine resources, and to provide for rational and responsible exploitation on a sustainable basis, in appropriate economic and social conditions for the sector, taking account of the implications for the marine ecosystem, and in particular taking account of the needs of both producers and consumers (Pope and Symes, 2006).

However, it was realized that the objectives of the CFP should be revised to eliminate inefficient economic conditions for which overfishing and overcapitalization cause. By 2002 reforms, primary objective of the CFP had been reoriented as the following:

> The primary objective of the new CFP is to ensure a sustainable future for the fisheries sector by guaranteeing stable incomes and jobs for fishermen while preserving the fragile balance of marine ecosystems and supplying consumers (CFP, 2009)

Primary objective of the CFP were reconsidered according to economic and social conditions. By 2002 reforms, the CFP had put more emphasis on stable incomes and employment in the fishing industry. These reforms show the benefits of implementing a separate policy for fisheries since these policies make it easier to act in accordance with the specific circumstances which is peculiar to the fishing industry.

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[4] The Common Fisheries Policy, Origins and Development. http://www.europarl.europa.eu/ftu/pdf/en/FTU_4.4.1.pdf

3.2 EU Fisheries

There are several reasons behind the EU's desire to have common and separately identified fisheries policy. First of all, the EU is a global fish producer. According to data provided by the European Commission, the EU represents about 4.60 % of global fisheries and aquaculture production which makes the EU the 4th largest fish and fish products producer worldwide (FAF, 2010). Furthermore, catches in the EU constitute the 3rd largest catch volume in total world catches.

Table 3.2.1 Main fish producers in 2007 (Catches & Aquaculture)

Country	**Total Catches & Aquaculture (volume in tonnes live weight)**	**Percentage of Total**
China	46,079,311	32.80 %
India	7,308,230	5.20 %
Peru	7,250,075	5.20 %
EU-27	6,443,127	4.60 %
Indonesia	6,329,533	4.50 %
United States	5,293,877	3.80 %
Japan	4,977,047	3.50 %
Chile	4,635,927	3.30 %
Vietnam	4,277,900	3.00 %
Thailand	3,858,815	2.70 %
Russian Federation	2,440,011	2.50 %
Philippines	2,464,328	2.30 %
Norway	2,840,240	2.30 %
Myanmar	3,209,140	2.00 %
South Korea	3,209,349	1.80 %
Bangladesh	3,559,717	1.70 %

Source: Facts and Figures on the Common Fisheries Policy, 2010

Table 3.2.2 Total catches of World's leading producers in 2007

Country	**Total Catches (volume in tonnes live weight)**	**Percentage of Total**
China	14,659,036	16.30 %
Peru	7,210,544	8.00 %
EU-27	5,135,540	5.70 %
Indonesia	4,936,629	5.50 %
United States	4,767,596	5.30 %
Japan	4,211,201	4.70 %
India	3,953,476	4.40 %
Chile	3,806,085	4.20 %
Russian Federation	3,454,214	3.80 %
Philippines	2,499,634	2.80 %
Thailand	2,468,784	2.70 %
Norway	2,378,950	2.60 %
Myanmar	2,235,580	2.50 %
Vietnam	2,121,400	2.40 %
South Korea	1,858,206	2.10 %
Bangladesh	1,494,199	1.70 %
Iceland	1,399,167	1.60 %

Source: Facts and Figures on the Common Fisheries Policy, 2010

The fishing industry is important not only for supplying food to consumers or supplying fish products to related industries but also for generating primary sources of income in some coastal areas. Nevertheless, European countries are still importing fish and fish products despite of high levels of fish production in Europe. Hence, the EU attaches the importance to management of fisheries in order to protect the fishing industry from inefficiencies in fishing process and heavy imports, through creating more efficient and more productive sector. In accordance with this purpose, increasing productivity in the fishing industry is one of the main concerns of the fisheries policy in the EU. In addition, the EU also often needs to update its common policy to prevent possible political problems among member states. In the light of the concerns above, CFP has always been a controversial topic because of the wide concepts including sustainability of fisheries, increasing productivity, protecting consumers and producers and preventing possible political problems in the fishing industry in Europe.

The next reform of the CFP will be carried out in 2013. The objectives of the reform are described as,

- providing stability and security conditions for healthy fish and fish products supply in the long term,
- bringing prosperity to the fishing sector by creating new employment opportunities, providing growth and ending subsidy dependency of the sector. [5]

Besides, discard ban, MSY, regionalization, social dimension and transferable fishing concessions come to the forefront in the reform package. As a result of high levels of fishing in time, 82 % of Mediterranean and 63 % of Atlantic stocks are overfished. [6]

Data analyses for production, consumption and employment in the EU fishing industry are crucial to understand recent situation of the fishing industry in Europe. To begin with, Table 3.2.3 indicates employment in the fish catching sector in European countries in 2007. Spain has the largest number of employment followed by Italy and Greece.

[5] European Commission, Fisheries, Reform of the Common Fisheries Policy http://ec.europa.eu/fisheries/reform/index_en.htm

[6] European Commission, Fisheries. http://ec.europa.eu/fisheries/reform/index_en.htm

Employment in sub-sectors of fisheries in 1996-8 and 2005 is given in Figure 3.2.1. It shows changes in employment levels in few years in sub-sectors of fisheries. It is observed that decline in employment level is experienced intensely in the fish catching sector, whereas employment level in processing sector is only decreased by 1 %.[7] Traditional fishing has been affected from new technologies used in catching. These technological developments may be shown as one of the main reasons of decreasing employment in fish catching sector. The other reason of decreasing employment level is the changing market conditions and elimination of small-scaled fishers which are resulted in decreasing number of workers in the fish catching sector.

Although the highest employment in the fish catching sector was owned by Spain as a quarter of the total employment in 2007, total catches in Spain constituted 14.33 % of the total catches in the EU in the same year. Besides, Denmark had the second largest volume of fish catches by 12.72 % of the total catches in the EU in 2007. The employment in fish catching sector in Denmark was only 1.38 % of the total in the EU. Hence, employment reflects neither the size nor the efficiency of the industry. However, changes in employment can be perceived as one of the results of change of production pattern in the fishing industry.

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[7] The Economic Performance of Fisheries and Aquaculture in the EU. http://www.cfp-reformwatch.eu/pdf/002.pdf

Table 3.2.3 Employment in the fisheries sector in 2007 [8]

Country	Employment in the Fish Catching Sector
Spain	35,274
Italy	25,426
Greece [9]	24,745
Portugal [10]	14,445
France	13,155
UK	8,064
Poland	2,664
Netherlands	1,966
Denmark	1,943
Sweden	1,879
Latvia	1,632
Germany	1,617
Cyprus	747
Lithuania	744
Malta [11]	345
Estonia	247
Slovenia	95
Total EU-27	141,110

Source: Facts and Figures on the Common Fisheries Policy, 2010

[8] Measured in full-time equivalent.

[9] Total employment (full-time and part-time).

[10] Excluding the Azores and Madeira.

[11] Figures for 2006.

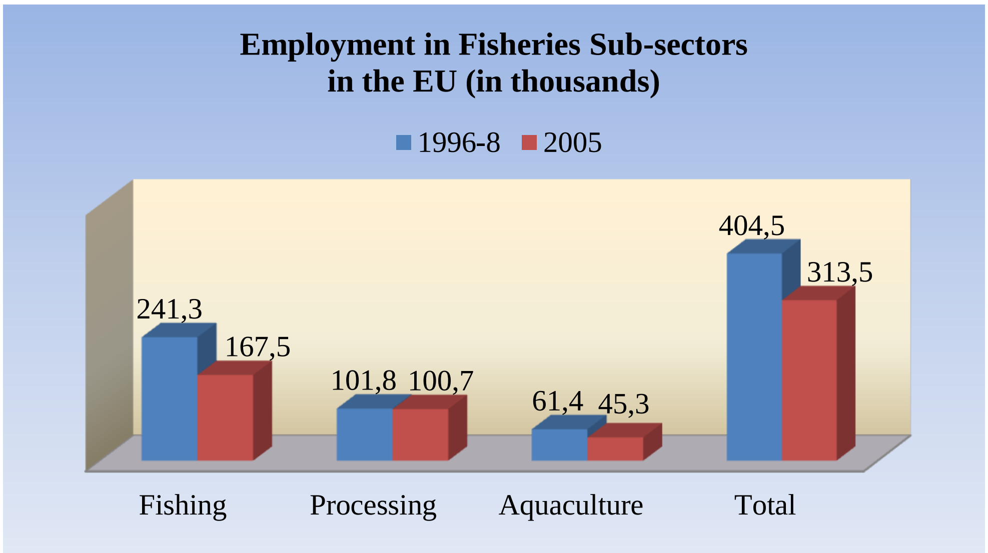

Figure 3.2.1 Employment in fisheries sub-sectors in the EU [12]

Table 3.2.4 Total catches per EU member state in 2007

Country	**Total Catches (volume in tonnes live weight)**	**Percentage of Total**
Spain	735,926	14.33%
Denmark	653,013	12.72%
UK	616,487	12.00%
France	557,862	10.86%
Netherlands	413,640	8.05%
Italy	286,643	5.58%
Portugal	253,033	4.93%
Germany	248,763	4.84%
Sweden	238,254	4.64%
Ireland	227,146	4.42%

[12] Source: The Economic Performance of Fisheries and Aquaculture in the EU. http://www.cfp-reformwatch.eu/pdf/002.pdf

Table 3.2.4 (continued)		
Lithuania	187,496	3.65%
Finland	164,373	3.20%
Latvia	155,272	3.02%
Poland	144,404	2.81%
Estonia	99,447	1.94%
Greece	95,078	1.85%
Belgium	24,539	0.48%
Bulgaria	8,876	0.17%
Hungary	7,024	0.14%
Romania	6,184	0.12%
Czech Republic	4,276	0.08%
Slovakia	2,872	0.06%
Cyprus	2,225	0.04%
Malta	1,245	0.02%
Slovenia	1,111	0.02%
Austria	350	0.01%

Source: Facts and Figures on the Common Fisheries Policy, 2010

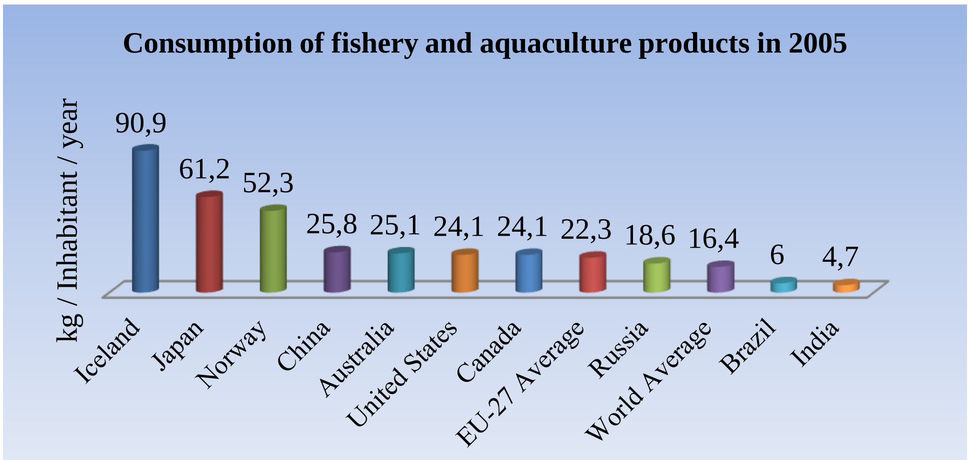

Figure 3.2.2 Consumption of fishery and aquaculture products by countries [13]

Figure 3.2.2 depicts the consumption of fishery and aquaculture products per person per year for different regions. In the light of the data, the EU has one of the largest markets for fish and fish products since both high levels of average consumption and population, which is estimated over five hundred millions, constitute one of the largest total amounts of fish and fish product consumption in the world. This high consumption of fish products in the EU is provided by high levels of imports.

The other important topic is the financial aids to the fisheries sector in the EU. Table 3.2.5 represents total community aid to the fisheries sector per member states between 2007 and 2013. Total aid in these six years is above 4.3 billion Euros.

[13] Source: Facts and Figures on the Common Fisheries Policy, 2010

Table 3.2.5 Total community aid to the fisheries sector per EU member state between 2007 and 2013 (in thousands of EUR)

Country	**Total Aid per Country**	**% per Country**
Austria	5,259	0.12 %
Slovakia	13,689	0.32 %
Cyprus	19,724	0.46 %
Slovenia	21,640	0.50 %
Belgium	26,262	0.61 %
Czech Republic	27,107	0.63 %
Hungary	34,851	0.81 %
Finland	39,449	0.92 %
Ireland	42,267	0.98 %
Netherlands	48,578	1.13 %
Lithuania	54,713	1.27 %
Sweden	54,665	1.27 %
Bulgaria	80,010	1.86 %
Estonia	84,568	1.96 %
Latvia	125,016	2.90 %
Denmark	133,675	3.11 %
UK	137,828	3.20 %
Germany	155,865	3.62 %
Greece	207,832	4.83 %
France	216,053	5.02 %
Romania	230,714	5.36 %
Portugal	246,485	5.73 %
Italy	424,343	9.86 %
Poland	734,093	17.05 %
Spain	1,131,891	26.29 %

Source: Facts and Figures on the Common Fisheries Policy, 2010

To sum up, fishing is a large scaled industry in the EU. Thus, the fishing industry is in need of well-designed management tools. Mismanagement of fisheries and high amounts of fish and fish products consumption in the EU have resulted in deteriorated environmental conditions for fisheries, higher levels of imports and high amounts of financial aids transferred to the fishing industry. On the other hand, employment in the fishing sector and traditional fishing in coastal areas are faced with alteration. Future of EU fisheries is being threatened by overfishing and overcapacity conditions. In these circumstances, overfishing and overcapacity problems should be analyzed as the main problems in the fishing industry to find solutions for recent problems and achieve long-run goals.

3.3 Overfishing and Overcapacity Problems in EU Fisheries

Fishery is one of the topics discussed in the green papers which are published to display debatable issues and lead to solutions to environmental problems. The vision for the European fisheries in 2020 is declared in the Green Paper. It is suggested that the most efficient mechanism for environment, producers, consumers and governments will be in operation in the future (GP, 2009)[14]. Furthermore, being aware of the fact that the current CFP is not enough to prevent problems in fishing sector, it is stated that the vision for the future is far away from current situation because of the problems with overfishing, fleet overcapacity, heavy subsidies, low economic resilience and decline in the volume of fish caught by European fishermen (GP, 2009). Hence, overfishing and overcapacity are immediate concerns for the next CFP Reform. In this part of the study, overfishing and overcapacity problems are debated to display the dynamics of the fishing industry in Europe.

[14] Green Paper, Reform of the Common Fisheries Policy, Commission of the European Communities, COM(2009)163 final, Brussels, 2009. Hereafter (GP, 2009).

3.3.1 Overfishing

As one of the worldwide problems in fishing industries, overfishing constitutes a big deal also for the European fisheries. European fish stocks have been overfished for decades and fishing fleets remain too large for the available resources (GP, 2009). In the guideline published by FAO, it is mentioned that 25 percent of worldwide major marine fisheries are subjected to overfishing and 52 percent of them, the most affected of which are highly valued stocks of fish, are completely exploited (FAO 4.3, 2008)[15]. Furthermore, Europe suffers from overfishing at a higher rate than world average. It is stated in the CFP that 29 of 33 most important commercial fish stocks in Europe were overfished (CFP, 2009). In addition, the Scientific Committee of the International Commission for Conservation of Atlantic Tunas (ICCAT) announced that recent catch levels were about 3 times the sustainable level (Sissenwine and Symes, 2007). As a result, the amount of seafood captured from Europe's waters has been continuously decreasing, even more than half of the fish consumed on the European market is now imported (GP, 2009).

Table 3.3.1.1 Imports and exports of fishery and aquaculture products in 2008

	Imports		**Exports**	
Country	**Volume in Tonnes**	**Value in Thousands of Euro**	**Volume in Tonnes**	**Value in Thousands of Euro**
LU	8,461	68,058	1,197	12,609
SI	16,371	58,004	4,581	16,398
CY	17,369	59,063	2,719	29,273
HU	18,429	48,341	965	2,095
MT	22,801	33,667	4,696	63,877

[15] FAO (2008). Fisheries management. 3. Managing fishing capacity. FAO Technical Guidelines for Responsible Fisheries. No. 4, Suppl. 3. Rome, FAO. 104p. Hereafter (FAO 4, 3, 2008).

Table 3.3.1.1 (continued)				
SK	23,366	47,724	283	5,160
BG	29,752	40,712	6,496	13,690
IE	38,531	162,488	162,924	332,335
LV	53,617	94,806	120,832	142,790
EE	54,224	89,694	123,122	98,095
FI	65,099	212,025	41,652	31,343
CZ	65,458	147,617	17,837	53,120
AT	66,178	301,773	5,208	24,824
RO	89,532	130,428	1,705	7,661
LT	100,456	189,370	92,527	195,585
EL	125,218	427,062	121,239	441,797
BE	317,362	1,516,041	176,986	847,915
PT	376,293	1,270,603	131,531	484,760
PL	411,817	854,222	220,043	807,108
SE	481,876	1,846,382	464,026	1,273,518
DK	689,367	1,876,573	793,551	2,787,494
NL	729,787	1,957,928	827,255	2,338,387
UK	774,594	2,731,827	414,046	1,258,970
IT	888,803	3,619,054	131,191	526,556
DE	956,782	3,081,955	624,020	1,566,120
FR	1,010,142	3,943,154	353,588	1,337,288
ES	1,497,790	4,823,554	934,793	2,337,415

Source: Facts and Figures on the Common Fisheries Policy, 2010

Table 3.3.1.1presents the imports and the exports of fishery and aquaculture products in the EU countries in 2008. According to the table, five EU countries had higher volumes of exports of fishery and aquaculture products than imports, and eight EU countries had positive net exports in trade of fishery and aquaculture products in 2008.

