Eel population and solution model

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Abstract

Almost two decades before, eel population had not waved quite hugely, but in this twenty years, it is changed. Eel population decreases very obviously on account of five main reasons—pollution, barriers, the change of ocean currents, overfishing, diseases. Base on this phenomena, though our research, we would like to suggest two solution for changing the decline. In short-term, aquaculture should be utilized widely; on the other hand, re-stocking is a quiet nice method for long-term.

Key Words

Eel, eel population, over fishing, aquaculture, re-stocking, management of fisheries, models
Acknowledgment

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With any problem that is being researched, the question comes up: Why do we care about the problem? Why should we care that the eel population decline and why should we build a management model? If we do not see a reason to solve the problem, then it will not be solved, no matter how well learned and how innovative the solution is. So we want and need try our best to study and solve the problem. We focus, learn and discuss activities on three main topics: the eel population, the solution methods and the eel solution model. All topics provide input to the multidisciplinary activities and knowledge of the project.

1.1 problem field

The eel has for long been the subject of speculation and research. Many aspects of its peculiar life-cycle, with its long transatlantic migration, development in fresh water, and eventual return to the sea, are reasons that make it easier to understand why we have chosen it as an object of intensive studies in this semester.

The overall downward trend continues for many fish populations in the world. It is a fact that not only natural phenomena such as flooding, predators, and changing ocean currents affect fish populations; but also human behaviour is a prodigious threat to fish survival. In our project, we will focus on why the eel population in European waters is declining.

According to recent data, we know that the numbers of young eel are now down on 99 percent from the 1970s. There are a number of possible causes, such as over fishing, damming up rivers, diseases, pollution and changing ocean currents (Ref1). Solving the problem may be a difficult process, more fish ladders and tubes over dams and barriers should be building, pollution should be controlled, and injurious parasites and diseases should be abated. However, the crucial and first thing is to limit commercial eel fishing. In the project, we will study the five probable main causes that affect the eel's living environment and the eel population. On the other hand, eel management is a problem, too. We will discuss aquaculture and re-stocking from a theoretical study and field observations. Finally we will draft a short-term and long-term management plan.
for the eel population.

1.2 Chapters and contents

1. **Introduction:** introduce main content what the project is about, why the project is worth doing, and why we choose this problem formulation.

2. **Problem Formulation:** problem for research, what we intend to accomplish in the project. Moreover, Explanation of key concepts. It will explain the reason behind the need to solve the problem.

3. **Project Methodology:** lay out the method we have selected to conduct our research and how it has been applied in the project.

4. **Project Background:** focus on simply introduces the background of eel the history of the eel, migration of eel, fishery monitoring and the five most probable causes.

5. **Project theory:** This is divided into three main parts. Firstly, the five causes affecting the eel population is analysed, then aquaculture and re-stocking are discussed as part of a possible short-term and long-term solution.

6. **Case study:** is a special part of the project. Where we present some of the models used in the management of eels.

7. **Model:** The solution and relationship model from “ICES” is presented and discussed.

8. **Analysis and Discussion:** in the research processes, we put forward some new questions in management model or case study. On the other hand, we will analyse some important content in project theory.

9. **Conclusion:** summary of the results of the problem formulation and a statement of how the results relate to the eels population and management. Reasons for the project gain the project plan and target.

10. **Appendix:**
   1) References: Information sources that include two part list of illustration and list of book.
   2) Photo from case study.

The decrease of the eel population is not only problem for the eels, but also for man. The eel fishery is one of the most popular fisheries all over the world. As a result, we want to know what reasons leads to the decrease and find out how to solve it.

We have researched the subject by searching the newest information about eels and eel populations, reading books and text at the web about eel life-cycle, the ocean current change, the biology of the eel, the fishery and so on. In addition, we use theoretical knowledge discussions with our supervisor we have tried to find question about eel. As a part of our search of knowledge we have visited following institutions:
10'th November: Attended a workshop on the ‘Artificial maturation of European eel: state of the art’ at The Danish Institute for Fisheries Research.
14'th and 17'th November group members went out fishing eels with poundnet-owner Jørgen Averfeldt, Mosede Havn.
15'th November visit and interviews with staff at Fishinspectorate East, Roskilde.
23’rd November visit to the eel farm ‘Jupiter Aal’ Stege.

We have also adopted some good ideas from our opponent group. With these works, we amended the main point several times which we want to focus on in order to find a suitable orientation for the deeper study. At the same time, our mind map in chapter 3 becomes more and more clear. Now we have our direction whose details can be found in the following articles.
2.1 Research question

“How to build a model to solve the problem of continued decrease of European eel?”

2.2 Purpose

The purpose of this study is to incorporate existing knowledge with new empirically derived results from our present study to determine how many reasons influences the eel population. Specifically, this study will look at how to build a management model to achieve solutions to the problem of continued decrease of European eel, analyzing aquaculture and re-stocking as means to solve the problem of eel population decline.

All of the project research is done with the goal of expressing a problem, and proposing an answer to the problem formulation.

Using the eel aquaculture factory as a case study, the aims of the project include:

1. An understanding of five possible causes influencing the eel population.
2. Building a model and analysis Length-weight relationship, Growth, Mortality about eel.
3. According to theory and case study, we have some solutions to how to solve the problem of eel population decline.

2.3 Approach

1. Compare population of eel status today and over the last 20 years. Describe the population of eel at present, and also collect data of population of eel in last 20 years, find out the population model of eel in these 20 years.

2. Cause of decreasing population of eel
   i. pollution
   ii. Barriers
iii. Ocean current change
iii. over fishing
iii. disease

3. Analysis and how to solution
i. Aquaculture could help solve the problem of population of European eel short-term:
ii. Re-stocking could help solve the problem of population of European eel in long-term:

4. Model

In the project, we will make a model that gives an idea of the solution to the problem, based on own knowledge and research. This is a key part in the project; because of solution models is the main focus in the project. All of the project research is done with the goal of expressing a problem, and proposing an answer to the problem formulation.

2.5 Intended beneficiaries

In our project, choosing an eel aquaculture factory and catch way in Denmark for our case study does not mean that we only focus on eel situation in Denmark. Our topic is European eel population decrease and we try to solve the problem. For this purpose we research eel aquaculture and eel restocking in different countries as the two may be best solutions to the eel population decrease. In addition, we try to find some reliable data to build three kinds of models, which are a conceptual model, an empirical model and a theory model. Our dream has been that our project could contribute to the finding of solutions to the problem of the decreasing European eel population. And that people can get benefits from our project, which is another important purpose for us doing this study.
The main focus of this chapter is to provide the background to how the investigation was approached, what methods were used to approach the research question, and how these methods aided in answering the research question. This chapter will also introduce the remaining chapter; explain why they were included, how they are related to each other and their purpose for reader. Reflections of the case study are included to help the reader to understand the strengths and weakness, and the problems that the investigation encountered through its course.

3.1 Project Organization

This part is to explain the thinking map of our project and make it easy for readers to understand the organization of our project.
Introduction of problem field of project

Problem formulation
How to build a management model to achieve solutions to the problem of continued decrease of European eel population size

Methodology
Background on the biology, use and threats to eel

Description of eel catches in 20 years

Introduction

Project of theory

Five cause

How to solve problem basic management model in both short-term and long-term

Analysis and discussion

Model

Conclusion
3.2 Approach

3.2.1 Background

The main focus of this chapter is to provide the background to how the investigation and learn was approached, what methods were used to approach the research question, and how these ways aided in answering the research question.

In this semester, all of members in our group pay more attention on the fish environment and want to use the knowledge we have learned and we will learn in the project. In addition, eel population declining and management are outstanding research question for us. So we decided to choose the topic is “eel population and management problem”.

3.2.2 Modeling

Due to models not only can show the data intuitionistically and clearly, and also can make reader to read the project easier, we make some models by ourselves. First step is searching related material in (Michael Ingemann Pedersens, 2005, drafted article’ Minimal length for yellow eel in Roskilde Fiord and Isefjord) then we collect the useful data, finally we analyses the data and use them to build models.

3.2.3 Methods

Main points

1. We used some references from books, magazines—as well as electronic sources.
2. Information from professionals: we contact department of inland fisheries and ICES gave us some important and experiment data.
3. Perform management model and field studies as a help to solve the eel management problem in the short-term and long-term.

We don’t want only data from books or what other people tell us. So we made a field study and tried to make a model ourselves and analyze some questions in the learning process.

