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CONTENTS

EXECUTIVE SUMMARY

Costs and Benefits of Control Strategies (COBECOS) is a Sixth Framework Programme (6FP) project that aims to support the drafting and implementation of Community policies. It started in February 2007 and finished in July 2009. The consortium consists of 12 partner Institutes from the EU, Iceland and Norway.

The primary objective of COBECOS is to conduct a cost-benefit analysis of control schemes for management strategies relevant for the EU Common Fisheries Policy (CFP) and, based on this analysis; infer the potential economic benefits which might accrue from proper enforcement of the management measures. Moreover, COBECOS can find optimal combinations and intensities of fisheries enforcement tools that maximise the benefits for the society.

The overall objective has been achieved on the basis of an appropriate theory of fisheries enforcement, empirical research involving intensive case studies and estimation of theoretical relationships and a full functioning software modelling fisheries enforcement, which allows users to investigate the costs and the benefits of enforcement tools of various EU fisheries and management situations.

A recent working paper by the European Commission estimates that 80 % of the European fish stocks are currently being over exploited. Out of these 30 % are outside safe biological limits[1]. One of the reasons of the overexploitation of the resources is that fishers have incentives to maximize their private benefits from fishing, without considering the true cost of fishing. When the stock externalities of fishing are neglected, the harvest level often exceeds the level that is optimal for the society, a phenomenon generally referred to as the common property problem.

The role of managers is to implement regulations that will minimize the occurrence of the common property problem. Most regulations aim at controlling the fishing activities by limiting the number of licenses, quotas or the fishing effort. Fishery regulations are not, in general, self-enforcing. This means that fisheries management is not useful unless it is enforced. Thus, an enforcement system must be present in order for the regulations to have the desired effects.

Enforcement of fisheries management systems is typically quite costly relative to the gross value of the fisheries. Available empirical estimates put the cost of fisheries enforcement between 2 and 8 % of the gross value of landings. As the total value of landings by the EU fleet is estimated to be more than seven billion Euros, the cost of fisheries enforcement might well be between 150 and 600 million Euros per annum. It is likely that these funds could be more effectively used.

The COBECOS theory and software has been tested in 9 case studies, from where it has been possible to obtain important implications. The heterogeneity of the case studies and the variety of dimensions considered demonstrates the generality of the theoretical enforcement model and its feasibility to be applied to real fisheries situations independently on the number of management and enforcement tools. Case studies have allowed us to analyse the effects of compliance and enforcement on a broad number of

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[1] Commission Working Document on the review of the Common Fisheries Policy, 29 September 2008.

fisheries management tools: TAC-restrictions, Effort restrictions, Technical restrictions, individual quotas, Minimum mesh sizes, Minimum fish size restrictions, Input restrictions, seasonal and area closures, discarding, etc. The fisheries analysed include mono-species and multi-species fisheries, pelagic and demersal fisheries, as well as mono-gear and multi-gear fisheries. For the enforcement system there have been analysed dock-side inspections and inspections at sea represent the prevalent enforcement tools considered in the simulation models, but also plane surveillance has been taken into account in some of the case studies. Case studies have simulated both very simple scenarios, defined by single management and enforcement tools, and complex combinations consisting in multiple management and enforcement tools. The optimal enforcement system maximizing social benefit, expressed in terms of enforcement tools and their optimal intensity, seems to be very far away from the current situation for most of the case studies analysed.

Variations in the enforcement effort affect the probability of being detected when violating, and consequently the private cost of violation. As fishers operate to maximize their profit, the level of violation will decrease if expected cost of violating increases. The optimal level of violation (i.e. compliance) for the fisher is obtained when the marginal cost of violating equals the marginal benefit of violating. Naturally, the enforcement effort is also affecting the cost of enforcement and has to be deducted from the benefits brought upon by it. As predicted by the theory, most fisheries in the project show that an increase in the enforcement level will increase the compliance and the social benefits up until the point where the costs of enforcement outweigh the benefits. The three case studies that also investigate the effects of the enforcement effort on the stock size have also found a positive relationship between the two. The improved stock size is explained by the increase in compliance that a higher enforcement effort produces.

Often full compliance is set as the target for enforcement management. Generally, an increase in the levels of enforcement effort and/or the amounts of fines is suggested in the case studies to improve the social benefits. However, the maximum social benefit is not normally coincident with a situation of full compliance for almost all case studies. This is due to the high costs needed to achieve full compliance, which are not justified from an economic perspective. This happens in many cases, as the cost of enforcement outweighs the benefits of enforcement when compliance is close to the 100 %. In these cases, increasing the enforcement effort further would decrease the benefits to the society and low level of violation of fisheries regulations would be considered acceptable.

Since the theory states that fishers will conduct in illegal activity as long as the expected benefits are greater than the expected costs of the action. Then by increasing the penalties the expected costs of illegal activities increases and so the illegal harvest is reduced. Thus, imposing higher sanctions when violations are detected represents an alternative to increasing enforcement effort. Both actions determine an improvement in the levels of compliance with regulations, but higher fines do not produce additional costs to the enforcement activity. Therefore, as enforcement effort is costly, the standard policy prescription should be to, as far as possible, increase the scale of the expected fines. However, even if fines cannot be increased indefinitely, the maximum social benefit can be achieved at lower enforcement effort and consequently lower costs when higher amounts of penalty are imposed.

1 INTRODUCTION

A recent working paper by the European Commission estimates that 80 % of the European fish stocks are currently being over exploited. Out of these 30 % are outside safe biological limits[2]. One of the reasons of the overexploitation of the resources is that fishers have incentives to maximize their private benefits from fishing, without considering the true cost of fishing. When the stock externalities of fishing are neglected, the harvest level often exceeds the level that is optimal for the society, a phenomenon generally referred to as the common property problem.

The role of managers is to implement regulations that will minimize the occurrence of the common property problem. Most regulations aim at controlling the fishing activities by limiting the number of licenses, quotas or the fishing effort. Fishery regulations are not, in general, self-enforcing. Neither other fishermen nor the crew of other maritime vessels inform the authorities of infringements they witness. This means that an enforcement system must be present in order for the regulations to have the desired effects.

1.1 STATE OF THE ART

The theory of fisheries enforcement is quite limited at present. It is a new topic in fisheries science and it was not introduced until 1985, by the study of fisheries law enforcement by Sutinen and Anderson (1985). The modern theory of fisheries enforcement stems from the general theory of economics of crime presented in Bekker's Crime and Punishment from 1968. In his study Bekker used economic theory as the basis to analyse how governments should choose enforcement levels and measures of punishment in order to maximise a social welfare function. Rationality by individual agents is an important assumption in the literature, and committing a harmful act is assumed to be a rational choice for the offender. Most articles in the field published after Becker (1968) are extensions of his model.

In 1985, Sutinen and Andersen (1985) published their study of fisheries law enforcement, where Becker's model was applied to analyse regulatory compliance in fisheries. The findings of Sutinen and Andersen have been extended in various studies by Charles (1993), Arnason (2003) etc.

Despite the recent development of the theory not many empirical studies have been carried out previous to COBECOS. In fact, COBECOS is the first study in which empirical research, including extensive data collection, estimation and simulations are being carried out to a large set of very different case study fisheries. Furthermore, COBECOS is pioneering by the development of a complete theoretical and computer bio economic model that is able to estimate the costs and the benefits of control strategies.

So far no other project or study has managed to achieve the outputs of COBECOS. Hence, the project is completely innovative.

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[2] Commission Working Document on the review of the Common Fisheries Policy, 29 September 2008.

1.2 SUMMARY DESCRIPTION OF THE PROJECT

Costs and Benefits of Control Strategies (COBECOS) is a sixth Framework project with the aim at supporting the drafting and implementation of Community Policies. It was initiated in February 2007 and finalised in the end of July 2009.

The project consists of 12 partner institutes from the EU, Iceland and Norway. Professor Ragnar Arnason at the University of Iceland is the overall coordinator and Jenny Nord of the Joint Research Centre of the European Commission is the scientific coordinator.

1.2.1 Project objectives

The primary objective of COBECOS is to conduct a cost-benefit analysis of control schemes for management strategies relevant for the EU Common Fisheries Policy (CFP) and, based on this analysis; infer the potential economic benefits which might accrue from proper enforcement of the management measures.

Moreover, COBECOS can find optimal combinations and intensities of fisheries enforcement tools that maximise the benefits for the society.

The overall objective will be achieved on the basis of:

1. an appropriate theory of fisheries enforcement,
2. empirical research involving intensive case studies and estimation of theoretical relationships,
3. computer modelling of fisheries enforcement

The output of COBECOS is therefore a consistent theory of fisheries enforcement as well as practical computer model that can be used by the EU and individual Member states to improve fisheries enforcement and management.

On the basis of the model the project is expected to be able to provide answers to practical management questions such as:

- What are the costs and benefits of increased enforcement effort in particular fisheries?
- If compliance alters (exogenously) in certain fisheries what are the costs and benefits?
- What are the impacts of increased penalties for violations of fisheries rules?
- How do different control schemes compare when the cost of enforcement is taken into account?

1.2.2 Partners

COBECOS consists of 12 highly ranked partner institutes from the EU, Iceland and Norway. Ragnar Arnason at the University of Iceland (IoES) is the overall project coordinator and Jenny Nord of the Joint Research Centre of the European Commission (JRC) is the scientific coordinator of the project. The project proposal was written jointly by Ragnar Arnason and Iain Shepherd (JRC).

Table 1 COBECOS partners

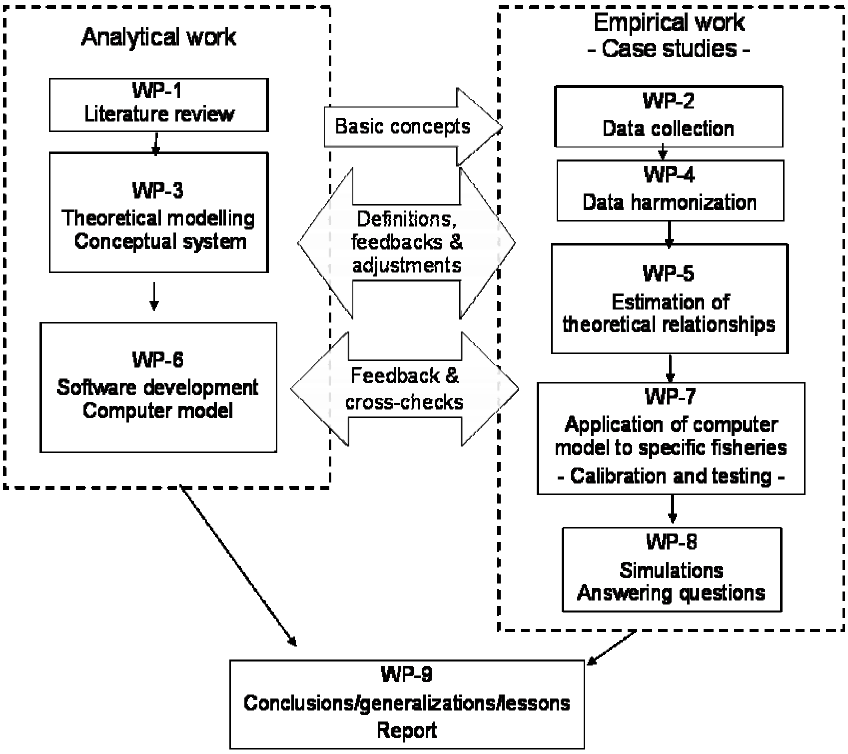
Institute	Abbreviation	Contact person
Institute of Economic Studies University of Iceland	IoES	Ragnar Arnason *(Project coordinator)*
European Commission Joint Research Centre, Ispra, Italy	JRC	Jenny Nord *(Scientific coordinator)*
Fundación AZTI, Spain	AZTI	Raúl Prellezzo
Centre for Marine Law and Economics Université de Bretagne Occidentale, France	CEDEM	Bertrand Le Gallic
L'Istituto di Ricerche Economiche per la Pesca e l'Acquacoltura, Italy	IREPA	Loretta Malvorosa
Department of Environmental and Business Economics, University of Southern Denmark	USD	Niels Vestergaard
Institute of Food and Resource Economics, The Royal Veterinary and Agricultural University, Denmark	FOI	Frank Jensen
Norwegian School of Economics and Business Administration, Bergen. Norway	NHH	Rögnvaldur Hanneson
Agricultural Economics Research Institute Netherlands	LEI	Erik Buisman
Centre for Environment, Fisheries & Aquaculture Science, UK	CEFAS	Laurence Kell, Trevor Hutton
Centre for the Economics and Management of Aquatic Resources , UK	CEMARE	Aaron Hatcher, Simon Mardle
Imperial College of Science and Technology, UK	IC	David Agnew, Richard Hillary

Furthermore, the project sub-contracts MRAG (Marine Resource and Fisheries Consultants) and Agrocampus Rennes for specific tasks.

1.2.3 Work packages

The effort of COBECOS is divided into nine work packages

Figure 1. Overview of work packages.



During the first three months of the project a thorough review of the existing literature was made. Based on this review the theoretical work package started to develop the model of fisheries enforcement. Once finalized, the model served as the blueprint for the estimation case study and to the software development.

In order to ensure a harmonized data collection, work package 4 defined which indicators to be collected within the data collection work package. Based on these, each case study carried out an extensive data collection that covered biological, socio-economic and technical characteristic indicators as well as data on the management system in place and cost of enforcement. The data has been stored in a database that will be kept for the benefit of future work within the area.

In the estimation work package the case studies developed its own empirical enforcement model based on the bio economic framework developed in work package 3. In order to investigate the costs and the benefits of control strategies a number of simulations were carried out within work package 8.

2 THEORY

This chapter summarizes the fisheries enforcement theory developed under the COBECOS project. This theory is intended to serve two practical purposes: (1) offer theoretical guidelines to practitioners of fisheries enforcement and (2) provide a theoretical foundation for the empirical case study work of the COBECOS project.

The basic theoretical elements are laid out in the first two sections. These sections are reasonably autonomous, developing the basic relationships and results of enforcement theory from first principles of economic behaviour employing standard analytical techniques. Thus, it can serve as a stand-alone presentation of the key elements of fisheries enforcement theory. It is also written in a way that should make it reasonably accessible to fisheries managers and others engaged in fisheries enforcement activities.

To meet objective (2); providing a foundation for the empirical case study work, the last section of the chapter is devoted to explaining how the theory can be applied. While this section does not claim to be anywhere near to being complete, it should provide empirical researchers with some useful guidelines as to how to apply the less standard and more involved parts of the theory.

In the deliverable D3, Fisheries Enforcement: Basic Theory and how to apply it, provides further details of the previous sections as well as a collection of essays, which have been developed in connection with this project, on interesting aspects of fisheries enforcement.

The importance of this chapter on the theory of fisheries enforcement comes from the fact that the existing theory of fisheries enforcement and, actually, enforcement in general, is quite underdeveloped. This does not mean, however, that the enforcement theory presented in this report is completely original, autonomous and owes no debt to previous work; on the contrary. First, the enforcement theory of this report is built on the customary neo-classical micro-economic theory and derives its results from axioms and theorems already developed within that theory. Crucial in that respect are the principles of profit and utility maximization. Second, the enforcement theory actually developed in the report follows the approach employed by early researchers in the field, foremost among whom are Becker (1968) and Stiegler (1970). Third, subsequent to the path-breaking contributions of Becker and Stiegler, many researchers have contributed to the theory of enforcement. Indeed, a few have developed their enforcement theory with a particular focus on fisheries, one of the earliest of which is Sutinen and Anderson (1985). Other references are provided in the bibliography at the end of this report. It would be misleading, however, to claim a particular affinity or influence between these earlier works in fisheries enforcement and the enforcement theory developed in this report. The link is merely that both stem from a common analytical approach initiated by Becker (1968) and Stiegler (1970). Thus, as is readily verifiable many of the results presented in this report are new or at least novel in the particular form presented. At the same time, not surprisingly, there are also many similarities to results in previous works in the field. Equally importantly, no obvious contradictions of significance with previous work have been spotted.

2.1 LITERATURE REVIEW

The general economic theory of economics of law enforcement dates back to the analysis of Becker (1968). In his work he stated that potential criminals rationally see that benefits from their crimes may outweigh the probability of detection, conviction and punishment. From the public point of view, the potential that crime is rational for criminals, forces the authorities to trade off a) the loss to society from increasing the resources spent detection, conviction and punishment of criminals with b) the loss to society from illegal activities taking place.

Sutinen and Anderson (1985) applied the theory of Becker (1968) to study regulatory compliance in a model of fisheries. Profits from taking part in the fisheries explain the behaviour of fishermen, both with respect to optimal private harvest and optimal private compliance. Since fisheries can be described by the 'Tragedy of the commons,' the social loss from not overseeing the fishery could be very high because the resource may be eradicated. Further, enforcing the fishery is costly. Accordingly, one should not eliminate all illegal fishery activities, but rather trade off the benefits to the costs of enforcing the harvesting. Several of the assumptions applied in the work of Sutinen and Anderson (1985) has been elaborated in the literature.

The analysis of Andersen and Sutinen (1985) assumes that there are individual non-transferable quotas, and there are now several analyses that builds on and extends the analysis of Sutinen and Anderson (1985). Some authors discuss whether one should include illegal profits as a part of social surplus or not, and one can demonstrate that this will have a significant impact on optimal public policies, see for instance Milliman (1986). Other authors solve the compliance problem by introducing individual taxes, while yet others discuss the use of individual transferable quotas instead of non-transferable quotas.

While the above-mentioned analyses are theoretical, there are also some empirical analyses. Sutinen and Kuperan (1999) argue that levels of compliance are high in most fisheries. This is not as expected since the same fisheries are characterized by having both relatively low fines and low probability of detecting illegal behavior. Sumaila et al (2006) argues that this is also the case in quite a few fisheries around the world.

Thus, there is a growing theoretical literature on the issues that is concerning the COBECOS-project. These analyses – like the COBECOS-modelling bases its analyses on the general economic theory of crime and punishment. However, as the modelling in Andersen and Sutinen (1985) demonstrates, non-compliance in fisheries must be adjusted to take into account the fact that fisheries are plagued with the common property problem. Furthermore, there are some empirically based analyses that indicate that overall compliance seem to be higher than what the pure rational choice model advocated by Becker (1968) suggests.

The interested reader is referred to deliverable D1 "Literature review" for the complete literature review.

2.2 THEORETICAL MODELLING AND CONCEPTUAL SYSTEM

2.2.1 Fisheries Enforcement: Basic Theory

The following represents the essentials of the theory of fisheries enforcement. In order to focus on these essentials, the following important simplifications are made:

- There is no attempt to distinguish between management systems. (This is a comparatively trivial extension, which is to a certain extent dealt with in Chapter 3).
- The dynamics of the fishery situation are modelled in a very simple manner (employing a resource depletion charge, λ which of course can vary from period to period).
- The number of exogenous variables entering the situation is kept to the strict minimum.

Following the theoretical analysis, the chapter offers a few comments about what empirical data needs to be collected to apply the theory. It concludes with a simple numerical example.

