



European
Commission

JRC SCIENTIFIC AND POLICY REPORTS

Swedish COBECOS Pilot Study

*Costs and Benefits of Control Strategies
in selected Swedish fisheries*

Final Report

Edited by

Jenny Nord, Malin Hultgren (SwAM)
Jann Martinsohn, Dimitrios Damalas (JRC)

Gothenburg, November 2013

This report has been prepared under contract ICEEF Service Contract Nr. 257233
by the Swedish Agency for Marine and Water Management (SwAM),
Gothenburg (Sweden)

Joint
Research
Centre

European Commission
Joint Research Centre
Institute for the Protection and Security of the Citizen

Contact information

Jann Martinsohn

Address: Joint Research Centre, Via Enrico Fermi 2749, TP 051, 21027 Ispra (VA), Italy

E-mail: jann.martinsohn@jrc.ec.europa.eu

Tel.: +39 0332 78 6567

Fax: +39 0332 78 9658

<http://www.jrc.ec.europa.eu/>

This publication is a Reference Report by the Joint Research Centre of the European Commission.

Legal Notice

Neither the European Commission nor any person acting on behalf of the Commission is responsible for the use which might be made of this publication.

Europe Direct is a service to help you find answers to your questions about the European Union

Freephone number (*): 00 800 6 7 8 9 10 11

(*) Certain mobile telephone operators do not allow access to 00 800 numbers or these calls may be billed.

A great deal of additional information on the European Union is available on the Internet.

It can be accessed through the Europa server <http://europa.eu/>.

JRC 87034

EUR 26406 EN

ISBN : 978-92-79-35002-3

ISSN : 1831-9424

doi: 10.2788/51025

Luxembourg: Publications Office of the European Union, 2013

© European Union, 2013

Reproduction is authorised provided the source is acknowledged.

Printed in Italy

Table of Contents

Deliverable 1: Description of enforcement variables.....	6
Deliverable 2: Estimation	9
Deliverable 3: Software & Simulations	48

Project Responsible: Jenny Nord

21/11/2012

Disclaimer

This report has been prepared under contract ICEEF Service Contract Nr. 257233 by the Swedish Agency for Marine and Water Management (SwAM), Gothenburg (Sweden). It does not necessarily reflect the view of the European Commission and in no way anticipates the Commission's future policy in this area.

Introduction:

Designing control and enforcement strategies in the fisheries sector to ensure compliance with existing rules is intricate and often hampered by costs.

The EU Sixth Framework Programme Project “Costs and benefits of Control Strategies” (COBECOS; <https://cobecos.jrc.ec.europa.eu>) tackled this impediment to successful fisheries control and enforcement schemes by developing computer based modelling approaches which help to optimise the cost/benefit ratio of envisioned control/enforcement strategies.

This modelling framework is based on theory and empirical estimations aimed at answering questions such as:

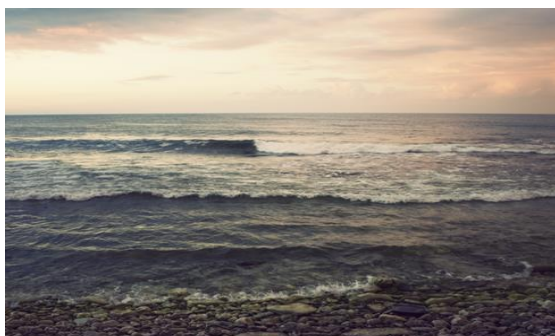
- What are the costs and benefits of increased enforcement effort in particular fisheries?
- If compliance alters (exogenously) in certain fisheries what are the costs and benefits?
- What are the impacts of increased penalties for violations of fisheries rules?
- How do different control schemes compare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

In order to test COBECOS using real scenarios, the Joint Research Centre in collaboration with the Swedish Agency for Marine and Water Management (SwAM), applied the COBECOS model to a selection of Swedish fisheries. One of the main deliverables of this project (lacking in the FP6 COBECOS) has been the production of a fully functioning user friendly software. This open source software allows the user to investigate the costs and the benefits of enforcement tools of various 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. Results and deliverables are documented in this report.

Swedish COBECOS Pilot Study

Deliverable 1

Description of enforcement variables



Preface

According to the Swedish COBECOS pilot study contractual obligations, a report on providing a thorough description of enforcement variables for the specific COBECOS fisheries in the form of tabulated data, should be made available as a deliverable (D1) in month 9. The following report and data tables constitute the fulfilment of this obligation.

Gothenburg 28 November 2012

For the contractor in the Swedish COBECOS Pilot Study,

Jenny Nord

1. Background

This report describes the data submitted to JRC in Excel files. The data concerns the two Swedish fisheries *COBECOS 1 W* referring to demersal trawlers on the west coast and *COBECOS 2 E* referring to cod trawlers in the Baltic Sea. In addition, in order to provide the full picture of Swedish fisheries some descriptive data of the entire Swedish fishing fleet have been submitted.

2. Definitions

Fisheries

The fisheries have been defined based on the gear types included in the management plans for cod (Council Regulation (EC) No 1098/2007 and 1342/2008).

Gear code	Gear name	Gear number (≥ 90 mm)	COBECOS 1 W (ICES 27.IIIa, IV)	COBECOS 1 E (ICES 27.IIIbcd)
SDN	Danish seiners	221	1	1
OTB	Otter trawl bottom	300	1	
OTB	Otter trawl bottom	309	1	
OTB	Otter trawl bottom	310	1	
OTB	Otter trawl bottom	312	1	1
OTB	Otter trawl bottom	319	1	1
PTB	Pair trawl bottom	320	1	1
OTB	Otter trawl bottom	330	1	1
OTB	Otter trawl bottom	331	1	
OTB	Otter trawl bottom	332	1	
OTB	Otter trawl bottom	333	1	
PTB	Pair trawl bottom	334	1	
OTM	Otter trawl midwater	323		1
OTM	Otter trawl midwater	324		1

Enforcement tools

Data on landings and administrative controls are provided. At the planning stage the model was foreseen to also include data on sea going controls. However, during the data collection it became apparent that there were no infringements at sea for the vessels of the two COBECOS segments in the last three years. Hence, sea-going control could not be included in the COBECOS model.