We have looked for three kinds of data:
- Catches (location/catchments, age- and size-structures)
- Effort (the number of boats or nets)
- CPUE (catch per unit effort, the efficiency of the effort)

Firstly, we wanted to study fishery management, where we needed data from
all areas. It means we can get data from commercial landings, angling and non-commercial landings.

How can we get information on catches?

This has three parts:
1) macroscopical: the large area likes international and national level; the minimum data required is total catch for each life stage (glass eel, yellow eel, and sliver eel).
2) microcosmic: the small area likes catchments and local places; these are detailed data for management.
3) Some specific data from catch, effort (CPUE) as well as size structure (age structure and sex ratio and the ratio yellow eel / silver eel), by gear type and location.

How can we get ideally catch and effort data? We had some ideas. First we thought we could get some logbooks from fishermen, that is recorded the weight of eels caught and the location on a daily basis. The second we can get the number of gears (hooks, trape, fyke net ends etc.).

How can we get more accurate data? First, we could be observers on board a fishing vessel. This gave us an opportunity to obtain supporting biological information. Second, the information on landing can be obtained from dealers, and customs.

However, all of these are very ideally, under our situation, we can’t make all studies. But we can get some ideas from these and understand all the theory. Then we can plan some method for ourselves (Ref2 P28).

3.2.4 Field Study

1. Before the visit to the eelfarm, we collect lots of data on the eel aquaculture and prepared some questions.

I. THE SITUATION OF DANMARK AND EURO EEL
II. The help from the aquaculture in restoring
III. THE POLICY AND AIDS FROM GOVERNMENT
IV. The reason why the director made the company
V. THE MANAGEMENT OF THE COMPANY NOW
VI. The milestones on the company developing road
VII. The growth for eels in the company
VIII. Some techniques and equipments used in the company

2. Search materials and data from the web, through internet for analysis.
3. Ask questions by interview logistical and organize the data we got after the study carefully so as to find some thing valuable to us.

4. Discussion among the members in the group and our supervisor.

5. Combine with the ICEC report find our project model style.

### 3.3 Reflections of Project

#### 3.3.1 Answer of Research Question

There are five main factor that are pollution barriers ocean current change over fishing and disease affect the population of European eel, and we think this problem could be solve by two ways, which are aquaculture in short-term and re-stocking in long-term.

#### 3.3.2 Chapter Components

There are, basically five essential elements of any thesis: Problem, theory, model, analysis, and conclusion. These five elements define the general outline of this paper. The 9 chapters in this thesis are based on of these elements. This section will describe what these chapters contain, its purpose, and how it related to the other chapters.

(Note: The introduction, problem formulation and conclusion will not be addressed here. These three chapters are self explanatory, with the introduction chapter simply introducing the problem, the study question and goals of the project, while the conclusion simply provides a short summary of the results and recommendation of the project.)

**Chapter 3: Methodology**

In the chapter, included is a description on how the project was formulated, the approach used in researching the problem, what was included in the study, problem encountered and how the dealt with. This will provide the reader with information on how the project was formed and the choices made, which will aid in the evaluation of the project.

**Chapter 5: Theory**

The aim of the chapter is simply to provide background on the concepts and science behind the problem. In addition, it explains how many causes influence the eel population and how to solve the problem in the short-term and long-term. Therefore this chapter was critical for the following chapters on modeling and analysis of the solution by eel aquaculture and re-stocking.
Chapter 6: Case study

The main purpose of the case study chapter is to introduce factory where the study is being conducted. A description of the location, the steps of eel’s growth in the aquaculture and system in the eel factory are provided. On the other hand, a detail description of the management objective for warm water system and oxygen automatic control system is provided.

In the part, we are not describing every chapter; because of vary considerably in length due to some chapters containing more background and theory. If any topics are mentioned in the text either as background or to show a relevant point but are not to be further explained later it is stated.

3.3.3 Problems encountered

The main focus of this section is to provide the background to how the investigation and learning was approached, what methods were used to approach the research question, and how these ways aided in answering the research question.

In addition, the project requirement of this semester is the project could be including modeling part. However it is not easy to find some reliable data. Because most of data which is from some fish man even agency is estimated. So our supervisor helps us to arrange some case study in order to know more about our eels, furthermore we were planning to obtain the first hand information of data. Nevertheless, we can not get the data that we expect, so we try another way. Because we can read some data about eels from ices report which is an agency of eel admissions in European country. And during the case study, we also meet some small problems. For example, when we go to eel’s farm where it was a sugar factory, the director was not allowed us to take picture, therefore this part we have lost some nice picture. And we divide into two groups when we go to visit the fishery factory, the fish man can not speak English, so the communication is difficult. It is much better that our supervisor go there with the first group members, because he can explain for us. But for the second group, we just go there by ourselves, so the language is a problem between fish man and students.

All in all, we met some problem as experience, however according hard individual work, closed group work and help from our supervisor, surely we think we can solve it.
4.1 Introduction of eel

Eels are bony fish that have a muscular and the body like a snake. There are about 500 species of eels in the world. Some Eels live in salt water, but most eels also live in fresh water (ref3).

There are two big eel species in the world. The conger eels (Conger conger) that only live in marine habitats and the common eels (Anguilla) that live in fresh water and inshore coastal water. The principal Anguilla species are European Eel -Anguilla anguilla, Japanese Anguilla japonica, and American eel Anguilla rostrata (“rostrata” is Latin means “long nose”), (ref4, 7).

Our project will concentrate on the European eel- Anguilla Anguilla. (The genus name “Anguilla” is Latin for “eel”). In Europe there are two forms different of the European Eel. (Figure1) One with a wide head (1) and one with a narrow head (2). From the figure, the differences are clearly discernible.

Two forms of European eels

Lifecycle of eels

Eels have a long and complex life cycle. They general need up to 20 years metamorphose from eegs to adult eels. In this period, eels come though 4 metamorphoses: Larva- Glass eels- elvers –yellow eels-silver eels. (ref6)

The freshwater eels are catadromous fishes, which spawn in salt water but live as adults in fresh water. The larvae drift in the Sargasso Sea (A vast area of the North Atlantic from the West Indies to the Azores that is dense with
After months or years, they grow to elvers and recross the Atlantic on the way to their original streams. The purpose of Eels migration is spawning. Generally the young elvers run up to fresh water in spring, and adults migrate downstream in autumn and to spawn in sea. (Figure 2)

*The life cycle of European eels* (ref8)

Figure 2

The names of the major life stages are indicated; spawning and eggs have never been found in the wild and therefore only temporary be included.

Larva - The larva (leptocephalus) hatch from eggs is transparent, gelatinous, leaf-shaped, and free-floating (ref3). (figure3) They have small pointed heads. The growth of larva drift with the ocean currents. (figure4)
Figure 3
The larva grows from length (7mm) to the 25mm and 75mm stages. But after while, the body is grow to shorter from 70mm to 65mm and they will become to glass eels (ref7).

- Glass eels- the body shape changes to cylindrical cross-section. The glass eels are shorter and have less body and body-water than larva.

    
    Larva and glass eel (ref8)

Figure 4

- Elvers- glass eels glow and mature more color and become to elvers. Some elvers remain stay in the coastal and estuarine waters but many migrate into fresh water.

- Yellow and sliver eels-As elvers grow they become to yellow eels. It will metamorphose one more time, becoming an adult silver eels which have adult coloration and is able to breed. The colors of adult eels are very various depending on where they live. Because the eels are dark if living in dark much tinged if living in white background. As a rule they are dark brown or olive-brown back, more or less tinged on the sides and the the belly is yellow-white. (Figure5) And scientists has found that they can change colors from tinged to dark about 1.5 hours if they moved from a white background to a black background and from dark to tinged just more than 3 hours if they moved from a back to a white background (ref9).
One of the European eel (ref5)

Different Size of eels between females and males

The sizes of eels are different from males to females in same age. Males are smaller than females at a same age. The young elvers’ average length is from 2 to 3.5 inches. Any eel more than 18 inches long would probably be a female, and more than 24 inches long would certainly be females. The smallest adult males are about 11 to 12 inches long, females about 18 inches. (ref10).

Spawning

The eels (Anguilla anguilla) often live in cool freshwater for more than 20 years achieve sexual maturity. In warmer water, eels can mature earlier. An eel normally spawns in midwinter after sexual maturity. The females with males which are both sexual maturity swim together to the river mouth and then arrive to their spawning grounds. (ref6) They will spend one to two months from the coast to the spawning ground. Although we never get confirmation where they spawning, the scientists are assumed that lie in the Sargasso Sea between the Bermudas and the Bahamas. In February. Eels will die after spawning. so the large eels never have been found run upstream again. They are probably “jellify” and disintegrate, same as conger does.