There are several reasons behind overfishing. FAO Technical Guideline draws attention to uncertainty in fisheries. Uncertainty is caused by the unexpected changes to the system, such as floods or sudden increase in fishing pressure due to migration as well as longer-term environmental variability and change due to climate change or factors such as overfishing (FAO 4.2.2, 2009)[16]. Uncertainty and lack of predictability are also pervasive in fisheries as in many other sectors (FAO 4.2.2, 2009). Jensen (1999) defines overfishing and overcapitalization (overcapacity) as classical distortions which can be discovered in the open access fishery caused by free entry and absence of well-defined property rights. Well-defined property rights will make it eligible to regulate fisheries sector effectively. Therefore, analyzing the roots of overfishing and overcapacity problems is crucial in fisheries research since these problems are highly related to lack of well-defined property rights.

Biologically, mismanagement of fisheries and unbalance between fishing fleets and available fish resources led to biological overfishing of many commercial fish stocks and inefficient usage of fishing capacity of Member State fleets (Lindebo et al., 2002). In this kind of a situation, fishermen not looking ahead may choose race to fish in an uncertain environment. Therefore, it is important to determine the limitations under well-defined property rights. It is stated in the CFP that the low prices in high costs environment is one of the main factors driving overfishing in the short term (CFP, 2009). Thus, insecure and uncertain conditions in fishing sector will lead to overfishing unless effective management policies are carried out.

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[16] FAO (2009). Fisheries management. 2. The ecosystem approach to fisheries. 2.2 Human dimensions of the ecosystem approach to fisheries. FAO Technical Guidelines for Responsible Fisheries. No. 4, Suppl. 2, Add. 2. Rome, FAO. 88p. Hereafter (FAO 4.2.2, 2009).

In accordance with the purpose of creating effective management strategies, the CFP serves for regulation of fisheries in Europe which suffer from a much higher rate of overfishing than observed in comparable developed countries (Sissenwine and Symes, 2007). It is predicted that the most valuable species of the Mediterranean Sea fish stocks are highly overfished expected for 'lightly' regulated fisheries (Sissenwine and Symes, 2007). In this sense, the EU is seeking for accurate policy which will prevent the industry from overfishing.

Particularly, overfishing is closely related with overcapitalization as Munro G. R. stated in the following:

> The root cause of the overcapitalization problem is identical to that of the overexploitation problem (in a sense the two are mirrors of one another). It is the perverse incentive system confronting fishers when property rights to the resource are ill defined. The ''optimal'' or ''target '' level of ''conventional'' capital, at any point in time, is then deemed to be optimal by the resource manager. Rational fishers will, collectively, have an incentive to invest in ''conventional'' capital to the level well beyond the ''optimal''. It is not at all clear that the problem will ever be dealt with effectively until the perverse incentive structure is corrected (Munro, 1999).

Overfishing in Europe is not today's issue. However, it is clearly realized in Europe in the last decades as a result of increased attentions to the problems in fisheries. As Munro (1999) states, overfishing is not an independent problem and it is growing in tandem with overcapacity. Hence, it is necessary to overcome overcapacity problem which supports propensity to overfish.

3.3.2 Overcapacity

Overcapacity is a multifaceted problem in fisheries. Recent developments in fishing technology, increasing numbers and sizes of fishing fleets lead to overcapitalization which is directly related to overfishing. Fishers intend to increase their profitability by reducing costs with the help of technological developments and by increasing total catches. .

Overcapacity is a debatable topic starting from the late 1980s due to the accelerated development of fishing technology (FAO 4.3, 2008). It is stated in the Article 6.3 in FAO Code of Conduct for Responsible Fisheries (CCRF) that the states should prevent overfishing and excess fishing capacity, and they should implement management measures to ensure that the fishing effort is commensurate with the productive capacity of the fishery resources and their sustainable utilization (COC, 1995)[17]. Therefore, preventing overcapacity is the initial condition for providing sustainable utilization and long-run profits in the sector.

There are different definitions of overcapacity. FAO defines the capacity in two different ways. According to the first definition, which is an input-based approach, the capacity is fishing vessels and potential effort. The second definition is an output-based approach to the capacity that is the potential catch (FAO 4.3, 2008). Lindebo et al. described the capacity as the ability to catch fish. The ability is the sum of number and physical characteristics of vessels, gear and fishing methods used, the time available for fishing, the human skills and experiences construct the fishing capacity (Lindebo et al., 2002). According to another definition by FAO, fishing capacity is the amount of fish that can be produced over a period of time by a fully utilized vessel or a fleet for the given conditions (FAO 4.3, 2008). In the light of the different definitions of capacity, overcapacity level is defined as the difference between the target capacity and the current potential capacity of a given fishing fleet (Lindebo et al., 2002). Porter (1998) defines overcapacity, in terms of biology, as the level of capacity which produces a level of fishing mortality that results in a fish stock biomass below the MSY; meanwhile, in terms of economics, overcapacity is the

[17] Code of Conduct for Responsible Fisheries, Rome, FAO. 1995. 41 p. Hereafter (COC, 1995).

capacity level that results in a fish stock biomass below the Maximum Economic Yield (MEY) level (Lindebo et al., 2002).

Overcapacity is an undesired result of developments in the fishing industry. Mismanagement of the fishing industry is the main reason behind overcapacity problem. For instance, government subsidies without necessary controls may be transferred to their expenses and used by fishermen in order to increase their fishing capacities. There are also other factors resulted in overcapitalization such as quota allocation problems or increasing incentives to race to fish due to uncertain conditions and lack of information. Fishing is an economic activity which is not easy to control because of high auditing costs. Hence, in a high control costs environment, taking precautions before the problems emerge is more important than struggling with the problems. In this regard, well-defined property rights, management of fisheries under efficient allocation systems and constructing efficient market mechanisms gain more importance to create a well functioning market for fisheries.

Consequences of overcapacity are faced in different areas. Overcapacity results in overexploitation of fish and inefficient usage of capital stock or productive factors involved in the fishing activity (FAO 4.3, 2008). Additionally, overfishing caused by overcapacity may lead to illegal, unreported and unregulated (IUU) fishing. For this reason, fisheries management and controls should be considered how they will inspire or deter IUU fishing under the conditions of overcapacity (FAO 4.3, 2008). Furthermore, overcapacity is a problem which not only results in inefficient usage of resources and deterioration of the environmental conditions but also triggers the competition in the fishing industry. This situation may result in a pressure on governments' policies. For instance, fishermen or fish product producers may demand increase in subsidies. In these hard conditions, the CFP has not performed well in coping with overcapacity problem. The main concern is that the EU is acting to reduce overcapacity but the progress is very slow due to the concurrent technological improvements in fisheries. A study by the International Council for

Exploration of the Sea indicates that the real effect of actual reductions in fleet capacity is compensated by introduction of new technology which increases fishing power by 1 % - 3 % annually (Sissenwine and Symes, 2007). Table 3.3.2.1 shows the decreasing fishing capacity in EU-27 countries between 2007 and 2010.

Table 3.3.2.1 Fishing fleets - Statistics for the EU-27

Fishing Fleets	**2007**	**2008**	**2009**	**2010**
Total Number of Vessels in EU-27 countries	88,998	86,587	84,502	83,796
Total Engine Power of Fishing Fleets (KW) in EU-27 Countries	7,060,096	6,878,037	6,677,415	6,543,252
Total Gross Tonnage of Fishing Fleets in EU-27 Countries	1,927,085	1,869,329	1,820,434	1,753,928

Source: Fisheries Statistics, EuroStat

In the Green Paper, it is stated that the future CFP must be eligible to create optimum mechanisms for the adaptation of size of European fishing fleets and their optimum proportion to available fish stocks which are pre-requisites for all other pillars of the policy to work (GP, 2009). Besides, different questions concerning legislation, common standards and policies or the allocation systems are asked in the Green Paper to solve this multifaceted problem. It is also stated that using market instruments such as transferable rights may be more efficient and less expensive way to reduce overcapacity (GP, 2009). In this sense, management systems for fisheries need to be evaluated in order to create efficient mechanisms which will be the most powerful tool to overcome overfishing and overcapacity problems. In Chapter 4, RBM systems which are perceived as a solution for the mentioned problems will be analyzed in detail.

3.3.3 Maximum Sustainable Yield (MSY)

The MSY is the optimal catch level while protecting the fish capacity to sustain regeneration for the future. Under the MSY approach, the management goal of the EU is converted to produce catch levels which is stable and sustainable since targeting a precise stock size creates economic inefficiencies. [18] In the Fact Sheet on MSY, it is stated that the EU has agreed to manage its fish stocks at MSY according to an international commitment made by the member states of the EU (Fact Sheet on MSY).

Providing MSY in all fisheries will bring sustainability and stability for EU fisheries. The benefits to be gained from a MSY approach are described by the EU Commission as the following:

- development of larger fish stocks which will lead to lower costs of fishing and higher unit value of catches,
- stability conditions will provide stable supply, thus more efficiency will be created in trade due to stability in long-term plans,
- costs reductions and increase in profits will be achieved for the fishing industry since the amount of effort required to catch fish will decrease.[19]

[18] Fact Sheet on Maximum Sustainable Yield. http://ec.europa.eu/fisheries/documentation/publications/cfp_factsheets/maximum_sustainable_yield_en.pdf. Hereafter (Fact Sheet on MSY).

[19] Implementing sustainability in EU fisheries through maximum sustainable yield. Commission of the European Communities, Brussels, 4.7.2006, COM(2006) 360 final. http://eur-lex.europa.eu/LexUriServ/site/en/com/2006/com2006_0360en01.pdf

In the Fact Sheet on MSY, the situation by main fishing areas of the EU is summarized as the following:

Table 3.3.3.1 MSY fishing in EU fisheries

Fishing Areas	**Number of Stocks**	**Number of evaluated stocks**	**Number of stocks exploited in accordance with MSY**	**Number of stocks overfished with respect to MSY**
North Sea, Eastern channel, Skagerrak and Kattegat	23	12	4	8
West of Scotland	10	3	1	2
Western Waters	26	14	1	13
Iberian Atlantic	11	7	2	5
Baltic Sea	13	2	0	2

Source: Fact Sheet on MSY

Despite of the recent developments in the EU on achieving MSY, MSY approach is not today's issue. Moreover, the roots of this objective date back to 1982 UN Convention on the Law of the Seas. However, implementation of necessary policies have iterated up to today. [20]

[20] European Commission, Fisheries Reform, CFP reform - Maximum Sustainable Yield. http://ec.europa.eu/fisheries/reform/docs/msy_en.pdf

MSY approach is discussed by scientists on the purpose of finding true estimation of MSY. Scheafer (1954) and Fox (1970) models are used for the estimation of MSY as the most common tools. These models estimate MSY by the calculations of,

$Y_i/f_i = a + (b\,.\,f_i),\ \ f_i \leq -a/b$ Scheafer Model

$\ln(Y_i/f_i) = c + (d\,.\,f_i),\ \ Y_i/f_i = \exp[c + (d\,.\,f_i)]$ Fox Model

f_i is the effort in year i and Y_i is the yield (in weight) per unit of effort in year i.
Y/f decreases for increasing effort, thus the slope, b, is negative. The intercept, a, is the Y/f value just observed after first fishing activity occurs. Hence, a is the highest value for Y/f. MSY and effort levels at MSY are calculated by Scheafer and Fox model, respectively as the following:

$f_{MSY} = -0.5\,.\,a/b$ and $MSY = -0.25\,.\,a^2/b$ Scheafer Model

$f_{MSY} = -1\,.\,d$ and $MSY = -1/d\,.\exp(c-1)$ Fox Model

Skonhoft et al. (2012) applied simple Lagrangian method to find fishing mortalities for the young mature and the old mature fish at MSY. Following to that, they estimated the optimal fishing efforts under perfect fishing selectivity and imperfect fishing selectivity for maximizing the profit under an age-structured fish population model. We used the fishing mortalities at MSY derived by Skonhoft et al., for our analyses. In Chapter 5, the economic model is demonstrated. Before that part, RBM systems are discussed in Chapter 4 to clarify the importance of output control regimes in management of fisheries.

CHAPTER 4

RIGHTS-BASED MANAGEMENT SYSTEMS IN FISHERIES

4.1 Property Rights

In an uncertain environment, actors become more sensitive to any given information which affects the way of their acting. Therefore, well-defined property rights should be involved to regulate market conditions and increase efficiency in the fishing industry. Arnason (2000) states that the people may take what they want to the level allowed by social custom if property rights are missing. This will cause an 'external effect' in the case of scarcity of resources. Adversely, 'taking' will not be permissible if property rights are well-defined, so there will not be 'negative externalities'. Furthermore, the importance of property rights is emphasized in the European Commission's report that the market system cannot work without property rights because the essence of market system is trading of property. Hence, there can be no trading and significant division of labor without property rights (RBM 2, 2009)[21]. However, it is not easy to properly define the property rights under uncertain conditions as experienced in fisheries. As mentioned in the same report, it is more difficult to categorize rights for managing the natural resources through a community-based body or organization, where access to a resource is limited for the community whose individuals rarely become a member of the relevant organization (RBM 2, 2009). There are several management systems in operation for fisheries management and they are based on the different approaches. Fisheries management

[21] MRAG, IFM, CEFAS, AZTI Tecnalia & 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: Part II. Catalogue of Rights-Based Management Instruments in coastal EU Member States, London: MRAG Ltd. 247 pp. Hereafter (RBM 2, 2009).

system is a different combination of rules in fishing times, fishing areas, fishing equipment, fishing vessels, species, harvesting volumes, discards and the other factors to carry-out fisheries (RBM 1, 2009)[22]. Therefore, there is no optimum management system to be implemented for the whole fisheries because different species and properties of fisheries will be managed more efficiently if the system operates in accordance with the specific circumstances of each fishery.

4.2 Rights-Based Management Systems

RBM system is one of total management systems applied for fisheries. According to the definition in *Terms of Reference*, any system of allocating fishing rights to fishermen, fishing vessels, enterprises, cooperatives or fishing communities are included in RBM (RBM 2, 2009). The question is that, how should property rights be characterized in fisheries and how should the rights be allocated in order to create optimum management strategies? Among the most commonly used characterizations of rights, Scott (1988) indicated 4 main characteristics of rights as exclusivity, duration, security and transferability. To begin with, exclusivity requires a holder's enjoyment from his rights without any interference. Exclusivity in fisheries is debatable regarding the issue of broadness of catching areas. Secondly, duration refers to the length of time that the rights owner may enjoy his rights. The third characteristics is security which is ensuring the security of rights and the quality of the title via legal system. The last one is the transferability that allows holder to decide on the best way of using his rights (Scott, 1988).

In the European Commission's staff working document it is stated that the strongest fisheries property system is provided by the least constrained characteristics of rights

[22] MRAG, IFM, CEFAS, AZTI Tecnalia & 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: Part I. London: MRAG Ltd. 117 pp. Hereafter (RBM 1, 2009).

and by offering the rights holders the greatest flexibility (COM, 2007)[23]. It is obvious that three of four characteristics of rights are essential and if any one of these is excluded, the right becomes essentially worthless. However, this necessity is not valid for transferability. Transferability is not one of the essential characteristics for rights. The implementation of transferability into an RBM system depends on market conditions. In most part of the Europe, RBM systems are created independently and they are significantly derived by local business or political needs in the region. Nevertheless, RBM systems serve for the sustainable and economically well-performed fisheries where rights are exclusive, secure, durable and tradable (RBM 1, 2009). However, it is not possible to have an RBM system at community level due to the principle of 'relative stability', but RBM systems can be implemented at national level.

There are several types of RBM systems which are implemented in national level in Europe. Main types of RBM systems are specified as (RBM 1, 2009):

- limited non-transferable licensing (LL)
- limited transferable licensing (LTL)
- community catch quotas (CQ)
- individual non-transferable effort quotas (IE)
- individual transferable effort quotas (ITE)
- individual non-transferable catch quotas (IQ)
- vessel catch limits (VC)
- individual transferable quotas (ITQ)
- territorial use rights in fisheries (TURF)

[23] Commission Staff Working Document, Accompanying the Communication from the Commission to the Council and the European Parliament on Rights-Based Management Tools in Fisheries, Commission of the European Communities, Brussels, 2007. Hereafter (COM, 2007).

In the report of the European Commission, four main characteristics of rights; exclusivity, security, validity and transferability are used to measure properties of different types of RBM systems. In that report, different RBM systems are measured regarding the attributes of rights on a scale from zero to unity (0 to 1), where zero means nothing of the attribute and unity means as much of the attribute as possible (RBM 2, 2009). Table 4.2.1 represents the scores of RBM systems related to four main characteristics of rights.