2.2.1.1 Basic modelling components

Social benefits from fishing:

(1) $B(q,x)-\lambda\cdot q.$[3]

$B(q,x)$ is the private benefit function (measured by profits, surplus salary, conservation sentiments etc. as the case may be). The variable q represents extraction and x biomass. $B(q,x)$ is assumed to be a jointly concave function, monotonically increasing in x and at least ultimately declining in q. It is convenient for representational purposes to assume $B(q,x)$ to be differentiable. The variable λ represents the shadow value of biomass, so $\lambda\cdot q$ is the social resource depletion charge.[4]

The ***management tool*** in this context is q.[5] This obviously corresponds exactly to a TAC regime. All fisheries management systems except the biological ones (mesh sizes,

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[3] More generally, social benefits of fishing would be written as $B(q,x)+\lambda\cdot\dot{x} \equiv B(q,x)+\lambda\cdot(G(x)-q)$, where $\dot{x}$ represents net biomass growth and $G(x)$ is the natural biomass growth function. However, if the only control is the volume of harvest, q, $\lambda\cdot G(x)$ is given at any point of time and can be omitted as in (1).

[4] This, of course, can reflect both fisheries and conservation values as well as other stock related concerns such as risk. There is a slight theoretical weakness in this formulation in that the correct λ generally depends on the level of harvest.

[5] The fisheries management system is a collection of fisheries management tools. A fisheries management tool is a variable that affects fishing behaviour and is (at least to an extent) controllable. A fisheries management measure is a value for one or more fisheries management tools.

MPAs, etc.) attempt to control q directly or indirectly. For instance, effort restrictions attempt to do that by controlling effort—an important determinant of q.

Once a value for the management tool has been selected, i.e. a management measure imposed, it needs to be enforced (provided of course it is binding) [6]. We consider two components of the ***enforcement activity***:

1. Enforcement effort, e.
   This is basically monitoring, surveillance and control activity. This can be affected by many means at-sea or on-land. It is generally quite demanding in terms of manpower and equipment and, therefore, costly.
2. Sanctions, f.
   It is convenient to think about the sanctions as fines. However, they can be harsher. In what follows we will, for simplicity, think of the fines as exogenous constants. To impose the sanctions generally requires certain administrative and legal proceedings. It is analytically convenient to think of these processes as a part of the enforcement effort.

The enforcement effort generates a certain probability of being observed violating management measure (restrictions) and apprehended (cited). It also generates a certain probability of having to suffer a sanction if apprehended. Let us represent this composite probability of having to suffer a penalty if one violates management measures by the following probability function, which we refer to as the ***penalty probability function***:

(2) $\pi(e)$, $\pi(0)=0$, $\lim_{e\to\infty}\pi(e)=1$.

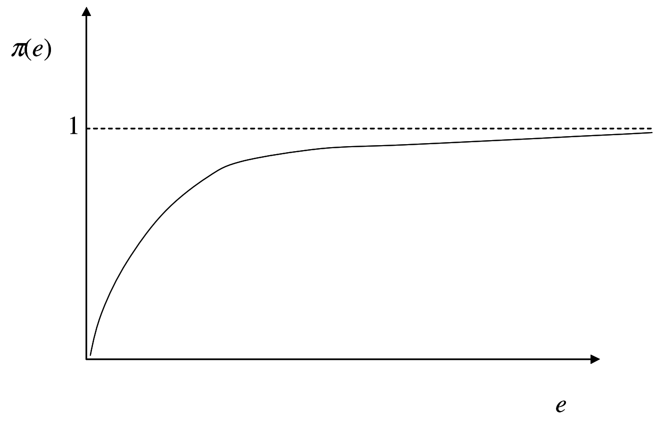
Most likely this function will look like the one depicted in Figure 2. This, obviously, is a concave smooth, monotonically increasing function.

Clearly, the main purpose of the enforcement activity is to increase the probability of a penalty. For a given enforcement technology, this can only be done by increasing enforcement effort.

There will of course be costs associated with the enforcement activity. Let us describe these costs by the ***enforcement cost function***:

Figure 2

The penalty probablity function: Illustration



(3) $C(e)$.

This function may be taken to be increasing in the enforcement effort and at least weakly convex.

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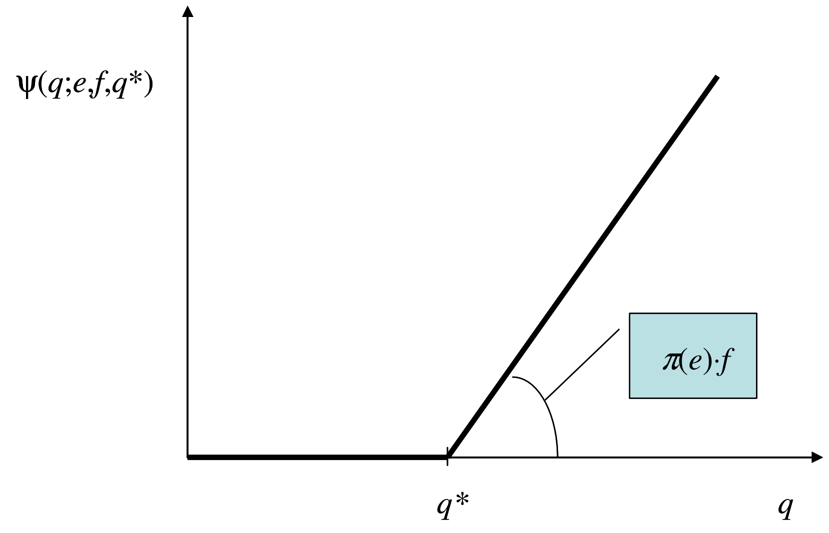
[6] If it is not binding, then it is irrelevant and there is no case to analyse.

The last basic component of this simple enforcement model is the cost to private operators, the fishers, of violating a management measure. Given the inherent uncertainty of having to suffer a penalty, this must be an expected cost. We refer to this expected cost function as the ***private costs of violations*** and write it simply as:[7]

$$(4)\quad \begin{aligned} \psi(q;e,f,q^*) &= \pi(e)\cdot f\cdot(q-q^*), \text{ if } q\geq q^*.\\ \psi(q;e,f,q^*) &= \quad 0 \qquad , \text{ if } q<q^*, \end{aligned}$$

where q^* is some management measure. Of course, as already mentioned, the second case, where $q<q^*$ is not of interest. The shape of private costs of violations function as a function of the extraction level is illustrated in Figure 3 Note the non-smoothness of this function at $q=q^*$. This is mathematically awkward but theoretically trivial. Clearly, the slope of this function is a major determinant of the deterrence against violating fisheries rules. Note that this increases with the penalty level, f, and the enforcement effort.

Figure 3
Private costs of violations function: Illustration



Combining the above basic elements of the theory, we can obtain the following two fundamental benefit functions:

From (1) and (3) we obtain the ***social benefits with costly enforcement***

$$(5)\qquad B(q,x)-\lambda\cdot q - C(e).$$

This is the appropriate function for the management authority to maximize. The function in (1) ignores fisheries management enforcement costs and is therefore not a measure of the social benefits from fisheries of management. Determining the management policy by maximizing (1) instead of (5) is generally a mistake which may be very costly.

Expressions (1) and (4) provide us with the ***private benefits from fishing under binding management***.

$$(6)\qquad B(q,x) - \pi(e)\cdot f\cdot(q-q^*)$$

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[7] Note that this formulation makes several implicit simplifying assumptions: (i) it assumes that all management measures can be expressed as an upper bound, (ii) it assumes risk neutrality and (iii) the penalty depends linearly on the amount of violations. The first assumption is, I believe, nonrestrictive. The second and third are more doubtful. To relax them, however, would, I believe, not change the essence of the analysis, only make it more complicated.

This is the function private operators, i.e. the fishers, will try to maximize at each point of time.

2.2.1.2 Analysis

We are now in a position to examine the situation analytically and draw certain important conclusions.

Private behaviour

Private behaviour (under restrictive management) is defined by the following:

(7) $q = \arg\max(B(q,x) - \pi(e) \cdot f \cdot (q - q^*))$

Assuming sufficient smoothness this implies the implicit equation:

$B_q(q,x) - \pi(e) \cdot f = 0$,

which implicitly defines the behavioural equation:

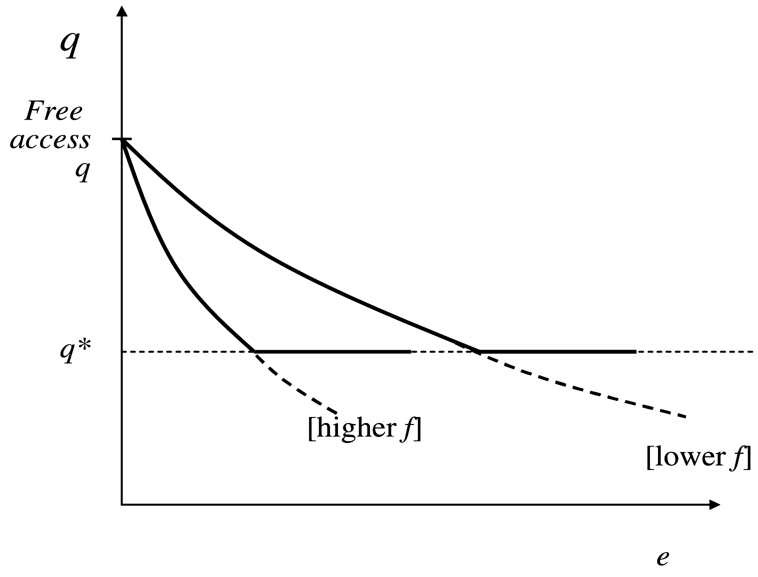
(8) $q = Q(e,f,x)$.

This equation is in many respects central in the analysis. It may be called the ***enforcement response function***. Given our previous specifications it is easy to show the following:

$\frac{\partial q}{\partial e} < 0$, $\frac{\partial q}{\partial f} < 0$, $\frac{\partial q}{\partial x} > 0$, provided $B_{qx} > 0$, i.e. increased biomass enhances the marginal benefits of harvesting. The likely shape of the enforcement response function is illustrated in Figure 4.

It is worth noting that the kinks in the curves in Figure 4 occurring at points where the actual catch is equal to q^* correspond to the situation where it is optimal for the fishers not to violate at all. This happens when $B_q(q^*,x) - \pi(e) \cdot f \leq 0$. At these points there is a discontinuity in the marginal private benefit function and a corresponding kink in the enforcement response function.

Figure 4
Likely shape of the enforcement response function



Note also that the greater (numerically) the slope of the enforcement response function, the more effective is the enforcement. This immediately implies that by the simple expedient of increasing the penalty, enforcement can be made more effective.

Compliance

With the enforcement response function in hand, we can now immediately obtain a measure of the compliance level. One such measure is simply:

(9) $q^*\text{-}Q(e,f,x)$.

Note that according to this measure, compliance increases in enforcement effort, e, and penalties, f, but decreases in the stock level, x. This is of course highly intuitive. With a higher stock level, the marginal benefits of catch generally increase (if only because the cost per unit of harvest falls).

It is convenient to define a dimensionless measure of compliance. There are of course many such measures. An attractive one is:

$$\Omega = \frac{q_{com} - Q(e,f,x)}{q_{com} - q^*} \in [0,1], \tag{10}$$

where Ω is the compliance level and q_{com} represents the open access (or unmanaged) harvest level. So, when there is no compliance, Ω assumes the value zero. When there is 100 % compliance, $Q(e,f,x)=q^*$ and Ω equals unity.

Social Optimality

The social problem is to maximize the social benefit function subject to the enforcement response function and other relevant constraints. More formally the social problem is to:

$$\underset{e}{Max}\ B(q,x)\text{-}\lambda\cdot q - C(e).$$

Subject to: $q= Q(e,f,x)$,
$e\geq 0$,
f fixed.[8]

Assuming sufficient smoothness and an interior solution, the solution to this problem may be written as:

$$(B_q(q,x)-\lambda)\cdot Q_e(e,f,x) = C_e(e). \tag{11}$$

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[8] Note that in this formulation λ, the shadow value of biomass, is taken to be independent of the control e. This holds generally when the optimal level of e (Kamien and Schwartz 1981). In reality, this would normally not be the case and it would be more appropriate to regard the shadow value of biomass as a function of e. However, since λ depends on the whole path of e and is therefore not much affected by a single change in e it may be a reasonable approximation, even in suboptimal cases, to regard λ as exogenous.

Equation (11) defines the socially optimal enforcement effort level, e_{opt}, say. By implication it also provides a measure of the socially optimal compliance level as

$$(12)\qquad \Omega_{opt} = \frac{q_{com} - Q(e_{opt}, f, x)}{q_{com} - q*}.$$

Obviously, the socially optimal compliance level would only rarely be unity.

Now, ignoring management costs (and assuming 100 % compliance) implies the social optimality condition:

$$(13)\qquad B_q(q,x) = \lambda .$$

We immediately draw the following important conclusions:

I Under costly enforcement, socially optimal harvesting levels will be greater than otherwise.

To see this, it is sufficient to note that (11) implies $B_q = \lambda + C_e / Q_e$ and the last term is, according to our assumptions, negative. Therefore, $B_q < \lambda$ and since B_{qq}<0. q must now be higher.

II. Only when 100 % compliance is achieved costlessly, will socially optimal harvesting levels be defined by (13).

This obviously happens in two cases: (i) the cost of enforcement is actually zero, (ii) the effectiveness of enforcement is infinite (vertical cost of violations function see Figure 3 or equivalently vertical enforcement response function see Figure 4) so infinitely small enforcement effort is sufficient to ensure 100 % compliance.

Benefits of increased compliance

Sometimes it is asked what would be the benefits of increased compliance. To answer this question one has to be very specific with respect to two aspects of the situation. First what benefits, if any, does the fishery produce. Second, where does the increased compliance come from.

Let us for convenience consider two alternatives for each variable. More precisely, let the fishery either be fully efficient (producing maximum benefits) or totally inefficient (producing no benefits). The former case would apply under perfect management and the second under a poor management regime. As regards the source of the increased compliance let us assume on the one hand that it increases without any change in enforcement effort and on the other hand that it increases because of increased enforcement effort. Obviously, these alternatives generate four different possibilities:

Consider first an ***efficient*** (perfectly managed) ***fishery***: Costless increase in compliance generates the benefits:

$$(14)\qquad -(B_q(q,x) - \lambda)\cdot dq ,$$

where $-dq<0$ is a measure of increased compliance (remember compliance is q^*-q).

The second possibility is that compliance increases because enforcement effort is increased. In that case the gain is

$$(15) \qquad -(B_q(q,x)-\lambda-C_e\cdot\frac{\partial e}{\partial q})\cdot dq\,.$$

Note that the derivative $\partial e/\partial q$ is positive, so for the same increase in compliance the gain in (15) is less than the gain in (14).

Consider now the ***inefficient*** (poorly managed) ***fishery***. In this fishery, the private benefits from fishing are approximately zero[9] and the private marginal benefits to harvest also. So in this case, the social benefit function (restricted to an inefficient fisheries management system) would approximately be (see (5) with $B(e,x)\equiv 0$):

$$-\lambda\cdot q - C(e).$$

Thus, the benefits of increased compliance when that happens costlessly would be:

$$(16) \qquad \lambda\cdot dq$$

I.e., it is just the shadow value of the biomass as assessed by society. As the shadow value of biomass to the fishery would be approximately zero, this would primarily represent the value of an improved fisheries management in the future and/or conservation demand.

The benefits of increased costly compliance would be:

$$(17) \qquad \lambda+C_e\cdot\frac{\partial e}{\partial q}\cdot dq\,.$$

Clearly, the outcome in (17) can easily be negative.

2.2.1.3 Empirical data needs

To do the calculations discussed in previous section, the following model components need to be known:

1. The private benefit function, $B(q,x)$.
2. The social shadow value of biomass, λ.
3. The enforcement cost function, $C(e)$
4. The probability of penalty function, $\pi(e)$.
5. The penalty schedule, f.

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[9] In equilibrium. Private benefits may be positive or negative along approach paths to this equilibrium, but most likely their present value is close to zero.

Not all of these functions are needed for all calculations. To estimate and predict compliance we only need 1, 4 and 5. To estimate and predict the social benefits from altered enforcement, however, we need all five.

2.4 A very simple example

To illustrate further, it may be helpful to construct a very simple example.

1. The private benefit function: $B(q,x) = p \cdot q - c \cdot \frac{q^2}{x}$.
2. The enforcement cost function: $C(e) = \pi(e)$[10]
3. The penalty probability function: $\pi(e) = 1 - \exp(-e)$

Given these specifications, the enforcement response function is: $q = \frac{(p - \pi(e) \cdot f) \cdot x}{2c}$

The privately optimal harvest under no management is: $q^\circ = \frac{p \cdot x}{2c}$.

The socially optimal harvest level under no enforcement costs is: $q = \frac{(p - \lambda) \cdot x}{2c}$.

The socially optimal harvest level with enforcement costs is:

$$q_{opt} = \frac{(p - \lambda) \cdot x}{2c} + \frac{1}{f}, \text{ for } f > 0 \text{ and } q^* < q_{opt}.$$

$$q_{opt} = q^\circ, \text{ for } f = 0.$$

Note that if fines are infinitely high the optimal harvest will be the zero enforcement cost harvest. This, of course, is intuitive.

Compliance is simply q^*- q_{opt} where q^* is the announced target and the socially optimal harvest.

Note that for any level of enforcement effort, fines and biomass, compliance can be selected by simply choosing the target q^*

The marginal benefits to increased compliance as specified in equations (14) and (15), i.e. under efficient management, are:

(18) $$\lambda - \left(p - \frac{2c \cdot q}{x}\right),$$

(19) $$\lambda - \left(p - \frac{2c \cdot q}{x}\right) - \frac{2c}{\exp(-e) \cdot f \cdot x}.$$

Other interesting expressions can be obtained in a similar manner.

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[10] This may be not very appropriate as $\pi(e)$ is a concave function. This is only done to simplify the algebra, which could otherwise become quite messy.

Numerical results are obtained by simply plugging numbers into the above equations.

2.2.2 Generalized enforcement theory

In this section an attempt is made to generalize the basic enforcement theory of previous section to include (i) multiple fisheries activities — not just the volume of harvest, and (ii) multiple management controls — not just enforcement effort. Note that different combinations of management controls constitute different management systems.

2.2.2.1 Generalized modelling

Fisheries actions

Let all possible fisheries inputs (including fishing time, search time, crew size, gear type, location etc.) be represented by the ($1\text{x}I$) vector $\boldsymbol{s}$.

Harvests are produced by:

$$q = Q(\boldsymbol{s}, x),$$

where x is biomass. It is convenient to refer to the (I+1) vector ($\boldsymbol{s}$,q) as the vector of possible fisheries actions.

With general fisheries actions, instead of just harvests in the basic formulation in section 2, there may be some impacts on the biomass growth function. For instance mesh size and fishing area selection may influence the growth of the biomass. A general modelling of this is:

$$G(x,\boldsymbol{s}),$$

Where $G(x,\boldsymbol{s})$ is the biomass growth function, which now depends on the fisheries actions. If some action, s_i, has no effect on the biomass growth function, the corresponding derivative, $G_{s_i}(\boldsymbol{s})$, is identically zero.

Private benefits from fishing before taxes and penalties are defined by:

(20) $B(\boldsymbol{s},x)=p\cdot Q(\boldsymbol{s},x)-C(\boldsymbol{s})$,

where p refers to the price of landings and $C(\boldsymbol{s})$ to the cost of fisheries inputs.

Management controls

To have an effect on behaviour, fisheries management must alter components of the function in (3.1). For instance, it may impose restrictions on the fisheries inputs, i.e. the vector $\boldsymbol{s}$, it may restrict harvests (landings) and it may alter the effective landings price or costs by taxation (positive or negative). Since taxes on inputs do not make much sense, it seems sufficient to consider taxes on harvests (landings).