Feeding

Eels feed mostly at night, and they have a very wide and varied diet. For example, aquatic insects, crayfish and other crustaceans, frogs, fishes and worms (ref6).

4.2 Background of recruitment

EEL recruitment and the stock have been decreasing since 1982 in Europe; scientists have suggested that fishery and anthropogenic impact should be the reduced to lowest level and a recovery plan should be developed. As show in figure, Stock and recruitment has proportional relationship, the recruitment is decreasing logistic, and it is down to minimum level in recent year. According to recruitment, we can judge that number of silver eel is very few.
Figure 3.2.1. Estimated stock-recruitment relationship for the European eel. Numbers indicate the year of recruitment. The spawning stock is assumed proportional to the landings from the continental stock (after Dekker 2004).
This chapter will introduce the theory behind the project to give the reader a thorough background and this knowledge can then be used to better understand the further chapters.

5.1 European eel Fishery

Total yield of European eels has declined to about half of the mid-1960s. All information indicates that the stock continue to decline. So over the last two decades, the number of recruits shows a downward trend in European countries. Recruitment means the arrival of new young eels to the exploited stock. Recruitment of European eels has been declining since 1980 and reached a historical minimum in 2001 which is 1-2% of the 1980 level. Fishing mortality is high both on young (glass eel) and older eel (yellow and silver eel) in wild water system.

5.1.1 How to solve the problem for the fishery

An estimated 20,000 to 25,000 people who include part-time fishermen are involved in eel fishing, and many of these are non-professional fishers. They are spread both in coastal areas and rivers. It is quite difficult to manage and control them. In order to solve this problem, The Commission of the European Communities plan for the management of European eel to introduce for example closed seasons, in order to reduce the pressure of fishing.

5.1.2 Season closures

1) Glass eel fisheries in Europe (several countries) are from October till May.

2) Generally, the yellow eel fisheries start in April with an increase catches to a maximum in June and July, thereafter with a decrease catches until October.

3) The most part of fisheries for silver eel is the same as for yellow eel, but the fisheries is being take a biter later and the maximum catches is in August, September and October.
The fishing can be rather intensive. In France, very high levels of fishing mortality have been recorded, ranging from 20-25 %. And also in Demark where e.g. in Roskilde Fjord almost all migrating silver eels are being caught.

Different net for catch glass eel, yellow eel and silver eel have been used for different counties.

**Glass eel**

Glass eels are caught in England, France, Spain, Portugal and Italy in Europe. The fisheries take place in mouth of rivers and dams where the natural concentration of glass eels can more easily to be catch.

Hand-held or ship-based nets are used for catches of glass eel. There are can be moved by hands or fixed. These include of trawls, stow net, and fyke nets etc. (ref11)

Hand-held nets

(ref11)
One kind of fyke net

(ref12)
trawls

(ref13)
Stow nets
In Spain and Portugal, fish men use hand-held nets and traps. In France, glass eels are caught by small trawlers use the wing nets and trawls. In UK, the only legal instrument for fishing glass eels is hand-held net. So the glass eel are caught in UK has the highest quality in Europe.

Yellow/Silver eel

In this part we will use CPUE – catch per unit of effort to measure the stock of eel catch. Depend on the different size structure and habitat of stock; the fish men will use different methods such as electro-fishing, fyke netting, long lining, trawling etc. It will have different results by different methods. (ref2) In Europe the major yellow/silver eel fisheries are the Italian lagoons and Netherlands, normally they use fyke net or long-line to catch eel (ref15).

And some of them catch with high mortality, therefore how to improve the tool of fishing are also important.

5.2 Five causes

Eel is a common fish species in Europe. 20 years ago, it could be found in nearly all European river systems and in the coastal waters. However, less and less glass eels have arrived at the European coasts and a dramatic decline in eel catches has been observed.

The number of European eels has decreased by more than 90 per cent during the last 20 years. In addition, recruitment reached a historic low level in 2001 (ref15). As a result, if people do not make plan or than action now to protect the European eel might become extinct. Europe’s fishermen are already finding a same thing that is less and less eels in their nets. (ref16)

What is causing the eel population to decline?

No one knows exactly what the causes are for the eel’s rise but there is certainly no lack of theories and attempts to explain the phenomenon that includes five main causes of pollution, barriers, ocean current change, over fishing and Diseases. Than we are going to analyses the causes in the part.

5.2.1 Pollution

Eel deaths occurred in a number of waterways in Europe between October
2004 and March 2005. Scientists have investigated possible causes of the eel deaths including pollution, poor water quality and toxic contamination or a combination of the above. No single cause for the eel deaths has been found.

Industrial waste water contains diverse organic and inorganic substances. Domestic waste water contains cleaning chemicals and washing powders with bacteria which is the most important pollutants in waste water. Also, the agriculture bring excessive concentrations of phosphate and nitrate to the water influencing the survival of fish and Toxic Chemical Pollution such as DDT, PCBs and Mirex (ref17) which are stored in their fatty tissues of the fish;

This figure shows a washed-up eel at the Hawthorn Rowing Club ramp. In the area, fish deaths tend to occur during the summer months, when warmer weather often triggers changes toxic chemical pollutant in water environments. Photo: (ref18)

5.2.2 Barriers

I. Fish ladder

**Explain:** Fish-way that includes fish ladders and fish passes, are structures placed on or around man-made barriers (such as dams and weirs) to assist the natural migration of eel.

**Function:** Most fishways enable fish to pass around the barrier by swimming and leaping up a series of relatively low steps into the waters on the other side. The velocity of water falling over the steps has to be great enough to attract the fish to the ladder, but it cannot be as great as to wash fish back downstream or to exhaust them to the point where they cannot continue their journey upriver.
Five primary types of fishways:

- Rock Ramp Fishway
- Pool and Weir
- Vertical Slot Fish Passage
- Denil Fishway
- Fish Elevator

Figure 8

Basic structure eel ladder for elever less than 15m. (ref20)

Why it especial for elever? In fact, many fish passes are not unsuitable for young eels because the water flow in them is too fast. As a result, other eel ladders have been installed next to the usual fish pass in many weirs.

II. Eel ladder

An eel ladder is type of fish ladder designed to help eels swim past barriers that includes: dams and weirs or even natural barriers and help eel to reach upriver feeding grounds. (Many eels are catadromous, living in fresh water but spawning at sea.) The basic design of an eel ladder has the eel swim over the barrier using an eel ascending ramp, which provides the eels a climbing substrate to "push against" while slithering upstream. For some higher barriers, elevator-style systems are also used. (ref21)

An eel ladder typically consists of four parts:

- **An eel ascending ramp**
- **A supporting structure**: It mounts the ladder to the barrier.
- **A water-feeding system**: It ensures the proper flow of water to the gutter and the ramp.
A side gutter: It provides an attraction flow to draw eels toward the ladder. Mounts the ladder to the barrier.

The eel ascending ramp can be a fairly simple constructions, such as a hollowed out tree filled with recycled fishing net, or a more complex structure designed to accommodate specific species or ages of eels. For example, the Canadian company Milieu Inc. manufactures eel ascending ramps made of moulded ABS with undulating side walls and staggered studs throughout the length of the ramp. These studs form the substrate the eels push against during the climb over the barrier. (ref20)

The truth and experience tell that dam and reservoir must have an effect on the fish in the river and fish migration to the upstream. Eels from the ocean could not find the new way to the spawning area again. They want to go through the following water which from the orientation of power station. So there are no eels that passed the dam and no spawning by the situation. In the same way, the glass eels from the upstream also have no living way to the downstream, and then they died, getting eaten by birds or other fish. And if there have no equipment for helping fish out of the dam, they will disappear.

5.2.3 Ocean currents change

Firstly, we will explain the definition about ocean current “it is any more or less permanent or continuous, directed movement of ocean water that flows in one of the Earth's oceans. Ocean currents can flow for thousands of kilometers. They are very important in determining the climates of the continents, especially those regions bordering on the ocean.” (ref22)
Global warming cause changes the major ocean currents, and then ecosystems will shifts as well. Because temperature can affect the physiological, metabolic process directly and hence growth rates. It is especially special for fish egg and larvae. This phenomenon happens in many oceans.

Larvae eel come from Sargasso Sea, and then some of them come to the American by Gulf Stream, some of them sweep to European coasts. The picture shows below is the different stage of larvae to glass eel in different situation in Gulf Stream.