Table 4.2.1 Scores of RBM systems in terms of 4 main characteristics

RBM System	**Country**	**Exclusivity**	**Period of Validity**	**Security**	**Transferability**
TURF	Spain	1	1	1	0
TURF	Italy	0.875	1	1	0.25
TURF(private)	Sweden	0.75	1	1	1
TURF (public)	Sweden	0	0.75	0.25	0
ITQ	Netherlands	0.75	1	0.5	0.75
ITQ BFT	Spain	0.75	1	0.5	0.75
ITQ NAFO	Portugal	0.75	1	0.5	0.9
ITQ NEAFC	Spain	0.75	1	0.5	0.75
ITQ / Swordf.	Spain	0.75	1	0.5	0.75
ITQ / Swordf.	Portugal	0.75	1	0.5	0.75
LL	Slovenia	0.25	1	0.5	0
CQ & IQ	Belgium	0.5	0.25	0.5	0.25
IQ	Sweden	0.5	0.25	0.5	0
LL	Belgium	0.25	0.25	0.5	0.25
LL	Greece	0.25	0.25	0.5	0.25
TURF	Malta	0.75	0.25	0.5	0
CQ / Block Q.	Poland	0.25	0.625	0.5	0.25

Table 4.2.1 (continued)					
IQ	Poland	0.5	0.625	0.5	0.5
IQ	Ireland	0.5	0.5	0.5	0.25
IQ / ITQ	UK	0.5	0.5	0.5	0.75
LL	Cyprus	0.25	0.5	0.5	0
LL	Finland	0.25	0.5	0.5	0
LL	Malta	0.25	0.5	0.5	0.25
ITE	UK	0.75	0.75	0.5	0.75
VTQ	Denmark	0.5	0.75	0.5	0.75
IQ	Finland	0.5	0.875	0.5	0.5
CQ	Portugal	1	1	0.75	0.5
TURF	Finland	0	1	0.75	1
TURF	UK	1	1	0.75	0.75
LL	France	0.25	0.25	0.75	0
LL	Sweden	0.25	0.25	0.75	0
LL	Denmark	0.25	0.5	0.75	0.1
IQ	Lithuania	0.5	0.625	0.75	0.25
ITE	Estonia	0.75	0.625	0.75	1
ITQ	Estonia	0.75	0.625	0.75	1
CQ & IQ	France	0.5	0.5	0.75	0.5
ITQ (2009)	Sweden	0.75	0.5	0.75	1
LL	Spain	0.5	0.5	0.75	0.125
IE	Latvia	0.5	0.75	0.75	0.25
IQ	Latvia	0.5	0.75	0.75	0.25
ITQ	Denmark	0.75	0.75	0.75	1
LL	Italy	0.25	0.75	0.75	0.25

Source: European Commission Staff Working Document[24]

[24] Source: Commission Staff Working Document, Accompanying the Communication from the Commission to the Council and the European Parliament on Rights-Based Management Tools in Fisheries, Commission of the European Communities, Brussels, 2007. Hereafter (COM, 2007).

The results show that higher rates for security is provided in different RBM systems and the score of security is equal to or above 0.5 in all cases. Moreover, TURF applications in Spain, Sweden and Italy have the highest scores for security, 1. Adversely, the only and the lowest security score in this scheme belongs to one of the TURF applications in Sweden. The reason is stated that the shrimp fisheries in public waters are managed through a TURF system in Sweden, and those fisheries are open to anyone with a license. Hence, there is no exclusivity in this fishery which impacts the quality of the right (RBM 1, 2009). Secondly, scores for exclusivity are observed in range from 0 to 1. The lowest and the highest scores for exclusivity are observed in different applications of TURF system. These results show that the RBM systems are operated in different ways for different fisheries. This constitutes an evidence for the statement that there is no optimum management system to be applied for all fisheries. Thirdly, scores for validity vary between 0.25 and 1, and unity is observed for validity in many applications. Most of the highest scored RBM systems in terms of validity are TURF and ITQ systems. These systems let the right holder to exercise the right to fish for a long time such as 10 years or more. Lastly, transferability scores range from 0 to 1 and scores for transferability are mostly observed at high or low values but not at middle values.

These scores provide us an idea about RBM systems. However, interpreting the combination of scores for an RBM system will make it easy to measure the quality of that system in the sense of characteristics of property rights. Arnason defines a measurement method for calculating the quality of property rights, the Q- measure (Arnason, 2007a). According to Arnason's measurement, ITQ management systems have higher quality values with 0.65 mode value among RBM systems. However, the question is that, are those high quality rights also generating well management systems in terms of economic performance? In the European Commission's report it is mentioned that the ITQ systems have very weak, weak or reasonable economic performances where some other RBM systems such as LL, CQ, TURF and IQ perform strongly. It is also stated that there are no clear relationships between quality of rights and stock status or economic profitability due to a number of factors such as using different RBM systems for same stocks, using a single RBM system to manage fleets which are targeting different stocks, lack of data and information about stock status and fishing fleet's economic performance or varying properties of fisheries and fleets (RBM 1, 2009). Hence, it is difficult to find a clear relationship between quality and economic performance of the system. Therefore, efficiency of ITQ systems should be discussed according to its history, characteristics and implementations.

4.3 Individual Transferable Quota System: History and Characteristics

History of implementation of ITQ systems in fisheries dates back to 1970s. Iceland implemented completely developed ITQ system in herring fisheries in 1979 and started to implement ITQs in its all important demersal fisheries in 1984 (Arnason, 2007b). New Zealand started to implement ITQs in its deep-sea fisheries in 1983 and adopted a uniform ITQ system in its all fisheries in 1986. It was the first such comprehensive ITQ system in the world (Arnason, 2007b). Iceland and New Zealand were the leading countries for the implementation of ITQ systems. However, leading scientific discussions about ITQ systems are not as old as their implementations. In the book of *Rights Based Fishing*, Neher, Arnason and Mollett stated that theory and practical sides of the ITQ fisheries management were firstly systematically and clearly expounded at the conference about rights-based fishing held in Reykjavik in 1988 (Arnason, 2007b).

ITQ management system is based on TAC system. TACs are distributed among EU countries and they are allocated to shareowners such as fishermen, communities or cooperatives. Those shares are called ITQs which also give the right to shareowners to sell or lease their quotas. There are limits on who can catch the fish in ITQ management systems. This property makes ITQ different from the traditional open access for commercial fisheries in which there are no limits on who can catch the fish (Parslow, 2010). Most deterministic characteristics of ITQ system is that the shares are transferable and fishing vessel owners can buy or sell ITQ certificates or can lease their quota shares according to their operation decisions (Buck, 1995).

Tradable quota systems are used as a policy tool to solve problems of air pollution, climate change, water pollution. For example, determining the amount of emission allowed for pollution control is used for solving problems of air pollution or determining the amount of water to be allocated is used for solving problems of water management. Tradable permits, which are usually called as ITQs, are most commonly used in fisheries management (Yandle and Dewees, 2008).

Tradable permits provide the allocation of the resource and privatization of the resulting access rights. By these properties, tradable permits address the commons problem (Tietenberg, 2002). Tietenberg stated also the importance of TACs that rationing access to the resource involves setting a limit on user access to the resource and TAC for fisheries is used in this step in fisheries (Tietenberg, 2002).

4.4 Total Allowable Catch and Relative Stability

The European Commission proposes TACs for every year. TACs are the maximum amount of catch allowed for that year and they are allocated according to the rule of ‘relative stability’. The principle of ‘relative stability’ refers to historical catches of countries in the EU. TACs are determined by scientific suggestions and mostly distributed as percentage of total quotas or as specific numbers of tones of harvesting. TAC system is the initial step of ITQ management system. Setting TACs is used for fixing maximum quantities of fish that can be landed from a specific stock in a given time (MEMO, 2009)[25]. TACs can vary from year to year due to changing environmental conditions to sustain the biodiversity of fish. However, there are some strict rules which are always valid except the situations in which there needs to be taken very strong measures for the sustainability of fisheries. For instance, according to general principles, the variation in TACs from one year to the next cannot exceed 15% unless it is necessary to save the species from collapsing via urgent reduction in total catches (MEMO, 2009).

TACs and quotas per species for EU vessels in 2011 were determined by the European Commission as in Table 4.4.1.

Table 4.4.1 TACs and quotas per species in 2011 (in tonnes)

Species Latin Name	**Species English Name**	**TACs 2011**	**Total Quotas 2011**
Engraulis encrasicolus	Anchovy	23,200	23,200
Lophiidae	Anglerfish	57,615	59,115
Salmo Salar	Atlantic salmon	NA	265,528
Molva dypterigia	Blue ling	2,913	2,598
Micromesistius poutassou	Blue whiting	40,100	11,072
Thunnus thynnus	Bluefin tuna	12,900	5,756.41
Caproidae	Boarfish	33,000	33,000
Gadus morhua	Cod	755,020	158,977
Limanda limanda	Dab	18,434	18,434
Reinhardtius hippoglossoides	Greenland halibut	13,254	17,335

[25] European Commission's proposal on fishing opportunities: why and how? http://europa.eu/rapid/pressReleasesAction.do?reference=MEMO/09/458&format=HTML&aged=0&language=EN&guiLanguage=en , MEMO/09/458, Brussels, 2009. Hereafter (MEMO, 2009).

Table 4.4.1 (continued)			
Melanogrammus aeglefinus	Haddock	56,538	50,882
Merluccius merluccius	Hake	65,800	65,800
Clupea harengus	Herring	1,470,799	565,626
Trachurus spp.	Horse mackerel	260,014	254,264
Microstomus kitt	Lemon sole	6,391	6,391
Molva molva	Ling	16,753	11,243
Scomber scombrus	Mackerel	NA	319,498
Lepidorhombus spp.	Megrims	26,432	26,432
Pandalus borealis	Northern prawn	31,128	20,595
Nephrops norvegicus	Norway lobster	68,357	69,557
Pleuronectes platessa	Plaice	94,432	89,735
Pollachius pollachius	Pollack	15,887	15,887
Sebastes spp.	Redfish	46,403	17,407
Coryphaenoides rupestris	Roundnose grenadier	8,362	8,362
Pollachius virens	Saithe	106,343	60,297
Ammodytidae	Sandeel	265,000	242,250
Rajidae	Skates and rays	30,361	25,917
Solea spp.	Sole	27,982	27,932
Sprattus sprattus	Sprat	227,421	503,686
Xiphias gladius	Swordfish	28,700	174,085.80
Psetta maxima	Turbot	4,642	4,728.40
Brosme brosme	Tusk	3,458	705
Merlangius merlangus	Whiting	36,066	34,754

Source: European Commission, Fishing Posters, Fishing TACs and Quotas, 2011

Total quotas exceed TACs for some species as given above. The reason is that the TACs for some species were not applicable or not relevant in some catching zones but catching for these species still maintains in these zones at the determined quota levels. Hence, actual quotas may exceed TACs for the mentioned species. Table 4.4.2 displays sustainability conditions of the species. Blue, red and green stars refer to different conditions and each star symbolizes a fishing zone in the EU. For example, recent conditions of the Herring are compatible with the conditions indicated by red star in 4 fishing zones, green star in 4 fishing zones and blue star in 5 fishing zones. The conditions of the Herring in other zones of the EU could not be estimated properly.

Table 4.4.2 Conditions of fish species at different fishing zones

Species Latin Name	**Species English Name**	**State of the species**
Engraulis encrasicolus	Anchovy	*
Salmo Salar	Atlantic salmon	**
Molva dypterigia	Blue ling	**
Micromesistius poutassou	Blue whiting	****
Thunnus thynnus	Bluefin tuna	*
Reinhardtius hippoglossoides	Greenland halibut	**
Reinhardtius hippoglossoides	Greenland halibut	*
Melanogrammus aeglefinus	Haddock	**
Melanogrammus aeglefinus	Haddock	****
Merluccius merluccius	Hake	*
Clupea harengus	Herring	****
Clupea harengus	Herring	****

Table 4.4.2 (continued)		
Clupea harengus	Herring	*****
Trachurus spp.	Horse mackerel	**
Scomber scombrus	Mackerel	****
Lepidorhombus spp.	Megrims	*
Pandalus borealis	Northern prawn	***
Nephrops norvegicus	Norway lobster	*
Nephrops norvegicus	Norway lobster	*
Pleuronectes platessa	Plaice	*
Pleuronectes platessa	Plaice	*
Lamna nasus	Porbeagle	*
Sebastes spp.	Redfish	**
Sebastes spp.	Redfish	*
Pollachius virens	Saithe	**
Pollachius virens	Saithe	***
Pollachius virens	Saithe	*
Solea spp.	Sole	***
Solea spp.	Sole	**
Solea spp.	Sole	**
Squalus acanthias	Spiny dogfish	***
Sprattus sprattus	Sprat	*
Sprattus sprattus	Sprat	*
Xiphias gladius	Swordfish	**
Psetta maxima	Turbot	*
Merlangius merlangus	Whiting	*
Merlangius merlangus	Whiting	**

Source: European Commission, Fishing Posters, Fishing TACs and Quotas, 2011

Meanings of the symbols are as the following:

* (Green Star): Stocks are exploited at a rate that is consistent with producing the highest catch from the stock in the long term.

* (Blue Star): The stock is overfished compared to producing the highest yield in the long term, but is inside safe biological limits or is being managed under a long-term plan which has been approved by scientific advice.

* (Red Star): The stock is outside safe biological limits while not under a long-term plan, or is subject to a scientific advice that there should be no fishing (Fishing TACs and Quotas, 2011).

Globally, TACs for each species are allocated through various ways. In the EU, TACs are allocated according to the principle of 'relative stability'. This principle prescribes that the countries' past catching records should be considered for allocation of TACs. This ensures Member States a fixed percentage share of fishing opportunities (MEMO, 2009).

Catch limits of the EU fleets were set firstly by the North East Atlantic Fisheries Commission (NEAFC) in 1975. European Council constituted the principle of relative stability in 1980 after the Hague Declaration of 1976 and it is firstly applied with the first CFP in 1983. Under this new system, TACs for each fish stocks were divided among member states based on a fixed proportion which is determined according to states' historic catches (CFP, 2009).

The principle of relative stability is one of the controversial issues of fisheries policy in the EU. Allocation of resources constitutes the second step of management of fisheries, following the initial step which is the determination of TACs. Reaching the compatibility of ITQ systems with the principle of relative stability is targeted and necessary regulations are made. These regulations serve to protect operation of both ITQ system and principle of relative stability in tandem. Implementation of transferable RBM systems at community level is faced with objections. Arguments were focused on incompatibility of ITQ with the principle of relative stability. ITQs were undermining the principle of relative stability since transferable rights system at community level gives operators the possibility of buying and selling rights that are currently managed and distributed by countries in accordance with countries' own rules (COM, 2007). A distinction needs to be made between transfers of fishing rights in a state and transfers between member states, but international transfers of fishing rights in the EU are expanding in a less visible way which circumventing the principle of relative stability (COM, 2007). Since EU is multinational, transferability of quotas is regarded as a threat on countries' own fisheries if transferable quota systems permit to high volume of trade between fishermen which can affect fisheries markets in the country. Hence, some limitations are designed such as prohibiting quota trade at international level or putting some restrictions on high volume of trade between fishing fleets. In the light of the discussions above it can be deduced that the allocation of natural resources is always at issue and allocation mechanism used in fisheries is important to create the conditions of economic efficiency. Anderson, Arnason and Libecap (2010) described different types of allocation systems for natural resources such as political allocation, uniform allocation, grandfathering and auctions. Ledyard (2009) compared grandfathering and auctioning in terms of initial allocation of fishing quotas and final quota decisions of fishermen.

In the EU, the principle of relative stability is positively judged that this principle is perceived as a security tool of the fishing industry which protects the industry from political problems and socially undesirable conditions. The fishing industry is highly attached to the principle of relative stability which is often perceived as an assurance against wholesale trade of fishing rights by irrelevant investors with the fishery of member state (COM, 2007). However, economic and environmental efficiency provided by this principle is a controversial topic.

4.5 ITQ as a Management Mechanism

Main aim of an ITQ system is increasing market efficiency by providing flexible conditions and creating self-control mechanism in the fishing industry. The primary purpose of ITQ systems are described by Buck. It is stated that the purpose of ITQ is creating an incentive for capital management such as reducing or controlling overcapitalization in commercial fisheries and to increase efficiency of the fishing industry (Buck, 1995). ITQ programs are intended to establish a stable and profitable market for commercial fishing and improve social benefits through controlling overcapitalization (Buck, 1995).

Management tools gain importance for the success of ITQ system. Two key management decisions in traditional fisheries management are determination of target biomass, fishing effort and harvest for a given species and determination of instruments to achieve this target (Grafton and Mcllgorm, 2009). Determination of TACs and quotas, regulations in the fishing industry by considering technological developments and socially desirable conditions, constituting rules on transfers of quotas and establishing necessary control systems are the main concerns of applying an ITQ system.

There are several reasons why ITQs became one of the inevitable management systems in fisheries and why ITQs are widely accepted worldwide. First of all, ITQ programs are intended to reduce overcapitalization, positively impact the conservation of stocks, improvement of market conditions and promoting safety in fishing fleet. Moreover, ITQs guarantee a catch share and this property of ITQs slows or eliminates the ‘race to fish’ and allows fishermen to be flexible about their timing and fishing rate decisions (Buck, 1995).