The data concerning landings controls concern Swedish fishing vessels landing in Swedish ports. A large part of the Swedish fleet is landing in Denmark but since we do not have enough information on enforcement activities in Denmark, fishing trips with landings in other countries than Sweden has been excluded.

A landing control is defined as the period between when the inspectors leave and return to the control station. Hence, both costs for travelling as well as for the actual control are included.

Administrative controls are defined as all verification made of incoming logbook sheets. Administrative controls have been carried out for all fishing trips disregarding the country of landing.

Infringement types

The vessels of the two segments could commit infringements of more than 20 fisheries rules. In order to ensure more observations per infringement type and to avoid having to estimate a vast number of probability functions the infringements have been group into four categories:

1. Logbook errors
2. Prenotification failures or delays
3. Other administrative sanctions
4. Court cases

3. Data

The data is provided in Excel form. In order to facilitate for the navigation of data sets, a data guide has been provided ("Data guide for JRC"). Here type, aggregation level, time period and name of the files are described. In addition, the guide is organised in a way that it becomes clear which data file should be used for each function.

4. Enquiries

Any questions of the data or the on-going work within the project can be addressed to:

Malin Hultgren:

malin.hultgren@havochvatten.se

0046 10 698 62 47

Swedish Agency for Marine and Water Management (SwAM)
Gothenburg (Sweden)

Swedish COBECOS Pilot Study

Deliverable 2

Estimation



Project Responsible: Jenny Nord

12/04/2013

Disclaimer

This report has been prepared under contract ICEEF Service Contract Nr. 257233 by the Swedish Agency for Marine and Water Management (SwAM), Gothenburg (Sweden). It does not necessarily reflect the view of the European Commission and in no way anticipates the Commission's future policy in this area.

Preface

According to the Swedish COBECOS pilot study contractual obligations, a report of assessment of estimations should be made available as a deliverable (D2) in month 12. The following report constitutes the fulfilment of this obligation.

The report is conducted in three parts:

- 1) Assessment of estimates of theoretical enforcement relationships.
- 2) Method for estimating the shadow value
- 3) Extension of the theory to include administrative and newer control tools.

In addition to the contractual obligations SwAM is also delivering two R- models of the two fisheries.

Gothenburg 18 March 2013

1. CONTENT

PART 1 Assessment of estimates of theoretical enforcement relationships.	12
1. Background.....	12
2. The model	13
3. Estimation.....	14
3.1 The probability of penalty function	14
3.2. The enforcement cost function.....	16
3.2.1 Landings control.....	16
3.2.2 Administrative control.....	17
3.3 Penalty function	17
3.4 Private benefit function	17
3.4. Shadow value.....	18
3.5. Social benefits	18
PART 2 Assessment of estimates of theoretical enforcement relationships.	19
PART 3 Extension of the theory to include administrative and newer control tools.	36

PART 1 Assessment of estimates of theoretical enforcement relationships.

1. Background

Fisheries

The fisheries have been defined based on the gear types included in the management plans for cod (Council Regulation (EC) No 1098/2007 and (EC) 1342/2008).

Table 1. Gear definitions

Gear code	Gear name	Gear identification (≥ 90 mm)	COBECOS 1 W (ICES 27.IIIa, IV)	COBECOS 1 E (ICES 27.IIIbcd)
SDN	Danish seiners	221	1	1
OTB	Otter trawl bottom	300	1	
OTB	Otter trawl bottom	309	1	
OTB	Otter trawl bottom	310	1	
OTB	Otter trawl bottom	312	1	1
OTB	Otter trawl bottom	319	1	1
PTB	Pair trawl bottom	320	1	1
OTB	Otter trawl bottom	330	1	1
OTB	Otter trawl bottom	331	1	
OTB	Otter trawl bottom	332	1	
OTB	Otter trawl bottom	333	1	
PTB	Pair trawl bottom	334	1	
OTM	Otter trawl midwater	323		1
OTM	Otter trawl midwater	324	1	1

Enforcement tools

Data on landings and administrative controls are provided. At the planning stage of the project the model was foreseen to also include data on sea going controls. However, during the data collection it became apparent that there were a very limited number of infringements at sea for the vessels of the two COBECOS fisheries in the last three years. Hence, sea-going control could not be included in the COBECOS model.

The data regarding landings controls concern Swedish fishing vessels landing in Swedish ports. A large part of the Swedish fleet is in fact landing abroad, in Denmark etc. However, there is currently not sufficient information for vessels landing abroad and fishing trips with landings in other countries than Sweden has been excluded.

A landing control is defined as the period between when the inspectors leave and return to the control station. Hence, costs for travelling as well as for the actual control are included.

Administrative controls are defined as all verification in logbooks regarding quantity and geographical position. Administrative controls have been carried out for all fishing trips disregarding the place of landing.