We refer to the above set of management restrictions and taxes (which are not strictly restrictions) as a management controls. Alternatively they may be referred to as management tools. Clearly, the maximum number of management controls is I+2. The actual number applied is generally much less.

Enforcement actions

Let all possible fisheries enforcement actions (including dock side monitoring, airplane hours, number of on-board observers, number of inspections etc.) be represented by the (1xJ) vector $\boldsymbol{e}$. Obviously, in principle, J can be a greater or smaller number than I.

There will generally be costs associated with the enforcement actions. Let us express these costs by the enforcement cost function:

$$(21) \qquad CE(\boldsymbol{e}).$$

Penalties

Penalties for violating management restrictions are given by the I+2 vector, $\boldsymbol{f}$. More precisely this vector would be:

$$\boldsymbol{f}=(f_1, f_2, \ldots.. f_I, f_q, f_\tau),$$

where $f_1, f_2, \ldots.. f_I$ refer to fines on violating restrictions on fisheries inputs and f_q and f_τ refer to fines for excessive harvest and tax violations, respectively. For unconstrained fisheries action the penalty is identically zero.

Probability of penalty

Probability of penalty for violating management restrictions — the production function for penalties — is given by the following I+2 vector production function corresponding to all possible fisheries actions and harvests:

$$(22) \qquad \boldsymbol{\pi}(\boldsymbol{e}) = (\pi_1(\boldsymbol{e}), \pi_2(\boldsymbol{e}), \ldots \pi_I(\boldsymbol{e}), \pi_q(\boldsymbol{e}), \pi_\tau(\boldsymbol{e})).$$

The last two terms in this vector represent the probability of suffering a penalty for violating landings restrictions and tax requirements, respectively.

For those actions which are not controlled (restricted) $\pi_i(\boldsymbol{e})$ is identically zero. More formally $\pi_i(\boldsymbol{e})=0$, $i=I_1+1$, $I_1+2, \ldots I$. If there are neither constraints on harvest nor landings taxes $\pi_q(\boldsymbol{e}) = \pi_\tau(\boldsymbol{e}) = 0$ also.

Private behaviour

Given the above specifications and a few additional simplifications, the private maximization problem may be expressed as:

$$\underset{s,q^d}{Max}\; B(\boldsymbol{s},x) - \sum_{i=1}^{I} f_i \cdot \pi_i(\boldsymbol{e}) \cdot (s_i - s^*) - \tau \cdot q^d - f_\tau \cdot \pi_\tau(\boldsymbol{e}) \cdot (Q(\boldsymbol{s},x) - q^d) - f_q \cdot \pi_q(\boldsymbol{e}) \cdot (Q(\boldsymbol{s},x) - q^*)$$

.

In this formulation starred, '*', variables refer to the allowable levels of fisheries actions. τ refers to the unit tax and q^d to the declared catch. The main simplification is that all restrictions are taken to impose an upper bound and assumed to be at least reached. A more general formulation is:

$$\underset{\boldsymbol{s},q^d}{Max}\ B(\boldsymbol{s},x)-\sum_{i=1}^{I} f_i\cdot\pi_i(\boldsymbol{e})\cdot\Gamma(s_i-s^*)-\tau\cdot q^d-f_\tau\cdot\pi_\tau(\boldsymbol{e})\cdot\Gamma(Q(\boldsymbol{s},x)-q^d)-f_q\cdot\pi_q(\boldsymbol{e})\cdot\Gamma(Q(\boldsymbol{s},x)-q^*)$$

,

where the function Γ(.) represents the nature of the restriction.

The solution to the private maximization problem may be written as the (1x*I*+1) vector function (more generally correspondence):

(23) $\left(\boldsymbol{S}(\boldsymbol{e};\boldsymbol{f},x,s^*,q^*),\quad q^d(\boldsymbol{e};\boldsymbol{f},x,s^*,q^*)\right)$.

In what follows the exogenous variables *s** and *q** will generally be dropped from the notation. Note that since in this formulation, the harvest depends on ***s***, *q* is not an independent choice variable for the fisher.

Social optimization

The social maximization problem is:

$$\underset{\boldsymbol{e}}{Max}\ B(\boldsymbol{S}(\boldsymbol{e},\boldsymbol{f},x),x)+\lambda\cdot(G(x,\boldsymbol{S}(\boldsymbol{e},\boldsymbol{f},x)-Q(\boldsymbol{S}(\boldsymbol{e},\boldsymbol{f},x),x))-CE(\boldsymbol{e})\,.$$

Apart from the generalizations there is one important difference between this social problem and the one in the basic model in chapter 2. This is the inclusion of the biomass growth function in the social benefit function. What counts for social benefits is of course the shadow value of biomass[11] multiplied by biomass growth, i.e., $\lambda\cdot(G(x,s)-Q(s,x))$. With general fisheries actions, the biomass growth function, not only harvest volume, can also be affected. Hence, in this generalized formulation, the biomass growth function cannot be ignored.

Necessary conditions for solving this problem include (Kuhn and Tucker 1951):

(24) $$\sum_{i=1}^{I}[B_{s_i}+\lambda\cdot(G_{s_i}-Q_{s_i})]\cdot\frac{\partial s_i}{\partial e_j}-CE_{e_j}\le 0,$$

$$e_j\ge 0,\left(\sum_{i=1}^{I}[B_{s_i}+\lambda\cdot(G_{s_i}-Q_{s_i})]\cdot\frac{\partial s_i}{\partial e_j}-CE_{e_j}\right)\cdot e_j=0,\ j=1,2\ldots J$$

Thus, for all management actions which are undertaken (>0), the following has to hold

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[11] Obviously, the shadow value of biomass, λ, may also be affected by improved enforcement. This applies in particular when the fisheries management system regime is efficient. While, this can easily be modelled along the lines of this chapter, the actual impact would generally be complicated. This is discussed at some length in chapter 10 on the shadow value of biomass.

$$\sum_{i=1}^{I}[B_{s_i}+\lambda\cdot(G_{s_i}-Q_{s_i})]\cdot\frac{\partial s_i}{\partial e_j}-CE_{e_j}=0,\quad \text{all } e_j>0.$$

Expression (24) defines the optimal level and therefore also the optimal mix of all possible enforcement actions. The principle is that the net marginal benefits of all employed management actions must be the same and equal to zero. The level of others must equal zero.

Obviously, to work this out requires knowledge of (i) the private benefit function, (ii) the cost of enforcement function and (iii) the probability of penalty function, i.e. functions (20), (21) and 22) above, as well as the penalty structure. With that knowledge in hand, the private maximizing solution in equation (23) can be derived and subsequently the expression for optimal management actions given in (24).

2.2.2.2 Examples: Some management controls

For expository purposes, let us classify all fisheries management controls (tools) into four categories:

1. Biological management methods
   Measures designed to increase biological productivity
2. Direct economic restrictions
   Measures designed to increase economic profitability
3. Taxes/subsidies
4. Property rights

The first two groups are direct controls (i.e. they directly control behaviour). The last two are indirect controls, i.e. they alter the operating conditions for the fishers and thus (indirectly) influence behaviour.

It appears that all management tools fall into at least one of these categories. Some, however, such as TACs might fall into more than one.

2.2.2.2.1 Biological management tools:

These are tools (instruments) designed to increase the productivity of the resource. They include mesh size regulations, other gear restrictions minimum landing sizes, time/area closures and so on.

Let us refer to these kind of management measures as α. Their immediate effect is to shift the biomass growth function upward and, since they impose added controls on the fishers, reduce the (instantaneous) benefit function. In the longer run these measures, if successful, will presumably increase the biomass, x, and may thus increase the benefit function.

For the basic enforcement model, the change is as follows:

Biomass growth: $G(x,\alpha)$. $G_\alpha>0$.

The private benefit function: $B(q,x,\alpha)$, $B_\alpha<0$.

The modifications to the basic enforcement theory of chapter 2 are now straightforward:

Social benefits from fishing is altered to:

$$B(q,x,\alpha)-\lambda(\alpha)\cdot(G(x,\alpha)-q)$$

The ***penalty probability function*** is unchanged:

$$\pi(e),\ \pi(0)=0,\ \lim_{e\to\infty}\pi(e)=1.$$

The ***enforcement cost function*** is unchanged:

$$C(e).$$

Private costs of violations is altered to:

$$\psi(\alpha;e,f,\alpha^*) = \pi(e)\cdot f\cdot(\alpha-\alpha^*),\ \text{if } \alpha\geq\alpha^*.$$

$$\psi(\alpha;e,f,\alpha^*) = 0\quad,\ \text{if } \alpha<\alpha^*,$$

Social benefits with costly enforcement

$$B(q,x,\alpha)-\lambda(\alpha)\cdot(G(x,\alpha)-q)-C(e).$$

Private benefits from fishing under binding management.

$$B(q,x,\alpha)-\pi(e)\cdot f\cdot(\alpha-\alpha^*)$$

With these modifications, the analysis proceeds as before and we believe the key qualitative results, although not the exact equations, continue to hold.

2.2.2.2.2 Direct economic restrictions:

These are direct restrictions designed to increase the profitability of the fishing operations. They include effort restrictions, capital restrictions, investment restrictions, power restrictions and so on.

Let us refer to these kind of management measures as β. Their immediate effect is to make the fishing operations less profitable and thus reduce the (instantaneous) benefit function.

For the enforcement model the change is as follows:

The private benefit function: $B(q,x,\beta)$, $B_{\beta}<0$.

The modifications to the basic enforcement theory previously discussed are now straightforward:

Social benefits from fishing is altered to:

$$B(q,x,\beta)-\lambda \cdot q.$$

The ***penalty probability function*** and the ***enforcement cost function*** are unchanged as before:

Private costs of violations is altered to:

$$\psi(\beta;e,f,\beta^{*}) = \pi(e)\cdot f\cdot(\beta-\beta^{*}), \text{ if } \beta\geq\beta^{*}.$$

$$\psi(\beta;e,f,\beta^{*}) = \quad 0 \quad , \text{ if } \beta<\beta^{*},$$

Social benefits with costly enforcement

$$B(q,x,\beta)-\lambda\cdot q - C(e).$$

Private benefits from fishing under binding management.

$$B(q,x,\beta) - \pi(e)\cdot f\cdot(\beta-\beta^{*})$$

Also, as in the biological management case, with these modifications, the analysis proceeds as before and we believe the key qualitative results, although not the exact equations, continue to hold.

2.2.2.2.3 Taxes/subsidies

Let the tax be assessed on harvest quantity. Let the amount of taxes/subsidies be represented by the function $F(q,\tau)$, where τ is the rate of tax. It appears reasonable that F_q, $F_{\tau}>0$. In simple cases this could be $F(q,\tau)=\tau\cdot q$. In what follows, we will assume this for simplicity.

For the enforcement model the change is as follows:

The private benefit function: $B(q,x) - \tau\cdot q$.

Social benefits from fishing is unchanged because the taxes subsidies are just transfers (assumed costless here which is probably very close to reality).

The ***penalty probability function***, the ***enforcement cost function*** are unchanged as before. Moreover, since the tax/subsidy is assessed on the harvest volume the ***private cost of violations*** is the same as in the base case.

So, compared to the base case (q restrictions), the only thing that changes is the private benefits under enforcement, which will be

Private benefits from fishing under binding management.

$$B(q,x) - \tau \cdot q - \pi(e) \cdot f \cdot (q-q^*).$$

This will in turn affect behaviour, which can be derived in the same way as in the base case.

2.2.2.2.4 Property rights

The most relevant property rights are:

- Sole ownership
- TURFS
- IQs/ITQs
- Community property rights

In all these cases, it would usually be harvesting volumes and/or area restrictions that would need to be enforced.

The harvesting volume restrictions are included in the basic case. The area restrictions are really a special case of biological measures discussed above.

2.2.2.2.5 TACs

TACs are in some respects special. They can be imposed for either biological or economic reasons and they form an integral part of many property rights regimes (IQs/ITQs). In their basic form, i.e. as an individual harvest restrictions, they have already been dealt with in the basic enforcement model (Memo-1, Arnason 2007).Often, however, TACs constitute an aggregate— not an individual restriction. Therefore, the enforcement problem is a bit different.

The question is how the TACs are implemented. The usual case is simply to close the fishery when the TAC has been reached. So, according to this procedure for implementing TACs, there are no harvesting restrictions initially. Subsequently, once the TAC is reached, there is a harvest moratorium. The allowable harvest is now zero for every participant in the fishery and we are back in the basic enforcement situation discussed in Arnason 2007.

Alternatively, a TAC restriction may be translated into limited fishing days. This then amounts to the direct controls discussed in section 2.2.2.2.2.

2.2.3 Discussion

The above discussion illustrates the working of the COBECOS-model, since this model is an applied cost-benefit model for analysing various fisheries. The aim of the COBECOS-model is to allow a social cost benefit analyses of fisheries in a general context, allowing for several management tools, several species and various specifications of the theoretical relationships. In order to apply the model one must have data on:

- Private benefit function
- The relationship between enforcement effort and enforcement costs
- The relationship between enforcement effort and probability of detection
- The shadow value of the biomass

The model opens for differences in costs of various management tools. For instance, controlling vessels at sea is most likely more expensive than controlling vessels at harbour. However, costs of enforcement are by far the only determinant of optimal use of management tools. Differences in detection probabilities are also included in the model. While the cost of detecting illegal behaviour is higher at sea than at land, the probability of detecting e.g. use of illegal gear is most likely a great deal higher if the control took place at sea (relative to controlling at harbours). Finally, differences in fishermen responses to various tools and fines are determined can be introduced into the model. Thus, the framework applied to the studied fisheries provides an efficient cost-benefit analysis of various policy tools applied in different jurisdictions today.

The interested reader is referred to deliverable D3 "Fisheries Enforcement: Basic theory and how to apply it" for an extensive report of the theoretical findings.

3 EMPIRICAL APPLICATIONS

3.1 DATA REQUIREMENTS & HARMONISATION

Empirical research of enforcement systems has been carried out in nine European fisheries. The fisheries are very different in terms of fishing activity, the type of management and the enforcement system in place. In order to ensure a certain degree of harmonisation of collected data and a standardisation of enforcement and management measures, a work package on data harmonisation was created.

The aim of that work package was also to facilitate for managers to describe and define their fisheries and enforcement situation in a common format, standard measures and units for collection of management and enforcement data. The standardisation allows baseline data to be established for each management measure that is enforced, to define the levels of current and future enforcement tools, and enables comparison between fisheries.

3.1.1 Empirical fisheries enforcement models: Data requirements

According to basic enforcement theory (chapter 2) an empirical fisheries enforcement model requires the following components:

(1) A private fisheries benefit function defined as a function of relevant fisheries inputs:

$$B(\boldsymbol{s},x)=p\cdot Q(\boldsymbol{s},x)-C(\boldsymbol{s}),$$

where p refers to the price of landings, $Q(\boldsymbol{s},x)$ to the volume of harvest as a function of the vector of fisheries inputs $\boldsymbol{s}$ and biomass and $C(\boldsymbol{s})$ to the cost of fisheries inputs. The fisheries inputs involves all relevant inputs including measures of fishing effort, gear and gear properties, type of fishing, location and so on. At least this function must include all fisheries inputs that are being controlled by fisheries management.

Note that this private fisheries benefit function is central to any reasonable bioeconomic fisheries model. If such a model is available, it will contain $B(\boldsymbol{s},x)$ in some form.

(2) A list of fisheries actions subject to management. This would normally be a sub-vector of the vector $(\boldsymbol{s},q)$ where q refers to the volume of harvest.

(3) A list of penalties for violations of management restrictions. This may be expressed by the vector $\boldsymbol{f}$ with the same dimensionality as the fisheries actions (the fisheries actions not subject to management would have penalties identically equal to zero). Note that the fs may be functions rather than constants.

(4) A list of enforcement actions (e.g. number of observers, flight hours, boardings, inspections etc.) represented by the vector ***e***.

(5) The vector function expressing the probabilities of having to pay a penalty for violating management restrictions expressed by:

$$\boldsymbol{\pi}(\boldsymbol{e}) = (\pi_1(\boldsymbol{e}), \pi_2(\boldsymbol{e}), ...\pi_I(\boldsymbol{e})) \ ,$$

where the vector ***e*** represents the enforcement actions and *I* refers to the number of fisheries actions.

(6) The cost of enforcement actions represented by the enforcement cost function

$CE(\boldsymbol{e})$.

(7) The evolutionary function for biomass (or biomasses if an age-disaggregated of a multispecies model is being used) represented by:

$$\dot{x} = G(x) - q,$$

where q represents the harvest. This function is needed for the calculation of the appropriate shadow value of biomass (or biomasses) as explained in Memo-5 (Arnason 2007)

Note that the biomass evolution function is included in any reasonable bioeconomic fisheries model. If such a model is available, it will contain $G(x)$ in some form.

To construct an empirical fisheries enforcement model, estimates of the all of the above seven components have to be obtained. Of them, two (namely (1) and (7)) are included in any reasonable bioeconomic fisheries model. The others ((2)-(6) are specific to the enforcement problem. Items (2), (3) and (4) would normally come out of a description of the fisheries management regime. The functions in components (5) and (6) have to be estimated on the basis of available data on (i) probabilities of violations leading to penalties, (2) enforcement actions and intensity, ***e***, and the (preferably minimum) cost of enforcement. Regarding the last part, it is quite possible that historically the enforcement activity has not been operating at minimum cost.

3.1.2 Essential data to apply the enforcement model

To apply the basic enforcement model discussed in Chapter 2, we need knowledge of the following:

(1) The fisheries private benefit function:
A simple version of this function is: $B(q,x)$

(2) The fisheries biomass growth function:
A simple version of this function is: $\dot{x} = G(x)$

(3) The enforcement cost function.
A simple version of this function is $C(e)$

(4) The probability of penalty function

A simple version of this function is: $\pi(e)$

(5) The penalty structure (in monetary terms); f

(1) and (2) come from a standard bioeconomic model. This has to be provided (hopefully already exists) for all the case studies. The actual models may well be more complicated but they cannot be much simpler. They must include the main controlled (managed) variables.

(3)-(5) are additions to the usual bioeconomic model. Data collection must obtain the necessary data to estimate these functions.

(4) basically defines a special production function (the probability of penalty) which may depend on many inputs (enforcement activities, *e*, and many probabilities (one for each offence). The appropriate level of aggregation depends on data and modelling convenience.

(3) is basically a straight-forward cost-identity. However, since it depends on enforcement effort, *e*, and enforcement effort is usually not a market commodity, this function would usually need to be estimated.

(3) and (4) combined constitute the usual economic production model for which economic theory and econometric estimation procedures are well developed. Both of these should be exploited to the fullest.

(5) is fairly straight-forward.

3.1.2.1 Minimum data for estimating the function in (3)-(5)

The following lists the minimum necessary data to estimate and construct an empirical version of the basic enforcement model. Further specifications to the form of data in the case studies can be found in the appendix.

(1) Fisheries management rules to be enforced (list over time)
(2) Enforcement categories (what are they)
(3) Level of enforcement activities along each category (over time)
(4) Corresponding cost of enforcement as disaggregated by enforcement categories as possible
(5) The probability of penalty for each enforcement category. This may be difficult to assess but is essential.
(6) The penalty structure (over time)

More precisely:

Let t=1,2, T be time periods for the data

Let $r(i,t)$ be management rule i at time t i=1,2,..I, where I is number of management rules to be enforced

Let $e(j,t)$ be management effort along management method (category) j at time t, $j=1,2,\ldots J$, where J is the number of management categories.