ITQs may create positive net returns for fishing industry if these programs are managed effectively. There are some necessary conditions need to be provided for success of ITQ programs. These pre-conditions are well defined by Grafton and Mcllgorm such as adequate monitoring and control, well defined and binding TACs and flexibility in reconciliation of quota (Grafton and Mcllgorm, 2009). According to Kompas and Che (2003), there are two necessary conditions at least to render ITQs efficient in management of fisheries. Firstly, there should be a well-organized market to implement transfer of quota effectively. Secondly, quota holders should participate in this market to transfer quotas from high to low marginal cost producers and also there should be an ex post transfer to compensate catches which are different than planned or prior quota holdings. The relative stability principle may be carried out in tandem with ITQ system if these kinds of market mechanisms are implemented in the European fisheries management.

Resource rents can also be used to evaluate efficiency of the management system. Resource rents are increased returns per unit effort and they occur when management systems such as ITQs reduce the level of fishing effort which is resulted in exit of less efficient operators and increase in catch rates and per unit of effort (Geen and Nayar, 1988). Geen and Nayar (1988) stated also that, according to the simulations resource rents under ITQ systems would be 25 % higher than the resource rents under alternative management systems for the same total catch. Moreover, capital employed in vessels under ITQ systems would be \$10 m to \$12 m less than the capital employed in vessels under alternative systems. ITQ management may be resulted in generation of economic rent and these rents can be used either as tax or capital in the industry. According to Hanneson, fishermen do not have a sole purpose of getting a share of the resource rents, their incentives are to invest by minimizing costs according to the quota shares, so the optimal level of investment is not guaranteed. He added that in the 'share system' there will be an incentive to overinvest or underinvest in the fishing fleets depending on the catch share of the quota owner (Hannesson, 2000).

4.5.1 Advantages and Disadvantages of ITQ Systems

ITQ system as an output control mechanisms brings some advantages and disadvantages to their application areas. Advantages of individual rights compared to other systems are summarized in the European Commission Staff Working Document that the individual rights eliminate encouragement of race to fish, provide security of access to stocks, harvesting through flexible fishing times and rates and development of the coordination between market supply and demand, seasonal supply and quality and thus increase value of landings (COM, 2007).

The most well known advantages of ITQ are reducing fishing efforts and overcapitalization through eliminating inefficient fishermen which is resulted in effective matching between capacity and stocks. It is illustrated in the Commission Staff Working Document the ITQ systems significantly reduced the total fleet capacity in the United States surf clam and ocean quahog fisheries, the Australian bluefin tuna fishery and in Iceland's purse seine fishing (COM, 2007).

However, in some cases individual transferable rights are not sufficient to reduce overcapacity such as in the Icelandic demersal fleet and the Netherlands flatfish fleet. There are several factors behind the inefficiency of ITQs in terms of reducing overcapacity. First of all, an exit from the fishing industry is not easy due to high sunk costs. Secondly, actions of fishermen are not fully compatible with ITQ system management. Fishermen may prefer to keep their vessels even if they sell their rights or they may target other fisheries which are not subject to ITQ system. Furthermore, high costs of output control may result in higher rate of fishing than determined quota levels. Hence, eliminating inefficient fishing vessels and creating a smoothly functioning industry will be achieved in the long-run.

In a case that these problems are overcome, the reduction of number of fishing vessels will be resulted in an increase in profitability of the remaining fleets. Geen and Nayar (1988) stated that under ITQ system the average catches per boat in Western Australia and South Australia to be 67 % and 28 % higher, respectively, than the average catches might have been under aggregate quota or limited entry system, and also 90 % higher in Western Australian system if they have maintained to implement previous aggregate quota system.

The Commission Staff Working Document (COM, 2007) displays four main critics of rights-based management systems as the following:

- Financial burden on owner of rights who buys it from first generation
- Encouragement to high grading within individual quota systems
- Less effective and permanent control on landings
- Concentration problem which effects small scale fishers negatively

Despite its effective outcomes such as reducing race to fish and overcapacity, ITQ system may create some negative conditions such as increasing discards and high grading. These negative sides of ITQs lead the questions about efficiency of ITQ systems. ITQs can create incentives to discard lower valued fish since returns from catches will increase if they catch higher valued fish rather than lower valued ones (Geen and Nayar, 1988).

In a case that the tradable quotas are allocated by charging a quota fee, fishermen may intend to increase their profits through high grading to compensate their quota expenses. However, incentives to have selective fishing methods will rise only if necessary regulations and controls are started to be implemented. Tietenberg (2002) stated that the fisheries face problems of poaching, unreported high grading, which means discarding low valued fish to use quota for higher valued fish, and bycatch discards. However, it is not certain that the ITQs are increasing bycatch or high grading in fisheries. According to OECD and National Research Council Committee to Review Individual Fishing Quotas, the implementation of ITQ may increase or decrease bycatch and high grading on the fishery (Tietenberg, 2002). Buck stated that the ITQ programs may encourage high grading if retained catch reporting continues rather than reporting of total catches since fishermen always try to maximize price received under individual quota systems (Buck, 1995).

Another aspect of transferable quota systems is the reduction in total employment. Under ITQ systems, total employment decreases due to the exits of fishing vessels from the industry. However, it is mentioned in the European Commission document that the RBM systems will provide more stable, more permanent and less seasonal employment in the long term (COM, 2007). Exits of vessels may result in decreasing employment in the sector. Employment in fish catching sector is highly affected from decreasing number of vessels rather than employment in processing and aquaculture sectors. Employment problem is one of the concomitants of ITQ systems. Governments' role on protecting social welfare gains importance in the circumstances of low level of employment.

The other much-debated issue about ITQ systems is the increasing costs under ITQs. Fixed costs, information costs and costs of control are due to change under ITQ management systems. Information costs are higher under ITQ management and other TAC-based systems compared to the systems which simply regulate fishing effort (Yandle and Dewees, 2008). Implementation of ITQs increased the fixed costs of production because of the 'user pays' principle for government services. This principle prescribes payments by fishermen to cover a portion of management costs in fisheries. Hence, the management levy paid by each fisherman is also higher under

ITQs (Geen and Nayar, 1988). On the other hand, total government financial transfers are much higher under input control systems than output control systems. The total government transfers were on average 20 % of the total landings value in OECD countries in 1999 while it reduced to 4 % in New Zealand and Iceland under individual transferable quota systems (Grafton et al., 2005). As a result, ITQ systems may reduce the financial burden on governments observed under input control systems.

One of the other problems about ITQ systems is the concentration problem. Small-scaled fishing enterprises are expecting to be protected because these enterprises are still the primary income resource in some coastal regions and create employment opportunities in these regions. Concentration of quotas refers to the exit of small-scaled enterprises from the fishing industry which may result in a threat to social welfare if necessary regulations are not made by governments. Tietenberg (2002) refers to a research of National Research Council[26] which gives information about the ways of protection against concentration of quotas. One of the mentioned strategies is putting a limit on the amount of quota that can be accumulated by a quota holder. The system in New Zealand permits to hold quota in a range from 20 % to 35 %, depending upon species. The permitted amount of quota to hold is 10 % for cod and 20 % for other species in Iceland (Tietenberg, 2002). ITQs may turn into a monopolistic control over the fishing industry unless effective strategies are developed. Therefore, regulations are necessary to establish a well operating ITQ system. Higashida and Takarada (2009) described low-cost fishers as efficient ones and high-cost fishers as inefficient ones in the sector. They claimed that the inefficiency may be more serious if the market power is belong to low-cost and efficient fishers because excess entry of low-cost fishers and inadequate exit of high-cost fishers may be observed in this kind of a situation.

[26] National Research Council Committee to Review Individual Fishing Quotas, 1999, Sharing the Fish: Toward a National Policy on Fishing Quotas. Washington, National Academy Press, pp. 90-91.

In this part of the study, output control regimes are discussed in detail. In the next part, an economic model is employed to establish a mechanism for optimal allocation of fishing quotas at different TAC levels, under an output rights system.

CHAPTER 5

THE MODEL

Research in economics of fisheries heavily focuses on providing environmental sustainability, increasing market efficiency and improving social welfare. Different types of economic models have been constructed so far to develop effective management systems for fisheries.

An economic model which does not refer to different characteristics of fish and fishermen may not be able to offer solution to the recent problems. In this context, we take into consideration biological properties such as fertility and natural mortality rates or input factors such as fishing technology in our analyses. An age-structured fish population model developed by Skonhoft et al. (2012) is employed for this study. We investigated the optimality conditions for the allocation of quotas at different TAC levels, in eight different cases. The former four cases are designed for the analyses of the impact of fishing on total biomass change. The sooner four cases are designed for the analyses of MSY. Additionally, for both parts, each case differs from the others according to the fishing technologies of fishermen. Firstly, we analyzed the total biomass change from the viewpoint of a myopic planner. Specifically, in the first part, we investigated the change in total biomass from year t to t+1 under fishing conditions and non-fishing conditions to detect the impact of fishing on total fish biomass. In this line, from a myopic planner's point of view, we designed a mechanism for allocation of fishing quotas at different TAC levels. The determined quota levels at any given TAC minimize the impact of fishing on total biomass change from year t to t+1. Secondly, we left myopic planners viewpoint aside and investigated MSY at fish population equilibrium. In this part, our analyses basically focus on how the fishing quotas should be allocated at a TAC level equal to MSY. As a result, we showed that the quota allocation is important both to minimize the impact of fishing on total biomass change from any time t to t+1 and achieve MSY at any time at the population equilibrium. We found that the optimality conditions for allocation of fishing quotas depend on fishing technologies of fishermen under an individual quota regime. We begin with explaining the population model.

5.1 The Population Model

The population model in this study is based on the three cohorts of the fish population as designed by Skonhoft et al. (2012). The juveniles refer to the youngest class in the population. The juveniles are not harvestable and they are not members of the spawning stock. The old mature class and the young mature class are both harvestable and members of the spawning stock. Different than the young matures, the old matures have higher fertility as supposed by Reed (1980). Moreover, weight per fish and price per weight are higher for the old mature fish than the young mature fish. We also assumed that the total biomass of the old mature fish is less than the total biomass of the young mature fish due to the high levels of historic catches of the old mature fish, which refers to a real life situation.

Juveniles, $X_{0,t}$ (age < 1)
Young matures, $X_{1,t}$ ($1 \leq$ age < 2)
Old matures, $X_{2,t}$ ($2 \leq$ age)

$w_0 < w_1 < w_2$
$p_1 < p_2$
$w_1 X_{1,t} < w_2 X_{2,t}$

The recruitment function is increasing and concave for both age classes and it is an endogenously determined Beverton-Holt type recruitment function. The numbers of recruits are,

$X_{0,t} = R(X_{1,t}, X_{2,t}) = a(X_{1,t} + \beta X_{2,t})/[b + (X_{1,t} + \beta X_{2,t})]$ (Beverton and Holt, 1957)

The number of recruits depends on the populations of the old mature and the young mature fish and parameters of a, b and β. The β is the fertility parameter which indicates the higher natural fertility of the old mature fish than the young mature fish. a and b are the scaling parameter and shape parameter, respectively. Life cycle scheme of an age-structured fish population is described at Table 5.1.1. Black arrows show the ageing structure from t to t+1 and red arrows show the recruitment structure of the fish population.

Table 5.1.1 Life cycle scheme of an age-structured fish population

t	**t+1**
$X_{0,t}$	$X_{0,t+1}$
$X_{1,t}$	$X_{1,t+1}$
$X_{2,t}$	$X_{2,t+1}$

The number of the young mature fish at t+1 is,

$X_{1,t+1} = s_0 X_{0,t}$, where s_0 is the fixed natural survival rate of juveniles.

$X_{0,t} = R(X_{1,t}, X_{2,t})$

$X_{0,t+1} = R(X_{1,t+1}, X_{2,t+1})$

$X_{1,t+1} = s_0\, R\big(X_{1,t}, X_{2,t}\big)$ (Recruitment constraint)

$X_{1,t+1} = s_0\, \{a\big(X_{1,t} + \beta X_{2,t}\big)/[b + (X_{1,t} + \beta X_{2,t})]\}$

The number of the old mature fish at t+1 is,

$X_{2,t+1} = s_1\,(1 - f_{1,t})\, X_{1,t} + s_2\,(1 - f_{2,t})\, X_{2,t}$ (Spawning constraint)

$f_{1,t}, s_1$ and $f_{2,t}, s_2$ are the fishing mortality rate and the fixed natural survival rate of the young mature and the old mature fish, respectively. In this population model, it is considered that the fishing activity occurs after spawning and before natural mortality.

There are two fishermen characterized by their technologies. Fishing technologies of fisherman 1 and fisherman 2 are denoted as j_1 and j_2, respectively. We considered that both fishermen target the old mature fish. However, due to the conditions in the fishing industry such as high costs of constructing high technology fishing vessels, some fishermen prefer to construct lower level of fishing technologies and bycatch higher amounts of young mature fish, which do not bring high revenue as old mature fish bring. In addition, we assumed that after the old mature fish population is fully caught the fishermen who have imperfect selectivity fulfill their remaining quotas through capturing young mature fish.

In this study, we use a technology-based quota allocation mechanism. The quota allocation mechanism is a tool that yields optimum quota levels to each fishermen under given conditions for achieving the targeted results. The higher technology rate of fisherman i results in a higher ratio of catch of targeted fish to catch of untargeted fish (bycatch) unless targeted fish population is fully caught. Technology level is an indicator which shows fishing selectivity of a fisherman. At a given j_i level, catch of targeted fish of fisherman i is equal to $j_i x 100$ percent of the total catches of fisherman i. For instance, $j_i = 0.8$ means 80 % of the total catches of fisherman i consists of catch of targeted fish and 20 % of the total catches of fisherman i consists of bycatch. Suppose that both fishermen target the old mature fish and α_1 is the quota ratio, as a percentage of TAC, of fisherman 1. The total harvest of fisherman 1 is equal to $\alpha_1\, TAC$ and consists of $h_2^1\, w_2\, X_{2,t}$ amounts of catch of targeted fish and $b_1^1\, w_1\, X_{1,t}$ amounts of bycatch. The same approach is valid for fisherman 2 who also targets the old mature fish. Total catches of fisherman 2 consists of $h_2^2\, w_2\, X_{2,t}$ amounts of old mature fish and $b_1^2\, w_1\, X_{1,t}$ amounts of young mature fish.

$\alpha_1\, TAC = h_2^1\, w_2\, X_{2,t} + b_1^1\, w_1\, X_{1,t}$

$\alpha_2\, TAC = h_2^2\, w_2\, X_{2,t} + b_1^2\, w_1\, X_{1,t}$, where $\alpha_1 + \alpha_2 = 1$

The amounts of catch of targeted fish and bycatch can be rewritten as technology-based such that,

$h_2^1\ w_2\, X_{2,t} = j_1\, \alpha_1\, TAC$, $b_1^1\ w_1\, X_{1,t} = (1 - j_1)\, \alpha_1\, TAC,$ $h_2^1\, w_2\, X_{2,t} > b_1^1\, w_1\, X_{1,t},$ $0.5 < j_1 \leq 1.$

$h_2^2\, w_2\, X_{2,t} = j_2\, \alpha_2\, TAC$, $b_1^2\, w_1\, X_{1,t} = (1 - j_2)\, \alpha_2\, TAC,$ $h_2^2\, w_2\, X_{2,t} > b_1^2\, w_1\, X_{1,t},$ $0.5 < j_2 \leq 1.$

These measurements are based on the assumption that the TAC is determined at a level lower than each age group's total biomass ($w_1\, X_{1,t},\ w_2\, X_{2,t} > TAC$). The simple example above is given to show how our methodology works under the assumption of $w_1\, X_{1,t},\ w_2\, X_{2,t} > TA$C. Under this assumption, the amount of catch of targeted fish of fisherman i is higher than the amount of bycatch of that fisherman because every fisherman sets up a fishing technology which is compatible with capturing the targeted fish. In this regard, $j_1$is greater than 0.5 to obtain the rule that $h_2^1\, w_2\, X_{2,t} > b_1^1 w_1\, X_{1,t}$ and j_2 is greater than 0.5 to obtain the rule that $h_2^2\, w_2\, X_{2,t} > b_1^2\, w_1\, X_{1,t}$.

However, TAC may be determined at different levels which do not provide the condition of $w_1 X_{1,t}$, $w_2 X_{2,t} > TAC$. In this sense, we used different intervals of TACs in our analyses. Firstly, as in the previous example, TAC may be determined at a level lower than each age group's total biomass. On the other hand, TAC may be determined at a level equal to or above the old mature fish biomass if a lower level of protection of the fish population is required ($w_2 X_{2,t} \leq TAC < w_1 X_{1,t}$).