Infringement types

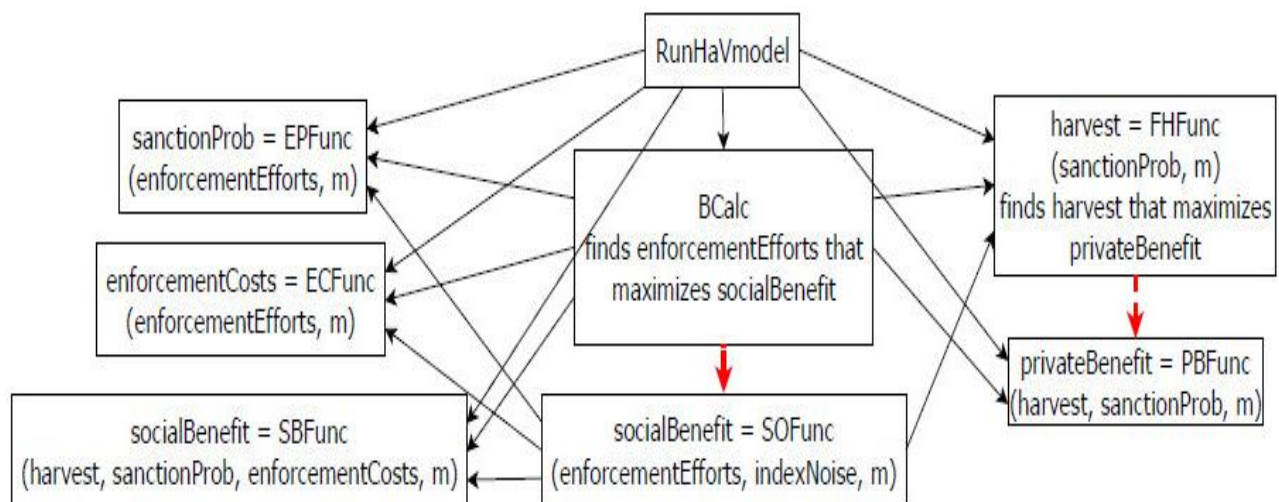
The vessels of the two COBECOS fisheries operate under more than 20 fisheries rules. In order to ensure more observations per infringement type and to avoid having to estimate a vast number of probability functions the infringements have been group into four categories:

1. Logbook errors
2. Prenotification failures or delays
3. Other administrative sanctions
4. Court cases

Since the COBECOS theory is built around detected infringements, the number of detected infringements is crucial for the outcome of the model. For the two Swedish fisheries chosen for analysis the number of detected infringements within the period was limited.

2. The model

In the estimation work SwAM decided to go further than indicated in the contract and develop a model in R of the two Swedish fisheries. The model is constructed according to the below illustration:



The script of the model is delivered in a separate document accompanying this report.

Considering that the COBECOS model was developed as a tool for managers and enforcement officers the aim of the Swedish modelling efforts was to build a model as simple and user-friendly as possible.

3. Estimation

In order to calculate the social benefits of the landings and administrative control activities the following five functional forms or estimates has been calculated:

- The probability of penalty function
- The enforcement cost function
- The penalty function
- The private benefit function
- The social benefit function

1.1 3.1 The probability of penalty function

The probability for the fisher to receive a penalty when violating depends on a number of factors such as the type of management measure and type of enforcement tools. In addition, a number of social factors such as peer pressure and the general compliance level in the country are driving factors of the probability of detection. Due to modelling difficulties of social factors only factors that are given in monetary terms or that can be translated into monetary terms (penalties, withdrawal of license etc.) are included as drivers of compliance in the COBECOS model.

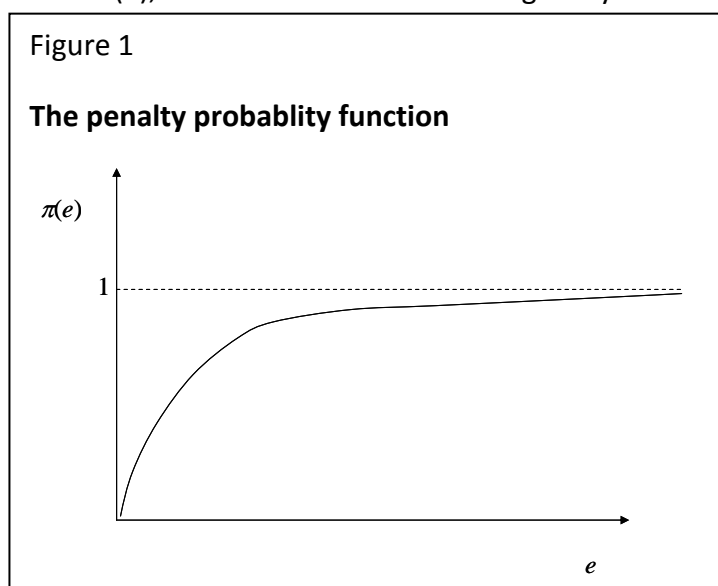
In the COBECOS model, the probability of penalty function is defined as the probability of receiving a sanction if violating a management measure.

$$\pi(e) = p(S|V)$$

A fair assumption is made stating that all detected infringements are sanctioned. That is:

$$\pi(e) = p(S|V \cap C) = 1$$

The probability of penalty is assumed to increase with the intensity of employed enforcement effort (e), i.e. number of controls in a given year.



In a scenario where all fishing activity is controlled it is thought that all or close to all infringements of the particular management tool will be detected. Hence,

$$\text{Max}(e) = 1$$

There were very few detected and sanctioned infringements in the two fisheries (see table 2 below). Hence, there were not enough observations to estimate the relationship between enforcement effort and the probability of detection.

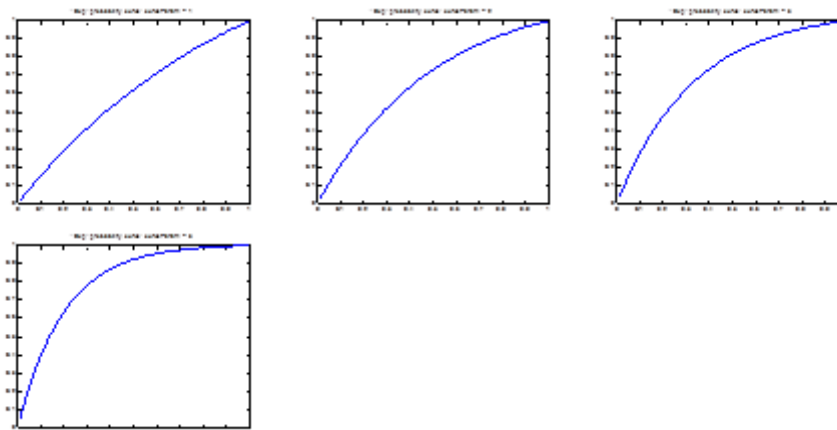
Table 2. Number of sanctions

	2009		2010			2011	
Fisheries	Admin.	Landings	Admin.	At sea	Landings	Admin.	Landings
Cobecos 1 W	27	5	8	1	8	13	1
Cobecos 2 E	10	2	-	-	3	3	5

To construct the model a set of different theoretical functional forms was tested. These are illustrated below.