![Figure 10](image)

The larvae of European eels travel with the Gulf Stream across the ocean and, after three years, reach England at a size of 45 mm. (ref24)

Such as Gulf Stream, which are driven by heat, freshwater runoff cycles and winds? The larvae of eel are affected by those factors directly. And actually this physiological already happened. Due to scientist found the glass eel have been reduced to 1%. (U.S. Global Change Research Information Office)

## 5.2.4 Over fishing

Over fishing means that harvesting more fish than a population can sustain, with a consequence that the future production decreases. Over fishing have been happened in most of fisheries, due to too many people
chase too few fish. In many places, benefit tempt more and more people to be involved in commercial fishing, which cause fewer and fewer fish. Contrary the price of fish become to higher and higher. This can cause overfishing. After that it also causes recruitment over fishing. This is very serious vicious circle.

Figure 11 the catch-effort curve. It will cause over fishing when the catch reach the point of peak catchments (maximum sustainable yield). If the effort goes up further it may lead to recruitment overfishing where also the recruitment start to decrease.

Figure 12 Global trends in marine fisheries show ever increasing proportion of stocks are fished at full capacity or overfished. The picture shows that over half of the world’s fish stocks are overfished. According the picture overfishing
began to appear from 1960, after that it developed rapidly, until now where over 50% of the fish stocks are overfished. European eel is one of the cases. The European eel is a species in trouble. Being catadromous and because the eel do cannot breed in captivity restocking is difficult.

(ref25)

<table>
<thead>
<tr>
<th>Annual catch of European eel (in tonnes)</th>
<th>in selected countries (FAO statistics)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Denmark</td>
<td>504</td>
</tr>
<tr>
<td>France</td>
<td>320</td>
</tr>
<tr>
<td>Germany</td>
<td>595</td>
</tr>
<tr>
<td>Ireland</td>
<td>100</td>
</tr>
<tr>
<td>Italy</td>
<td>588</td>
</tr>
<tr>
<td>Netherlands</td>
<td>432</td>
</tr>
<tr>
<td>Norway</td>
<td>454</td>
</tr>
<tr>
<td>Poland</td>
<td>627</td>
</tr>
<tr>
<td>Sweden</td>
<td>1093</td>
</tr>
<tr>
<td>UK</td>
<td>506</td>
</tr>
</tbody>
</table>

Figure 13

The table tells us that most of annual catch of European eel decreased from 1995 to 2002, except in France and Germany from 1995 to 2002. In almost half of the countries the annual catch of eel nearly reduced by half. It tells us that over fishing will cause the population decrease, and it will continue, - or vice versa. If nobody intervene successfully with management of the fishing, the eel might, as a worse case, become extinct.

Eel has been capture in many ways due to high price of eel (especial for glass eels). Different fisheries are arriving at different stages of eels that include glass eel, yellow eels and silver eels. Normally, glass eels are either caught for human consumption. Used for aquaculture or re-stocking. Also some of yellow eels are caught for this purpose, but most yellow eel and silver eels are used for consumption directly.

5.2.5 Diseases

In many case stocking or intensive pond culture results in eel population of a particular high density, and for this reason, various serious diseases are not uncommon in the eel stocks.

Fresh water and salt water eel diseases

There are two different common bacterial diseases, fresh water disease is caused by the bacterium *Aeromonas punctata*(ref26); Salt water disease is
caused by the bacterium *Vibrio anguillarum* (ref27). We will compare two diseases in the below.

<table>
<thead>
<tr>
<th>Freshwater eel disease</th>
<th>Saltwater eel disease</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eel without external symptoms of the disease swim around slowly; shortly before death they hang, crumpled up.</td>
<td>Sudden death without any external indications of disease. Shortly before death the eels come to the surface.</td>
</tr>
<tr>
<td>Red spots, bands or flecks spread, with varying intensity, over the whole body.</td>
<td>Rash-like reddening of the skin, fin margins and anus.</td>
</tr>
<tr>
<td>Blindness</td>
<td>Swelling and reddening of the musculature around the heart region.</td>
</tr>
</tbody>
</table>

According to the compare, it is clear that two diseases are very similar. In the case of both them, external symptoms cannot be seen if the eel begin to die in the large number.

Another disease is the nematode *Anguillicola crassus* which came from Asia at the beginning of the early 1980s. It is supposed that infested eels are no longer capable of migrating to the spawning grounds in the Sargasso Sea. In Europe, eel populations are already from 30% to 100% infected with the nematode (ref28).

### 5.3 Short term solution by eel aquaculture

In eel aquaculture, the glass eels are placed and fed in the freshwater and growing to a marketable size (weight about 200g). In addition the running requirement of a eel farm request to know eel culture, such as fishing gear, harvest operation, transport glass eel and feeding eels. Depending on understanding and controlling this knowledge of eel culture. Eel aquaculture can improve the quantity and the quality of adult eel for supplying the market.

#### 5.3.1 Main factors influence eel aquaculture

1. Qualities of glass eel

   Glass eels are captured in the wild and sold to the eel farm. Eel farms as the main buyer surely hope that the glass eels were not damaged when they were caught. The healthier the glass eel the better for the eel aquaculture. Glass eels are fished on the west coasts of Portugal, Spain, France and Union Kingdom. According to the Mr. Morten Lauritzen (director of eel farm Jupiter in Stege farmer sugar plant) said, at present the best quality of glass eels come from the UK, however the price has risen to almost 1000 euro per kilo.

2. Water quality requirements
Temperature
Water temperature has influence on the activity of eel if the temperature is warmer, the eels will grow faster. In the wild, when the temperature is between 5 and 6 degree, the activity of eel reduces to zero (ref29). In eel farm, eel stop feeding when the temperature below 10 degree. It took a long time to find out the preferred range of water temperature for eels. Since in 1976, Jellyman report that temperature 20-25 degree is suitable for eel. Until in 1995 Jellyman suggest that the temperature 25-26 would be optimum for eel culture. At present we can see the parameter of water temperature is 22-28 degree in the table below.

Oxygen
Oxygen is also a very important living factor for the production. Eel need enough oxygen for living. Because the eel culture prefers warmer water than cold water, however there is less oxygen in warmer water. So as a rule of thumb, the oxygen level must not fall below 1 mg/L.

Other water quality criteria
PH is another crucial factor; it has an effect on toxicity of free ammonia. The toxicity of free ammonia increases with increasing PH.
Organic matter is also a problem that can produce extra ammonia during the decomposition process. Therefore it is also important to remove organic matter.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Acceptable Range</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature©</td>
<td>22-28</td>
<td>Growth will be optimized in this range</td>
</tr>
<tr>
<td>Dissolved Oxygen (mg/L)</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>PH</td>
<td>7 - 9</td>
<td>Eels prefer shaded or subdued light (including dark conditions)</td>
</tr>
<tr>
<td>Light</td>
<td>Intense light to be avoided</td>
<td></td>
</tr>
<tr>
<td>Total hardness (mg/L as CaCo3)</td>
<td>&gt;50-&lt;500</td>
<td></td>
</tr>
<tr>
<td>Total nitrogen (mg/L)</td>
<td>&lt;0.5</td>
<td>Ammonia toxicity increases with inch. PH and 7</td>
</tr>
<tr>
<td>Suspended solids (mg/L)</td>
<td>&lt;40</td>
<td>Eels are adaptable to a wide turbidity range.</td>
</tr>
</tbody>
</table>
5.3.2 Culture methods

At present, there are three main methods used for eel culture. 1) pond culture, 2) accelerated temperature culture, 3) the use of recirculating systems. Most of the culture methods use fresh water, but saltwater for eel aquaculture can also be used.

1. Pond culture
   This method was originated in Japan but is also used in Europe. It uses open ponds. During the glass eel on growing to the market size, four different sizes of ponds are used. Initially, glass eels are placed into the first pond, which can be considered as a 'training pond', the pond may be only 5m in diameter and stocked with a density of about 400g/m². However, mortality during the first month may reach percentages from 10 to 30% of glass eels, because the new environment is not suited for them. After nearly one month, the glass eels reach between 8 cm and 12 cm in length. They are caught and divided into two grades for transferring into a second size of pond which is 30 m² - 100 m² in area and stocked with a density of about 100g/m². After a further 20 to 30 days, the glass eels are almost 12 cm long and are caught again in order to be sorted by size, and then placed in outdoor ponds until they are big enough to be transferred into an adult eel pond. (ref31)

   The rate of eel growth is depending on the efficiency of operation, technique of pond culture and experience of farmer, so the time that eel culture need for reaching marketable size varies.