Let $C(j,t)$ be management costs of method j at time t

Let $\pi(i,t)$ be the probability of penalty for violating control i at time t. [Note that this probability is conditional on violation]

With sufficient data in hand it should be obvious that the penalty function and the cost functions can be estimated, at least in principle. The exact functional form and modelling of the production process depends on the situation but needs in all cases to be studied carefully. The estimation procedure, similarly, needs to be well thought out.

So need data on: $r(i,t)$, $e(j,t)$ $C(j,t)$ and Let $\pi(i,t)$

For statistical and comparison purposes, these data need to be over some time period.
To the extent possible the study as a whole should use uniform categories, measures, and definitions. This would help in comparisons across cases but, of course, is not necessary as the cases are separate.

3.1.3 Standardised description of management measures and enforcement tools

In order to facilitate for managers to describe and define their fisheries and enforcement situation in a common format, standard measures and units for collection of management and enforcement data were defined within the project. The standardisation allows baseline data to be established for each management measure that is enforced, to define the levels of current and future enforcement tools, and enables comparison between fisheries.

3.1.3.1 Management measures

Management measures define the limits for a particular fishery. In COBECOS the management measures have been classified into three groups;

- Output restrictions
- Input restrictions
- Efficiency restrictions

3.1.3.1.1 Output restrictions

Output restrictions define the levels of fish that can be harvested in a fishery. These are usually defined as quotas in terms of weight of the target species. Output restrictions may also be placed on non target species caught as by catch or on the level of incidental mortality of protected, endangered or threatened (PET) species. Output restrictions have been classified in the below categories:

- Target species quota (TACs)
- By-catch species quota
- PET (protected, endangered and threatened) species quotas

3.1.3.1.2 Input restrictions

Input restrictions are defined in COBECOS as those placed on a fishery related to the level of effort that is permitted in each fishery. Input restrictions can be addressed by limiting the number and or size of vessels (capacity control) or the time spent fishing (effort control). Input restrictions such as these have been introduced primarily where the level of outputs from a fishery are difficult to monitor, for instance when a large number of small vessels land into a large number of ports making effective monitoring of catches and landings difficult. The level of effort allowed in the fishery is typically set at a level such that given average fishing patterns and efficiency, the level of output is at or within the levels required. Input restrictions have been classified in the below categories:

- Restriction of the fleet Size (Number of vessels / Power of vessels/GRT,GT)
- Restriction of Effort (Days at sea, kilowatt-hours, kilowatt-days)
- Closed seasons for a fishery (cross-over to efficiency restrictions)

3.1.3.1.3 Efficiency restrictions

Efficiency restrictions are those management measures that can affect the catch per unit of effort of a particular fishery or part of a fishery. They include management measures typically used to protect a vulnerable element of a stock such as juvenile or undersized fish, spawning aggregations of adult fish or essential fish habitats for juvenile fish. The stock that is limited by the management measure may not actually be the target species concerned, as for the output restrictions, but may be a by catch species or a PET species that are impacted by the fishery. Efficiency restrictions have been classified in the below categories:

- Closed Areas
- Gear Restrictions
- Engine Size
- Move on Rules (relating to the by-catch of any one species)
- Size Restrictions (mesh size restrictions)
- Discard Ban

The classification of the management measures and their related indicator measures and units for collection can be summarised as below:

Table 2: Summary of management measures

Control Type	**Management Measure**	**Indicator Measure**	**Indicator Units**
Output controls	Target species quota	Quota	Metric tonnes (t) Numbers
	Bycatch species quota	Quota	Metric tonnes (t) Numbers
	PET species limits	Quota	Numbers
Input controls	Fleet Size	Number of vessels Fleet size (tonnage) Fleet size (power)	Number of vessels Tonnage (GRT) Power (kW)
	Effort days at sea	Days at sea	Number of days
	Effort	Power x time	kWh
	Closed seasons	Time period of closure Area of closure	Dates of closure (plus derived length of closure) (See below)
Efficiency controls	Closed Areas	Size of closed area Complexity of closed area	Surface area in km² Size of protected habitat in km² Complexity of shape
	Gear Restrictions	Mesh size / type Number of pots / hooks	Size of mesh (with standard gauge and weight). Mesh type (square / diagonal). Number of specific gear
	Engine Size	Vessel size (power)	Power (kW)
	Move on Rules	Trigger: Catch (total or proportion). Area: Area of closure Time: Period of closure	Catch or proportion of indicator species or size class. Surface area in km² Dates of closure (plus derived length of closure)
	Size Restrictions	Minimum size	Size (length or weight of landed fish) Proportion of catch undersized (by weight or numbers)
	Discard Ban	Weight of fish discarded Species and size composition of catch to verify discard ban.	Catch weights of landed fish. Species composition. Size composition within each species.

3.1.3.2 Enforcement tools

Enforcement tools refers to any vessel (patrol vessel, aircraft), personnel (fisheries inspectors, navy, observers or customs) or tools (radar, VMS, SAR imaging) or combination of any of the above that can be used to detect infringements in the control mechanisms used in a fishery.

For completeness a wide range of measures that cover the most common possible means of enforcement that can be used within the majority of European fisheries, have been included:

- Patrol vessels
- On-board observers
- Aerial Surveillance
- Remote Sensing (AIS, VDS)
- Dockside Monitoring
- Logbooks
- Video Surveillance
- Transhipment Monitoring
- Marketing and Sales Monitoring

Indicators have been selected and 'normalised' for each enforcement measure to provide indices for evaluating the capability and capacity and the efficiency and effectiveness of the control operations and resources for a fishery. Table 3 provides an overview of the indicator measures and the related units.

Table 3: Summary of Enforcement Tools

Tool	Indicator Measure	Indicator Units
Patrol vessels	Number of patrol days Number of inspections Infractions per inspection Coverage of vessels Coverage of patrol area Cost per patrol day Cost per inspection	Number Number Number Percentage of total vessels Percentage of total area € / day € / inspection
Onboard observers	Number of observer days Number of infractions Infractions per observer day Percentage observer days vs. total fishing days Cost per observer day	Number Number Infractions / day Percentage € / day
Aerial Surveillance	Number of patrol hours Number of sightings Infractions per patrol hour Coverage of vessels Coverage of patrol area Cost per patrol hour	Number Number Number Percentage of total vessels Percentage of total area € / day
Vessel Monitoring Systems	Number of vessels covered Number of VMS inspections Number of VMS infractions Coverage by fleet (usually 0 % or	Number Number Number Percentage of total vessels

Tool	Indicator Measure	Indicator Units
	100 % for a fleet) Cost per vessel per year	€ / vessel
Remote Sensing	Number of contacts Coverage by area (and time) Cost per km^2 per image or per month or year	Number Percentage € / km^2 (/period)
Dockside Monitoring	Number of inspections Weight of fish inspected Infractions per inspection Infractions per t of fish Coverage of inspections (landings) Coverage of inspections (by weight) Cost per inspection	Number t Number Number per t Percentage of total landings by number Percentage of total landings by weight € / inspection
Logbooks	Logbook returns made Number logbooks verified Infractions detected Infractions per logbook Coverage by fleet (verification) Cost per fishing day Cost per t landed weight	Number Number Number Number Percentage € / day € / t
Video Surveillance	Number of hours observed Coverage hours observed /. total fishing hours Cost per hour Cost per vessel	Number Percentage € / hour € per vessel
Transhipments Monitoring	Number of transhipments Weight of catch transhipped Coverage rate Cost per day monitoring Cost per tonne monitored	Number Tonnes Percentage € / day € / t
Marketing and Sales Monitoring	Number of inspections Volume of fish inspection. Number of infractions per inspection or per t of fish inspected. Cost per inspection Cost per infraction Cost per t of fish inspected	Number Tonnes Infractions / Inspection Infractions / t € / inspection € / infraction € / t

3.1.4 Comparison of Management Measures and Enforcement Tools

It is important to understand that a single management measure cannot be enforced through all enforcement tools and vice versa an enforcement tool cannot enforce all management measures. Each enforcement tool will have different relative efficiencies and detection profiles in terms of the detection of infractions of each management measure, they will have different qualities of evidence and possibly the level of fine or sanction that can therefore be imposed and of course some may not have the power of arrest at all and may require the use of one or more means to facilitate arrest, (e.g. you can detect a zone violation with VMS, but you may need a patrol vessel or aerial surveillance to prove fishing is taking place, and a patrol vessel or port inspection team to actually arrest and detain the vessel).

A summary of the different management measures and enforcement means previously described are shown in table 4, detailing which enforcement means can be applied to each management measure.

Table 4. Summary of the different management measures and enforcement means detailing which enforcement means can be applied to each management measure.

Dark Green:	Applicable with power of arrest
Light Green	Applicable but without power of arrest
Orange:	Partly applicable
Red:	Not applicable

		Management measures												
		Output			Input				Efficiency					
		Target species quota	By catch species quota	PET species limits	Fleet Size	Effort days at sea	Effort	Closed seasons	Closed Areas	Gear Restrictions	Engine Size	Move on Rules	Size Restrictions	Discard Ban
Enforcement tools	Patrol vessels	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	On-board observers	🟢	🟢	🟢	🟥	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢
	Aerial Surveillance	🟥	🟥	🟥	🟢	🟢	🟧	🟢	🟢	🟥	🟥	🟢	🟥	🟥
	Vessel Monitoring Systems	🟥	🟥	🟥	🟧	🟢	🟧	🟢	🟢	🟥	🟥	🟢	🟥	🟥
	Remote Sensing	🟥	🟥	🟥	🟢	🟢	🟢	🟢	🟢	🟥	🟥	🟧	🟥	🟥
	Dockside Monitoring	🟩	🟩	🟩	🟩	🟩	🟧	🟩	🟥	🟩	🟩	🟥	🟧	🟧
	Logbooks	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	Video Surveillance	🟧	🟧	🟧	🟥	🟧	🟧	🟢	🟥	🟧	🟥	🟧	🟧	🟢
	Transshipments Monitoring	🟢	🟢	🟢	🟥	🟥	🟥	🟧	🟧	🟥	🟥	🟥	🟢	🟥
	Marketing and Sales Monitoring	🟧	🟧	🟧	🟥	🟥	🟥	🟧	🟧	🟥	🟥	🟥	🟢	🟥

3.1.5 Standard description of COBECOS Fisheries

The aim of a set of standardised fisheries classifications that will incorporate all European fisheries is to help end users of the COBECOS model to match their own fishery to a similar COBECOS fishery. Although no fisheries will be identical the broad classifications presented in this chapter may help users so that the questions, such as the ones given below, can be answered:

- What are the costs and benefits of increased enforcement effort in particular **fisheries**?
- If compliance alters in certain **fisheries** what are the costs and benefits?

3.1.5.1 Fishing vessel length class

Fishing vessel types have been defined by the FAO Coordinating Working Party on Fishery Statistics (CWP). The classifications currently in use can be found below;

Table 5: Classification of fishing vessel length classes.

Code	**Vessel Size by L.o.A. Classes (meters)** **lower limit**		**upper limit**
210	0	-	5.9
221	6	-	11.9
222	12	-	17.9
223	18	-	23.9
224	24	-	29.9
225	30	-	35.9
230	36	-	44.9
240	45	-	59.9
250	60	-	74.9
260	75	-	99.9
270	100 and over		

3.1.5.2 Fishing gear type

The 'International Standard Statistical Classification of Fishery Vessels by Vessel Types' (ISSCFV), based on the type of gear used by the vessels, was approved by the CWP in 1984[12]. This complex hierarchical list was simplified to the current "Simplified

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[12] ftp://ftp.fao.org/FI/DOCUMENT/cwp/handbook/annex/annexLII.pdf

Classification of Fishing Vessels by Vessel Types"[13] in 1996 (see below). The classifications currently in use can be found below;

Table 6: Classification of fishing gear type

CODE	STANDARD ABBREVIATION	VESSEL TYPE
01.00	TO	TRAWLERS
02.00	SP	PURSE SEINERS
03.00	SOX	OTHER SEINERS
04.00	GO	GILL NETTERS
05.00	WO	TRAP SETTERS
06.00	LL	LONG LINERS
07.00	LOX	OTHER LINERS
08.00	MO	MULTIPURPOSE VESSELS
09.10	DO	DREDGERS
09.00	FX	OTHER FISHING VESSELS

The current proposed changes to the vessel types show a partial return to the original hierarchical structure and are as follows;

Table 7: Proposed changes to the classification of gear types

TRAWLERS Otter trawler Pair trawler Beam trawler	**LONG LINERS** Auto liner Manual liner
PURSE SEINERS American seiner European seiner Drum seiner	**LINE VESSELS** Jigger vessels Pole and Line vessels American style Japanese style Trollers
SEINERS Anchor seiner Scottish seiner	**GILL NETTERS** Drifter Set netter Lift netter
TRAP SETTERS Pot vessels Trap setters	**DREDGERS**

3.1.5.3 Fisheries size and value

There is currently no agreed standard classification for the size of fisheries as they may vary greatly in the number of fishers and fishing vessels, the size composition of the fleet and the types of vessels involved. However, the fisheries size scale suggested below could help to identify the approximate scale of the fishery.

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[13] ftp://ftp.fao.org/FI/DOCUMENT/cwp/handbook/annex/ANNEX_LIII.pdf

Table 8: Classification of fisheries size and value

Code	Range	Description
1	Artisanal	Small scale fisheries with typically a traditional, artisanal or subsistence character with potentially large numbers of fishing vessels and / or fishers, with simple fishing vessels and gear. The total commercial value of the fisheries should not exceed <€50,000 per fisher per annum.
2	Small scale semi-industrial	Small scale fishery with small number of fishing vessels usually < 10.5m with a total catch value per vessel of between €10,000 and €50,000.
3	Small Industrial	Small scale Industrial fishery with small to moderate number of fishing vessels (typically between 10.5m and 25m) and / or fishers with a total catch of up to 1000t or a total catch value per vessel of between €50,000 and €250,000
4	Medium Industrial	Industrial fishery with moderate to large fishing vessels (>25m) and / or fishers with a total catch of between 1000t and 5000t or a total catch value of between €250,000 and €1,000,000
5	Large Industrial	Large scale industrial fishery with large numbers of fishing vessels and / or fishers with a total catch of > 5000t or a total catch value of >€1,000,000

3.1.6 Target species

There are two levels of identification of the target species. The first and more generic level is the "International Standard Statistical Classification of Aquatic Animals and Plants" (ISSCAAP) which was last modified in 2000. This list divides commercial species into 50 groups on the basis of their "taxonomic, ecological and economic characteristics". The current ISSCAAP list is shown in Table 9 below. The more detailed Aquatic Sciences and Fisheries Information System (ASFIS) list contains 10,755 species and species groups (at February 2008) that are commonly encountered in fisheries data submissions.

The current ASFIS list is available at ftp://ftp.fao.org/FI/STAT/DATA/ASFIS_sp.zip.

Table 9: Classification of target species

ISSCAAP Group	**ISSCAAP Subgroup**	**Description**
1	**Freshwater fishes**	
	11	Carps, barbels and other cyprinids
	12	Tilapias and other cichlids
	13	Miscellaneous freshwater fishes
2	**Diadromous fishes**	
	21	Sturgeons, paddlefishes
	22	River eels
	23	Salmons, trouts, smelts
	24	Shads
	25	Miscellaneous diadromous fishes
3	**Marine fishes**	
	31	Flounders, halibuts, soles
	32	Cods, hakes, haddocks
	33	Miscellaneous coastal fishes

ISSCAAP Group	ISSCAAP Subgroup	Description
	34	Miscellaneous demersal fishes
	35	Herrings, sardines, anchovies
	36	Tunas, bonitos, billfishes
	37	Miscellaneous pelagic fishes
	38	Sharks, rays, chimaeras
	39	Marine fishes not identified
4	**Crustaceans**	
	41	Freshwater crustaceans
	42	Crabs, sea-spiders
	43	Lobsters, spiny-rock lobsters
	44	King crabs, squat-lobsters
	45	Shrimps, prawns
	46	Krill, planktonic crustaceans
	47	Miscellaneous marine crustaceans
5	**Molluscs**	
	51	Freshwater molluscs
	52	Abalones, winkles, conchs
	53	Oysters
	54	Mussels
	55	Scallops, pectens
	56	Clams, cockles, arkshells
	57	Squids, cuttlefishes, octopuses
	58	Miscellaneous marine molluscs
6	**Whales, seals and other aquatic mammals**	
	61	Blue-whales, fin-whales
	62	Sperm-whales, pilot-whales
	63	Eared seals, hair seals, walruses
	64	Miscellaneous aquatic mammals
7	**Miscellaneous aquatic animals**	
	71	Frogs and other amphibians
	72	Turtles
	73	Crocodiles and alligators
	74	Sea-squirts and other tunicates
	75	Horseshoe crabs and other arachnoids
	76	Sea-urchins and other echinoderms
	77	Miscellaneous aquatic invertebrates
8	**Miscellaneous aquatic animal products**	
	81	Pearls, mother-of-pearl, shells
	82	Corals
	83	Sponges
9	**Aquatic plants**	
	91	Brown seaweeds
	92	Red seaweeds
	93	Green seaweeds
	94	Miscellaneous aquatic plants

3.1.6.1 Fisheries Location

There are two classifications that are used with respect to the location of a particular fishery. The first is a description of its geographical location, the second related to the remoteness of the fishery away from land.

3.1.6.2 Geographical Location

The geographical location of the fishery could be described using FAO areas or ICES zones.