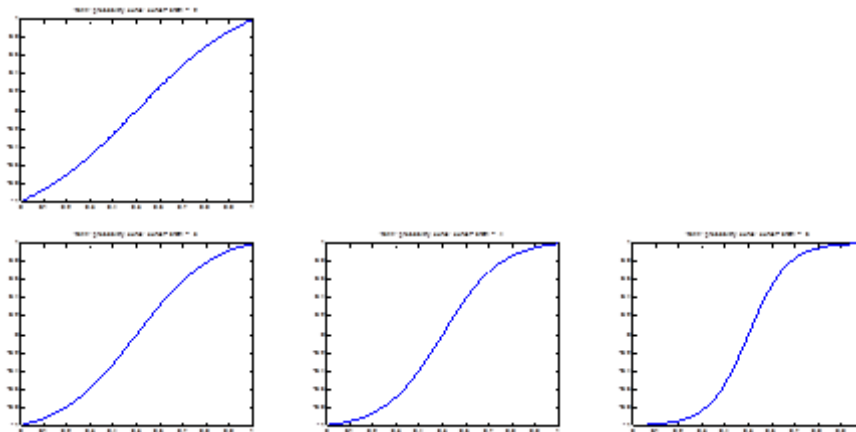
Example 'Exponential' curves with different parameter values, 1.0, 2.0, 3.0, 5.0:

$$p = (1.0 - \exp(-\text{curveParam} * e)) / (1 - \exp(-\text{curveParam}))$$



Example 'tanh' curves with different parameter values 2, 3, 4, 6:

$$p = \tanh(\text{curveParam} * (e - 0.5)) / \tanh(\text{curveParam} * 0.5)$$



The parameter values indicated with a box are used in the model.

1.2 3.2. The enforcement cost function

The two enforcement types included in the model generate two different cost functions:

C_1 = cost per landings control

C_2 = cost per administrative control

3.2.1 Landings control

The cost per control is defined as all costs associated with preparation, travelling to the control location, inspection and legal costs in the case infringements were detected. The data collection was exhaustive and the cost per landings control can be described as below:

Cost per control (c_l) = $C_{inspector}$

*$(t_{preparation} + t_{admin} + 2t_{inspection} + 2t_{travel}) + 2(C_{travel} * C_{inspector}) + C_{legal} + C_{variable}$*

$C_{inspector}$ = Wage per hour (including social costs).

$t_{preparation}$ = Preparation time per inspection.

t_{admin} = Time for administration per inspection

$t_{inspection}$ = Time per inspection

t_{travel} = travel time from control office to the inspection site.

C_{travel} = travelling cost (cost of cars and fuel)

C_{legal} = legal cost per control (calculated from the legal cost per infringement)

$C_{variable}$ = variable costs

The cost per control is inserted as a cost parameter in the model.

3.2.2 Administrative control

The cost per control is associated with all costs verifying catch quantity and geographical position.

$$\text{Cost per administrative control } (C_2) = c_{\text{inspector}} * (t_{\text{inspection}} + t_{\text{admin}} + t_{\text{preparation}}) + c_{\text{legal}} * t_{\text{infringement}}$$

$c_{\text{inspector}}$ = wage per hour (including social costs).

$t_{\text{preparation}}$ = preparation time per inspection.

t_{admin} = time for administration per inspection

$t_{\text{inspection}}$ = time per inspection

c_{legal} = legal cost per inspection (calculated from the legal cost per infringement)

$t_{\text{infringement}}$ = time for legal expert per inspection (calculated from the legal time per infringement)

3.3 Penalty function

According to the COBECOS theory a penalty function that illustrates how the penalty changes with the level of infringement should be estimated. Sweden has two legal systems for fisheries offences, criminal and administrative sanctions. There were too few criminal sanctions to include these in the model for the two fisheries. Therefore, only administrative sanctions are included. The level of these sanctions are fixed in accordance with national legislation and not dependent on the level of infringements. For this reason a penalty parameter was used in the model.

3.4 Private benefit function

In the COBECOS theory it is assumed that the fisher will fish up to the point, legally or illegally, that maximises the private benefit. The private benefit function can take various forms. SwAM has for the sake of simplicity, chosen to use the function given in the COBECOS theory:

$$PB(f,x) = p*q - c_f * c_{\text{adj}} * q^2/x$$

p = price

q = catch

c_f = fishing cost

c_{adj} = cost adjustment factor

x = the biomass

The derivative shows that there is a marginal stock effect, i.e. that CPUE increased with the size of the biomass.

3.4. Shadow value

Based on the data available the shadow value could not be assessed. For modelling purposes a “guesstimate” was used.

3.5. Social benefits

The following model was used to calculate the Social benefit function.

$$SB = (p - \lambda) * q - c_{adj} * c_f * \frac{(q^2 - c_e)}{x}$$

P= price

λ = shadow value of biomass

q = catch

c_{adj} = cost adjustment factor

c_f = fishing costs

c_e = control cost

Concluding remarks

The number of infringements coupled with the very low penalty level for the infringements carried out prevented SwAM to run the COBECOS model successfully with empirical data. In order to make it run some adjustment factors had to be included. These are given in detail in the script of the R model.

Efforts have been made to design a simulation tool. With the anticipation of being used as inspiration for future work, an illustration of the tool is included in the deliverables.

PART 2 Assessment of estimates of theoretical enforcement relationships.

On January 13, 2012, I contracted with the Swedish Agency for Marine and Water Management (SwAM) to assist in a pilot study for applying the COBECOS fisheries enforcement methodology. This report constitutes a partial fulfilment of my obligations under this contract, namely item 3.c of the contract.