2. Accelerated temperature culture
   Eel grow faster in warmer water. The temperature of range 24-26 degree is optimum. Jupiter Eel in Stege use 26 degrees. This type of culture use water from two sources. One is called greenhouse system that use solar energy for warming the water which is used for aquaculture; another thermal water source is using water that comes from heated effluent from industry.

Greenhouse systems
   This system make use of solar radiation to maintain warmer water in summer, during winter some equipment for heating water is also required. Greenhouse
systems are a cheaper setting and a good heating collector for eel culture. There are some advantages, that all are used in Jupiter Eel, compared to pond culture show below.

- Reduced water consumption
- Higher rearing density
- Improved food conversion
- Improved growth rate
- Higher production
  (ref29)

**Thermal water source**

Warm water effluent from industrial process can be suited for eel culture. The power from the industry can produce a large amount of heated water. At present using this method of eel farm gives some problems in Europe. The first is lack of reliability in the quality and quantity of the effluent, the second is the running cost of the water feeding system and also disease problems. Although these problems are important but water quality remains the main problem. If the water quality is not good enough for aquaculture, one has to change other source and heat it exchange with the thermal water gravity filter(ref29).

3. The use of recalculating system

This type of eel culture is used widely in European countries. There are two main explanations. One is in northern Europe, during the winter, the climate make greenhouse culture limited. In the other hand, some rule of regulating effluent heat is also limited as source of thermal water, in countries like Denmark, Germany and Holland.

This method of eel culture and also lower the organic matter, suspended solid and nitrogen product for improving the water quality by an intensive purification process (ref29). Suspended solid is mainly from faeces and the the feed waste are removed by gravity filter or mechanical sieving filters and also trapped by the biofilter (ref29).

The recalculating systems has an advantage that it can keep heating costs down, the water is recycled used, not only to conserve water but also can save the expensive electricity that need heat water turn warm.

5.3.3  **Trends in aquaculture**

In this part, we focus on the trend of aquaculture in Denmark, which is our study region. From ICES report (2005), recruitment of young eel to freshwater is decreasing in our region, we know that very high eel densities were found in the beginning of the 1980s, however trends go down until 2003 all the time, especially in 2003 the number of recruitment of young eel is nearly close to zero. It could be a reason why captures of glass eels for any purpose even for
aquaculture has been stopped since 1990 in Denmark. In addition it has some management to protect glass eels, such as minimum legal size for glass eels. They are protected on yellow eels which in fresh water is 45cm, in salt water 29 - 34 - 35 - 38 cm depending on the region. And another way is to put eel passes at all freshwater barriers, which are in operation from April through October. (ref2) So the aquaculture in Denmark is depending on imported glass eel from other countries, such as UK, France, and Spain.

During last 20 years, aquaculture has developed very quickly in Denmark. Following is three figures showing the development situation of the aquaculture. All production takes place at indoor, in heated aquaculture systems.

Figure 15
This figure shows the number of production units from 1984 to 2003. From 1984 to 1988 the unit of production is a bit change, from 1989 to 1991 rise sharply and then it decline, in 1998 it seems to rise up a little; however it dose goes down until 2003. The main reason should be influenced by the price of glass eels.(ref2). Today there is only 8 units in reductions (ref32).
Figure 16
This figure shows the number of production units from 1984 to 2003. From 1984 to 1988 the unit of production is stable, from 1989 to 1991 rise sharply and then it decline, in 1998 it seems to rise up a little; however it dose goes down again until 2003. The main reason could be influenced by the price of glass eels (see figure 15). Today there are only 8 units in Denmark (ref2).

Figure 17
From this figure we can see the trend of the production per unit during last 20 years is increasing and develop rapidly. (ref2)

The development has been less production unit, but more production mass. There may be several reasons for that. Firstly the area of the production unit may not be the same, the eel farm or the pond for aquaculture has become bigger and bigger. Secondly the quality of glass eels for supplying aquaculture
is higher than before, thus it can avoid many problem during eels aquaculture (such as mortality caused by diseases) and this can also improve the production. The last one could be changes in the technique giving room for a larger and more intensive production like e.g. automatized control-systems.

During our project, we were not only on field trips; we also attended a scientific workshop at the Danish institute for fisheries research at Charlotte Lund Castle Copenhagen. The title of lectures was ‘Artificial reproduction of European eel and attempts to induce sexual maturation in the European eel.’

Supply of glass eels is a bottleneck into the present production. Until now nobody have succeed in breeding eels in captivity. So several scientists and among these the scientist Jonna Tomkiewicz who is Ph.D senior scientist is making research on it.

In the abstract from the workshop she writes: ‘The project is running over 14 months with the tasks to standardize experimental protocols, improve the nutritional status of parental eels, and to apply histology combined with ultrasound scanning to describe the hormonally induced development of female eels. The intention is to implement ultrasound scanning to optimize the final hormone treatment used to induce ovulation and thereby improve the egg quality and fertilization rate. This method represents a non-invasive alternative to the present use of ovarian biopsies during female ripening’. And continues: ‘Different hormones and methods were used in the attempts to mature male and female silver eels and their influence on the gonadal development was studied macroscopically and microscopically. Also the influence of temperature and other environmental factors was investigated. This pioneering work resulted in successful ripening of female and male eels and in a few instances fertilization of eggs.

Therefore, while the species of European eels decrease rapidly and the problem of population of eels is serious, we can consider the management of aquaculture is a potential way to solve the population of eels. Because it can offer the requirement of market that we need. However, this kind of method is unstable. The main problem is the scarcity and hence the price of glass eels. Prices are now over 500 Euro per kilo of glass eel (ref32). In fact according the purpose that deal with the population of eels, aquaculture cannot increase the natural population of eels. We anticipate that we one day can artificially reproducte of European eel. All in all, at present aquaculture cannot solve the eel population, but it could however be used with positive effect on the eel stock. No wonder that many in the eel-sector are longing for a break through in the techniques of artificial breeding.
5.3.4 The ways that present aquaculture can influence stock

The aquaculture depends on wild stocks of glass eel. However, the stock in Europe is decreasing sharply. Glass eel catches from South Europe are generally of low quality. Poor quality catches and high prices for glass eel make imported numbers stock to Europe down to 2-4 million fishes. (ref34) The aquaculture can help the wild stock in some ways. Glass eel and yellow eel from aquaculture can be used for restocking. That can help stocks to increase. Tone of the effects aquaculture can have is that it can help reducing the mortality of glass eel due to parasites, barriers, predators, and environmental changes. These threats may easily depending on the period of time reduce the number of small eels with 50%. However, the glass eel grown in artificial tank which are safe and warm, and fed with cod roe and small pellets have a high growth rate and a much lower mortality. Glass eel are usually fed up to a weight of 5 gram before being restocked. The mortality of glass eel reduces to 10-20% (Article: live eels for the Dutch market). Thirdly, aquaculture also shortens the time that eel grow to maturity. In the wild, it takes up to 25 years (depending on the temperature) for eel to grow to maturity. In aquaculture, it can be 30 times faster than wild process. The fast grown Eel from aquaculture can almost saturate the market, and thus reduce the pressure on the fishery on the wild stocks.

Figure 18 it shows the relationship between Aquaculture, Wild stock and restocking. The aquaculture depends on the wild stock. But some of the glass eels from aquaculture can be used for restocking.

5.4 Long-term solution by re-stocking

5.4.1 Re-stocking

Re-stocking means to catch eels from the wild and then release them in another region. The purpose of re-stocking is to make optimal use of all
potential habitats. There are two ways to help glass eels continue survival, which are put eel’s ladder so they can come through the dams to other areas, or bring captured eels from one area to another area.

Eel’s ladder could help glass eel come through the dams to continue survival. Since the building of more and more dams fish have become less and less, as they can be obstructed by dams, which can prevent the fish migrations that take place in all three directions, upstream and downstream. For instance eels cannot jump out of the dams to the other side of rivers or streams. Therefore they have to stop there. And can not successfully reach the sea to propagate. In order to solve this problem it need eels ladder to pass through to other areas. The picture shown below is a special design for catadromous eel. The nets inside the pipe can help the eels to come through to the other side.