Figure 2: FAO areas

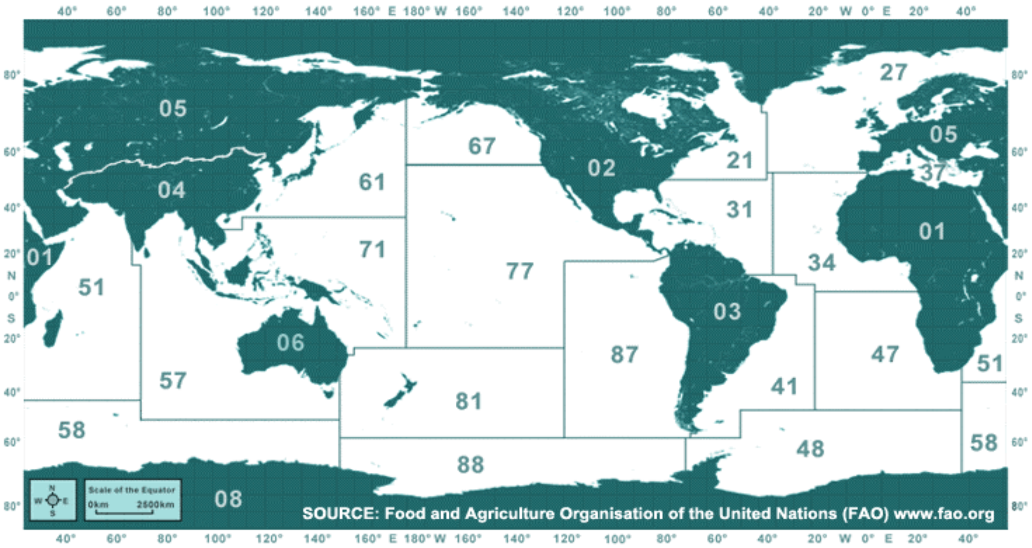
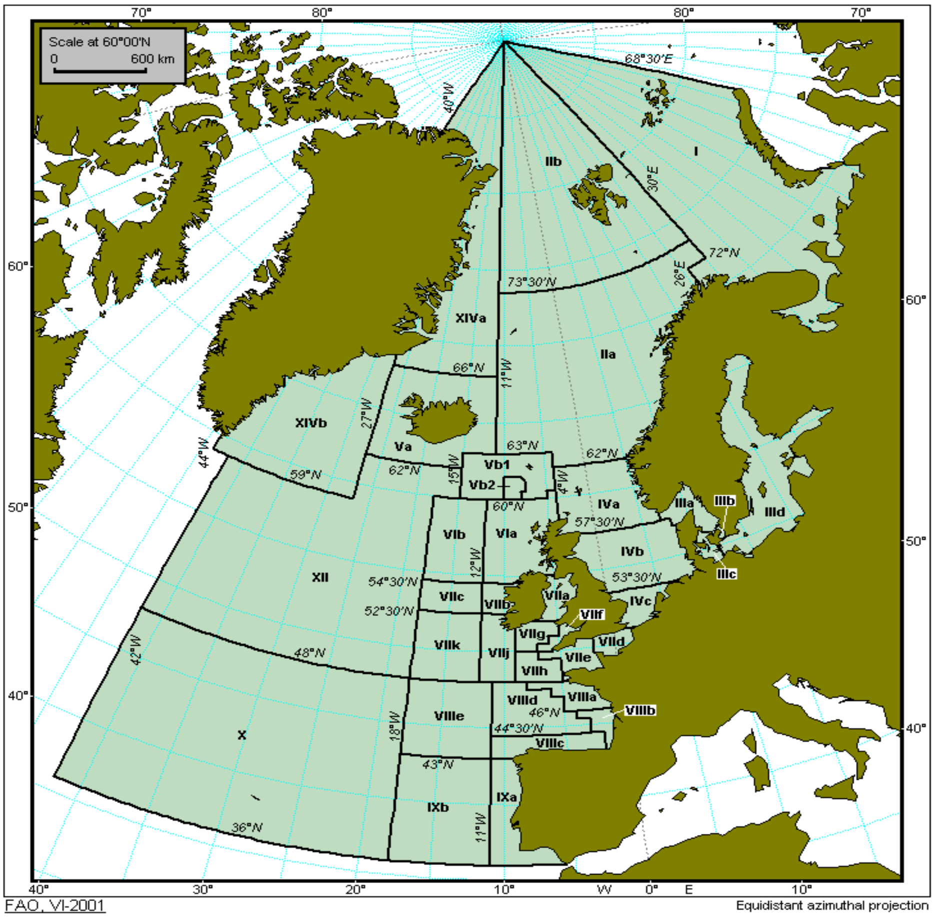


Figure 3: ICES areas



3.1.6.3 Remoteness

The following simple classification has been developed to define the remoteness of the fishery.

The remoteness of the fishery will along with the size of the vessels affect the way in which a fishery will be managed. Small scale fisheries close to shore will have different control problems then distant water fisheries that have vessels staying at sea for several months at a time.

Table 10: Classification of the remoteness of the fishery

Code	Range	Description
1	Inshore	Fisheries are conducted close to the shore within the territorial sea or contiguous zones of coastal states. Boats will operate on a daily basis returning to port within a 24hr period.
2	EEZ < 50nm	Fisheries are conducted in the territorial seas and EEZs in shallow water often on the continental shelf. Boats operate on a daily basis or for a few days at a time.
3	EEZ	Fisheries are conducted in the EEZs of coastal states on the continental shelf or in deeper waters. Boats will have trip lengths of several days at a time.
4	High Seas < 600nm	Fisheries conducted in the outer reaches of the EEZs of EU coastal states and in adjacent high seas areas. Boats will have trip lengths of several weeks at a time.
5	Distant Water	Fisheries conducted in the EEZs of third party coastal states outside the EU and in high seas areas. Boats will have trip lengths of several months at a time.

3.1.6.4 COBECOS Case Studies

The below table provides an overview of the COBECOS case studies against the standard description.

Table 11: Summary of COBECOS case studies

Fishery	Fishing vessel size *average	Fishing gear type *predominant	Fisheries size and value	Target fish	Fisheries Location
Northern hake	Trawlers (225 primarily also 224, 223) Gil netters and long liners (222, 223, 225)	Trawlers 60 % (Gillnetters 35 % Long liners 5 %)	90 m.Euro Large scale high value fishery (5) but with different vessel classes ranging from (1-5)	32	27
Icelandic		Trawlers	Small to large industrial. (3-5)	32	27
Bay of Saint – Brieuc Scallops	221	Trawlers (Line vessels Gill netters Trap Setters)	4.5 - 15mEuro	55	27

Fishery	Fishing vessel size *average	Fishing gear type *predominant	Fisheries size and value	Target fish	Fisheries Location
Norwegian	<28 m 703 >28 m con 43 63 Cod trawlers	(Coastal vessels? Conventional (non trawler >28)) Trawlers	Small industrial Costal vessels, (88 m€) to Large industrial trawlers (220m€)	32	27
Ligurian	223	Trawlers	Overall high value fishery (5) but with different vessel classes ranging from (1-3), with low – medium value per vessel.	3	27
Kattegat nephrops	18	Trawlers	Medium high value fishery. Ranging from low value for small vessels to high value for large vessels.	45	27
Dutch beam trawls	40	Trawlers	Medium industrial scale and high value fishery (Sole 112 m€, Plaice 52 m€)	34	27
Western channel fisheries	<30 >30	Trawlers	Small - medium industrial scale,	34	27
South Georgia / Kerguelen toothfish fisheries	240	Long liners	Medium Industrial scale and high value fishery (	34	48 .3 / 58.5.1

3.1.7 Overview by case study fisheries from the COBECOS data base

In this section the coverage of data that has been uploaded to the project database is investigated.

In the initial phase of the project, prior to the finalization of the theoretical model, the case studies were asked to collect information regarding their fishery following a specification document of potentially required indicators for the analytical model. The aim of the document was to provide guidelines for the data collection within the case studies and a complete set of indicators were not necessary to analyse the case study fishery.

Even though substantial efforts were made to collect the data identified in the specification document, due to confidentiality constrains or non availability in the national authorities, not all case studies managed to obtain all the data.

Table 12 below summarises the coverage of available data based on the keys defined in table 13.

Table 12 Summary of available data

		Data Requirements (Collected vs. Required)					
		Background to the fishery	Technical Characteristics of the Fleet	Biological Characteristics of the Fishery	Socio-Economic Characteristics of the Fishery	Management of the Fishery	Enforcement of the Fishery
Case Study Fisheries	Northern hake	🟩	🟩	🟩	🟩	🟩	🟨
	Icelandic cod	🟨	🟩	🟨	🟩	🟩	🟩
	Bay of Saint Brieuc	🟩	🟩	🟩	🟩	🟩	🟩
	Norwegian fisheries	🟩	🟩	🟩	🟩	🟩	🟥
	Ligurian bottom trawl	🟩	🟩	🟨	🟨	🟨	🟨
	Kattegat nephrops	🟩	🟩	🟨	🟩	🟩	🟩
	Dutch beam trawls	🟩	🟩	🟩	🟩	🟩	🟨
	Western channel	🟩	🟩	🟩	🟩	🟩	🟩
	CCAMLR	🟩	🟩	🟩	🟨	🟩	🟩

Table 13 contains the keys for describing the data availability in table 12 above.

Table 13: Key to summary table 13

	🟩	🟨	🟥
Time series	Data referring to 2004 or later	And/or time series referring to 2004 and older	-
Background to the fishery	1.Target species 2.Size of the area 3.Area of control zones 4.Landing ports 5.Effort	1.Taget species 2.Size of the area 3.Area of control zones	Insufficient
Technical Characteristics of the Fleet	1.Number of vessels 2.Tonnage 3.Engine power	1.Number of vessels 2.Tonnage	Insufficient
Biological Characteristics of the Fishery	1.Landings 2. Catches 3. Biomass	1. Landings 2. Catches	Insufficient
Socio-Economic Characteristics of the Fishery	1. All variables needed to calculate profitability of the fishery. 2.Crew	1.Some variables needed to calculate profitability	Insufficient
Management of the Fishery	1. All relevant management systems given	1.Some relevant management systems given	Insufficient
Enforcement of the Fishery	1. Cost of enforcement tools 2.Intensity of enforcement tools 3.Average penalty level	1. Cost of enforcement tools 2.Intensity of enforcement tools	Insufficient

Table 12 shows that most of the data identified in the specification document has been collected and uploaded to the data base.

The interested reader is referred to the deliverable “Data harmonisation” for a detail overview of the data harmonization efforts conducted within the project.

3.2 SOFTWARE DEVELOPMENT AND COMPUTER MODELLING

3.2.1 Introduction and background

The COBECOS software uses object oriented programming and pre-written R functions to provide a powerful and flexible means of undertaking cost-benefit analysis of enforcement strategies. The software is designed to be accessible to users without a background in R programming whilst providing more experienced R programmers with sufficient control and flexibility to carry out management strategy evaluation using the COBECOS functions and methods. The code is open source and available from http://cobecos-wp6.googlecode.com/svn/trunk/, along with tutorials and manuals that detail installation, interpretation and implementation of the software.

The software developed during COBECOS and described here primarily relates enforcement effort expenditure with societal economic returns. Enforcement effort has a direct economic cost and a benefit relating from the prescription of illegal activity. This illegal activity has the potential to jeopardize future economic returns, with the immediate loss parameterised through the shadow value of biomass, λ. Thus enforcement effort has a potential economic benefit, and it is this cost-benefit trade-off that the software is designed to evaluate. Optimisation methods can be optionally employed, providing insight into the economic enforcement level that maximises societal returns.

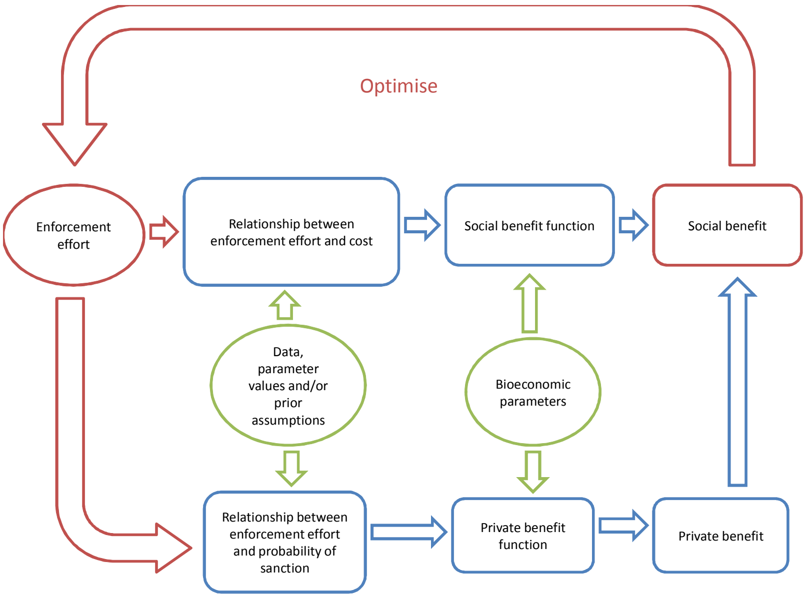
Implementation of the software requires user input at two stages. First, a relationship between enforcement effort and the probability of sanction, and enforcement effort and economic cost must be described for the bioeconomic system being modelled. Second, the consequences of a particular effort level, which will act to influence fisher behaviour, and the costs involved must be related to the overall economic returns to both the fishers and society as a whole. The fishers are assumed to be economically rational and will act to maximise their own private benefit. The optimal enforcement effort is that which ensures the fishers behaviour yields the maximum benefit to society, by taking into account societal costs (through λ).

Illegal activity can take a variety of forms, but frequently involves breach of catch (TAC) or effort restrictions. Clearly multiple infringement types can occur simultaneously, however such a problem is computationally intractable for such a generic software application, and thus only a single infringement type is considered.

It is often the case that multiple enforcement types act simultaneously to influence a particular infringement type. Similarly, a single infringement type may have consequences for more than one stock. For example a breach of effort limitations will have an impact on all the stocks targeted by a particular métier. Or a fisher may seek to maximise returns by catching from two stocks simultaneously. Multi-stock, multi-enforcement type scenarios are clearly more complex than single-stock, single enforcement type scenarios, particularly due to the difficulty of optimising enforcement effort over an increasing number of potentially conflicting objectives. It is also conceptually undesirable to automate a model fitting process that can fit multivariate effort-probability and effort-cost relationships, within the software package, whereas it is a simple process when only a single enforcement type is being considered. Therefore two versions of the code exist. Version 1 considers only a single enforcement type and single stock. It is relatively simple and easily accessible to the inexperienced user. Version 2 is supplied to deal with more complex situations involving multiple enforcement types and multiple stocks. It also requires a greater level of user involvement in setting up and running the program. This includes the estimation of effort-cost and effort-probability relationships externally, which are then input into the software program. To be consistent with the presumed interdependence of enforcement types, multiple enforcement types are allowed to act simultaneously within the model provided they only yield a single detection probability for a single infringement type. To improve the accessibility of the software, a user friendly interface (UFI) has been developed for version 1 of the code. This is introduced following a brief outline of the dataflow within the generic software and its functionality. This outline is intended to illustrate the capabilities of the software. The reader is referred to the user Manuals v1 and v2 for a detailed description of how the software can be implemented in practice.

To facilitate description of the software functionality, it is helpful to first outline how the software proceeds from user input to output. Figure 4, illustrates this data flow, showing schematically how assumed levels of enforcement effort are used to calculate the resultant social benefit, using information on the effort-cost and effort-probability relationships and bioeconomic parameters supplied by the user. When optimising, the software will adjust the enforcement effort in an iterative process until the social benefit is maximised.

Figure 4: Data flow for the generic COBECOS software



3.2.2 Version 1 – One enforcement tool single species

Version 1 of the computer code defines a range of theoretical relationships between enforcement effort and the probability of detecting violations (EP). These are given in
to
, where E represents enforcement effort and p1 to p3 represent the defining variables.

Logistic EP relationship (eq. 25)

$$P(E) = \frac{p_1}{1 + e^{(p_2 - E)/p_3}}$$

Exponential EP relationship (with intercept) (eq. 26)

$$P(E) = (1 - e^{-p_1 E})(1 - p_2) + p_2$$

Exponential EP relationship (without intercept) (eq. 27)

$$P(E) = (1 - e^{-p_1 E})$$

Defines a range of theoretical relationships between enforcement effort and cost (EC), listed in
to
, where again E represents enforcement effort and p1 to p4 represent the defining variables.

Non-linear EC relationship (with intercept) (eq. 28)

$$C(E) = p_1 E^{p_3} + p_2$$

Non-linear EC relationship (eq. 29)

$$C(E) = p_1 E^{p_3} + p_2$$

Linear EC relationship (with intercept) (eq. 30)

$$C(E) = p_1 E + p_2$$

Linear EC relationship (eq. 31)

$$C(E) = p_1 E$$

The above relationships can be specified in a control file or selected automatically by the software. If the later then the software will fit the above theoretical EC and EP relationships to inputted data and selecting the best fitting EC and EP models according to model selection criteria. Parameters defining the functional form of the relationship are estimated.

3.2.3 Version 2 - Multiple enforcement tools multiple species fishery

Allows user specification of multivariate EP and EC relationships that relate the effort values of multiple enforcement types to a single cost and probability of detection

3.2.4 Versions 1 and 2

Version 1 and 2 of the generic COBECOS code defines the functional forms of the private and social benefit functions. Default functional forms exist but can also be specified by the user (see Manuals).

and
specify the default relationships between private and social benefit, catch *q*, biomass *x*, cost of fishing *c* and fine *f*, given *P(E)* and *C(E)*.

Default private benefit function (eq. 32)

$$B_P(q,E) = pq - c\frac{q^2}{x} \qquad q \le TAC$$

$$B_P(q,E) = pq - c\frac{q^2}{x} - fP(E)(q - TAC) \qquad q > TAC$$

Default social benefit function (eq. 33)

$$B_S(E) = (p -)q^* - c\frac{(q^*)^2}{x} - C(E)$$

$$q^* = \max_q B(q,E)$$

The code evaluates the private and social benefits at a user defined level of enforcement effort. Given a level of enforcement effort (that can be 'real world' or hypothetical) the software returns the social and private benefits at that effort level given the EC and EP relationships. If utilising the default equations (
and
), this requires user input of the p, x, c, f and TAC parameters. The fisher's response variable q is estimated internally by the program through maximisation of the private benefit function (giving q*), with a plot produced of private benefit against q to illustrate.

Furthermore, it evaluates the private and social benefits at optimal levels of enforcement effort. Optimisation routines select the enforcement effort to maximise the social benefit, returning the social and private benefits at this effort level given the EC and EP relationships.

The software produces plots of the marginal social benefit(s) across the enforcement level and returns the predicted level of illegal catch.

Finally, it allows the user to specify types of stochastic uncertainty and evaluate social and private benefits. Implementation error introduces uncertainty in the fisher's response to a specific enforcement effort level. Estimation error introduces uncertainty around the estimated EC and EP relationships. Either or both types of uncertainty can be included.

3.2.5 User friendly application for version 1

To improve the accessibility of the software, a user friendly interface (UFI) has also been developed for version 1 of the code.

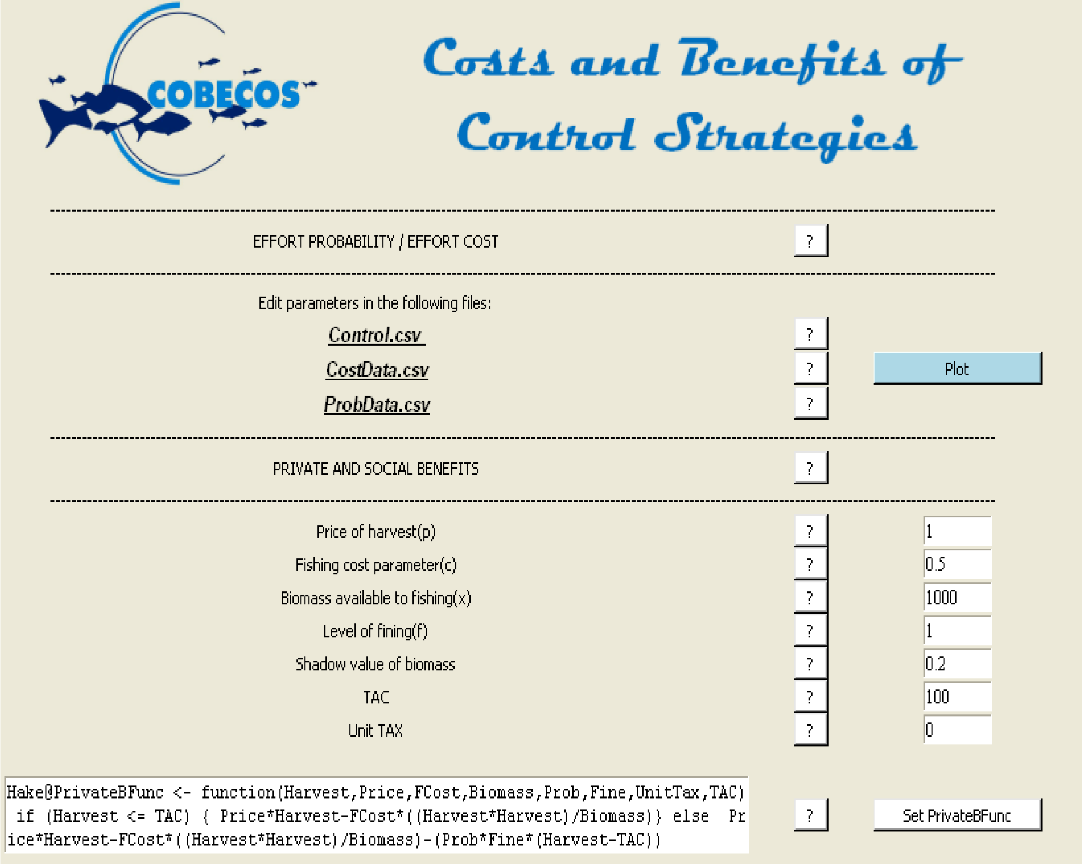
The UFI provides an accessible implementation of version 1 of the generic COBECOS code, specifically allowing the user to investigate single-stock, single enforcement type situations with no previous experience of R programming. Implementation of the COBECOS theory within the UFI can be achieved in two simple steps.