Reykjavik 29. April 2012



Ragnar Arnason

1. Cobecos enforcement theory: A brief review

The following summarizes the essentials of the fisheries enforcement theory as outlined in the Cobecos project (COBECOS 2009). The term “essentials” is used because the presentation ignores the numerous details of any actual enforcement situation. It should be noted that this theory is not limited to fisheries but covers essentially any centralized enforcement situation.

Faced with a binding harvest constraint, q^* , a fisher is assumed to have the following expected benefit function:

$$(1) \quad B(q, x) - \pi(e) \cdot f \cdot (q - q^*),$$

where the variables q , x and e refer to the volume of harvest, the size of the biomass and enforcement effort, respectively. The function $B(q, x)$ measures the private benefits (profits and/or utility) the fisher gains from fishing. This naturally depends both on the level of harvest, q , and (positively) on the level of biomass, x . The second term in (1) represents his expected costs of violating the harvest constraint. The difference $(q - q^*)$, which is nonnegative since the constraint is supposed to be binding (the other case is not of interest) is the level of infraction. The parameter f is the penalty for a unit of infraction and the function $\pi(e)$ measures the probability of having to pay that penalty. This of course is monotonically increasing in the enforcement effort, e .¹

Maximizing these benefits with respect to the harvest volume yields the enforcement response function:

$$(2) \quad q = Q(e, x, f, q^*).$$

Since (2) assumes fishers have maximized their benefits (implies the function $B(q, x)$ is concave), the first derivatives of the enforcement response function, Q_e and Q_f are negative. If also B_{qx} is positive, which seems very likely, then Q_x is positive.

The enforcement problem is to select the path of enforcement effort, $\{e\}$, over time such that the present value of private benefits less enforcement costs are maximized subject to the relevant constraints of the problem. Formally:

$$(I) \quad \underset{\{e\}}{\text{Max}} \int_0^T (B(q, x) - C(e)) \cdot e^{-r \cdot t} dt$$

¹ The probability and penalty functions in (1) may of course be made more general. E.g. the separable expression $f(q - q^*)$ could more generally be written as the increasing function $f(q - q^*)$.

Subject to: $q = Q(e, f, x, q^*),$

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

where $G(x)$ is the natural biomass growth function and $C(e)$ is the enforcement cost function. The term $e^{-r \cdot t}$ is the discount factor with r being the rate of discount. The upper limit of the integral, T , is the terminal time which may be infinite. Obviously this problem includes as a sub-problem the selection of enforcement effort at the current time. In what follows, (I) will be referred to as the *Basic enforcement problem*.

The enforcement problem (I) may (but does not have to) be restated in the very convenient form:

$$(II) \quad \underset{e}{\text{Max}} \quad B(Q(e, f, x, q^*), x) - C(e) + \lambda \cdot (G(x) - Q(e, f, x, q^*)),$$

where λ is the shadow value of biomass. It is worth noting that the rule expressed in (II) is really the Maximum Principle of dynamic maximization theory made famous by Pontryagin and his collaborators (1962). Note also that (II) is merely a particular restatement of the *Basic Enforcement Problem*.

In the COBECOS theory, the shadow value of biomass, λ , and biomass, x , were taken to be exogenous data and suggested that current enforcement effort be adjusted to maximize (II). Assuming sufficient smoothness and an interior solution, the solution to this problem is expressed by:

$$(4) \quad (B_q(Q(e, f, x, q^*), x) - \lambda) \cdot Q_e(e, f, x, q^*) = C_e(e).$$

So, according to this, to be able to carry out optimal enforcement, the enforcement agency has to know the following²:

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

This paper is concerned with how to obtain numerical estimates of λ assuming knowledge of the other items of knowledge.

² Note that the fishers' enforcement response function, $Q(e, x, f)$, can be derived on the basis of 1, 2 and 4.

1.1 It is not strictly necessary to know λ

Since this paper is concerned with finding practical ways to estimate λ , it should be mentioned that it is not strictly necessary to include λ in the enforcement problem. λ is included in the restatement of the Basic enforcement problem in (II) merely because it is convenient, which is the same reason it is included in maximization problems in general. It is possible to restate the Basic enforcement problem in forms that do not involve λ . One such variant is the calculus of variations version of the basic enforcement problem (I)

$$(IIb) \quad \text{Max } B(Q(E(x, \dot{x}, f), f, x), x) - C(E(x, \dot{x}, f),$$

where the role of enforcement effort, e , is played by the expression $E(x, \dot{x}, f)$ derived from the dynamic constraint $\dot{x} = G(x) - Q(e, f, x)$.³ Solving (IIb) yields an optimal path for x and, therefore, also \dot{x} . Given this, the optimal enforcement at each point of time can be obtained from $\dot{x} = G(x) - Q(e, f, x)$.

While (IIb) avoids the explicit use of λ , this is at the cost of a much more complicated expression and a certain reduction in transparency. It should be noted that λ has not really disappeared from the problem. In (IIb) its role is simply played by other expressions. Thus, the problem of estimating λ in (II) is simply replaced by the problem of obtaining and working with more complicated expressions in (IIb).

2. The shadow value of biomass

In this section, the theory of shadow prices is briefly discussed. This is useful for understanding the proposed method to estimate these prices in section 3 below.

2.1 The general theory of shadow values

The basic enforcement problem is but a special case of the general optimal-control problem (see e.g. Kamien and Schwartz 1981)

$$(III) \quad \underset{\{u(t)\}}{\text{Maximize}} \quad J = \int_0^T I(x(t), u(t), t) dt + F(x(T), T)$$

$$\begin{aligned} p.a. \quad & \dot{x} = f(x(t), u(t), t), \\ & x(0) = x_0, \\ & u(t) \in U, \text{ all } t. \end{aligned}$$

³ There are certain technical difficulties with the expression $E(x, \dot{x}, f)$. For instance, it does not strictly exist as a function over the whole range of positive x .