![Figure 19 Bring glass eel from one area to another area](image)

Some glass eels can be capture from area of high abundance, and then used for re-stocking in order to use all potential habitats. Normally there are plenty of glass eels in the coastal waters, and not all of them can come to the rivers or stream, so people catch them and then release them above barriers in rivers or streams. And another reason of capture of glass eel from one region then bring them to another area is change the environment, because some environments are not suited for eel’s life. For instance some waters have been polluted, and it will affect the eels. According to the basic knowledge that oxygen can be produced in water by photosynthesis, therefore plant will affect how much oxygen is produced directly. And eels survival depends on oxygen. Oxygen deficits are one of the most common causes of eel’s kills, which damage the eel’s population. In order to solve the problem with the environment for eels, it could hypothetically be a good way to capture eels from bad quality water and bring them to good quality water.

5.4.2 Glass eels can be re-stocked in two ways

Capture glass eel from wild to wild
Mostly re-stocking of eels aim at glass eel stage, but some of yellow eels can also can be used for this purpose (ref33). The amount of re-stocked glass eels has been decreased rapidly in last 20 years. And the total European eel re-stocking dropped to less than 20 000 tones a year in the 1990s (ref34). Due to glass eels decrease. It is because less and less glass eels can be found in the nature. The figures below demonstrate that the conditions are extremely threatening for the population of glass eels. This is the example (figure 20) of the trend of the amount of glass eels for re-stocking in Netherlands. The figure shows that the number of re-stocked glass eels has been decreased rapidly from 1980 (almost 25 million) to 1991 (only 1.6 million). After that the number go up and down in different years, until it reach the lowest point (only 0.3 million) in 2004.

Figure 20 Re-stocking of glass eel. Numbers of glass eels (in million) re-stocked in Netherlands.

Another example shows in picture 21 an even more serious of decrease of glass eel in the river Ems at Herbrum in German from 1980 to 1997. there were caught about 3200 KG glass eel catches for re-stocking in 1980, and after that the amount of glass eel drastically down in 1981, and then continue go down slowly until 1987, from 1987 to 1997 only few glass eel have been caught for re-stocking.
Release glass eel from aquaculture to wild

Another possibility is re-stocking of glass eel from aquaculture. In the EU there are plans that will obligate the eel-farmers to release 10% of total glass eel, due to less and less glass eel in the wild. In order to increase more glass eel, the eel farms can keep 90% glass eel for the aquaculture; the 10% of the glass eel have to contribute for the re-stocking. It is a good way to protect and maybe raise the number of glass eel in the wild.

5.4.3 How to help protect the population of glass eels

According our research found that only 5% of catch glass eel used for re-stocking. Although in some way it could help to protect the number of glass eel, but not contribute too much. Therefore it is necessary to add more percent of the catch glass eel for re-stocking. Although the habits of eating glass eel have been forbidden in many European countries, it still goes on in few countries, such as Spain and Portugal. Therefore it is necessary to make a law that prohibits eating of glass eels in those countries.

But it will take long time to see the result; due to the fact that it will take 20 to 30 years for a glass eel to be mature. Therefore we call this kind of management of population of the eel in long-term.
6.1 Poundnets

The purpose of this case study is to review how the fish men use net to catch the eel in the sea. Today our group goes to the haven named Mosede Harbour, which is located in the south to Copenhagen, and near the Atlantic. It is a famous haven and the Danish queen has been here in September.

At 7:30 am we start to embark with fish men, who are family company working here. The wind is very strong, mews following the boat in group. It is first time to watch the fish men catching fish in sea for us, so it is pretty exciting. First it takes about 10 minutes that we have been a maritime space. The deep of sea is about 5 meters. Then a young fish man use two ropes to moor the boat and they start to use a net to catch fish, but this time they only catch some small fish and shrimp, which are no value for them, so they throw them back to sea. The mews already have been ready to eat them, it is the reason why they following the boat.

Figure 22(ref 35) this picture is about we see the net from high place. From this
picture we can see many poles in the sea; we drive the boat to catch eel around this net. The poles and rows compose a huge net.

This is the clear picture for the net; we can see the net how to catch the fish.

So we will continue our trip, we come another maritime space. This space is deeper than last space. This time we catch some bigger fish, the fishes are: cod, plaice and gar pike. We are happy to find some silver eels in them. Then the fish men put the fish in the cabin, different some kinds and put the same kind in the same place. Most of eels are female, and the length is about 1 meter. The fish men told us that they almost fish from May to November, because the fish need time to spawn, and they also like better weather to work, only do little work in December. In November and December most of fish are consumed for Christmas. If they catch some fish which have marker in their stomach, they will return them to the department of studying fish. Because these fishes are
already catch and marked for studying by department, and then the department get them form the fish men again. They will study the living habit of fish and so on.

After that we go to about 3 and 4 the similar space, at last we catch totally about 200 fishes. Among them there are about 50 and 60 eels. This number is smaller than normally average number, because this season is not good time to fish.

Through this case study, we watch the approach how the fish men use net to catch fish, and the daily living of the fish men. We have a deep impression about it.

6.2 Eel Farm

6.2.1 Purpose for the case

How aquaculture work and how they follow some laws that government made for protect the population European eel.

In the question about the situation for eels in the Denmark and Europe natural resources, the governments change its policy with the market challenge and the introduction of new techniques and management for the eel aquaculture.

In order to protect dwindling eel stocks in Denmark and Europe, the government makes a series of laws and treaties. Normally we can consider this article is some Legal Elements.

6.2.2 Legal level elements

First, the most important part of Regulation is to develop the plans for the national eel managements, which means that each member state has the obligation and responsibility to keep the catch numbers of the eels (adult silver eels especially) at a reasonable level.

Facing the urgent situation, the governments set some restrictions. Generally eelfishing is only allowed 15 days each month stay in force The last but not the least all member states should strive to protect the eel populations so they do not continue to decrease. Each member should find the benefits of the balance between the local state and community.

6.2.3 Background information
Case company: Jupiter Aal a/s
Director: Morten Lauritzen

Jupiter Aal A/s Company raises glass eels to yellow eel at a size of about 200g the eels still do not decrease definitely. Following the Japan and some Asian countries. Historically most of the fishermen there were just fishing not farming. This means that they are interested in only the silver eels or some yellow eel. But with the development of the modern aquaculture technique, the requirements of glass eels have been up to the water. And in the cycle of the eel life, the numbers of glass eel like the base of the pyramid. The effect of the decreasing glass eel number will not only impact on the present but the future as well.

Further more, this will form a vicious circle, although, as the director said, the price of glass eels hardly was growing geometrically. The entire production equipments are housed in a large three-floored old sugar factory.

Many years ago, Morten Lauritzen, the director of the eel company think the price for farmed eels was good and the inputs costs were manageable. But today the price for glass eels has arrived to Euro 500 per kilogram last year from Euro 350 and seems to double once more in 2005. The price really reached the cutting edge for.

If we will find the most probable reason for the incredible price increase during these years, first the consumer increasing, new markets in China like elephant and rhinoceros because of the market requirements.

6.2.4 The steps of eel’s growth in the aquaculture

Glass eels are fished on the western coasts of Portugal, Spain, France and UK. Methods of catching are hand nets, traps and trawls. Because of the different catching methods the quality of the glass eels is not the same. Like French glass eels, 5% will be dead one week after arrival. The reason for this is the damage that has been inflicted on them in the trawls.

The glass eels weigh around 0.3 gram each. When the glass eels were transported to the factory the water should be kept around 6 to 8 degrees centigrade.

At first 7 kilo glass eels almost 25000 pieces will live in a tank. When the size reached 3 gram, they will move to a new level in the building. Like this model, the eels move from one tank to the next until they have gained ca. 200 grams, enough meet the requirement of the market.
6.2.5 Some ingenious system in the eel farm

In the eel factory, we found two interesting systems inside. The one is the warm water system; the other is the oxygen system.

The warm water system

The system let the warm water Recycle in order to save energy (and water). On the other hand this raises the requirement to an effective water purification system.

Oxygen automatic control system

When the oxygen was below the 5% in the tank, the system will start to work automatically. Further more if there would be some problem, the system will report to the main control computer and send short massage to the managing person in the eel company. This system is very important because it offer guardianship to the company.

6.2.6 Summary

Through the visit to the eel-factory we learned something about a modern eel’s aquaculture company like the equipments, management, some government statute and some new conceptions. Before the study we tried to read some books and articles on the aquaculture. For instance before arrival to the factory building, none of us had imagined that the surrounding in the eel company was such bad smelling. We found that the technology of eel aquaculture is very high in Denmark as fact during case study. And we have learn more about practice experience.
Models are pictures of the real world. We will build a conceptual model, empiric models and theoretical models to describe the reasons that make eel decreasing. The conceptual model shows the life cycle of eel and how the eel is caught and used for restocking at each stage. It tells us what might be the reasons why eel population decreases. The empirical models are the relationship between catch and effort, growth and mortality. The Catch and effort model describe the situation that if the over fishing happens in Denmark. Growth and mortality are the common management models for fish stocks, which can reflect whether the stocks assessment are increasing or decreasing.