1. **Specification of the effort-cost and effort-probability relationships.** This can be achieved by either providing the effort-cost ('CostData.csv') and effort-probability ('ProbData.csv') data directly in the form of comma-delimited files and allowing the programme to select or estimate the appropriate relationships, or by simply specifying the relationships *a priori*. These two options are controlled by entries into a third file ('Control.csv') in a manner analogous to implementation of version 1 of the code. The available functional forms are identical to those specified for version 1 of the code above.

2. **Specification of the bio-economic parameters.** Boxes are provided for each of the bioeconomic model parameters, for the user to fill in. The user is further able to specify the private benefit and social benefit functional forms, select whether to optimize enforcement effort and plot the results. A text output of the results is also given. Stochasticity (estimation or implementation error) can be specified as required from a drop-down menu.

At each stage, a help window can be opened explaining what is required to run the UFI successfully, with example plots given to illustrate. The theoretical foundations are the same as for version 1 of the code and are given in appropriate detail in the version 1 manual.

Figure 5 User-friendly application of version 1 of the generic COBECOS software.



Price of harvest(p) 1
Fishing cost parameter(c) 0.5
Biomass available to fishing(x) 1000
Level of fining(f) 1
Shadow value of biomass 0.2
TAC 100
Unit TAX 0

```
Hake@PrivateBFunc <- function(Harvest,Price,FCost,Biomass,Prob,Fine,UnitTax,TAC)
 if (Harvest <= TAC) { Price*Harvest-FCost*((Harvest*Harvest)/Biomass)} else  Pr
ice*Harvest-FCost*((Harvest*Harvest)/Biomass)-(Prob*Fine*(Harvest-TAC))
```

3.2.6 Other software used

Within the COBECOS project full functioning generic software that allows the user to investigate the costs and the benefits of enforcement tools of various EU fisheries and management situations has been developed. The fact that the COBECOS software is generic represents both a benefit and a drawback. As in most generic models there is a trade of between the flexibility and the ability to facilitate for case specific factors. Additional computer models with greater ability to describe the case study fisheries in more detail, was therefore developed in some fisheries. In every case study however, to show that the COBECOS software works, at least some simulations were run using the COBECOS software. Table 14 below provides an overview of the different software used for simulations in the case studies.

Table 14. Overview of the extent the COBECOS software is used.

Case study	COBECOS software for some simulations	COBECOS software for ALL simulations	Additional software used for some simulations
Northern hake	YES	NO	R
Bay of Saint-Brieuc	YES	YES	n.a
CCAMLR	YES	YES	n.a
Ligurian bottom trawl	YES	NO	Excel
Norwegian fisheries	YES	NO	Maple/Excel
Icelandic cod	YES	NO	Mathlab
Dutch beam trawl	YES	YES	n.a
Kattegat and Skagerrak nephrops fishery	YES	YES	n.a
Western channel fisheries	YES	YES	n.a

As seen in the table above the COBECOS software can successfully be used to conduct cost benefit analysis in all case study fisheries. Half of the case studies have used the COBECOS generic software for all simulations while the other half has run some of the simulations in other software.

3.3 CASE STUDIES

The basic enforcement model that has been developed within the project consists of two main functions, the private and the social benefit functions. These functions represent a general framework for which each case study has developed its own empirical enforcement model taking into account the specific characteristics of the fishery.

The case specific enforcement models have been used to investigate the effects of altering particular management or enforcement tools and to investigate possible improvements in the management and enforcement systems in place.

This section describes and compares the results obtained from simulations of scenarios in the nine case study fisheries.

3.3.1 Description of Case Studies

The case studies of COBECOS consist of a set of nine different fisheries from within the EU, Norway, Iceland and the CCMLAR islands. They were partly chosen as to ensure that a broad range of fisheries characteristics would be included and to guarantee that most enforcement and management issues would be investigated within the project. The heterogeneity of the case studies also allowed for the enforcement theory developed within the project to be tested on a wide variety of fisheries, management and enforcement systems.

The fisheries analysed include mono-species and multi-species fisheries, pelagic and demersal fisheries as well as mono-gear and multi-gear fisheries. Management is generally based on output control systems such as TAC and other quotas regimes but also input control systems such as fishing effort limitations, and technical measures such as mesh size restrictions or area and season closed are included in at least one case study. As for the enforcement system, dock-side inspections and inspections at sea represent the prevalent enforcement tools considered in the simulation models, but also plane surveillance has been taken into account in some of the case studies.

In order to define the empirical functions each case study has conducted thorough data collection and an estimation and calibration procedure. A detailed description of the efforts within the case studies is available in the Case Study Summaries report as well in deliverables D2, D5 and D7.

Table 15: Overview of enforcement and management tools by case study

Case Study	Enforcement Tools	Management Tools	Model specifications
Northern Hake	Dock side inspections	TAC hake	
Bay of Saint-Brieuc Scallops	Plane inspections Inspections at sea Dock side inspections	Non-transferable effort quotas	
CCAMLR SG/Kerguelen	Fishing patrol vessels	TAC toothfish	-Static and dynamic analysis -With and without consideration of IUU when setting the TAC.
Ligurian and N. Tyrrhenian S. Bottom Trawling	Inspections at sea Dock side inspections	Fishing without license Using prohibited fishing gears Unauthorized fishing	
Norwegian Fisheries	Inspections at sea Dock side inspections	Quota restriction Mesh size restriction	
Icelandic cod fishery	Plane inspections Inspectors Observers	TAC cod	
Dutch beam trawl	Dock side inspections	TAC sole TAC plaice	
Kattegat & Skagerrak nephrops	Dock side inspections Boarding	TAC Norway lobster TAC Atlantic cod	Two analysis carried out: -Singles species, single enforcement tool -Multiple species, multiple enforcement tools
Western Channel Fisheries	Dock side inspections	TAC sole	

3.3.2 Specification of Key Questions Answered by Simulations

In order to ensure a certain degree of harmonisation in the presentation of the case study results, a set of key questions to be answered by the case studies has been defined. The questions are related to the simulated effects of changes in particular management or enforcement elements, and to the optimal combinations of enforcement instruments and the intensity of their applications in particular fisheries.

The questions for simulation are organised in six simulation categories: Enforcement intensity, enforcement tools, penalties, management measures, management tools, and combinations of the previous categories. For each of the six categories, the simulation results are measured in some or all of the depend variables below:

- level of compliance
- private benefits
- social benefits
- penalties
- enforcement costs
- biomass of each of the target species

3.3.3 Generic Software

Within the project a full functioning generic software that allows the user to investigate the costs and the benefits of enforcement tools of various EU fisheries and management situations has been developed. It includes default functions but it is flexible enough to allow the user to introduce their own estimations, modify the parameters etc. if so wanted.

The fact that the COBECOS software is generic represents both a benefit and a drawback. As in most generic models there is a trade of between the flexibility and the ability to facilitate for case specific factors. Additional computer models with greater ability to describe the case study fisheries in more detail, was therefore developed in some fisheries. In every case study however, to show that the COBECOS software works, at least some simulations were run using the COBECOS software. Table 16 below provides an overview of the different software used for simulations in the case studies.

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Ligurian bottom trawl	YES	NO	Excel
Norwegian fisheries	YES	NO	Maple/Excel
Icelandic cod	YES	NO	Mathlab
Dutch beam trawl	YES	YES	n.a
Kattegat and Skagerrak nephrops fishery	YES	YES	n.a
Western channel fisheries	YES	YES	n.a

3.3.4 Case Study Results

Given the current status of the fisheries under investigation, simulations have been performed to answer the questions summarised in Appendix 2.

The simulation procedure was initiated by estimation of the current situation (base case) by using data on fisheries, enforcement and management system. The values estimated at the baseline were then modified by the software to perform simulations and estimations of the effects on the system. Generally, the simulations were performed by a static approach where year by year results were not produced. An exception is represented by the CCAMLR case study where both static and dynamic simulations have been performed.

This section presents the results from the simulations by simulation categories:

- Simulation of the enforcement level
- Simulation of penalties
- Optimal combination of enforcement tools

Due to the differences in the fisheries characteristics and management system in place, some of the defined questions for simulations were not relevant for all case studies and in some case simulations that had not previously been defined were performed.

3.3.4.1 Simulation of enforcement level

In the first simulation the enforcement level is altered in relation to the base case to investigate the effects of the dependent variables; compliance, private benefits, social benefits, enforcement costs and the biomass level.

Variations in the enforcement effort affect the probability of being detected when violating, and consequently the private cost of violation. As fishers operate to maximize their profit, the level of violation will decrease if expected cost of violating increases. The optimal level of violation (i.e. compliance) for the fisherman is obtained when the marginal cost of violating equals the marginal benefit of violating. Naturally, the enforcement effort is also affecting the cost of enforcement and has to be deducted from the benefits brought upon by it.

Northern Hake
An increase in the enforcement effort leads to higher compliance and social benefits, up to the point where the costs of enforcement outweighs the benefits. The optimal level of enforcement effort is achieved at a 97 % compliance level. Hence, full compliance is not optimal.

In a scenario with no enforcement effort, the compliance level is around 70 % of the TAC (i.e. 30 % of illegal landings). At this level the harvest would increase by 8 % and the social benefits would be reduced by 32 % relative to the base case, which would force the fishery to close in the long-term (less than 10 years).

Bay of Saint-Brieuc

Unlike all other case studies an increase in the enforcement level does not increase the social benefits. Instead there is a negative relationship between enforcement effort and social benefits. This relationship is not anticipated in the theory and is explained by the chosen modelling approach in which the compliance rate is kept constant and is hence not affected by the enforcement intensity (further explanation is available in D7).

The analysis further suggests that the current level of enforcement is too high and have to be reduced in order to increase social benefits. The optimal enforcement level occurs at very low levels of enforcement (close to zero).

CCAMLR

An increase in the enforcement effort leads to higher compliance and social benefits up to the point where the costs of enforcement outweighs the benefits[14]

A static and a dynamic analysis were carried out for the case study fishery. The analyses show that the current level of enforcement of 200 days is too high. The static approach using 2007 as the base year suggests that the number of patrolling days should be decrease to just 120 days, in order to optimise the social benefits. The dynamic model suggests an even lower level of 90 patrolling days to maximise the social benefits.

At the current level of enforcement effort the compliance has reached 100 % but as stated above it needs to be decreased to maximise the social benefits. The dynamic simulations suggest that the minimum number of patrolling days to ensure full compliance amounts to 120 days.

The case study has also investigated the effect of the level of enforcement intensity on the biomass level and concludes that there is a positive relationship between them when TAC was not adjusted for illegal activity. If the TAC is adjusted for illegal activity the average biomass is in fact lower for higher enforcement levels. This suggests that the TAC procedure is overcompensating for IUU fishing.

Ligurian and Northern Tyrrhenian Sea bottom trawling fishery

The current level of enforcement effort of 6.8 % for landings control and 3.6% for at sea inspections generates very high compliance level for the three violations included in the analysis (99.2 % fishing without a license, 99.8 % keeping prohibited gears onboard and 99.43 % unauthorized fishing). Furthermore, at the current level of enforcement intensity the social benefit is merely 0.59 % away from the optimal level.

The simulations show that the level of compliance increases with increasing enforcement effort in the fishery. However, the effect of compliance depends on the specific illegal behaviour and the enforcement tool measured. Unauthorised fishing is the illegal behaviour that is affected the most of changes in the enforcement intensity. Furthermore, the analysis shows that inspection at sea is more efficient than landings inspections in improving the compliance with fisheries regulations. Full compliance with all regulations can be achieved when 16.3 % of all fishing effort is inspected by landings inspections or 7.6 % controlled by inspections at sea.

---

[14] The case study has conducted simulations for two scenarios; when illegal activity is taken into account in setting the TAC and when it is not. The results presented here refer to the case when illegal activity is taken into account when setting the TAC.

Even though inspection at sea is more efficient then landings inspections in detecting illegal behaviour, the cost benefit analysis show that landings inspections can improve the level of compliance at a lower cost since the marginal cost of inspection at sea is significantly higher than the marginal cost for landings inspections.

An increase in the enforcement level has a positive effect of the stock status since it affects compliance positively. In a simulation of no landings inspections the biomass of the three target species decreases by 14.8 % for mullet, 2.4 % for hake and 3.2 % for shrimp.

Norwegian fisheries

An increase in the enforcement effort of the two tools leads to higher compliance and social benefits up to the point where the costs of enforcement outweighs the benefits.

Due to the high cost of at sea inspections compared to the harbour inspections, although sea inspections are more efficient, an increase in the enforcement level gives a lower social benefit than what an increase in the harbour control generates. This is also evident when investigating the effect of enforcement costs. A much larger reduction in the enforcement activities at sea is needed to provide a similar gain in social benefits than a reduction in harbour enforcement activities.

However, the analysis shows no improvement for removing one of the two tools completely based on social benefits. Furthermore, it is shown that an abolishment of any of the two enforcement tools would reduce the biomass substantially.

Icelandic cod fishery

Increasing enforcement effort leads to higher compliance and social benefits until the optimal enforcement level is reached.

Full compliance (100 %) is not optimal since at this enforcement level the costs of enforcement will outweigh the benefits of enforcement to the society.

Dutch beam trawl

An increase in the enforcement effort leads to higher compliance. The current enforcement level of 2 028 port inspections in the year is sufficient to achieve full compliance for sole and plaice. This is due to the fact that the analysis is considering compliance on the aggregated fisheries level and the aggregated landings of the two species do not exceed the total TAC in the base year. The minimum number of port inspections to achieve full compliance is shown to be 2 000 for plaice and 1 600 for sole.

The analysis shows that the social benefits are negative for each level of enforcement since the private benefits do not compensate for the costs associated with the fished biomass (shadow value) and the enforcement costs. In fact, the analysis shows that at the current TAC level and enforcement effort the fleet is not making any profits. This finding is explained by the fact that fleet suffered an aggregated loss of 10 mEuro in the base year.

The maximum social benefit is reached when the number of port inspections amounts to 1 800 inspections in the year suggesting that some over fishing is acceptable in order to maximise social benefits.

In absence of enforcement the non-compliance (here defined as over quota catch as percentage of the fleet's quota) for plaice is estimated to be around 55 % and for sole 250 %. At this level the social benefits would be reduced by 26 million Euros. After one year of no enforcement the biomass of plaice and sole would have decreased by 50 % and 30 % respectively.

Kattegat and Skagerrak nephrops
The case study has performed two analyses; one includes one species and one enforcement tool. The second includes two species and two enforcement tools.

i) Single species single enforcement tool
An increase in the single enforcement level increases the level of compliance and social benefits as expected by the theory.

The optimal level of enforcement is reached at 100 % compliance. This stems from the fact that the TAC is higher than what is the social optimal response. In order to achieve full compliance the enforcement level has to be increased from the current level of 4 % to 18.3 %.

A scenario with no enforcement results in a compliance level of 95 %. At this level the private and the social benefit have not changed much compared to the base case.

ii) Multiple species – multiple enforcement tools
By introducing two enforcement tools synergies is created between them. An increase in the enforcement intensity both individually and simultaneously increases the compliance level and the social benefits up to a certain level of enforcement intensity.

In a simulation of zero enforcement effort the compliance level will be 92.8 % and 77 % for lobster and for cod, respectively, for the regulatory measures. If only one tool is abolished at the time the compliance remains relatively unchanged for both species.

(Western) channel fisheries
The case study has conducted their analysis based on three scenarios of the level of enforcement costs; low medium and high.

For all scenarios it is evident that an increase in enforcement effort will increase the compliance rate and the social benefits up until the maximum point has been reached.

3.3.4.1.1 Summary of the results obtained from simulations of enforcement level

As predicted by the theory, the analysis shows that for most fisheries an increase in the enforcement level will increase the compliance and the social benefits up until the point where the costs of enforcement outweigh the benefits. The three case studies that also investigate the effects of the enforcement effort on the stock size have also found a positive relationship between the two. The improved stock size is explained by the increase in compliance that a higher enforcement effort produces.

Full compliance is often set as the target for enforcement management. However, the high cost of enforcement is in many cases outweighing the benefits of enforcement when compliance reaches 100 %. In these cases, increasing the enforcement effort further would decrease the benefits to the society and a low level of violation of fisheries regulations would be considered acceptable. This is evident in the case study analyses that show that in 5 out of 6 cases studies 100 % compliance would not maximise the benefits to the society. The northern hake fishery for example shows that the social benefits are maximised at 97 % compliance level. An increase in the enforcement level in the fishery to achieve full compliance would in this case reduce the social benefits.

The optimal enforcement situation in terms of the choice of enforcement tools and its intensity appears to be very far from the current situation in the included fisheries. The only exception to the rule is the Ligurian case study that found that the current level of landings inspections only have to be increased by 0.59 % in order to achieve maximum social benefits. Furthermore, in three of the case study fisheries the enforcement level is currently too high and need to be reduced in order to achieve maximum social benefits. In the CCAMLR fishery the optimal level of patrolling days is estimated to 90 days instead of the current level of 200 days.

Table 17 Overview of the results obtained from simulations of the enforcement level

	CASE STUDY		
	YES	**NO**	**Not investigated**
Does an increase in the enforcement effort lead to higher compliance and social benefits?*	*Northern hake* *CCAMLR* *Ligurian bottom trawl* *Norwegian fisheries* *Icelandic cod fisheries* *Dutch beam trawl* *Kattegat nephrops* *Western channels*	*Bay of Saint-Brieuc*	-
Is the enforcement level optimal (in terms of social benefits) at 100 % compliance?	*Kattegat nephrops*	*Northern hake* *CCAMLR* *Ligurian bottom trawl* *Icelandic cod fisheries* *Dutch beam trawl*	*Bay of Saint-Brieuc* *Norwegian fisheries* *Western channels*
Does the current level of enforcement result in 100 % (or close to) compliance.	*CCAMLR* *Ligurian bottom trawl* *Dutch beam trawl*	*Northern hake* *Bay of Saint-Brieuc* *Icelandic cod fisheries* *Kattegat nephrops*	*Norwegian fisheries* *Western channels*
Is the current situation optimal (or close to) in terms of social benefits?	*Ligurian bottom trawl*	*Northern hake* *CCAMLR* *Icelandic cod fisheries* *Dutch beam trawl* *Kattegat nephrops*	*Norwegian fisheries* *Western channels*
Is there a need to decrease the enforcement effort to achieve maximum social benefits?	*Bay of Saint-Brieuc* *CCAMLR* *Dutch beam trawl*	*Ligurian bottom trawl* *Icelandic cod fisheries* *Kattegat nephrops* *Northern hake*	*Norwegian fisheries* *Western channels*
Is the biomass level affected by the enforcement level?	*Northern hake* *Ligurian bottom trawl* *CCAMLR*** *Norwegian fisheries* *Dutch beam trawl*		*Bay of Saint-Brieuc* *Icelandic cod fisheries* *Kattegat nephrops* *Western channels*

* Up until the point where the costs of enforcement outweighs the benefits

** Relevant only when the TAC is not adjusted for illegal activities

3.3.4.2 Simulations of penalties

Penalties are associated to each of the management tools considered in the simulations. Generally, an average fine per unit of violation is used to estimate the total amount to be paid by a fleet for its illegal behaviours. When the fisheries are managed by harvest control rules, the unit of violation is generally associated to the weight unit overcoming the limit imposed by TAC or other quotas regimes. When the management system is based on input control measures, the unit of violation generally coincides with the single infringement.