In addition, there are other specific conditions for TAC depending on the fishing technologies of fishermen. For instance, in a case that the fisherman 1 has imperfect fishing selectivity and all of the fishing quotas are assigned to fisherman 1 ($\alpha_1 = 1$, $\alpha_2 = 0$), then different TAC levels result in different catching conditions. If TAC is determined at a level providing $w_2 X_{2,t} \leq TAC < w_2 X_{2,t} + [(1 - j_1)/j_1]\, w_2 X_{2,t}$, then total catches of targeted fish of fisherman 1 will be equal to $j_1 TAC$ and total amount of bycatch of fisherman 1 will be equal to the $(1 - j_1) TAC$. On the other hand, if TAC is set at a level providing $TAC \geq w_2 X_{2,t} + [(1 - j_1)/j_1]\, w_2 X_{2,t}$, then the total amount of catch of targeted fish for fisherman 1 will be equal to $w_2 X_{2,t}$. The rest of his catches will consist of young mature fish at an amount of $TAC - w_2 X_{2,t}$. The calculations are simply based on a fix ratio of catch of targeted fish to bycatch derived from the catchability coefficients for each fisherman. For instance, at the corner solution of $\alpha_1 = 1, \alpha_2 = 0$, if fisherman 1 captures n ($n < w_2 X_{2,t}$) amount of targeted fish, then he captures untargeted fish at an amount of $[(1 - j_1)/j_1]$ n, at a TAC level providing $TAC \leq w_2 X_{2,t} + [(1 - j_1)/j_1]\, w_2 X_{2,t}$. The measurement methods change at different TAC levels.

At some TAC levels, the relation between catch of targeted fish and bycatch are $h_2^1 w_2 X_{2,t} > b_1^1 w_1 X_{1,t}$ and $h_2^2 w_2 X_{2,t} > b_1^2 w_1 X_{1,t}$ according to the fix ratio of catch of targeted fish to bycatch. On the other hand, if TAC is determined at a high enough level, catch of young mature fish of fisherman i may exceed the level derived from this given ratio. In our analyses, we dealt with the optimal allocation of quotas at different TAC levels. Suppose that, fisherman 1 targets the old mature fish and bycatches the young mature fish. The ratio of the amount of catch of targeted fish to the amount of bycatch is provided until the old mature fish population is fully caught, but after the old mature fish population is fully caught, the remaining catch of fisherman i only involves young mature fish. In this case, fisherman 1 fulfills his remaining quota through capturing young mature fish. Hence, total catches of fisherman 1 may consist of higher amounts of catch of untargeted fish than the calculated level according to the fix ratio of catch of targeted fish to bycatch. Additionally, we did not take into consideration the TAC levels providing $w_1 X_{1,t} \leq TAC$.

We begin by investigating the impact of fishing on total biomass change from any time t to t+1.

5.2 The Impact of Fishing on Total Biomass Change under an Age-Structured Model

In this part, we mainly investigated whether the total biomass change depends on allocation of quotas and fishing technologies at different TAC levels. We measured the impact of fishing on the amount of change in total biomass from time t to time t+1. It is assumed that the total population of the young (old) mature fish under natural conditions at the beginning of time t is equal to the total population of the young (old) mature fish under fishing conditions at the beginning of time t. This assumption will not change the results, but calculations are done more easily under this assumption. Lastly, B_{t+1} and $X_{i,t+1}$ refer to the total biomass and the population of age class i at time t+1, respectively, under fishing conditions. Besides $B^*_{t+1}$and $X^*_{i,t+1}$ refer to the total biomass and the population of age class i at time t+1, respectively, if there is no fishing activity at time t.

The total biomass at time t after spawning is,

$$B_t = w_0 R(X_{1,t}, X_{2,t}) + w_1\, X_{1,t} + w_2\, X_{2,t}$$

If there is no fishing activity, the total biomass at time t+1 after spawning will be as following:

$$B_{t+1}^* = w_0 R(X_{1,t+1}^*, X_{2,t+1}^*) + w_1 X_{1,t+1}^* + w_2 X_{2,t+1}^*$$

At time t, there will be supply of new individuals to the fish population at an amount of $R(X_{1,t}, X_{2,t})$ and these new individuals will constitute the young mature fish population at time t+1.

$$X_{0,t} = R(X_{1,t}, X_{2,t})$$
$$X_{1,t+1}^* = s_0\, X_{0,t}$$
$$X_{2,t+1}^* = s_1\, X_{1,t} + s_2\, X_{2,t}$$

The virgin fish biomass at the beginning of time t+1 is,

$$B_{t+1}^* = w_0 R(X_{1,t+1}^*, X_{2,t+1}^*) + w_1\, s_0\, R(X_{1,t}, X_{2,t}) + w_2(s_1\, X_{1,t} + s_2\, X_{2,t})$$

The total biomass change between time t and t+1 is ρ^*,

$$\rho^* = B_{t+1}^* - B_t$$
$$\rho^* = w_0\, R(X_{1,t+1}^*, X_{2,t+1}^*) - w_0\, R(X_{1,t}, X_{2,t}) + w_1\, s_0\, R(X_{1,t}, X_{2,t}) + w_2\, s_1\, X_{1,t} + w_2\, s_2\, X_{2,t} - w_1\, X_{1,t} - w_2\, X_{2,t}$$

On the other hand, under fishing conditions, the total biomass change at time t and t+1 will be as the following:

$$B_t = w_0\, R(X_{1,t}, X_{2,t}) + w_1\, X_{1,t} + w_2\, X_{2,t}$$
$$B_{t+1} = w_0\, R(X_{1,t+1}, X_{2,t+1}) + w_1\, X_{1,t+1} + w_2\, X_{2,t+1}$$
$$B_{t+1} = w_0 R(X_{1,t+1}, X_{2,t+1}) + w_1\, s_0\, R(X_{1,t}, X_{2,t}) + w_2\, s_1\, (1 - f_{1,t})\, X_{1,t} +$$
$$w_2\, s_2\, (1 - f_{2,t})\, X_{2,t}$$

$$\rho = B_{t+1} - B_t$$
$$\rho = w_0\, R(X_{1,t+1}, X_{2,t+1}) - w_0\, R(X_{1,t}, X_{2,t}) + w_1\, s_0\, R(X_{1,t}, X_{2,t}) + w_2\, s_1\, X_{1,t} +$$
$$w_2\, s_2\, X_{2,t} - w_2\, s_1\, f_{1,t}\, X_{1,t} - w_2\, s_2\, f_{2,t}\, X_{2,t} - w_1\, X_{1,t} - w_2\, X_{2,t}$$

The impact of fishing on total biomass change is the difference between the total biomass change under non-fishing conditions and the total biomass change under fishing conditions ($\rho^* - \rho$). It is equal to,

$$\rho^* - \rho = w_0\left[R(X^*_{1,t+1}, X^*_{2,t+1}) - R(X_{1,t+1}, X_{2,t+1})\right] + w_2(s_1\, f_{1,t}\, X_{1,t} + s_2\, f_{2,t}\, X_{2,t})$$

This equation simply shows that the impact of fishing on total biomass change depends on the allocation of fishing quotas. Fishing mortalities are stated below.

$$\alpha_1\, TAC \geq h_2^1\, w_2\, X_{2,t} + b_1^1\, w_1\, X_{1,t} \quad , \quad f_{1,t}\, w_1\, X_{1,t} = b_1^1\, w_1\, X_{1,t} + b_1^2\, w_1\, X_{1,t}$$
$$\alpha_2\, TAC \geq h_2^2\, w_2\, X_{2,t} + b_1^2\, w_1\, X_{1,t} \quad , \quad f_{2,t}\, w_2\, X_{2,t} = h_2^1\, w_2\, X_{2,t} + h_2^2\, w_2\, X_{2,t}$$

As a result, levels of $f_{1,t}X_{1,t}$ and $f_{2,t}X_{2,t}$ depend on the allocation of quotas among fishermen.

- **Result 1:** Allocation mechanism for fishing quotas is a determinant to achieve the minimum level of the impact of fishing on total biomass.

We can minimize the impact of fishing by maximizing $X_{2,t+1}$ and hence by minimizing the function of $w_2(s_1\, f_{1,t}\, X_{1,t} + s_2\, f_{2,t}\, X_{2,t})$. The reason is that $X^*_{1,t+1} = X_{1,t+1}$, therefore the difference between $R\left(X^*_{1,t+1}, X^*_{2,t+1}\right)$ and $R\left(X_{1,t+1},\, X_{2,t+1}\right)$ is shaped by $X_{2,t+1}$. Thus, the function of $w_2(s_1\, f_{1,t}\, X_{1,t} + s_2\, f_{2,t}\, X_{2,t})$ will be the objective function of our minimization problem. If the given objective function is minimized, then $X_{2,t+1}$ is maximized and the difference between the recruitment functions is minimized. As a result, the impact of fishing will be minimized. We simply denote our objective function as 'd' and $d = w_2(s_1 f_{1,t} X_{1,t} + s_2 f_{2,t} X_{2,t})$. Our analyses are simply based on the minimization of the objective function.

The impact of fishing on the total biomass change is measured in four different cases. Cases differ from each other according to fishing technology levels of fishermen.

Table 5.2.1 shows four different cases of fishing technologies of fishermen. We begin with the first case in which both fishermen have perfect fishing selectivity and hence there is no bycatch of young mature fish.

Table 5.2.1 The four cases of technology-based fishing

	Fishing technology level of fisherman 1 (old mature fish is targeted)	**Fishing technology level of fisherman 2 (old mature fish is targeted)**
Case 1	$j_1 = 1$ (No bycatch)	$j_2 = 1$ (No bycatch)
Case 2	$j_1 = 1$ (No bycatch)	$j_2 < 1$ (Bycatch)
Case 3	$j_1 < 1$ (Bycatch)	$j_2 = 1$ (No bycatch)
Case 4	$j_1 < 1$ (Bycatch)	$j_2 < 1$ (Bycatch)

Case 1: Suppose that both fishermen have perfect fishing selectivity ($j_1 = j_2 = 1$).

Case 1.1 TAC is set at a level satisfying the condition of $TAC \leq w_2 X_{2,t}$. The quota shares of fisherman 1 and fisherman 2 are as the following:

$$\alpha_1 TAC = h_2^1 \; w_2 X_{2,t}$$
$$\alpha_2 TAC = h_2^2 w_2 X_{2,t}$$
$$f_{1,t} w_1 X_{1,t} = 0$$
$$f_{2,t} w_2 X_{2,t} = w_2(h_2^1 X_{2,t} \; + h_2^2 X_{2,t})$$

Given these observations, the objective function becomes,

$$d = s_2(\alpha_1 + \alpha_2) TAC \text{ , where } (\alpha_1 + \alpha_2) = 1$$
$$d = s_2 TAC \leq s_2 w_2 X_{2,t}$$

Under the circumstances, the impact of fishing does not depend on quota allocations. Every combination of α_1 and α_2 result in same level of impact of fishing.

Case 1.2 TAC is set at a level satisfying the condition of $TAC > w_2 X_{2,t}$. In this case, the objective function becomes,

$$d = s_2(\alpha_1 + \alpha_2) TAC + s_2 (TAC - w_2 X_{2,t})$$
$$d = s_2 w_2 X_{2,t}$$

As in the previous case, the impact of fishing does not depend on quota allocations.

As a result, for Case 1, the impact of fishing is independent of fishing quota allocations and it simply depends on s_2 and TAC for Case 1.1 and s_2 and $w_2 X_{2,t}$ for Case 1.2. Determining TAC level below or above $w_2 X_{2,t}$ will not change the results for optimality conditions for the allocation of quotas, in Case 2. However the amount of the impact of fishing will change according to TAC level. The optimal allocations of quotas for different TAC levels are depicted in Table 5.2.2.

Table 5.2.2 Quota allocation mechanism at different TAC levels for Case 1

	$\boldsymbol{TAC \leq w_2\, X_{2,t}}$	$\boldsymbol{TAC > w_2\, X_{2,t}}$
Case 1 $j_1 = j_2 = 1$	$\{\, \alpha \mid \alpha_i \in [0,1] \;\wedge\; \alpha_1 + \alpha_2 = 1\}$	

- **Result 2:** In the case that both fishermen have perfect fishing selectivity, the impact of fishing will be independent of quota allocation at different TAC levels since fishermen are identical in terms of fishing technology.

Case 2: Suppose that fisherman 1 has perfect fishing selectivity and fisherman 2 has imperfect fishing selectivity ($j_1 = 1,\; j_2 < 1$).

Case.2.1 TAC is set at a level satisfying the condition of $TAC \leq w_2\, X_{2,t}$. The quota shares of fisherman 1 and fisherman 2 and fishing mortalities of each group of fish are as the following,

$$\alpha_1\;\; TAC = h_2^1\, w_2\, X_{2,t}$$
$$\alpha_2\;\; TAC = h_2^2\, w_2\, X_{2,t} + b_1^2\, w_1\, X_{1,t}$$
$$f_{1,t}\, w_1\, X_{1,t} \;\; = b_1^2\, w_1\, X_{1,t}$$
$$f_{2,t}\, w_2\, X_{2,t} = h_2^1\, w_2\, X_{2,t} + h_2^2\, w_2\, X_{2,t}$$

Then, the objective function becomes,

$$d = w_2(s_1\, f_{1,t}\, X_{1,t} + s_2\, f_{2,t}\, X_{2,t})$$

$$d = w_2\, s_1\, \left(b_1^2\, X_{1,t} + h_2^2\, X_{2,t} + h_2^1\, X_{2,t}\right) + \, w_2[(s_2 - s_1)(h_2^2\, X_{2,t} + h_2^1\, X_{2,t})]$$

$$d = w_2\, s_1\, TAC + w_2[(s_2 - s_1)(\alpha_1\, TAC + h_2^2\, X_{2,t})]$$

$$\alpha_1\, TAC + h_2^2\, w_2\, X_{2,t} = TAC - b_1^2\, w_1\, X_{1,t}$$

$$d = w_2\, s_1\, TAC + w_2[(s_2 - s_1)(TAC - b_1^2\, w_1\, X_{1,t})]$$

Under these conditions, if $s_1 < s_2$, then $b_1^2\, w_1\, X_{1,t}$ should be maximized to minimize the impact of fishing. The amount of bycatch is maximized if the quotas are allocated as $\alpha_1 = 0$, $\alpha_2 = 1$. If $s_2 < s_1$, then $b_1^2\, w_1\, X_{1,t}$ should be minimized to minimize the impact of fishing. Hence, if quotas are allocated as $\alpha_1 = 1$, $\alpha_2 = 0$, then the impact of fishing is minimized.

Case.2.2 TAC is set at a level satisfying the condition of,
$w_2\, X_{2,t} < TAC < w_2\, X_{2,t} + [(1 - j_2)/j_2]\, w_2\, X_{2,t}$

This implies that, at the given TAC level, if all of the quotas are assigned to fisherman 1, he catches $w_2\, X_{2,t}$ amount of old mature fish $(w_2\, X_{2,t} < TAC)$. The rest of TAC is not used since fisherman 1 does not bycatch. The objective function becomes,

$$d_1 = s_2\, w_2\, X_{2,t}$$

On the other hand, if all of the quotas are assigned to fisherman 2, he catches $j_2\, TAC$ amount of old mature fish $(j_2\, TAC < \, w_2\, X_{2,t})$, and bycatches $(1 - j_2)\, TAC$ amount of young mature fish. The objective function becomes,

$$d_2 = s_1\, (1 - j_2)\, TAC + s_2\, j_2\, TAC$$

If $s_2 \, w_2 \, X_{2,t} < s_1 \, (1 - j_2) \, TAC + s_2 \, j_2 \, TAC$, which can be rewritten as $s_1/s_2 > (w_2 \, X_{2,t} - j_2 \, TAC)/(1 - j_2) \, TAC$, then the corner solution of $\alpha_1 = 1$ and $\alpha_2 = 0$ can be the candidate corner solution of our minimization problem. On the other hand, if $s_1/s_2 < (w_2 \, X_{2,t} - j_2 \, TAC)/(1 - j_2) \, TAC$, then the corner solution of $\alpha_1 = 0$, $\alpha_2 = 1$ can be the candidate corner solution. We should check also for the interior solutions. The value of the objective function under a quota allocation satisfying $\alpha_1, \alpha_2 > 0$ depends on four different conditions.

1) All of the old mature fish are captured before both fishermen fulfill their quotas. In this case, there is wasted quota of fisherman 1.
2) All of the old mature fish are captured after fisherman 1 fulfills his quotas but before fisherman 2 fulfills his quotas. There is no waste of quota.
3) All of the old mature fish are captured after fisherman 2 fulfills his quotas but before fisherman 1 fulfills his quotas. In this case, there is wasted quota of fisherman 1.
4) There is still remaining old mature fish after both fishermen fulfill their quotas.

To have an interior solution, the possible conditions among those four are the conditions resulted in a quota waste. The reason is that, depending on the level of natural mortality rates, the optimality condition will converge to one of the corner solutions. However, if there is a quota waste, which means that the TAC is not fulfilled, then we check for the interior solutions whether there is a possibility of a lower level of the impact of fishing at an interior solution or not. The reason behind this intuition is that if there is a quota waste, it means that the fewer amounts of fish are captured in total, which may compensate the natural mortality rate effect. In addition, a fisherman may waste some amounts of quota only if he does not bycatch and the old mature fish population is fully caught. According to our consideration, the fisherman who bycatches will catch young mature fish until he fulfills his quotas.