In this formulation the function $l(x(t), u(t), t)$ is the objective function, the function $F(x(T), T)$ the terminal function and the function $f(x(t), u(t), t)$ the function of motion. The control variables are denoted $u(t)$ and $x(t)$ represents the state variables. U denotes the set from which the control variables may be selected.

Now assume problem (III) has been solved. That yields a certain value of the functional J which depends on all the data of the problem. Write this as:

$$J^*(x(0); T, r, U).$$

Given this maximum value, the shadow value of the state variables measures the marginal benefits of an increase in the initial level of the respective state variables, $x(0)$ (see e.g. Kamien and Schwartz 1981). Thus, the shadow value of state variable i is defined as:

$$(5) \quad \lambda^*(i) = \frac{\partial J^*(x(0); T, r, U)}{\partial x(0; i)}.$$

It is well-known that these mathematical shadow values correspond exactly to perfect market prices (see e.g. Dorfman 1969, Kamien and Schwartz 1981, Dixit 1990).

The existence of shadow prices does not depend on the optimal solution to the problem (III). Let $u(x, t)$ represent any rule for the control variable u . Given this feedback rule, and other particulars of the problem, a certain value for the functional J is defined. Write this as the constrained value function:

$$J(x(0); T, r, U).$$

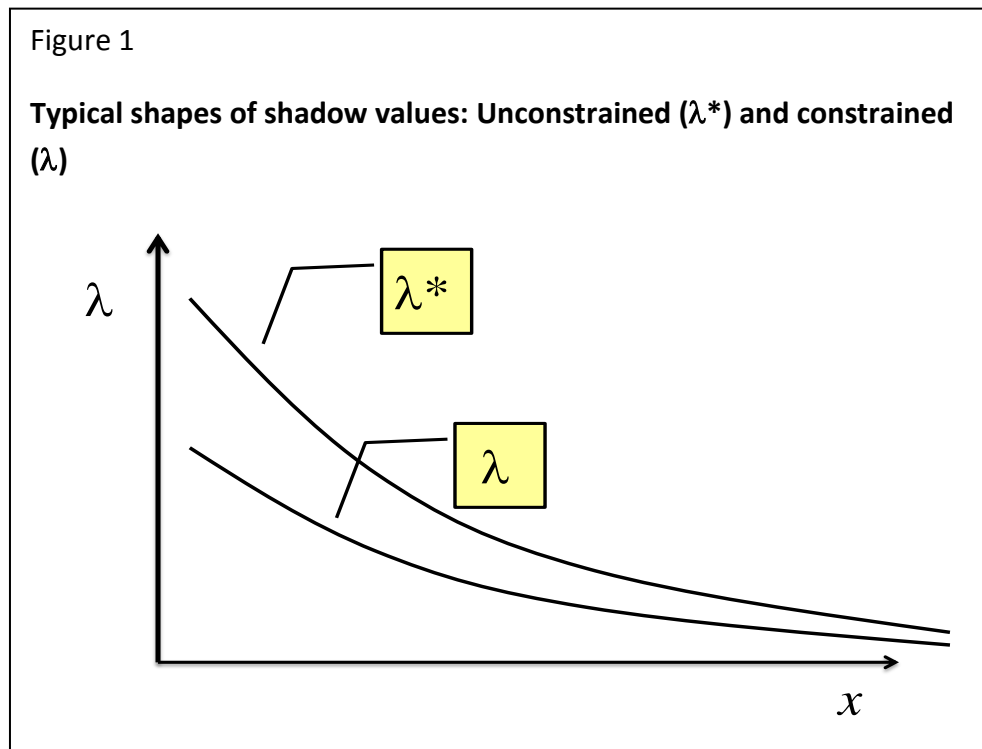
Then the shadow value of state variable i given this particular control rule is defined exactly as in (5)

$$(6) \quad \lambda(i) = \frac{\partial J(x(0); T, r, U)}{\partial x(0; i)}.$$

This shadow value, however, will generally be different from the one corresponding to the optimal policy and defined in (5). For the same level of initial biomass, it will normally be lower. The reason is that normally the optimal policy will make better use of additional biomass. This, however, does not have to be the case in general.

It is useful to note that if x is beneficial the value function J will be an increasing function of $x(0)$. In those cases, λ will be positive. Moreover, J will often be a concave function of $x(0)$. This applies for instance if there are diminishing marginal returns (to utility or production) which is a common rule in economics. In those cases, λ will be a declining function of $x(0)$. Figure 1 illustrates the shape of the shadow values of a

beneficial state variable x for the optimal and constrained case under these assumptions.



2.2 Fisheries: Shadow value of biomass

For fisheries the above theory of shadow values carries through in a straightforward manner. Consider for instance the fisheries problem

$$(IV) \quad \underset{\{q\}}{\text{Max}} \quad V = \int_0^{\infty} B(q, x) \cdot e^{-r \cdot t} dt$$

$$\text{Subject to:} \quad \dot{x} = G(x) - q,$$

$$x(0) \text{ given}$$

Assume some rule for the level of fishing, i.e. a fisheries feed-back rule. Write this rule as:

$$(7) \quad q = Q(x; r).$$

This rule is perfectly general. It depends on all the data of the problem and can take any form as long as it is a function. It may be the solution to the dynamic maximization problem or some other rule. It may be regarded as simply any fishing policy or harvesting rule.

Substituting the feed-back rule into the differential equation and solving it yields the biomass path $\{x\}$ as a function of the initial biomass $x(0)$. Substituting that path into the integral yields the value function $V(x(0);r)$. On that basis the shadow value of biomass can be calculated as:

$$(8) \quad \lambda = \frac{\partial V(x(0);r)}{\partial x(0)}.$$

This shadow value will in general have the same shape as illustrated in Figure 1.

It is important to note the following:

1. The shadow value depends on not only on biomass, which is endogenous to the fishery, but all the other parameters of the problem. These include:
 - a. the rate of discount, r ,
 - b. prices which are not explicitly represented in (7)
 - c. the fisheries feed-back rule, $Q(x;r)$ which is also not explicit in (7) and
 - d. the fisheries management system not explicit in (7)
2. If the value function is low, for instance because of an inefficient fisheries management system, shadow of biomass will be low.