Northern Hake
The analysis shows that an increase in the fine level of 0.5 % relative to the base level produces the same social benefits as an increase in the enforcement level by 10 %. However, the level of compliance does not increase to the same extent as when enforcement effort is increased.

Bay of Saint-Brieuc
The private benefit is negatively related to the increased penalty level as expected. However, the social benefit decreases with increasing fines. This result contradicts the theory and is explained because the fishery is not sufficiently profitable; the shadow value of biomass for the target species is very low.

CCAMLR
From the static analysis it is evident that an increase in the fine level leads to increased social benefits. In the dynamic approach, since the number of illegal vessels is small, the effect of increasing the fine level on the social benefits is negligible.

The current fine level in the fishery is set to 500 000 GBP. By fixing the number of enforcement days to 120 days the optimal fine level was found to be 750 000 GBP in the dynamic simulations, both when the TAC was adjusted for IUU activity and not.

The synergistic effects of the fine level and the enforcement level on the compliance level were investigated by investigating how the optimal enforcement level changes by increasing the fine level by 50 % and 100 %. In both the simulations the optimal enforcement level remained constant at 90 days. This suggests that the interaction effect between the enforcement level and the penalty is minimal with the enforcement effort being the determinant of compliance.

Ligurian bottom trawling
As anticipated in the theory an increased penalty level increases the social benefits since it reduces the illegal activity.

Due to model assumptions penalties will only affect the specific illegal activity and not the fishery as a whole. The analysis shows that out of the three types of illegal behaviours that have been included in the analysis, compliance with the regulation regarding unauthorized fishing is affected the most by variations in the penalty amount. Furthermore, it is shown that at the current level of enforcement effort the penalty must be increased by 22.3 %, 57.2 % and 38.5 % for unauthorized fishing, fishing without holding a license and keeping prohibited gears on board respectively, to achieve full compliance.

Since full compliance can be achieved at lower enforcement levels if the penalty is increased, the case study investigated the synergistic effects of the fine level and the enforcement level. The simulations show that an increase of 50 % of the penalties can reduce the enforcement intensity with a third and the costs associated with full compliance with more than 2 million Euros in a year. If the penalty level is increased by 100 %, the enforcement intensity and the enforcement costs could be reduced in half. At this level the social benefits would increase by 5.7 %.

Due to the fact that changes in the penalty level can modify illegal and legal behaviours of the fleet it will also affect the biomass level. The effect of varying the penalty levels for infringements of the different regulations on hake, mullet and shrimp has therefore been investigated. The analysis shows that the penalty amount that produces full compliance with the regulations regarding unauthorized fishing and use or keeping prohibited fishing gears onboard, increase the level of biomass of stripped mullet of 6.4 % and 4 % respectively. The most affected species by variation associated with using prohibited gears on board is European hake, which increases in biomass between 3 and 4 % when compliance is maximised.

Norwegian fisheries

An increase in the penalty level increases the biomass level which also affects the TAC level positively in the long run.

The analysis shows that an increase in the penalty level by 50 % leads to less use of illegal mesh-size which leads to increased harvest and biomass but hardly any change in the social benefits. A 100 % increase in the penalty level leads to a reduction in social benefit despite the increase in harvest and biomass.

Icelandic cod fishery

An increased fine level increases the social benefits and compliance. The analysis shows that the private benefits decreases with the increase in the fine level until the harvest reaches the TAC as then it is no longer profitable to harvest above the TAC.

In a scenario of the penalty level set to 500 ISK/kg the harvest is about 75 % higher than the TAC. If the penalty is increased, the harvest decreases with the fine level until it has reached the TAC level at fines of 3500 ISK/kg or higher. The analysis shows that the harvest level is not influenced greatly for fines ranging between 1 476 to 3000 ISK/kg which suggests that the current level of fine of 1 476 ISK/kg might be close to producing full compliance

An increase in the penalty level to 50 % at the optimal enforcement level reduces the harvest rate and causes the social benefits to increase. If the penalty level increases by 100 % the harvest is reduced to the level of the TAC and the private and social benefits are reduced to levels below the base case.

Dutch beam trawl

The current fine of 2 200 Euro in combination with confiscation of over-quota catches is sufficient to induce full compliance in the fishery. The analysis shows that at the current level of enforcement the fine level could in fact be reduced to 1 800 Euro without diverging from full compliance.

In order to achieve maximum social benefits a decrease in the fine level is needed to allow for some illegal activity. Any fine between 0 and 1700 only causes a difference in private benefits due to payments of fines but as these are exactly compensated by differences in non private benefits (income from fines to the government) social benefits are the same for all fine levels.

The social benefits reach a maximum at 80 % of the current penalty level. At this level 80 % of the over quota catches is confiscated and the fine level is 1 760 Euro. This leads to both higher private benefits and higher social benefits than the full compliance level.

In a simulation of increasing the fine with 100 % the optimal enforcement level is decreased from 1 800 to 1 360 port inspections. If full compliance is the target the optimal number of inspections amounts to 1 480.

The effect of the fine level on the biomass level is also investigated and it is concluded that penalty levels below 80 % of the current level will cause the stock to shrink affecting next year's TAC's and the private and social benefits negatively.

Kattegat and Skagerrak nephrops

i) Single species single enforcement tool
In the model the fine is dual since the violator is facing both a fine and has to repay the value of the illegal catch.

Increasing the fine level increases the compliance level and the social benefits. The analysis further shows that in order to achieve full compliance at the enforcement level of the baseline case, the penalty has to be increased three folds.

The case study has further investigated the relationship between the fine level and the optimal enforcement level by simulating an increase of 50 and 100 % increase in the fine. It is concluded that as a response to the increased fine levels the enforcement intensity can be decreased.

ii) Multiple species – multiple enforcement tools
In the analysis of multiple enforcement tools penalty is not as an effective mean to reach full compliance (in this case study equal to the optimal level of social benefits) since it would require a 15 doubling of the fine level to achieve full compliance for both species.

(Western) channel fisheries

The analysis shows that the social benefits are not significantly affected by the level of the fine. This can be explained by the relatively small cost of enforcement and the relatively low expected penalties in relation to the value of landings. However, it is evident that the enforcement effort and hence the cost of enforcement can be decreased at the optimal level if the penalties are increased.

3.3.4.2.1 Summary of the results obtained from simulations of the penalty level

The theory states that fishermen will conduct in illegal activity as long as the expected benefits are greater than the expected costs of the action. By increasing the penalties the expected costs of illegal activities increases which reduces the illegal harvest. Since increases the fine level do not impose additional costs to the enforcement activity it represents a good alternative to increasing the enforcement level.

This relationship is confirmed in 8 out of 9 fisheries.

Table 18. Overview of the results obtained from simulations of the fine level

	CASE STUDY		
	YES	**NO**	**Not investigated**
Are social benefits positively affected by the level of the fine?	*Northern hake* *CCAMLR** *Ligurian bottom trawling* *Icelandic cod fisheries* *Dutch beam trawl* *Kattegat nephrops*	*Bay of Saint-Brieuc* *Western channels*	*Norwegian fisheries*
Does an increase in the penalty level affect the biomass level positively	*CCAMLR** *Ligurian bottom trawling* *Norwegian fisheries* *Icelandic cod fisheries* *Dutch beam trawl*		*Northern hake* *Kattegat nephrops* *Western channels* *Bay of Saint-Brieuc*
Simulations conducted in which the fine level is increased with 50 and 100 %	*CCAMLR* *Ligurian bottom trawling* *Norwegian fisheries* *Icelandic cod fisheries* *Dutch beam trawl* *Kattegat nephrops* *Bay of Saint-Brieuc*		*Western channels*

*Valid for the static model. Only negligible increase in the social benefits in the dynamic model.

*Valid for the dynamic model without adjustment for illegal activity when setting the TAC

3.3.4.3 Optimal combination of enforcement tools and other additional simulations

Northern Hake

The case study fishery consists of one enforcement tool. No additional simulations were conducted.

Bay of Saint-Brieuc

The case study has run simulations to find the optimal mix and the intensity of the enforcement tools in the fishery. It is concluded that the optimal social benefits are achieved at an intensity of 0.1 air patrol, landings control and sea patrol, respectively. The equal enforcement intensity between the tools suggests a constant rate between the efficiency (i.e. its ability to detect illegal activity) and the costs of the tool.

When analysing the effect of abolishing one of the enforcement tools it is evident that that the social benefits will increase regardless of which of the three enforcement tools that is abolished.

CCAMLR

The effect of a 10 % and a 20 % reduction in the enforcement cost per day were investigated by the case study. The reduction in enforcement costs did not change the optimal situation and the social benefits are still maximised at 90 days.

Ligurian bottom trawling

The optimal mix of enforcement tools has been investigated in terms of compliance level and social benefits. Full compliance of the fishery regulations can be found at an infinite number of combinations of the three enforcement tools present in the fishery. Therefore the combination of tools that produce full compliance at the lowest cost is considered optimal. The case study found that inspection at sea represents the most efficient enforcement tool in increasing the compliance level but it is also the most expensive enforcement tool. The analysis shows full compliance with all regulations can be found if inspection at sea is abolished completely and 26.16 % of all fishing effort is controlled at landings. The enforcement cost at this level of enforcement is 40 % less than the current enforcement expenditures representing a cost saving of 2.5 million Euro.

When the optimal mix of enforcement tools in terms of social benefits are being considered it is again evident that, due the high costs of inspection at sea, this tool should be abolished and landings controlled increased in order assure maximum social benefits. The optimal solution appears when inspection at sea is set to 0 and landings inspection at 20.36 %. This combination of enforcement tools produces an increase in social benefits of more than 20 %, from 35 to 42 million Euros and a slight decrease in private benefits of 0.16 %. The increase in the social benefits stems from the reduced enforcement costs and the optimal level of biomass for each of the target species. This solution produces full compliance with one of the three regulations while it appears to be acceptable with a low level of violation with the other regulations.

A simulation of the cost per unit of enforcement effort by a reduction of 10 and 20 % shows that the compliance level would remain unchanged compared to the base case.

However, with such a price decrease the social benefit increases with 1 % and 2.3 % respectively.

Norwegian fisheries

The affect of enforcement costs on the biomass, harvest and social benefit was investigated by performing simulations of a 10 % decrease and a 10 % increase in the cost. When enforcement costs increase it becomes relatively more attractive to allow for illegal activities. An increase in the enforcement cost by 10 % has a small impact on the harvest and the biomass and since the cost to the society increases by increasing the cost of enforcement the social benefits drops. If the enforcement cost instead decreases the opposite holds and there is an increase in the biomass and harvest.

Icelandic cod fishery

The optimal combination of enforcement tools is found at 42 % on board inspectors, 34 % inspection by plane and 65 % observer coverage. At this level of inspection the 232 tonnes will be harvested, exceeding the TAC of 215 tonnes. Hence, some illegal activity is necessary to maximize social benefits.

At the optimal mix of enforcement tools the effects of changing the TAC level was investigated. It was found that as the TAC increased the harvest increases until it reaches the maximum possible value, i.e. base year biomass in which the private benefit is maximised. Simultaneously, the social benefits decreases with the increase in harvest due to the increase in the TAC.

A marginal increase in the enforcement cost of 10 % and 20 % is proven to have very little effect on the harvest level and the social benefits.

Dutch beam trawl

A simulation of a reduction of the enforcement costs by 10 % and by 20 % has no effect on the optimal level of enforcement.

Apart from investigating the effects on compliance and social benefits of altering the penalty level different penalty structures are compared. The alternative penalty structure of introducing a fine proportional to over-quota catches but with no confiscation of catches is compared to the current penalty of fine plus confiscation of over-quota species. From the analysis it is evident that even though different penalty structures might provide different incentives to the fishermen it has little effect on the social benefits in this fishery if compliance is maximised. However, the optimal solutions differ in private and social benefits and a degree of compliance with quota regulations for sole and plaice.

The case study has also investigated the synergistic effects between enforcement effort and the fine level. The analysis shows that the minimum level of enforcement that produces full compliance (1800 port inspections) could be decreased to 1400 if the fine level amounts to 61 000 Euro.

Kattegat and Skagerrak nephrops

The effect of varying the management measure on the level of compliance, private and social benefits has been investigated. The baseline case the TAC is set to 8000kg. The analysis shows that if the regulatory measure is too binding it is not socially optimal to achieve full compliance. For higher levels of TAC it is socially optimal to apply enforcement effort until full compliance has been reached. Furthermore, it is shown that a more binding regulatory measure (low TAC) requires a higher enforcement effort to ensure maximal social benefits.

The analysis further shows that the optimal mix of enforcement tools is achieved at 10.2 % for docks side frequency and 8 % boarding control in relation to the current level of 4 % for both the enforcement tools. The optimal combination of enforcement tools implies full implies full compliance since the TAC is above the social optimal point.

In the model of two species and two tools changing the regulatory measure for one species has no effect on the harvest of the other species since there is no interaction in the harvest function between the species, i.e. the fisherman has full selectivity between the species. In this case the social benefits are unchanged for more restrictive measures. For lower levels of TAC it is evident that due to the increased harvest the social benefits will decrease due to the shadow value of biomass.

The effect of the enforcement costs on the social benefits is calculated by a ten doubling of the enforcement costs. In this simulation the social benefits are more or less unchanged (provides sensitivity test).

(Western) channel fisheries

No additional simulations were conducted

Table 20 Overview of the results obtained from simulations of optimal mix of enforcement tools..

	CASE STUDY	
	YES	**NO**
Optimal mix of enforcement tools	*-Bay of Saint Brieuc* *- Ligurian bottom trawling* *-Icelandic cod* *-Norwegian fisheries* *-Kattegat nephrops*	*CCAMLR* *Northern hake* *(Western channels)*

3.3.4.4 Summary of simulations

Simulations outcomes generally confirm the hypotheses formulated in the theoretical fisheries enforcement model. However, these results are based on quite limited empirical data and, in some cases, not actually verified assumptions. The main problem is related to the lack of empirical data which produces a wide level of uncertainty in the parameters estimation. Indeed, a robust estimation of the model parameters should be based on longer time series. Unfortunately, at the moment, the absence of a systematic collection of data on the enforcement activities does not ensure the availability of these data.

3.3.4.5 Summary of the case studies results

The heterogeneity of the case studies has allowed the enforcement theory developed within the project to be tested on a wide variety of fisheries, management and enforcement systems.

The fisheries analysed include mono-species and multi-species fisheries, pelagic and demersal fisheries, as well as mono-gear and multi-gear fisheries. There are cases of management based on output control systems such as TAC and other quotas regimes, but also input control systems such as fishing effort limitations, and technical measures such as mesh size restrictions or area and season closed are included in at least one case study. As for the enforcement system, dock-side inspections and inspections at sea represent the prevalent enforcement tools considered in the simulation models, but also plane surveillance has been taken into account in some of the case studies.

Case studies have simulated both very simple scenarios, defined by single management and enforcement tools, and complex combinations consisting in multiple management and enforcement tools.

Notwithstanding the differences between case studies, the common approach adopted to model the enforcement system has been proved to be suitable to represent the real world. The heterogeneity of the case studies and the variety of dimensions considered demonstrates the generality of the theoretical enforcement model and its feasibility to be applied to real fisheries situations independently on the number of management and enforcement tools.

One of the deliverables of the project has been the production of a fully-functioning software. This generic software allows the user to investigate the costs and the benefits of enforcement tools of various EU fisheries and management situations. It includes default functions but it is flexible enough to allow the user to introduce their own estimations, modify the parameters etc. if so wanted. Moreover, in order to define the empirical functions used each case study has conducted thorough data collection and estimation and calibration procedures.

All case studies have used the COBECOS software. In addition, half of the case studies are running some of the simulations in some other software to better capture the particularities of determined fisheries. As have been seen on the case studies' summaries, results do not vary significantly depending on the software employed.

The optimal enforcement system maximizing social benefit, expressed in terms of enforcement tools and their optimal intensity, seems to be very far away from the current situation for most of the case studies analysed.

Variations in the enforcement effort affect the probability of being detected when violating, and consequently the private cost of violation. As fishers operate to maximize their profit, the level of violation will decrease if expected cost of violating increases. The optimal level of violation (i.e. compliance) for the fisher is obtained when the marginal cost of violating equals the marginal benefit of violating. Naturally, the enforcement effort is also affecting the cost of enforcement and has to be deducted from the benefits brought upon by it. As predicted by the theory, most fisheries in the project show that an increase in the enforcement level will increase the compliance and the social benefits up until the point where the costs of enforcement outweigh the benefits. The three case studies that also investigate the effects of the enforcement effort on the stock size have also found a positive relationship between the two. The improved stock size is explained by the increase in compliance that a higher enforcement effort produces.

Full compliance is often set as the target for enforcement management. Generally, an increase in the levels of enforcement effort and/or the amounts of fines is suggested in the case studies to improve the social benefits. However, the maximum social benefit is not normally coincident with a situation of full compliance for almost all case studies. This is due to the high costs needed to achieve full compliance, which are not justified from an economic perspective. This happens in many cases, as the cost of enforcement outweighs the benefits of enforcement when compliance is close to the 100 %. In these cases, increasing the enforcement effort further would decrease the benefits to the society and low level of violation of fisheries regulations would be considered acceptable. This happens on the case study analyses for the South Georgia toothfish fishery and the Dutch beam trawl fishery, where the optimal enforcement levels seem to be somewhat lower than the current levels. In these fisheries, a reduction in the enforcement intensity could produce higher social benefits. However, it should be noticed that the analysis is restricted to one type of violation, while the enforcement effort is generally used to detect a multitude of illegal behaviours. Expanding the analysis to include other categories of violation could produce different results.

The theory states that fishermen will conduct in illegal activity as long as the expected benefits are greater than the expected costs of the action. By increasing the penalties the expected costs of illegal activities increases which reduces the illegal harvest.

Thus, imposing higher sanctions when violations are detected represents an alternative to increasing enforcement effort. Both actions determine an improvement in the levels of compliance with regulations, but higher fines do not produce additional costs to the enforcement activity. Therefore, as enforcement effort is costly, the standard policy prescription should be to, as far as possible, increase the scale of the expected fines. However, even if fines cannot be increased indefinitely, the maximum social benefit can be achieved at lower enforcement effort and consequently lower costs when higher amounts of penalty are imposed.

4 CONCLUSIONS

The overall objective of COBECOS, to conduct a cost-benefit analysis of control schemes for management strategies relevant for the EU Common Fisheries Policy (CFP) and, based on this analysis; infer the potential economic benefits which might accrue from proper enforcement of the management measures, has been achieved.

COBECOS accomplishes this and, additionally, can find optimal combinations and intensities of fisheries enforcement tools that maximise the benefits for the society.