7.1 conceptual model of the life cycle of eel
Figure 24 The life cycle of eel. It shows in the life cycle of the eel each stage. Aquaculture, restocking and current changes influence glass eels. Dams stop the way when elver enters the river. Disease like swim bladder reduces number of silver eel which can go back to the Sargasso Sea to spawn. Over fishing and pollution can influence the eel at each stage.

This conceptual model shows the life steps of European eels and during it grows, some factors affect the eel population.

Silver eels spawn eggs in Sargasso Sea. However the large amount of eel eggs will be decrease. It could be as food eaten by other species of fish. The rate of mortality for eel egg is very high. Then the eggs will be growing to be laver eels. At this time the main factor influence the growth and population is ocean current. Following laver eels grow to be glass eels which living nearby European coast, it exist a problem of overfishing for glass eel population. Glass eels are fished on the west coasts of Portugal, Spain, France and Union Kingdom. They are captured for two main purposes. One is for eel aquaculture and another one is for restocking. Some countries fishing glass eels also transport to market directly like Spain. Glass eels continue to grow up and become elver then yellow eels. Water pollution affect them growth. In addition it also influences the population of silver eels. At present the fish man main captures silver eels for supplying to market, so overfishing is also a factor here. There is also another problem that is the bladder worm. This decease always happens in silver eels. At last, the rest living silver eel return to Sargasso Sea and spawn eggs then most of silver will die.

European eel’s population is not just influenced by the courses we have mentioned above; maybe we can consider that the living habit of eel is also a factor. It spawns eggs in the ocean, so the recruitment could be unstable. Furthermore, most of silver eels will be die after spawning, it decrease the population either.

7.2 Catch, effort and CPUE model

There are some data about Roskilde Fjord nets number. However, 72% of the fyke nets belonged to recreational fishermen and only 28% to the professional fishermen, suggesting that the unrecorded recreational fishery is important. Furthermore, selling fish on the black market is part of the fishermen's culture. We can not get exact number for eel catch. However Roskild Fjord catch is around 2% catch of whole Denmark, According to the limit number we make some assumption when we calculate catch and effort. We assume 10 fyke nets = 1 pound net; and Roskilde Fjord constitutes a rather small part (2%) of the total landings. We also assume CPUE of Roskilde Fjord is the CPUE of Denamrk.
CPUE is catch effort per unit effort, the equation is CPUE = catch / effort. Pound net reduced from 1950 to 2000. The highest catch level is in 1950 and lowest level in 2005. Decreasing catch indicates that overfishing is the fishery situation in Denmark. That gives pressure to fishman to reduce their nets. What is worse, eel population is close to biological limits has been a fact.

Catch has a highest point in 1970, after the catch has been going down. Indifferently, CPUE has been up from 1980 to 2000. Catch has a highest point in 1970, after the catch has been going down. Indifferently, CPUE has been up from 1980 to 2000. In the theory model, down trend CPUE indicates the stock is decreasing. However, the Roskilde Forjde case, CPUE has up trend, the reasons might be the technology of fishing has be improved. Electric gear, ecco sound and power of boat are all useful tool in fishing.

Figure 3. Total official catch (yellow and silver)

Figure 25 Total official catch from 1920 to 2000. Catch is decreasing sharply from 1980, it reach a lowest level recent year (ref34).

### Nets number catch and CPUE

<table>
<thead>
<tr>
<th>Year</th>
<th>Fyke net</th>
<th>Pound net</th>
<th>Total pound net</th>
<th>The total of catching eel (tons) per year</th>
<th>The catching eel Roskilde Fjord (tons) per year</th>
<th>CPUE (kg/net)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1950</td>
<td>2000</td>
<td>500</td>
<td>700</td>
<td>4500</td>
<td>90</td>
<td>130</td>
</tr>
<tr>
<td>1970</td>
<td>7000</td>
<td>800</td>
<td>1500</td>
<td>3250</td>
<td>65</td>
<td>40</td>
</tr>
<tr>
<td>2003</td>
<td>485</td>
<td>146</td>
<td>194.5</td>
<td>600</td>
<td>12</td>
<td>60</td>
</tr>
</tbody>
</table>

Figure 26 Nets number catch and CPUE. The figure shows the Fyke net and Pound numbers. We calculate total pound net, catch in Roskilde Fjord, and
CPEU (ref34).

Figure 27 overfishing, pound net reduced from 1950 to 2000. Figure shows the highest catch level in 1950 and lowest level in 2005. Decreasing catch indicates that overfishing is the fishery situation in Denmark.

Empiric model of CPUE

Figure 28 the relation between catch of eels and the number of pound nets, catch has a highest point in 1970, after the catch has been going down. Indifferently, CPUE has been up from 1980 to 2000 (ref34).

Theory model of CPUE
7.3 Objective of empirical model

In a drafted article ‘Mindstemål på gule ål I Roskilde Fjord og Isefjorden’ (Minimal length for yellow eel in Roskilde Fiord and Isefiord). There are some data on length, weight and number at age in a sample of 321 eels. We use length against age to demonstrate growth model, age against number to build mortality.

Data:

<table>
<thead>
<tr>
<th>Age</th>
<th>Average length</th>
<th>Average weight</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>t</td>
<td>L_t</td>
<td>W_t</td>
<td>N_t</td>
</tr>
<tr>
<td>2</td>
<td>26.5 cm</td>
<td>25.2 g</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>30.2</td>
<td>47.2</td>
<td>15</td>
</tr>
<tr>
<td>4</td>
<td>32.4</td>
<td>56.5</td>
<td>36</td>
</tr>
<tr>
<td>5</td>
<td>34.2</td>
<td>63.8</td>
<td>68</td>
</tr>
<tr>
<td>6</td>
<td>35.9</td>
<td>75.5</td>
<td>126</td>
</tr>
<tr>
<td>7</td>
<td>38.6</td>
<td>96.4</td>
<td>54</td>
</tr>
<tr>
<td>8</td>
<td>38.6</td>
<td>94.1</td>
<td>12</td>
</tr>
<tr>
<td>9</td>
<td>45.6</td>
<td>176.8</td>
<td>5</td>
</tr>
<tr>
<td>10</td>
<td>37.5</td>
<td>83.4</td>
<td>2</td>
</tr>
<tr>
<td>11</td>
<td>41.5</td>
<td>117.1</td>
<td>1</td>
</tr>
<tr>
<td>12+</td>
<td>74.0</td>
<td>1020.0</td>
<td>1</td>
</tr>
</tbody>
</table>

These are real data obtained from the commercial fishery in the fiords during
Eel population & Solution Model

the season 1994. As always with real data they do not fit 100% to our expectations by various reasons. For example is the average weight of 10-year old fish in the sample less than the average weight of 9-year old fishes. (ref36)

**First model: Age vLt----Growth model**

In fishery biology the so-called Bertalanffy’s growth equation is the most commonly used model for describing fish growth, we build the model in order know how fast eel grow in the natural environmental. As show in the figure, eel grow faster in early age, so we can conclude that glass eel grow faster than yellow eel, until it grows to silver eel and stops growing. The growth decrease parameter is 0.5. However, we only have limited data to make one plot, it is not possible to compare the grow rate.

We use matlab to plot the data and get the figure. The equation is

\[ L_t = L_{\text{infinite}} (1 - e^{-K(t - t_{\text{cero}})}) \quad \text{or} \quad L_{t+1} = a + b L_t; \quad (\text{ref38}) \]

Where \( L_t \) is the length at age \( t \)
\( L_{\text{infinite}} \) is the average max length for en infinite old fish
\( K \) is a parameter telling how fast the growth decrease
And \( t_{\text{cero}} \) is the ‘age at length cero’ i.e. the ‘age’ at which the growth-curve intercepts with the X-axis in the plot.

**Difficulties of plotting data:** When we use the last fish (12 years old), it is quite big fish with 74 cm. \( L_{t+1} = a + b L_t \) and \( x = y \) can not cross each other and so that it is not possible to find out \( L_{\text{infinite}} \). We assume the it is 70cm, the graph can look much nicer.