To calculate the value of (8), it is obviously necessary to:

1. Obtain the feed-back rule $Q(x;r)$ (This may involve solving the maximization problem).
2. Calculate the integral V to obtain the maximum value function $V(x(0);r)$
3. Perform the differentiation in (7). This may of course be approximated by
$$\lambda = \frac{\partial V(x(0);r)}{\partial x} \approx \frac{V(x(0) + \varepsilon; r) - V(x(0); r)}{\varepsilon},$$
 where ε is some small addition to the biomass.

2.3 The shadow value under fisheries enforcement

Fisheries enforcement theory shows that the shadow value of the biomass depends not primarily on the fishing policy (harvesting rule) but the level of enforcement (COBECOS 2009). In other words, a more appropriate formulation of the fisheries problem than (IV) is problem (I) as stated in the review of the COBECOS theory in section 1.

$$(I) \quad \underset{\{e\}}{\text{Max}} \int_0^T (B(q, x) - C(e)) \cdot e^{-r \cdot t} dt$$

Subject to: $q = Q(e, f, x, q^*),$

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

$x(0)$ given

So in this, more realistic fisheries management, the proper control variable is fisheries enforcement rather than the level of harvesting.

The same general principles carry through. Any policy for enforcement can be written as the enforcement feed-back rule:

$$(9) \quad e = E(x; r, f, q^*).$$

Note that the only endogenous variable in this formulation is the biomass level, x . All the other arguments in (9) are parameters, i.e. exogenous constants.

Substituting (9) into problem (I) and solving it leads to the value function $V(x(0); r, f, q^*)$. On that basis, the shadow value can be calculated as:

$$(10) \quad \lambda = \frac{\partial V(x(0); r, f, q^*)}{\partial x(0)},$$

And this shadow value can be approximated in the same way as before, namely as:

$$(11) \quad \lambda = \frac{\partial V(x(0); r, f, q^*)}{\partial x(0)} \approx \frac{V(x(0) + \varepsilon; r, f, q^*) - V(x(0); r, f, q^*)}{\varepsilon}$$

To calculate this shadow value, therefore, it is necessary to have an estimate of the value function, $V(x(0); r, f, q^*)$. To obtain that function it is necessary to have the following information.

1. The fishers' private benefit function, $B(q, x)$.
2. The probability of penalty function, $\pi(e)$.
3. The cost of enforcement function, $C(e)$
4. The enforcement response function, $q = Q(e, f, x, q^*)$. This may be derived from the other data.
5. The enforcement feed-back rule, $e = E(x; r, f, q^*)$
6. The current level of biomass, x
7. The penalty parameter, f
8. The rate of discount, r
9. The various prices entering the cost and benefit functions and therefore also the enforcement response function and possibly the enforcement feed-back rule.

2.4 A note on the endogeneity of λ

The shadow value of biomass, λ , is fundamentally endogenous in the enforcement problem as well as other control problems. In the COBECOS theory (see section 1 and, in particular rule (II)), the optimal enforcement effort at each point of time depends on the number used for the shadow value of biomass. The enforcement picked, leads to a specific value function which as described in (8) and (10) defines the shadow value of biomass.

Thus, ideally, the optimal effort level and the shadow value of biomass should be determined simultaneously. Indeed this is the procedure in theoretical optimization theory (Kamien and Schwartz 1981, Dixit 1990).

3. Theoretically consistent optimal enforcement

The dynamic enforcement problem is to select a path of enforcement effort, $\{e\}$, that maximizes the present value of net benefits from the fishery. Formally:

$$(V) \quad \underset{\{e\}}{Max} \quad V = \int_0^{\infty} [B(Q(e, x; f, q^*), x) - C(e)] \cdot e^{-r \cdot t} dt.$$

$$\text{Subject to: } \dot{x} = G(x) - Q(e, x; f, q^*),$$

$$x(0), \text{ given.}$$

Where all the functions and variables have been defined above.

The Hamiltonian appropriate to this problem may be written as:

$$(11) \quad H = B(Q(e, x; f, q^*), x) - C(e) + \lambda \cdot (G(x) - Q(e, x; f, q^*)),$$

where λ represents the shadow value of biomass.

Necessary conditions for solving this problem include (Pontryagin et al. 1962, Kamien and Schwartz 1981):

(11.1) e should maximize H , all t . (Pontryagin's maximum principle) \Rightarrow

$$(B_q - \lambda) \cdot Q_e = C_e, \text{ all } t$$

$$(11.2) \quad \dot{\lambda} - r \cdot \lambda = -B_q \cdot Q_x - B_x - \lambda \cdot (G_x - Q_x), \text{ all } t.$$

$$(11.3) \quad \dot{x} = G(x) - Q(e, x; f, q^*), \text{ all } t$$

$$(11.4) \quad x(0) = \text{the } x(0) \text{ that is given.}$$

(11.5) An appropriate transversality condition.

Solving (11.1)-(11.5) together yields the optimal paths of enforcement, biomass and shadow value of biomass over time. While this is theoretically sound, this joint solution is computationally quite demanding and therefore not very practical.

The COBECOS theory attempts to provide a practical approximate solution to the enforcement problem. How does the COBECOS approach compare to the theoretically consistent solution defined by (11.1)-(11.5) above.

- First note that the Hamilton function (11) is identical to the function in the Basic Enforcement Problem in (II) above.
- Second, note that the Basic Enforcement Problem as stated in (II) is exactly Pontryagin's maximum principle (Pontryagin et al. 1962). Indeed the necessary condition (11.1) confirms the COBECOS solution to the enforcement problem as expressed by equation (4). Thus, dynamic optimization theory confirms that rule as being dynamically correct.
- Third, note that under the COBECOS theory necessary conditions (11.3) and (11.4) will be automatically satisfied (facts of life).
- Fourth, the COBECOS theory ignores conditions (11.3) and (11.5), that is the dynamic evolution of the shadow value of biomass. Instead the COBECOS theory takes the current λ simply as a given datum.