Under the first and third conditions, the total amount of catch of old mature fish is $w_2 X_{2,t}$. Hence, to have a lower level of impact of fishing provided by an interior solution, the condition of $s_1/s_2 < (w_2 X_{2,t} - j_2 TAC)/(1 - j_2) TAC$ should be satisfied. If $s_1/s_2 > (w_2 X_{2,t} - j_2 TAC)/(1 - j_2) TAC$, then the corner solution of $\alpha_1 = 1$ and $\alpha_2 = 0$ will be the candidate corner solution. In this case, regardless of the allocation of quotas, any interior solution will provide a higher level of impact of fishing than the corner solution of $\alpha_1 = 1$ and $\alpha_2 = 0$ because total amount of catch of old mature fish will be equal to $w_2 X_{2,t}$ and there will also be catch of young mature fish at any interior solution. Hence to have a candidate interior solution, the initial condition of $s_1/s_2 < (w_2 X_{2,t} - j_2 TAC)/(1 - j_2) TAC$ should be satisfied. Now, we compare the impact of fishing at the corner solution of $\alpha_1 = 0$, $\alpha_2 = 1$ with the impact of fishing at an interior solution.

At $\alpha_1 = 0$, $\alpha_2 = 1$, the total catch of the old mature fish is equal to $j_2 TAC$ and the total catch of the young mature fish is equal to $(1 - j_2) TAC$. The objective function becomes,

$$d_2 = s_1 (1 - j_2) TAC + s_2 j_2 TAC$$

Besides, if quotas are allocated as $\alpha_1 > 0$, $\alpha_2 > 0$ rather than $\alpha_1 = 0$, $\alpha_2 = 1$, then we should check for the interior solutions which results in $w_2 X_{2,t}$ amount of catch of old mature fish. If we move to this kind of an interior solution from the quota allocation of $\alpha_1 = 0$, $\alpha_2 = 1$, then the increase in the amount of catch of old mature fish will be $w_2 X_{2,t} - j_2 TAC$. There will also be wasted quota of fisherman 1 at an amount of $[(\alpha_1 TAC - w_2 X_{2,t}) + j_2 \alpha_2 TAC)]$ since fisherman 1 cannot fulfill his quota after all of the old mature fish are captured. With this regard, total catch of the young mature fish at an interior solution will be equal to $(1 - j_2) TAC - (\alpha_1 TAC - w_2 X_{2,t} + j_2 \alpha_2 TAC) - (w_2 X_{2,t} - j_2 TAC)$. The decrease in the catch of young mature fish will be equal to $(\alpha_1 TAC - w_2 X_{2,t} + j_2 \alpha_2 TAC) + (w_2 X_{2,t} -$

$j_2\, TAC)$ which is equal to the amount of wasted quota plus the amount of the increase in the catch of old mature fish.

As a result, the value of the objective function will increase at an amount of $s_2\,(w_2\, X_{2,t} - j_2 TAC)$ and decrease at an amount of $s_1\,[(\alpha_1\, TAC - w_2\, X_{2,t} + j_2\, \alpha_2\, TAC) + (w_2\, X_{2,t} - j_2\, TAC)]$. Since we try to minimize the objective function, if the condition of $s_2\,(w_2\, X_{2,t} - j_2\, TAC) < s_1\,[(\alpha_1 TAC - w_2\, X_{2,t} + j_2\, \alpha_2\, TAC) + (w_2\, X_{2,t} - j_2\, TAC)]$ is satisfied, then it means that there is an optimum interior solution. On the other hand, if $s_2\;(w_2\, X_{2,t} - j_2\, TAC) > s_1\,[(\alpha_1\, TAC - w_2\, X_{2,t} + j_2\, \alpha_2\, TAC) + (w_2\, X_{2,t} - j_2\, TAC)]$, then the impact of fishing at an interior solution is higher than the impact of fishing at the candidate corner solution.

$s_1\,[(\alpha_1\, TAC - w_2\, X_{2,t} + j_2\, \alpha_2\, TAC) + (w_2\, X_{2,t} - j_2\, TAC)]$ can be rewritten as $s_1\,(1 - j_2)\,\alpha_1 TAC$.

We know that $s_1(1 - j_2)\, TAC < s_2\,(w_2\, X_{2,t} - j_2\, TAC)$ should be satisfied as the initial condition. It can be extracted from the initial condition that $s_1\,(1 - j_2)\,\alpha_1 TAC < s_2\,(w_2\, X_{2,t} - j_2\, TAC)$ since $\alpha_1 < 1$. As a result, there is no interior solution.

Case.2.3 TAC is set at a level satisfying the condition of,
$TAC \geq w_2\, X_{2,t} + [(1 - j_2)/j_2]\, w_2\, X_{2,t}$

This implies that, at the given TAC level, if all of the quotas are assigned to fisherman 1, he catches $w_2\, X_{2,t}$ amount of targeted fish where $w_2\, X_{2,t} < TAC$ and the rest of the total allowable catch is not fulfilled. The objective function becomes,

$d_1 = s_2\, w_2\, X_{2,t}$

However, if all of the quotas are assigned to fisherman 2, the amount of catch of old mature fish will be equal to $w_2\, X_{2,t}$ and the amount of catch of young mature fish will be equal to $TAC - w_2\, X_{2,t}$. The objective function becomes,

$d_2 = s_1\big(TAC - w_2\, X_{2,t}\big) + s_2\, w_2\, X_{2,t}$

On the other hand, if quotas are allocated such as $\alpha_1 > 0$, $\alpha_2 > 0$, then waste of quota will only be observed at the interior solutions which satisfies that $w_2\, X_{2,t}$ amount of old mature fish are caught. Therefore, the corner solution of $\alpha_1 = 1, \alpha_2 = 0$ will result in a fewer level of impact of fishing since there will also be catch of young mature fish at an interior solution.

Thus, the impact of fishing will be higher if all of the quotas are assigned to fisherman 2 or quotas are allocated such as $\alpha_1 > 0$, $\alpha_2 > 0$. As a result, the optimal allocation of quotas is $\alpha_1 = 1$ and $\alpha_2 = 0$.

Table 5.2.3 summarizes the optimal allocation of quotas depending on natural survival rates and fishing technologies of fishermen at different TAC levels, for Case 2.

Table 5.2.3 Quota allocation mechanism at different TAC levels for Case 2

<table>
<tr><td rowspan="8">Case 2

$j_1 = 1,$
$j_2 < 1$</td><td colspan="2">i. $\boldsymbol{TAC \leq w_2\, X_{2,t}}$</td></tr>
<tr><td>$s_1 < s_2$</td><td>$\alpha_1 = 0, \alpha_2 = 1$</td></tr>
<tr><td>$s_2 < s_1$</td><td>$\alpha_1 = 1, \alpha_2 = 0$</td></tr>
<tr><td colspan="2">ii. $\boldsymbol{w_2\, X_{2,t} < TAC < w_2\, X_{2,t} + [(1 - j_2)/j_2]\, w_2\, X_{2,t}}$</td></tr>
<tr><td>$s_1/s_2 < (w_2\, X_{2,t} - j_2\, TAC)/(1 - j_2)\, TAC$</td><td>$\alpha_1 = 0, \alpha_2 = 1$</td></tr>
<tr><td>$s_1/s_2 > (w_2\, X_{2,t} - j_2\, TAC)/(1 - j_2)\, TAC$</td><td>$\alpha_1 = 1, \alpha_2 = 0$</td></tr>
<tr><td colspan="2">iii. $\boldsymbol{TAC \geq w_2\, X_{2,t} + [(1 - j_2)/j_2]\, w_2\, X_{2,t}}$</td></tr>
<tr><td colspan="2">$\alpha_1 = 1, \alpha_2 = 0$</td></tr>
</table>

- **Result 3:** In the case that the fisherman 1 has perfect fishing selectivity and fisherman 2 has imperfect fishing selectivity, the impact of fishing depends on the allocation of fishing quotas. Corner solutions at different TAC levels provide optimality conditions for minimizing the impact of fishing on total biomass change from any time t to t+1. At given levels of $X_{2,t}, w_2$, j_2, s_1 and s_2; optimal allocation of quotas can be calculated for different TAC levels.

Case 3: Suppose that the fisherman 1 has imperfect fishing selectivity and fisherman 2 has perfect fishing selectivity ($j_1 < 1,\ j_2 = 1$).

The minimization problem can be solved with the same methodology used in the previous case. Hence, we do not write down the mechanism in detail.

Table 5.2.4 Quota allocation mechanism at different TAC levels for Case 3

Case 3	**i.** $\boldsymbol{TAC \leq w_2\, X_{2,t}}$	
	$s_1 < s_2$	$\alpha_1 = 1, \alpha_2 = 0$
	$s_2 < s_1$	$\alpha_1 = 0, \alpha_2 = 1$
$j_1 < 1,$	**ii.** $\boldsymbol{w_2\, X_{2,t} < TAC < w_2\, X_{2,t} + [(1 - j_1)/j_1]\, w_2\, X_{2,t}}$	
$j_2 = 1$	$s_1/s_2 < (w_2\, X_{2,t} - j_1\, TAC)/(1 - j_1)\, TAC$	$\alpha_1 = 1, \alpha_2 = 0$
	$s_1/s_2 > (w_2\, X_{2,t} - j_1\, TAC)/(1 - j_1)\, TAC$	$\alpha_1 = 0, \alpha_2 = 1$
	iii. $\boldsymbol{TAC \geq w_2\, X_{2,t} + [(1 - j_1)/j_1]\, w_2\, X_{2,t}}$	
	$\alpha_1 = 0, \quad \alpha_2 = 1$	

Case 4: Suppose that both fishermen have imperfect fishing selectivity (j_1, $j_2 < 1$). The quota shares of fisherman 1 and fisherman 2 and fishing mortalities of each group of fish are as the following:

$$\alpha_1\ TAC = h_2^1\, w_2\, X_{2,t} + b_1^1\, w_1\, X_{1,t}$$
$$\alpha_2\ TAC = h_2^2\, w_2\, X_{2,t} + b_1^2\, w_1\, X_{1,t}$$
$$f_{1,t}\, w_1\, X_{1,t} = b_1^1\, w_1\, X_{1,t} + b_1^2\, w_1\, X_{1,t}$$
$$f_{2,t}\, w_2\, X_{2,t} = h_2^1\, w_2\, X_{2,t} + h_2^2\, w_2\, X_{2,t}$$

Case.4.1 TAC is set at a level satisfying the condition of,

$TAC < \min\{w_2\, X_{2,t} + [(1 - j_1)/j_1]\ w_2\, X_{2,t}\ ,\ w_2\, X_{2,t} + [(1 - j_2)/j_2]\ w_2\, X_{2,t}\}$

In this case, if all of the quotas are assigned to fisherman 1, he catches $j_1\, TAC$ amount of old mature fish and bycatches young mature fish at an amount of $(1 - j_1)\, TAC$. The objective function becomes,

$$d_1 = s_1\, (1 - j_1)\, TAC + s_2\, j_1\, TAC$$

If all of the quotas are assigned to fisherman 2, he catches $j_2\,TAC$ amount of old mature fish and bycatches young mature fish at an amount of $(1-j_2)\,TAC$. The objective function becomes,

$$d_2 = s_1(1-j_2)\,TAC + s_2\,j_2\,TAC$$

Under the circumstances, if $s_1\,(1-j_1)\,TAC + s_2\;j_1\,TAC\; < s_1\,(1-j_2)\,TAC + s_2\;j_2\,TAC$, which can be rewritten as $s_1\,(j_2-j_1) < s_2\,(j_2-j_1)$, then $\alpha_1 = 1$ and $\alpha_2 = 0$ will be the optimal allocation. On the other hand, if $s_1\,(j_2-j_1) > s_2\,(j_2-j_1)$, then $\alpha_1 = 0$ and $\alpha_2 = 1$ will be the optimum solution.

We do not need to check for the interior solutions also in this case since there is no quota waste for this case. As a result, if $s_1 < s_2$ and $j_1 < j_2$ ($j_2 < j_1$) or $s_1 > s_2$ and $j_2 < j_1$ ($j_1 < j_2$), then $\alpha_1 = 1$ and $\alpha_2 = 0$ ($\alpha_1 = 0$ and $\alpha_2 = 1$) will be the optimal allocation.

Case.4.2 TAC is set at a level satisfying the condition of,

$w_2\,X_{2,t} + [(1-j_2)/j_2]\,w_2\,X_{2,t} \le TAC < w_2\,X_{2,t} + [(1-j_1)/j_1]\,w_2\,X_{2,t}$, ($j_1 < j_2$)

Under the circumstances, if all of the quotas are assigned to fisherman 1, he captures $j_1\,TAC$ amount of old mature fish and bycatches $(1-j_1)\,TAC$ amount of young mature fish. The objective function becomes,

$$d_1 = s_1(1-j_1)\,TAC + s_2\,j_1\,TAC$$

If all of the quotas are assigned to fisherman 2, he captures $w_2\,X_{2,t}$ amount of old mature fish and bycatches $TAC - w_2\,X_{2,t}$ amount of young mature fish. The objective function becomes,

$d_2 = s_1(TAC - w_2 X_{2,t}) + s_2 w_2 X_{2,t}$

It can be extracted from the given TAC level that $j_1 TAC < w_2 X_{2,t}$. Under the circumstances, if $s_1 (1 - j_1) TAC + s_2 j_1 TAC < s_1(TAC - w_2 X_{2,t}) + s_2 w_2 X_{2,t}$, which can be rewritten as $(s_2 - s_1) j_1 TAC < (s_2 - s_1) w_2 X_{2,t}$, then $\alpha_1 = 1$ and $\alpha_2 = 0$ will be the optimal allocation. It is satisfied under the condition of $s_1 < s_2$. Besides, if $s_1 (1 - j_1) TAC + s_2 j_1 TAC > s_1(TAC - w_2 X_{2,t}) + s_2 w_2 X_{2,t}$ which can be rewritten as $(s_2 - s_1) j_1 TAC > (s_2 - s_1) w_2 X_{2,t}$, then $\alpha_1 = 0$ and $\alpha_2 = 1$ will be the optimal corner solution. It is satisfied under the condition of $s_1 > s_2$.

We do not need to check for the interior solutions since there will be no quota waste which means that the initial condition to have a candidate interior solution is not satisfied. If there is no quota waste, one of the corner solutions will always satisfy the least impact of fishing according to the values of s_1 and s_2. As a result, optimal allocation of quotas is satisfied at corner solutions. If $s_1 < s_2$, then $\alpha_1 = 1, \alpha_2 = 0$ is the optimal allocation and if $s_1 > s_2$, then $\alpha_1 = 0$ and $\alpha_2 = 1$ is the optimal allocation.

Case.4.3 TAC is set at a level satisfying the condition of,
$w_2 X_{2,t} + [j_1/(1 - j_1)] w_2 X_{2,t} \leq TAC < w_2 X_{2,t} + [(1 - j_2)/j_2] w_2 X_{2,t}$, $(j_2 < j_1)$

This case can be solved with the same methodology applied for Case 4.2.

Case.4.4 TAC is set at a level satisfying the condition of,
$TAC \geq \max \{ w_2 X_{2,t} + [(1 - j_1)/j_1]\ w_2 X_{2,t}\ ,\ w_2 X_{2,t} + [(1 - j_2)/j_2]\ w_2 X_{2,t} \}$

In this case, if all of the quotas are assigned to fisherman 1, he captures $w_2 X_{2,t}$ amount of old mature fish and $TAC - w_2 X_{2,t}$ amount of young mature fish. Likewise, if all of the quotas are assigned to fisherman 2, he captures $w_2 X_{2,t}$ amount of old mature fish and $TAC - w_2\, X_{2,t}$ amount of young mature fish. If we consider interior solutions such as $\alpha_1,\ \alpha_2 > 0$, total amount of catch old mature and young mature fish will be at the same level with the total fishing amounts at corner solutions because both fishermen will capture young mature fish to fulfill their quotas after the old mature fish population is fully caught. As a result, the impact of fishing on total biomass change is independent of quota allocations for this case. Every combination of α_1 and α_2 result in same level of fishing impact on total biomass.