This has been achieved with the development of an appropriate theory of fisheries enforcement, empirical research involving intensive case studies and estimation of theoretical relationships and a full functioning software modelling fisheries enforcement, which allows users to investigate the costs and the benefits of enforcement tools of various EU fisheries and management situations.

This is relevant because COBECOS can be of great help in order to better allocate resources in different enforcement tools, so that the optimal level of control is achieved at the lower costs. With this optimal level of control it is also expected to obtain much higher benefits from the fishery for the society. This relevance increases when we consider that in many cases we are currently far away from the optimal control levels.

A recent working paper by the European Commission estimates that 80 % of the European fish stocks are currently being over exploited. Out of these 30 % are outside safe biological limits. One of the reasons of the overexploitation of the resources is that fishers have incentives to maximize their private benefits from fishing, without considering the true cost of fishing. When the stock externalities of fishing are neglected, the harvest level often exceeds the level that is optimal for the society, a phenomenon generally referred to as the common property problem.

The role of managers is to implement regulations that will minimize the occurrence of the common property problem. Most regulations aim at controlling the fishing activities by limiting the number of licenses, quotas or the fishing effort. Fishery regulations are not, in general, self-enforcing. This means that fisheries management is not useful unless it is enforced. Thus, an enforcement system must be present in order for the regulations to have the desired effects.

Enforcement of fisheries management systems is typically quite costly relative to the gross value of the fisheries. Available empirical estimates put the cost of fisheries enforcement between 2 and 8 % of the gross value of landings. As the total value of landings by the EU fleet is estimated to be more than seven billion Euros, the cost of fisheries enforcement might well be between 150 and 600 million Euros per annum. It is likely that these funds could be more effectively used.

The main findings from the theory and also confirmed through the empirical work in the case studies are:

- *Compliance can be improved by increasing the enforcement intensity and/or the financial penalty.* As fishers operate to maximize their profit, their level of violation will decrease if the expected cost of violating increases (higher probability of being detected and/or higher costs for non-compliance).

- *The current enforcement situation is not optimal.* The current enforcement intensity across EU as well as the fine levels are not optimal, nor is the current combination of tools. Important gains can be obtained from setting the combination of enforcement intensity and penalties at the appropriate levels.
- *An increase in the level of enforcement intensity is generally suggested to enhance the benefits to society.* When the enforcement intensity increases, the cost of enforcement increases; but the probability of detecting fishers who are violating regulations and, consequently, the cost of violation to the fishers also increases. As a result, compliance and societal benefits increase.
- *An increase in the level of fines is suggested to improve benefits to society.* By increasing the fines, the expected costs of illegal activities increase for the fishers and so the illegal harvest is reduced. Thus, imposing higher sanctions when violations are detected represents an alternative to increasing enforcement intensity. But since higher fines do not produce additional enforcement costs and because increasing enforcement effort is costly, the standard policy prescription should be to increase the fines, with priority.
- *100 % compliance is often not the optimal solution.* The maximum benefits for society do not normally coincide with a situation of full compliance. This is due to the high costs needed to achieve full compliance. After a certain level, increasing further the enforcement effort would decrease the benefits to society with prohibitive costs for a very small gain.
- *Increased enforcement intensity has a positive effect on the stock size.* Normally, a higher stock size results from the increase in compliance that a higher enforcement effort produces.
- *Increased level of fines has a positive effect on the stock size.* The improved stock size results from the increase in compliance that a higher fine level can produce.
- The COBECOS framework is therefore recommended for the analysis of enforcement options and scenarios.

The heterogeneity of the case studies and the variety of dimensions considered demonstrates the generality of the theoretical enforcement model and its feasibility to be applied to real fisheries situations independently on the number of management and enforcement tools. Case studies have allowed us to analyse the effects of compliance and enforcement on a broad number of fisheries management tools: TAC-restrictions, Effort restrictions, Technical restrictions, individual quotas, Minimum mesh sizes, Minimum fish size restrictions, Input restrictions, seasonal and area closures, discarding, etc.

The fisheries analysed include mono-species and multi-species fisheries, pelagic and demersal fisheries, as well as mono-gear and multi-gear fisheries. For the enforcement system there have been analysed dock-side inspections and inspections at sea represent the prevalent enforcement tools considered in the simulation models, but also plane surveillance has been taken into account in some of the case studies.

Case studies have simulated both very simple scenarios, defined by single management and enforcement tools, and complex combinations consisting in multiple management and enforcement tools. The optimal enforcement system maximizing social benefit, expressed in terms of enforcement tools and their optimal intensity, seems to be very far away from the current situation for most of the case studies analysed.

Variations in the enforcement effort affect the probability of being detected when violating, and consequently the private cost of violation. As fishers operate to maximize their profit, the level of violation will decrease if expected cost of violating increases. The optimal level of violation (i.e. compliance) for the fisher is obtained when the marginal cost of violating equals the marginal benefit of violating. Naturally, the enforcement effort is also affecting the cost of enforcement and has to be deducted from the benefits brought upon by it. As predicted by the theory, most fisheries in the project show that an increase in the enforcement level will increase the compliance and the social benefits up until the point where the costs of enforcement outweigh the benefits. The three case studies that also investigate the effects of the enforcement effort on the stock size have also found a positive relationship between the two. The improved stock size is explained by the increase in compliance that a higher enforcement effort produces.

Often full compliance is set as the target for enforcement management. Generally, an increase in the levels of enforcement effort and/or the amounts of fines is suggested in the case studies to improve the social benefits. However, the maximum social benefit is not normally coincident with a situation of full compliance for almost all case studies. This is due to the high costs needed to achieve full compliance, which are not justified from an economic perspective. This happens in many cases, as the cost of enforcement outweighs the benefits of enforcement when compliance is close to the 100 %. In these cases, increasing the enforcement effort further would decrease the benefits to the society and low level of violation of fisheries regulations would be considered acceptable.

Since the theory states that fishers will conduct in illegal activity as long as the expected benefits are greater than the expected costs of the action. Then by increasing the penalties the expected costs of illegal activities increases and so the illegal harvest is reduced. Thus, imposing higher sanctions when violations are detected represents an alternative to increasing enforcement effort. Both actions determine an improvement in the levels of compliance with regulations, but higher fines do not produce additional costs to the enforcement activity. Therefore, as enforcement effort is costly, the standard policy prescription should be to, as far as possible, increase the scale of the expected fines. However, even if fines cannot be increased indefinitely, the maximum social benefit can be achieved at lower enforcement effort and consequently lower costs when higher amounts of penalty are imposed.

As a conclusion, we would like to highlight that COBECOS results have provide the basis of an appropriate theory of fisheries enforcement, software for modelling fisheries enforcement and case studies with parameters and relationships estimated. This makes COBECOS an important educational tool, especially for control agencies, where it can be check the effects that may have changes in some parameters (if-then scenarios that need to be validated). In addition, it may also allow us to analyse the expected effects of different and innovative penalty systems (such as quota deductions or fishing rights reductions for the infractor). Moreover, it can also analyse the effects on the fisheries of new fishing monitoring and control tools, given that the performance if these tools is known.

But more important, COBECOS could help national authorities to find the most cost-beneficial distribution of control means and inspection in the country.. Furthermore, COBECOS could also help the EU Fisheries Control Agency to coordinate control means and inspection between MS in the implementation of joint deployment plans, in the most cost-beneficial way.

4.1 RECOMMENDATIONS

Based on the theoretical and empirical findings of the project the following recommendations are emphasised:

- The COBECOS results should be used in order to find the enforcement intensity that optimizes the social net benefits in fisheries.

- The COBECOS results should be used to find the optimal mix and intensity of enforcement tools in fisheries

- The national enforcement agencies:
  - should initiate detailed data collection at the fisheries level in order to be able to conduct cost benefit analysis. The results from the data harmonization work package are a good starting point.
  - should apply economic theory in their enforcement policy and to ensure efficiency of their national enforcement systems.

- The generic COBECOS software for enforcement analysis should be used with caution. User courses for enforcement officers and managers on the application of the theory and the software should be organised to avoid erroneous results.

- Countries should communicate and collaborate between themselves for enforcement issues. For shared fisheries the control means should be shared between member states in order to create a harmonized European control system.

- A centralized data collection scheme including enforcement data and its costs is needed in Europe.

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APPENDIX 1 DEFINITION OF INDICATORS FOR DATA COLLECTION

Guidelines for describing the fisheries of COBECOS

General setting of the fishery

This set of information aims at clarifying, *broadly*, the type of fishery studied (to allow rapid cross comparisons for instance, see OECD, 2003, "The Costs of Managing Fisheries). It may cover:

Text

- the type of fishery *(single species vs. multispecies, multigear fishery)*
- the type of species targeted *(esp. demersal vs. pelagic ; long live vs. short live; sedentary vs. migratory species)*
- the type of fleet concerned *(coastal vs. large-scale vessels)*
- the size of the fishery
- the location of the fishery *(e.g. inshore vs. offshore fishery) – map preferably indicating ICES area*
- the "market" structure *(concentrated vs. "small-units", export oriented vs. local consumption)*
- the management regime in place
- the sovereignty regime *(ICES waters, shared stocks, EU-waters, territorial waters)*

Indicators

Description	Indicator	Unit	Aggregation level	Data source
Vessel segments	Names of Vessel segment	Names of segments		
Target Species	Average value of landings	euro	species, segment-, year	
Ratio of Demersal vs. pelagic catch (volume)	Demersal vs. pelagic species	%	segment year	
Size of fishing area	Area	square nautical miles		
Area of control zones	Authority controlling fishery	Percentage covered by each authority		
Coastline adjacent to fishing area	Coastline	Km	Total	
Landing ports	Landing ports	Number	Segment, year	
Effort	Total number of days at Sea	Days	Segment year	

Technical characteristics of the fleet.

Text
This set of information aims at describing the dynamic of the fleet. It may cover:

- the evolution of the size of the fleet – *figure*
- the structure of the fleet *(including the level of homogeneity / heterogeneity regarding the type and the size of the vessels)*
- the evolution of the – *nominal* - fishing effort during the last years (decades) – *figure (GT, kw, Number of vessels)*
- the evolution of the fishing techniques *(and relative importance of use in the case of multi-gears fisheries)*
- the possibility to transfer the fishing effort to an other fishery *(yes or no)*

Indicators

Description	Indicator	Unit	Aggregation level	Data source
Size of the fleet(vessels)	Vessels	Number	Segment, year	
Size of the fleet (tonnage)	Tonnage	GT/GRT	Segment, year	
Size of the fleet (engine power)	Engine power	kW	Segment, year	
Demography/Crew	FTE or Engaged crew	Number	Segment, year	
VMS usage	Fleet equipped with VMS	percentage	Segment year	

Biological characteristics of the fishery.

Text
This set of information aims at describing the dynamic of the resource(s) targeted. It may cover:

- the type of species targeted *(demersal vs pelagic ; long live vs short live; sedentary vs migratory species…)*
- the type of biological interactions, if appropriate *(prey-predator, "food competition" , joint production)*
- the recruitment dynamic
  - e.g. existence of a relationship between stock and recruitment *(yes or no)*
  - level of variability *(low or strong)*
- the evolution of the stocks during the last years *(decades) –figure biomass (tonnes)*
- the evolution of the production during the last years *(decades) – figure*
- the evolution of the – *effective* - fishing effort during the last years *(decades) – figure*

Indicators

Description	Indicator	Unit	Aggregation level	Data source
Official landings from project fisheries	Landings	Tonnes	Segment species year	
Total estimated removals from sea of stock (includes other fleets not included in project, discards etc	Catch	Tonnes	Species year	
Partial F	F		Segment species year	
Catchability C=qEB, F= qE	Catchability (q)		Segment species year	
Level of biomass	Biomass of stock	Tonnes	Species year	
Natrual growth rate	Natural growth rate (r)		Species year	
Ratio of demersal vs pelagic catch	Ratio demersal/pelagic	%	year	

Socio-economic characteristics of the fishery.

Text

This set of information aims at describing the evolution of the – private and collective– performances of the fisheries. It may cover:

- the evolution of fishing profitability *(by metier, by vessel – average - and total) – figure-*
- the evolution of the employment level– *figure*

Indicators

Description	Indicator	Unit	Aggregation level	Data source
Landings value	Landings	Euro	Segment species year	
Prices of species	Prices	Euro/kg	Species year	
Operational costs (fuel, crew etc).	Operational costs	Euro	Segment year	
Capital costs (depreciation)	Capital costs	Euro	Segment year	
Financial burden	Interest	Euro	Segment year	
Gross cash flow	Gross cash flow	Euro	Segment, year	
Net profit	Net profit	Euro	Segment year	
Gross value added	Gross value added	Euro	Segment year	
Employment	Full-time equivalent or Engaged crew	Number	Segment year	
Average penalty level	Fines	Average Euro	Type of measure, year	
Costs of court actions	Legal costs	Euro	Type of measure, year	
Confiscation of gears or license (lost income)	Period of confiscation Quantity of lost catch Price of lost catch	Average Days Average Kg Average Euro	Segment year	

NB: From the above, it may be interesting to derive an "index of sensitivity" of the fishery, 0 – 5 (O = minimum, 5 maximum) based on:

- *the "hierarchy" of the fishery at the national / EU (in terms of production, turnover, employment, contribution to the GDP)*
- *the level of conflict with other fisheries / fleet*
- *the "political agenda"*

Management of the fishery

Text

This set of information aims at describing the institutional settings of the fishery, including the governance and the compliance issues. It may cover:

1. The categorization of the management system, using the three criteria proposed the OECD (OECD, 2006, "*Using market mechanism to manage fisheries*"):

   a) the description and evolution of the management approach *(administrative or "command and control" vs incentive / economic instruments)*
   b) the description and evolution of the main management objective(s) followed *(e.g. maintaining fish stock productivity vs regulating access)*
   c) the variable of control used: *input (fishing effort) vs output (catch) based methods*

2. The description of the management system:

   d) the main objective followed *(profitability, biological, employment, environmental)*
   e) the organisation of the decision-making process *(Top-down vs. self management)*

f) the quantitative evolution of the management regime *(Number of licenses or other access rights)*
g) the evolution of the cost of managing fisheries during the last years *(decades) – figure*
h) the existence of cost recovery schemes

3. A list of the main stakeholders by importance if relevant

Indicators

Description	Indicator	Unit	Aggregation level	Data source
Number of licenses	Licenses	Number	Segment year	
Catch quota	Catch quota	Kg	Species segment year	
Allowed fishing days	Fishing days	Days	Segment year	
Minimum landing size	Landing size	Cm	Species year	
Minimum mesh size	Mesh size	Cm	Segment year	
Marine protected areas	Protected zones	Square nautical miles		
Seasonal closures	Seasonal closures	Days	species year	
Cost recovery	Cost recovery	% total management cost	Segment year	

Enforcement of the fishery

Text

The description of the enforcement system should include:

- the organisation of the system of control: *type (VMS, control at sea, log-books…) - including its coverage (e.g. % of the fleet equipped with VMS)*
- the evolution of the system of control during the last years *(decades)*
- the evolution of the enforcement cost during the last years *(decades) – figure*
- the evolution of compliance *(if possible quantitative data or at least indication of the trends – increase or decrease)*
- the evolution of the type *(fine, licence withdrawal)* and structure *(administrative vs. penal)* of expected sanctions (the "penalty structure") *(if possible quantitative data or at least indication of the trends – increase or decrease)*
- the efficacy of the system, in particular with respect to the perceived probability of being apprehended *(yes or no, explain).*
- the expected link between the evolution of the management systems in the country and the evolution of compliance *(i.e. whether the move towards increased regulations modified the compliance behaviour)*
- the expected link between the evolution of the management systems and the – effective – fishing pressure *(i.e. whether the move towards increased regulations affected the fishing pressure)*

Indicators

Description	Indicator	Unit	Aggregation level	Data source
Total cost of VMS	Total VMS cost	Euro	Segment year	
Average cost of VMS poll	Cost of VMS poll	Euro	National fleet/Year	
Control area	Controlled fisheries area as percentage of total are to be policed by country	%	Country	
Number of patrol vessels	Number of Patrol vessels	Number	Country/Year	
Number of on board inspections	On board, documentation	Number	Fishery year if known otherwise Country/Year	
Cost per boarding	Costs per boarding	Euro	Fishery year if known otherwise Country/Year	
Hours of air observation	Air observations	Hours	Country year	
Sightings per hour	Sightings		Country year	
Cost per hour	Costs per hour	Euro	Country year	
Number of on-board observers	On board observers	Number	Country year	
Cost per onboard observer	Cost of onboard observer	Euro	Country year	
Number of dock-side inspections	Dock-side monitoring	Number	Country year	
Cost of dock-side monitoring	Cost of dock-side monitoring	Euro	Country Year	
proportion of landings checked	percentage	%	Fishery year if known otherwise Country/Year	
Number of wholesale controls (minimum size or illegal species)	Wholesale controls	Number	Country Year	
Cost of wholesale controls (minimum size or illegal species)	Cost of wholesale controls	Euro	Country Year	
Number of recorded infractions at	Recorded infractions	Number	infringement category, segment, year	
Estimates of IUU fishing -*quantity*	IUU quantity	Kg	Segment species year	
Estimates of IUU fishing -*value*	IUU value	Euro	Segment species year	
Average penalty level	Penalty	Euro	Infringement category/Year	
Probability of being apprehended and convicted	Probability of being apprehended and convicted	probability	Infringement category/segment/ Year	

APPENDIX 2 SIMULATIONS OF ENFORCEMENT INTESITY

What are the effects of varying the enforcement effort on the following variables for each of the enforcement tools:

- the level of compliance with each of the management tools
- private benefit
- social benefit
- enforcement cost
- biomass of each of the target species

What is the optimal combination of enforcement tools, in terms of units of effort allocated to each of them, maximizing the following entities:

- *the level of compliance* (full compliance, if possible) with each of the management tools. If more than one solution is available, find the combination with the lowest cost of enforcement.
- *the social benefit*. Specify the level of compliance, the private benefit, the enforcement cost and the biomass of each of the target species associated to the optimal combination identified.

Simulations of enforcement tools

What is the effect, for each of the enforcement tools, of abolishing one enforcement tool (enforcement effort equal to zero) on the following variables:

- the level of compliance with each of the management tools
- private benefit
- social benefit
- enforcement cost
- biomass of each of the target species

Simulations of penalties

For each of the illegal behaviours, what are the effects of varying penalty amounts on the following variables:

- the level of compliance with each of the management tools
- private benefit
- social benefit
- biomass of each of the target species
- with each of the management tools.

For each of the management tools, what is the minimum amount of penalty that produces full compliance?

Simulations of management measures

Given the differences between management systems, common simulations are not defined. However, questions specific to each case study can be formulated.

Simulations of management tools

Given the differences between management systems, common simulations are not defined. However, questions specific to each case study can be formulated.

Simulations of a combination of the above categories

Combination of Penalty and Enforcement intensity:

- Given an increase of 50 % in the amount of penalties for each of the illegal behaviours, see questions 2) in the category "Enforcement intensity"
- Given an increase of 100 % in the amount of penalties for each of the illegal behaviours, see questions 2) in the category "Enforcement intensity"

Combination of Enforcement tools and Enforcement intensity:

- Given a decrease of 10 % in the cost per unit of enforcement effort for each of the enforcement tools, see questions 2) in the category "Enforcement intensity"
- Given a decrease of 20 % in the cost per unit of enforcement effort for each of the enforcement tools, see questions 2) in the category "Enforcement intensity"