**Finding better data:** number of eel multiples length can give more accurate data for length of eel.
It means the length of eel in some age, L(t+1) means the length of eel in the age later than Lt one year.
When we put y=x into y=0.9537x+5.0215, L(t+1)=108cm
The relationship between age and length: Growth model

Figure 30: The relationship between age and length: Growth model. The model shows how fast eel grow in the natural environment. K 0.5 is the number for the grow decrease.

Second model: Mortality

Mortality is the outflow of k biomass. In this case, the mortality is the death rate from glass eel and silver eel. It can show if the stock biomass is in good size. As shown in the figure, mortality is 42%. That happens because the five causes that we mention above.

We apply the most common sub-model for mortality. The equation is

\[ N_t = N_{cero} e^{-Zt} \]

or

\[ \ln N_t = \ln N_{cero} - Zt \] (ref 39)

Where \( N_t \) is the number of the age of t years

\( N_{cero} \) is the number of fish when the yearclass enter the fishery. (Number of recruits).

When eel reach 6 years old, it can fully recruit. We use the number after 6 years.

And \( Z \) is the coefficient for the total mortality i.e. the Fishing mortality \( F \) plus the natural mortality \( M \).
Figure 31. The relationship between the age and the number of eel. X is age, Z mortality is 42%, We get the mortality rate is Ncero is the number of fish when the yearclass enter the fishery is 1.71
This chapter will bring together the results from the previous along with the theory presented in chapter 3. Comparisons will be made between the modeling results, with a discussion on differences between the conceptual model of the lifecycle of eel, empiric model and theoretical model. The discussion in this chapter will, in part, provide the basis for the suggested solutions, which are presented in Chapter 10.

Fisheries Research is studying at a complete and successful reproduction of eel in captivity for many years. Certainly, if this project success it will solve the very low levels of eel populations all over the world easily. But as far as we know until 2003 although Danish scientists succeeded to hatch a few larvae of the European eel, but they only survived up to 2.5 days post hatching. Therefore even it is good idea but we do not know when it will be succeed. Therefore handle both re-stocking and aquaculture is very indispensable at present.

The effects of global warming effect spread all over the world, and it is a global problem, which is not easy to solve by short-term. Actually nobody know exactly why the population of European eel decrease, scientist research found that glass eel have been drop to 1%, which can guess is the most important factor of decreasing population. Because of Global warming cause the temperature of sea become higher, which affect the livability of larvae of eel, after that cause eel decrease as well. In addition as the basic knowledge shows that the temperature of the water will decide the speed of the water flow directly, and it will because no so much glass eel can swim to the coast as before, instead some of glass eel will stay in the sea because the ocean current became slowly. And those glass eel will be die, due to there are no enough food to support them and also many other reason. But as we know the problem with Global warming cannot be solved in short time, it need everyone in the world to protect the environment. the problem above will be disappear when Global warming have been solve. Contrary it is more important focus on how to improve the eel’s output and how to protect them, for instance keep eel in the farming where can ensure their survival without pollution water, Aquaculture can also ensure enough amounts of glass eel in the wild, and thus contribute to the number of
silver el that migrate back to the Sargasso Sea for breeding.

According our research we found that re-stocking and aquaculture could help increase the population of eel in long-term and short-term. Consider many seas, rivers and streams have been polluted, which will affect population of most of fishes include eel, and also some eels have diseases, which will affect the eel population as well. Of course those factors could not be solved in the wild, contrary aquaculture would solve problems at least for the supply of eels. For instance there is good enough water supply for eel in aquaculture, and if any eel has disease the farmer finds, then they separate the infected eels from healthy eel, then treat them with medicine. Further more aquaculture have many advantage for eels that we have described in more detail in part 6.3.4. But nothing is perfect, everything has its advantage and disadvantage at the same time, the same goes for aquaculture: even aquaculture have many advantages for eel, but it still have few detrimental consequences for the eel. For example eels which live in the farm will lose their natural habitat. But anyway aquaculture still has more advantage than disadvantage, so we can say aquaculture is useful.

Re-stocking of glass eel gives long-term benefits; due to people have no ability to help eel breed in farming. Therefore it is necessary to ensure enough glass eel can survival, until they become silver eel, and after that swim back to the Sargasso Sea to breed. The same as we discussed above that aquaculture have both advantage and disadvantage, re-stocking has it in the same way. Where the glass eel can continue survival by bringing them from one area where the environment is not good enough for glass eel to another region, or somewhere the glass eel could not pass the other side and so on. Those methods help the glass eels to continue living in the wild, and the advantage is that the glass eel will not lose their habitat, and continue to live in their own way. But mortality will be higher than in aquaculture, due to glass eel in the aquaculture can be controlled by the farmer, but their life is depending on the natural environment completely.

We think both aquaculture and re-stocking are important for the eel, and we can not say which one is better, contrary we only can say that aquaculture is better for short-term, and re-stocking is better for long-term.

During the last 20 years, the population of the European eel (Anguilla anguilla) decline quickly, it is related with the many factor is cause the decline of the eel population: fisheries at different life stages of eel, hampering the immigration of glass eel, mortality due to water quality issues, parasites (e.g. Anguillicola crassus) or ocean currents etc. Natural mortality rate would vary with age and area. The mortality ranges was narrow which between 6-12% for northern area and wild which between 11-32% for southern area. There are high
of mortality rate in the early life stages. (ref37)

According the picture 32 shows that different mortality rate in the different stage, which are glass eel, yellow eel and silver eel. The highest mortality rate is glass eel, and the yellow eel is not so easy die, then the mortality rate of silver eel is also high, but not as high as glass eel. Therefore it will be very great way that capture glass eel from wild then cultivate them in farming, then the mortality rate will reduce very much from glass eel to silver eel, we can see the result clear in the picture 32. Despite this method is perfect in some way, we suggest it would be used, but at present nobody adoptive it, due to no one merchant would like to business without benefit. The problem of it is not the technology or other reason problem, the main problem who would like to do, government or businessmen. We think government has to make law to stimulate farming to deal with. And we suggest government would adopt the similar method as protect field. As we know it is not every fields be used, in order to protect the quality of fields that not be used, government pay money for the farming to protect them by plant glass, which can protect the quality of the soil. The same as eel, it also imitate the method of protect the soil. Government should pay eel farming, and the farming have to follow the rule the government made. But if the technology of breed the larvae in the aquaculture successful, of course it will be the best way to solve the problem. We can see the curve of future shows that farmer can produce larvae in the aquaculture, and feed, protect them until they became silver eel which can consumption for people. But this technology still in the way of study, we hope it will come true soon.
t0  glass eel  t1  t2  yellow eel  t3  silver eel

t0 to t2; glass eel
T1 to t2; re-stocking glass eel
T2 to t3; yellow eel
after t3; silver eel

Figure 32 Aquaculture could help protect the population of the eel compared with nature, due to there are more higher mortality in nature than in aquaculture during the life of glass eel to silver eel. But the problem of eel will disappear if scientists could breed larvae in the aquaculture.

Conclusion 9
From our group research we found that the problem of decrease population of European eel cause by five factors. It tells us that lead to this problem could be taken in short time, but it will affect us for a long time. Furthermore solve the problem will be more difficult, not only spend more energy by human being, but also cost higher economic expense. Even some case could not retrieve, such as extinction. Fortunately the population of European eel still did not dangerously close to collapse. Therefore we still have opportunity to retrieval it. And actually these problems already have been attaching importance, and try many ways to solve it as well. Such as issue for enforcement for fish men, farming and so on who are oblige to follow the law that the government made. Our group suggests two ways can solve the problem as well, which are solute the problem both by aquaculture and re-stocking in short-term and long-term. Also we also analysis capture more glass eel to cultivate in the farming until they become silver eel. then release enough silver eel in the wild, and the purpose of this is ensure enough silver eel downstream to sea where they can contribute to breed enough glass eel. We are thing this is very great way, and we hope this method would be adopt.

We also made three kinds model, which are conceptual model, empirical model and theory model. Conceptual model can see the result of population of European eel by five causes. The second kind of model is empirical model, we have build three model, which are catch, effort and CPUE, growth and mortality. From those models we can see the phenomenon of the problem both at present and future, if the phenomenon continues. Those model would help to remind of people what it will be happened if we do not solute it. Also can tell us which way is better to solve the problem, for instance combine the model mortality and theory model of imagine catch more glass eel in farming until silver eel, which tell us that the eel mortality in the wild is much high than aquaculture.
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10.2 Photo from case study
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[Image of a boat on the water]

[Image of the sea at sunset]

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