Table 5.2.5 Quota allocation mechanism at different TAC levels for Case 4

<table>
<tr><td rowspan="16">Case 4

$j_1 < 1,$
$j_2 < 1$</td><td colspan="2">i. $\boldsymbol{TAC} < \mathbf{min}\,\{\boldsymbol{w_2\, X_{2,t}} + [(\mathbf{1} - \boldsymbol{j_1})/\boldsymbol{j_1}]\ \boldsymbol{w_2\, X_{2,t}}\,,\ \boldsymbol{w_2\, X_{2,t}} + [(\mathbf{1} - \boldsymbol{j_2})/\boldsymbol{j_2}]\ \boldsymbol{w_2\, X_{2,t}}\}$</td></tr>
<tr><td>$s_1 < s_2,\ \ j_1 > j_2$</td><td>$\alpha_1 = 0, \alpha_2 = 1$</td></tr>
<tr><td>$s_1 < s_2,\ \ j_2 > j_1$</td><td>$\alpha_1 = 1, \alpha_2 = 0$</td></tr>
<tr><td>$s_2 < s_1,\ \ j_1 > j_2$</td><td>$\alpha_1 = 1, \alpha_2 = 0$</td></tr>
<tr><td>$s_2 < s_1,\ \ j_2 > j_1$</td><td>$\alpha_1 = 0, \alpha_2 = 1$</td></tr>
<tr><td colspan="2">ii. $\boldsymbol{TAC} \geq \boldsymbol{w_2\, X_{2,t}} + [(\mathbf{1} - \boldsymbol{j_2})/\boldsymbol{j_2}]\, \boldsymbol{w_2\, X_{2,t}}$
$\boldsymbol{TAC} < \boldsymbol{w_2\, X_{2,t}} + [(\mathbf{1} - \boldsymbol{j_1})/\boldsymbol{j_1}]\, \boldsymbol{w_2\, X_{2,t}}$</td></tr>
<tr><td>$s_1 < s_2$</td><td>$\alpha_1 = 1, \alpha_2 = 0$</td></tr>
<tr><td>$s_2 < s_1$</td><td>$\alpha_1 = 0, \alpha_2 = 1$</td></tr>
<tr><td colspan="2">iii. $\boldsymbol{TAC} \geq \boldsymbol{w_2\, X_{2,t}} + [(\mathbf{1} - \boldsymbol{j_1})/\boldsymbol{j_1}]\, \boldsymbol{w_2\, X_{2,t}}$
$\boldsymbol{TAC} < \boldsymbol{w_2\, X_{2,t}} + [(\mathbf{1} - \boldsymbol{j_2})/\boldsymbol{j_2}]\, \boldsymbol{w_2\, X_{2,t}}$</td></tr>
<tr><td>$s_1 < s_2$</td><td>$\alpha_1 = 0, \alpha_2 = 1$</td></tr>
<tr><td>$s_2 < s_1$</td><td>$\alpha_1 = 1, \alpha_2 = 0$</td></tr>
<tr><td colspan="2">iv. $\boldsymbol{TAC} \geq \mathbf{max}\,\{\boldsymbol{w_2\, X_{2,t}} + [(\mathbf{1} - \boldsymbol{j_1})/\boldsymbol{j_1}]\ \boldsymbol{w_2\, X_{2,t}}\,,\ \boldsymbol{w_2\, X_{2,t}} + [(\mathbf{1} - \boldsymbol{j_2})/\boldsymbol{j_2}]\ \boldsymbol{w_2\, X_{2,t}}\}$</td></tr>
<tr><td colspan="2">$\{\,\alpha \mid \alpha_i \in [0,1]\ \wedge\ \alpha_1 + \alpha_2 = 1\}$</td></tr>
</table>

- **Result 4:** In the case that both fishermen have imperfect fishing selectivity, the impact of fishing on total biomass change depends on the quota allocations, TAC level, natural survival rates and fishing technology rates. Apart from this rule, the impact of fishing will be independent of quota allocation if TAC is determined at a level satisfying $\mathrm{TAC} \geq w_2\, X_{2,t} + [(1-\mathrm{j}_1)/\mathrm{j}_1]\, w_2\, X_{2,t}$, $\mathrm{TAC} \geq \mathrm{w}_2\, \mathrm{X}_{2,\mathrm{t}} + [(1-\mathrm{j}_2)/\mathrm{j}_2]\, w_2\, X_{2,t}$.

In the light of four different cases, we basically showed that the total biomass change from any time t to t+1 depends on quota allocations at different TAC levels. Furthermore, at given values of w_2, s_1, s_2, $X_{1,t}$, $X_{2,t}$, j_1 and j_2; the optimality conditions for α_1, α_2 and TAC can be found, simultaneously. We investigated the impact of fishing on total biomass change from a myopic planner's point of view who only considers the change in total biomass in one period. The results for the impact of fishing at steady state may not be the same with the results that we found here because steady state amounts of X_1 and X_2 will be different at fishing conditions and non-fishing conditions. However, in any case, regardless of the initial total biomass of both age groups of fish, total biomass change depends on quota allocations.

Suppose that the old mature and the young mature fish populations at steady state under natural conditions are X_1^* and X_2^*, respectively. Besides, the old mature and the young mature fish populations at steady state under fishing conditions are $X_1^{'}$ and $X_2^{'}$, respectively. The impact of fishing on total biomass at steady state is shown by the following equation of $\rho^* - \rho$.

$$\rho^* = s_0\ R(X_1^*, X_2^*)\, w_1 + s_1\, w_2\, X_1^* + s_2\, w_2\, X_2^* - w_1\, X_1^* - w_2\, X_2^*$$
$$\rho = s_0\, R\left(X_1^{'}, X_2^{'}\right) w_1 + s_1\left(1 - f_{1,t}\right) w_2\, X_1^{'} + s_2\left(1 - f_{2,t}\right) w_2\, X_2^{'} - w_1\, X_1^{'} - w_2\, X_2^{'}$$

$$\rho^{*} - \rho = w_1 [s_0 \; R(X_1^{*}, X_2^{*}) + s_0 \, R(X_1^{'}, X_2^{'})] + w_2 \, s_1 \, (X_1^{*} - X_1^{'}) + w_2 \, s_2 \, (X_2^{*} - X_2^{'}) + w_1 (X_1^{'} - X_1^{*}) + w_2 (X_2^{'} - X_2^{*}) + w_2 \, (s_1 \, f_{1,t} \, X_1^{'} + s_2 \, f_{2,t} \, X_2^{'})$$

The equation above shows the impact of fishing on total biomass change at steady state. It can be extracted from the equation that the impact of fishing depends on quota allocations because the objective function of $w_2 \, (s_1 \, f_{1,t} \, X_1^{'} + s_2 \, f_{2,t} \, X_2^{'})$ depends on quota allocations as we discussed in four different cases.

5.3 Maximum Sustainable Biomass Yield under an Age-Structured Model

In this part of the study, the maximum sustainable biomass yield under an age-structured fish population model is investigated. As a result, we showed that the quota allocation is important to achieve MSY in different equality conditions of $w_2/s_2 \; and \, w_1/s_1$. We analyzed the conditions to achieve MSY at the population equilibrium. The fishing mortalities are fixed at the population equilibrium ($X_{i,t+1} = X_{i,t} = X_i$).

We applied the same approach with Skonhoft et al. (2012) to show the optimal fishing mortality conditions at MSY. The harvest function is,

$$Y = \; f_1 \, w_1 \, X_1 + \; f_2 \, w_2 \, X_2$$

The constraints for the maximization problem are,

$X_1 = s_0 \; R(X_1, X_2)$ (Recruitment constraint)

$X_2 = \; s_1 \; (1 - \; f_1) \, X_1 + s_2 \, (1 - \; f_2) \, X_2$ (Spawning constraint)

The Lagrangian function and the first order necessary conditions derived from the simple Lagrangian model are as the following:

$$L = f_1 w_1 X_1 + f_2 w_2 X_2 - \varphi [X_1 - s_0 R(X_1, X_2)] - \mu [X_2 - s_1 (1 - f_1) X_1 + s_2 (1 - f_2) X_2]$$

The first order necessary conditions are,

$$\partial_L / \partial_{f_1} = (w_1 - \mu s_1) X_1 \leq 0; 0 \leq f_1 < 1$$
$$\partial_L / \partial_{f_2} = (w_2 - \mu s_2) X_2 \leq, \geq 0; 0 \leq f_2 \leq 1$$
$$\partial_L / \partial_{X_1} = f_1 w_1 + \varphi \left(s_0 R_1' - 1\right) + \mu s_1 (1 - f_1) = 0$$
$$\partial_L / \partial_{X_2} = f_2 w_2 + \varphi s_0 R_2' + \mu s_2 [(1 - f_2) - 1] = 0$$

It can be extracted from the first order conditions that $\partial_L / \partial_{f_1}$ and $\partial_L / \partial_{f_2}$ are independent of the recruitment function. In this part, it is assumed that the natural survival rates of old and the young mature fish do not differ at a significant level. Hence, the ratios of weights to natural survival rates satisfy the inequality of $w_2/s_2 > w_1/s_1$ (Skonhoft et al., 2012). The optimal levels for $f_1$and f_2 at MSY can be derived from the first order conditions. The conditions for fishing mortalities are as the following:

1) If $\mu = w_1/s_1 < w_2/s_2$, then $\partial_L / \partial_{f_1} = 0$ and $\partial_L / \partial_{f_2} > 0$. A one unit increase in f_1 does not change the value of the objective function. However, one unit increase in f_2 results in an increase in the value of the objective function at an amount of $(w_2 - \mu s_2) X_2$. Hence, f_2 should be maximized and f_1 should be minimized. It is satisfied at $f_1 = 0$ and $f_2 = 1$.

2) If $w_1/s_1 < \mu < w_2/s_2$, then $\partial_L/\partial_{f_1} < 0$ and $\partial_L/\partial_{f_2} > 0$. Hence, f_2 should be maximized and f_1 should be minimized to maximize the objective function. f_1 and f_2 should be 0 and 1, respectively.

3) If $w_1/s_1 < \mu = w_2/s_2$, then $\partial_L/\partial_{f_1} < 0$ and $\partial_L/\partial_{f_2} = 0$. Hence, f_2 should be such that $0 < f_2 < 1$, and f_1 should be minimized, which is satisfied at $f_1 = 0$.

4) If $w_1/s_1 < w_2/s_2 < \mu$, then $\partial_L/\partial_{f_1} < 0$ and $\partial_L/\partial_{f_2} < 0$. Hence, f_2 and f_1 should be minimized. This cannot be an optimal allocation since it requires no fishing activity.

5) If $\mu < w_1/s_1 < w_2/s_2$, then $\partial_L/\partial_{f_1} > 0$ and $\partial_L/\partial_{f_2} > 0$. Hence, f_2 and f_1 should be maximized. This cannot be an optimal allocation since fishing mortality of the young mature fish should be less than 1 ($f_1 < 1$) to provide the sustainability of the fish population.

Table 5.3.1 Fishing mortality rates at MSY

	$\partial_L/\partial_{f_1}$	$\partial_L/\partial_{f_2}$	f_1	f_2
1) $\mu = w_1/s_1 < w_2/s_2$	$= 0$	> 0	$0 < f_1 < 1$	$= 1$
2) $w_1/s_1 < \mu < w_2/s_2$	< 0	> 0	$= 0$	$= 1$
3) $w_1/s_1 < \mu = w_2/s_2$	< 0	$= 0$	$= 0$	$0 < f_2 < 1$
4) $w_1/s_1 < w_2/s_2 < \mu$	< 0	< 0	$= 0$	$= 0$
5) $\mu < w_1/s_1 < w_2/s_2$	> 0	> 0	$= 1$	$= 1$

Table 5.3.1 summarizes the results for fishing mortality rates at MSY. Inequalities of 4 and 5 ($w_1/s_1 < w_2/s_2 < \mu$ and $\mu < w_1/s_1 < w_2/s_2$) do not satisfy the optimality conditions. If the shadow value of the spawning constraint is as given in inequalities of 4 and 5, MSY will not be achieved. Therefore, the shadow value of the spawning constraint should satisfy the inequalities of 1, 2 or 3 to achieve MSY.

We investigated the importance of quota allocation to achieve maximum sustainable biomass yield under different fishing technologies. There are four different cases to be investigated as we discussed in the previous part of the study. Cases differ from each other according to the fishing technologies of fishermen. Through the maximization problem, we can find the optimum fishing mortalities which maximize the equilibrium biomass yield. TAC is set at MSY which is also equal to total fishing mortalities derived by the maximization problem ($TAC = f_1\, w_1\, X_1 + f_2\, w_2\, X_2$). In each case, we considered the fishing mortality solutions which are compatible with the fishing structure given in that case. For instance, if it is given that both fishermen bycatch, then we do not take the fishing mortality solutions such as $f_1 = 0$, $f_2 = 1$ or $f_1 = 0$, $f_2 < 1$ into consideration for that case. Due to the structure of the fishing industry, achieving the MSY at $f_1 = 0$ will not be possible. Hence, we check for the optimal allocation of quotas at fishing mortalities compatible with the given structure of the fishing industry.

In this part of the study, we demonstrated the optimal allocation of quotas at population equilibrium. Different than the previous part, we do not consider the quota waste. The reason is that, in this part of the study we know the optimum TAC level which is equal to MSY. Hence, we are searching for the optimal allocation of quotas at the calculated TAC, rather than investigating the optimality conditions at any given TAC.

Case 5: Suppose that both fishermen have perfect fishing selectivity ($j_1 = j_2 = 1$).

Case.5.1 If the optimum fishing mortalities of the young mature and the old mature fish are found as $f_1 = 0$ and $0 < f_2 < 1$, then TAC is determined at a level such that $TAC = f_2\, w_2\, X_2$. Under these conditions, MSY is achieved regardless of quota allocation. Total amount of catches will be equal to $f_2\, w_2\, X_2$.

Case.5.2 If the optimum fishing mortalities of the young mature and the old mature fish are found as $f_1 = 0$ and $f_2 = 1$, then TAC is equal to $w_2\, X_2$. Under these conditions, MSY is achieved regardless of quota allocation. Total amount of catches will be equal to $w_2\, X_2$.

Optimal allocation of quotas at different fishing mortalities for Case 5 is summarized in Table 5.3.2.

Table 5.3.2 Quota allocation mechanism for Case 5

	The discounted biomass conditions	Fishing mortality rates at MSY	Optimal allocation of quotas at MSY
Case 5 $j_1 = 1$, $j_2 = 1$	**i.** $\boldsymbol{TAC = f_2\, w_2\, X_2} < w_2\, \boldsymbol{X_2}$		
	$w_1/s_1 < \mu = w_2/s_2$	$f_1 = 0$, $0 < f_2 < 1$	$\{\, \alpha \mid \alpha_i \in [0,1] \wedge \alpha_1 + \alpha_2 = 1\}$
	ii. $\boldsymbol{w_2\, X_2 \leq TAC = f_1\, w_1\, X_1 + w_2\, X_2}$		
	$w_1/s_1 < \mu < w_2/s_2$	$f_1 = 0$, $f_2 = 1$	$\{\, \alpha \mid \alpha_i \in [0,1] \wedge \alpha_1 + \alpha_2 = 1\}$

- **Result 5:** In the case that both fishermen have perfect fishing selectivity, MSY will be achieved regardless of the quota allocation, in two different conditions. Firstly, if the optimum fishing mortalities of the young mature and the old mature fish are $f_1 = 0$ and $0 < f_2 < 1$ and TAC is set at $f_2\, w_2\, X_2$ and secondly, if the optimum fishing mortalities of the young mature and the old mature fish are $f_1 = 0$ and $f_2 = 1$ and TAC is set at $w_2\, X_2$, then MSY is achieved. Otherwise, MSY is not achieved.

Case 6: Suppose that the fisherman 1 has perfect fishing selectivity and fisherman 2 has imperfect fishing selectivity ($j_1 = 1,\ j_2 < 1$).

Case.6.1 If the optimum fishing mortalities of the young mature and the old mature fish are found as $f_1 = 0$ and $0 < f_2 < 1$, then TAC is determined at a level of $TAC = f_2\, w_2\, X_2 < w_2\, X_2$. Under these conditions, MSY is achieved if all of the quotas are assigned to fisherman 1 since fishing mortality of the young mature fish can only be equal to zero under the quota allocation of $\alpha_1 = 1$ and $\alpha_2 = 0$. Hence, MSY will be achieved just at the corner solution of $\alpha_1 = 1$ and $\alpha_2 = 0$.

Case.6.2.1 If the optimum fishing mortalities of the young mature and the old mature fish are found as $0 < f_1 < 1$ and $f_2 = 1$ and TAC is set at a level satisfying $w_2\, X_2 \leq TAC = f_1\, w_1\, X_1 + f_2\, w_2\, X_2 < w_2\, X_2 + [(1 - j_2)/j_2]\, w_2\, X_2$.

To achieve MSY, total amount of bycatch of fisherman 2 should be equal to $f_1\, w_1\, X_1$. Under this allocation, total amount of catch of old mature fish of fisherman 2 is equal to $[j_2/(1 - j_2)]\, f_1\, w_1\, X_1$ and hence total catch of fisherman 2 is equal to $\{[1/(1 - j_2)]\, f_1\, w_1\, X_1\}$. Thus, if quotas are allocated such that $\alpha_2 = \{[1/(1 - j_2)]\, f_1\, w_1\, X_1\} / TAC$, then MSY is achieved. Under this allocation, total catch of old mature fish will be equal to $w_2\, X_2$. At an α_2 level higher than this, total catch of old mature fish will be less than $w_2\, X_2$. At an α_2 level lower than this, the old mature fish population will be fully caught but there will be wasted quota of fisherman 1, which means that the amount of bycatch of fisherman 2 will be less than $f_1\, w_1\, X_1$ since $TAC = f_1\, w_1\, X_1 + w_2\, X_2$. As a result, the only optimal solution for this case is $\alpha_2 = \{[1/(1-j_2)]\, f_1\, w_1\, X_1\}/TAC,\ \alpha_1 = 1 - \alpha_2$.

Case.6.2.2 If the optimum fishing mortalities of the young mature and the old mature fish are found as $f_1 = 0$ and $f_2 = 1$, then TAC is equal to $w_2\, X_2$. Under these conditions, MSY is achieved if quotas are allocated such that $\alpha_1 = 1,\ \alpha_2 = 0$. Fishing mortality of the young mature fish can only be equal to zero if all of the quotas are assigned to fisherman 1.

Case.6.3 If the optimum fishing mortalities of the young mature and the old mature fish are found as $0 < f_1 < 1$ and $f_2 = 1$ and TAC is determined at a level satisfying $w_2\, X_2 + [(1-j_2)\, /\, j_2]\, w_2\, X_2 \leq TAC = f_1\, w_1\, X_1 + f_2\, w_2\, X_2$, then MSY is achieved if all of the quotas are assigned to fisherman 2 since fishermen 2 captures all of the old mature fish and also captures young mature fish at an amount of $f_1\, w_1\, X_1$, under this allocation.

We check for the interior solutions. Since TAC is set at a level higher than $w_2\, X_2 + [(1-j_2)\, /\, j_2]\, w_2\, X_2$, all of the old mature fish are captured regardless of the quota allocation. However, if there is a quota waste at an interior solution, it means that the total catch of young mature fish is less than $f_1\, w_1\, X_1$. Hence, the quota allocations satisfying that there is no waste of quota will be the optimal allocations for this case. According to the fishing technology levels, we know that at any time period, if fisherman 1 captures n amount of old mature fish, fisherman 2 captures $j_2\, n$ amount of old mature fish and $(1-j_2)\, n$ amount of young mature fish. At an interior solution satisfying $\alpha_1 TAC > n$, where $n + j_2\, n = w_2\, X_2$, there is waste of quota and total catch of young mature fish is less than $f_1\, w_1\, X_1$. Therefore, quota allocations satisfying $0 \leq \alpha_1 \leq w_2\, X_2 /\, (1+j_2)\, TAC$, will result in MSY.

Optimal allocation of quotas at different fishing mortalities for Case 6 is summarized in Table 5.3.3.

Table 5.3.3 Quota allocation mechanism for Case 6

	The discounted biomass conditions	Fishing mortality rates at MSY	Optimal allocation of quotas at MSY
Case 6 $j_1 = 1,$ $j_2 < 1$	**i.** $\boldsymbol{TAC = f_2\, w_2\, X_2} < w_2\, X_2$		
	$w_1/s_1 < \mu = w_2/s_2$	$f_1 = 0\ ,\ 0 < f_2 < 1$	$\alpha_1 = 1, \alpha_2 = 0$
	ii. $\boldsymbol{w_2\, X_2 \leq TAC = f_1\, w_1\, X_1 + w_2\, X_2 <}$ $\boldsymbol{w_2\, X_2 + [(1 - j_2)/j_2]\, w_2\, X_2}$		
	$\mu = w_1/s_1$ $< w_2/s_2$	$0 < f_1 < 1\,,$ $f_2 = 1$	$\alpha_2 = \{[1/(1 - j_2)]\, f_1\, w_1\, X_1\}/TAC$ $\alpha_1 = 1 - \alpha_2$
	$w_1/s_1 < \mu < w_2/s_2$	$f_1 = 0\ ,\ f_2 = 1$	$\alpha_1 = 1,\ \alpha_2 = 0$
	iii. $\boldsymbol{w_2\, X_2 + [(1 - j_2)\, /\, j_2]\, w_2\, X_2 \leq TAC = f_1\, w_1\, X_1 + w_2\, X_2}$		
	$\mu = w_1/s_1$ $< w_2/s_2$	$0 < f_1 < 1\,,$ $f_2 = 1$	$0 \leq\ \alpha_1 \leq\ w_2\, X_2/\,(1 + j_2)\, TAC$ $\alpha_2 = 1 - \alpha_1$

- **Result 6:** In a fishery consisting of two fishermen characterized by their fishing technologies such that the fisherman 1 has perfect fishing selectivity and fisherman 2 has imperfect fishing selectivity, MSY is achieved at different quota allocations.

    - If the optimal fishing mortalities are found such that $f_1 = 0$ and $0 < f_2 < 1$, then MSY is achieved if all of the fishing quotas are assigned to the fisherman who has perfect fishing selectivity, at a TAC level satisfying $TAC = f_2\, w_2\, X_2 < w_2\, X_2$.

- If the optimal fishing mortalities are found such that $0 < f_1 < 1$ and $f_2 = 1$, then MSY is achieved under the quota allocation of $\alpha_2 = \{[1/(1-j_2)]\, f_1\, w_1\, X_1\} \,/\, TAC$ and $\alpha_1 = 1 - \alpha_2$ if the TAC is set at a level satisfying $w_2\, X_2 \leq TAC = f_1\, w_1\, X_1 + f_2\, w_2\, X_2 < w_2\, X_2 + [(1-j_2)/j_2]\, w_2\, X_2$. Besides, if the TAC is set at a level satisfying $w_2\, X_2 + [(1-j_2)\,/\,j_2]\, w_2\, X_2 \leq TAC = f_1\, w_1\, X_1 + f_2\, w_2\, X_2,$ then optimal allocation of quotas is $0 \leq \alpha_1 \leq w_2\, X_2 /\, (1+j_2)\, TAC$ and $\alpha_2 = 1 - \alpha_1$.

- If the optimal fishing mortalities are found such that $f_1 = 0$ and $f_2 = 1$, then MSY is achieved if all of the fishing quotas are assigned to the fisherman who has perfect fishing selectivity, at a TAC level satisfying $w_2\, X_2 \leq TAC = f_1\, w_1\, X_1 + f_2\, w_2\, X_2 < w_2\, X_2 + [(1-j_2)/j_2]\, w_2\, X_2$.

Case 7: Suppose that the fisherman 1 has imperfect fishing selectivity and fisherman 2 has perfect fishing selectivity ($j_1 < 1, j_2 = 1$).

The difference of this case from the previous one is that the fishing technologies are switched which reversed the optimality solutions. We do not write down the mechanism in detail. Optimal allocation of quotas at different fishing mortalities for Case 7 is summarized in Table 5.3.4.

Table 5.3.4 Quota allocation mechanism for Case 7

	The discounted biomass conditions	Fishing mortality rates at MSY	Optimal allocation of quotas at MSY
Case 7 $j_1 < 1$, $j_2 = 1$	**i.** $\boldsymbol{TAC = f_2\, w_2\, X_2} < w_2\, \boldsymbol{X_2}$		
	$w_1/s_1 < \mu = w_2/s_2$	$f_1 = 0$, $0 < f_2 < 1$	$\alpha_1 = 0, \alpha_2 = 1$
	ii. $\boldsymbol{w_2\, X_2 \leq TAC = f_1\, w_1\, X_1 + w_2\, X_2 <}$ $\boldsymbol{w_2\, X_2 + [(1 - j_1)/j_1]\, w_2\, X_2}$		
	$\mu = w_1/s_1 < w_2/s_2$	$0 < f_1 < 1$, $f_2 = 1$	$\alpha_1 = \{[1/(1 - j_1)]\, f_1\, w_1\, X_1\}/TAC$ $\alpha_2 = 1 - \alpha_1$
	$w_1/s_1 < \mu < w_2/s_2$	$f_1 = 0$, $f_2 = 1$	$\alpha_1 = 0,\ \alpha_2 = 1$
	iii. $\boldsymbol{w_2\, X_2 + [(1 - j_1)\, /\, j_1]\, w_2\, X_2 \leq TAC = f_1\, w_1\, X_1 + w_2\, X_2}$		
	$\mu = w_1/s_1 < w_2/s_2$	$0 < f_1 < 1$, $f_2 = 1$	$0 \leq \alpha_2 \leq w_2\, X_2/\, (1 + j_1)\, TAC$ $\alpha_1 = 1 - \alpha_2$

Case 8: Suppose that both fishermen have imperfect fishing selectivity ($j_1 < 1,\ j_2 < 1$). This implies that,

$$\alpha_1\ TAC = h_2^1\, w_2\, X_2 + b_1^1\, w_1\, X_1$$
$$\alpha_2\ TAC = h_2^2\, w_2\, X_2 + b_1^2\, w_1\, X_1$$

Case.8.1 If the optimum fishing mortalities of the young mature and the old mature fish are found as $0 < f_1 < 1$ and $f_2 = 1$ and TAC is set at a level satisfying the conditions of,

$w_2\, X_2 \leq TAC = \ f_1\, w_1\, X_1 + f_2\, w_2\, X_2 < w_2\, X_2 + [(1 - j_1)/j_1]\ w_2\, X_2$

$w_2\, X_2 \leq TAC = \ f_1\, w_1\, X_1 + f_2\, w_2\, X_2 < w_2\, X_2 + [(1 - j_2)/j_2]\ w_2\, X_2$

Then, MSY will not be achieved since the old mature fish population will not be fully caught. The amount of catch of old mature fish will be equal to,

$j_1\, \alpha_1\, TAC + j_2\, \alpha_2\, TAC = h_2^1\, w_2\, X_2 + h_2^2\, w_2\, X_2 < w_2\, X_2.$

Case.8.2 If the optimum fishing mortalities of the young mature and the old mature fish are found as $0 < f_1 < 1$ and $f_2 = 1$ and TAC is determined at a level satisfying the condition of $w_2\, X_2 + [(1 - j_2)\ /\ j_2]\ w_2\, X_2\ \leq TAC = f_1\, w_1\, X_1 +\ w_2\, X_2 < w_2\, X_2 + [(1 - j_1)/j_1]\ w_2\, X_2$, then MSY is achieved if all of the quotas are assigned to fisherman 2. Under this type of an allocation, he catches $w_2\, X_2$ amount of old mature fish and $f_1\, w_1\, X_1$ amount of young mature fish, where $f_1\, w_1\, X_1 = n + [(1 - j_2)\ /\ j_2]\ w_2\, X_2$ and n is equal to the amount of his catch of young mature fish to fulfill his remaining quotas after the old mature fish population is fully caught.

However, at the corner solution of $\alpha_1 = 1,\ \alpha_2 = 0$, fisherman 1 fulfills his quota before the old mature fish population is fully caught. Hence, MSY will not be achieved.

We check for the interior solutions. To have an interior solution, the old mature fish population should be fully caught. As we discussed before, the larger α_2 results in a higher amounts of catch of old mature fish until all of the old mature fish are captured. Hence, there is a minimum level for α_2 . Below this α_2 level, total catch of old mature fish will be less than $w_2 X_2$. In this case, there is no waste of quota since both fishermen fulfill their remaining quotas by capturing young mature fish after the old mature fish population is fully caught. In this sense, fishing quota allocations satisfying the condition of $j_1\,\alpha_1 TAC + j_2\,\alpha_2\,TAC \geq w_2\,X_2$ provide the conditions to achieve MSY.

$j_1\,\alpha_1 TAC + j_2\,\alpha_2\,TAC \geq w_2\,X_2$ can be rewritten as,
$\alpha_2 \geq (w_2 X_2 - j_1\,TAC)/(j_2 - j_1)TAC$

At the interior solutions satisfying the condition above, the old mature fish population will be fully caught and the total catch of young mature fish will be equal to $f_1\,w_1\,X_1$.

Case.8.3 If the optimum fishing mortalities of the young mature and the old mature fish are found as $0 < f_1 < 1$ and $f_2 = 1$ and TAC is determined at a level satisfying the conditions of,

$TAC = f_1\,w_1\,X_1 + f_2\,w_2\,X_2 \geq w_2\,X_2 + [(1-j_1)/j_1]\,w_2\,X_2$ and
$TAC = f_1\,w_1\,X_1 + f_2\,w_2\,X_2 \geq w_2\,X_2 + [(1-j_2)/j_2]\,w_2\,X_2$

Then, MSY is achieved regardless of the quota allocation. Under the circumstances, total amount of catch of old mature fish is equal to $w_2\,X_2$.

Both fishermen catch only young mature fish to fulfill their quotas after the old mature fish population is fully caught, since $f_1\,w_1\,X_1 \geq [(1-j_1)/j_1]\,w_2\,X_2$ and $f_1\,w_1\,X_1 \geq [(1-j_2)/j_2]\,w_2\,X_2$. The total catch of young mature fish is equal to $f_1\,w_1\,X_1$.

Optimal allocation of quotas at different fishing mortalities for Case 8 is summarized in Table 5.3.5.

Table 5.3.5 Quota allocation mechanism for Case 8

<table>
<tr><td rowspan="7">Case 8

$j_1 < 1$,
$j_2 < 1$</td><td>The discounted biomass conditions</td><td>Fishing mortality rates at MSY</td><td>Optimal allocation of quotas at MSY</td></tr>
<tr><td colspan="3">i. $\boldsymbol{w_2\, X_2 \leq TAC = f_1\, w_1\, X_1 + w_2\, X_2 < \min\{w_2\, X_2 + [(1 - j_1)/j_1]\; w_2\, X_2 ,\; w_2\, X_2 + [(1 - j_2)/j_2]\; w_2\, X_2\}}$</td></tr>
<tr><td>$\mu = w_1/s_1 < w_2/s_2$</td><td>$0 < f_1 < 1 , f_2 = 1$</td><td>MSY is not achieved</td></tr>
<tr><td colspan="3">ii. $\boldsymbol{w_2\, X_2 + w_2\, X_2\, [(1 - j_2)\,/\,j_2] \leq TAC = f_1\, w_1\, X_1 + w_2\, X_2}$
$\boldsymbol{TAC = f_1\, w_1\, X_1 + w_2\, X_2 < w_2\, X_2 + [(1 - j_1)/j_1]\; w_2\, X_2}$</td></tr>
<tr><td>$\mu = w_1/s_1 < w_2/s_2$</td><td>$0 < f_1 < 1 , f_2 = 1$</td><td>$\frac{(w_2 X_2 - j_1\, TAC)}{(j_2 - j_1) TAC} \leq \alpha_2 \leq 1$
$\alpha_1 = 1 - \alpha_2$</td></tr>
<tr><td colspan="3">iii. $\boldsymbol{TAC = f_1\, w_1\, X_1 + w_2\, X_2 \geq \max\{w_2\, X_2 + [(1 - j_1)/j_1]\; w_2\, X_2 ,\; w_2\, X_2 + [(1 - j_2)/j_2]\; w_2\, X_2\}}$</td></tr>
<tr><td>$\mu = w_1/s_1 < w_2/s_2$</td><td>$0 < f_1 < 1 , f_2 = 1$</td><td>$\{ \alpha \mid \alpha_i \in [0,1] \wedge \alpha_1 + \alpha_2 = 1\}$</td></tr>
</table>

Result 7: If the optimal fishing mortalities are found such that $0 < f_1 < 1$ and $0 < f_2 < 1$, then MSY is achieved under different quota allocations depending on the level of $f_1\, w_1\, X_1$. Firstly, if $f_1\, w_1\, X_1$ is equal to or greater than $[(1 - j_2)\,/\,j_2]\; w_2\, X_2$ and less than $[(1 - j_1)/j_1]\; w_2\, X_2$, then MSY is achieved under a quota allocation such that $(w_2 X_2 - j_1\, TAC)/(j_2 - j_1) TAC \leq \alpha_2 \leq 1$ and $\alpha_1 = 1 - \alpha_2$. Besides, if $f_1\, w_1\, X_1$ is equal to or greater than both $[(1 - j_1)/j_1]\; w_2\, X_2$ and $[(1 - j_2)\,/\,j_2]\; w_2\, X_2$, then MSY is achieved regardless of the quota allocation.

CHAPTER 6

CONCLUSION

In this study, we investigated the EU fishing industry and the CFP of the EU. In the reform process of the CFP, the EU is seeking for an economically and socially viable, well-designed management system for EU fisheries. Furthermore, the EU promotes measures for minimizing the impact of fishing on marine ecosystems.

In this regard, we designed a mechanism for allocation of quotas at different TAC levels, which plays key role in effectiveness of the RBM systems. Fishing technologies are embedded in the economic model as a key determinant. As a result, it is shown that the allocation of fishing quotas is important to minimize the impact of fishing on total fish biomass and achieve MSY. We indicated technology-based optimality conditions for quota allocations at different TAC levels, which minimize the impact of fishing on total fish biomass. Furthermore, in the analyses of MSY, we specified optimal allocation of quotas at the TAC level which is equal to MSY. In our analyses, we used the population model developed by Skonhoft et al. (2012) and fishing mortalities at MSY derived by Skonhoft et al. (2012). In addition, under the consideration that the fishermen fulfill their remaining quotas through capturing untargeted (less revenue-generating) fish after the targeted fish population is fully caught, the fix ratio of catch of targeted fish to bycatch is not valid anymore. Optimal allocations of quotas are determined under this consideration. Concordantly, we indicated fishing technology-based optimal quota levels including the interior solutions.

Ledyard (2009) showed that the initial fishing quota allocation is not important for transferable quota systems since fishermen achieve their targeted quota levels after quota trade is carried out. Moreover, as represented in Table 4.2.1, perfect transferability of quotas under ITQ systems is achieved only in three of ten different ITQ applications. Therefore, the appropriate management system providing the efficiency depends on the market conditions. In this study, we analyzed the optimality conditions for fishing quotas regardless of their transferability. We simply checked the optimality conditions for final fishing quotas. The specified quota levels can be considered as the optimal allocation of quotas under a transferable quota system after quota trade is finalized or under a non-transferable quota system.

In the EU, TACs are determined at the Union level and distributed to the EU countries based on the principle of ‘relative stability’. The provided that the TACs are distributed according to the principle of ‘relative stability’, achieving MSY or minimizing the impact of fishing will be harder since allocating the quotas according to the principle of ‘relative stability’ may not provide economically and biologically viable solutions. Therefore, our main suggestion is that the structure of the fishing industry should be considered in the process of distributing TACs so as to minimize the impact of fishing on total fish biomass or achieve MSY.

Furthermore, under the specified quota levels, total catches of targeted fish and untargeted fish for each fisherman can be estimated, which enable us to prevent high grading under a well-functioning output control system.

In this study, we concentrate on a simple model to show the effects of quota allocation mechanism. It is left for further research to develop technology-based optimality conditions for fishing quota allocations including the operating costs analyses.

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