Thus, the COBECOS theory deviates from the theoretical ideal by taking λ as given. Note, however, that from a practical perspective this is not much of an error. The reason is that in applying the COBECOS theory, enforcement effort is set at a point of time (or rather for a period such as a year) and not for the whole future. At this point of time, λ , is for the most part given as a function of future expectations for the fishery partly expressed by the enforcement feed-back rule as discussed above. Thus, whatever is done during the first period is not going to alter λ drastically, especially if enforcement effort is set optimally.

4. Theoretically consistent optimal enforcement

The dynamic enforcement problem is to select a path of enforcement effort, $\{e\}$, that maximizes the present value of net benefits from the fishery. Formally:

$$(V) \quad \underset{\{e\}}{Max} \quad V = \int_0^{\infty} [B(Q(e, x; f, q^*), x) - C(e)] \cdot e^{-r \cdot t} dt.$$

$$\text{Subject to: } \dot{x} = G(x) - Q(e, x; f, q^*), \\ x(0), \text{ given.}$$

Where all the functions and variables have been defined above.

The Hamiltonian appropriate to this problem may be written as:

$$(11) \quad H = B(Q(e, x; f, q^*), x) - C(e) + \lambda \cdot (G(x) - Q(e, x; f, q^*)),$$

where λ represents the shadow value of biomass.

Necessary conditions for solving this problem include (Pontryagin et al. 1962, Kamien and Schwartz 1981):

(11.1) e should maximize H , all t . (Pontryagin's maximum principle) \Rightarrow

$$(B_q - \lambda) \cdot Q_e = C_e, \text{ all } t$$

(11.2) $\dot{\lambda} - r \cdot \lambda = -B_q \cdot Q_x - B_x - \lambda \cdot (G_x - Q_x), \text{ all } t.$

(11.3) $\dot{x} = G(x) - Q(e, x; f, q^*), \text{ all } t$

(11.4) $x(0) = \text{the } x(0) \text{ that is given.}$

(11.5) An appropriate transversality condition.

Solving (11.1)-(11.5) together yields the optimal paths of enforcement, biomass and shadow value of biomass over time. While this is theoretically sound, this joint solution is computationally quite demanding and therefore not very practical.

The COBECOS theory attempts to provide a practical approximate solution to the enforcement problem. How does the COBECOS approach compare to the theoretically consistent solution defined by (11.1)-(11.5) above?

- First note that the Hamilton function (11) is identical to the function in the Basic Enforcement Problem in (II) above.
- Second, note that the Basic Enforcement Problem as stated in (II) is exactly Pontryagin's maximum principle (Pontryagin et al. 1962). Indeed the necessary condition (11.1) confirms the COBECOS solution to the enforcement problem as expressed by equation (4). Thus, dynamic optimization theory confirms that rule as being dynamically correct.
- Third, note that under the COBECOS theory necessary conditions (11.3) and (11.4) will be automatically satisfied (facts of life).
- Fourth, the COBECOS theory ignores conditions (11.3) and (11.5), that is the dynamic evolution of the shadow value of biomass. Instead the COBECOS theory takes the current λ simply as a given datum.

Thus, the COBECOS theory deviates from the theoretical ideal by taking λ as given. Note, however, that from a practical perspective this is not much of an error. The reason is that in applying the COBECOS theory, enforcement effort is set at a point of time (or rather for a period such as a year) and not for the whole future. At this point of time, λ , is for the most part given as a function of future expectations for the fishery partly expressed by the enforcement feed-back rule as discussed above. Thus, whatever is done during the first period is not going to alter λ drastically, especially if enforcement effort is set optimally.

5. Practical estimation of the shadow value of biomass

It is not very practical to solve the complete dynamic enforcement problem described in section 3. This is quite demanding even for just one enforcement control and one state variable, i.e. biomass (Sandal et al. 2004). In real fisheries enforcement there are usually several enforcement tools over which enforcement effort can be defined and often several state variables in terms of stocks and stock subsets. This level of complexity renders direct calculation according to the theoretical prescripts virtually infeasible. For this reason, it is of great practical importance to develop a feasible method for selecting a reasonably efficient enforcement effort

The COBECOS theory (expressed by (II) in section 1) is an attempt in this direction. However, to apply this theory it is necessary to obtain estimates of the shadow value of biomass. A practical approximate approach to do this is described below:

Fisheries enforcement effort (over the various enforcement tools) is usually determined for a period of time, often a year. At this point of decision, future fisheries enforcement effort and harvesting in future periods may be taken for granted e.g. as reflected in a presumed enforcement and/or harvesting feed-back rule as discussed in section 2. On this basis and the theory discussed in section 2 and 3 above, the following practical approach to determining the shadow value of biomass consisting of six steps is proposed.

1. Obtain the basic enforcement model

This is summarized by the expression:

$$B(Q(e, x; f, q^*), x) - C(e) + \lambda \cdot (G(x) - Q(e, x; f, q^*)).$$

And requires knowledge of the items discussed in 2.3

2. Specify the enforcement feed-back rule, $e = E(x; r, f, q^*)$. Alternatively, the harvesting rule $Q(x; r)$ may be used (see 2.2). These rules may be dynamic, i.e. shift over time.
3. Assume future values of the exogenous parameters such as r, f, q^* and prices.
4. Calculate the value function $V(x(0); r, f, q^*)$ for a few strategically selected $x(0)$'s.
5. Fit with the help of regression methods a simple function to these calculated points. This yields an estimated value function as a function of the initial biomass level which may be denoted as:

$$\hat{V}(x(0); r, f, q^*)$$

6. For the current initial biomass level, $\bar{x}(0)$, say, calculate the shadow value of biomass.

Clarifications

Step 1. The construction of the basic enforcement model requires knowledge of the items discussed in section 2.3

1. The fishers' private benefit function, $B(q,x)$.
2. The probability of penalty function, $\pi(e)$.
3. The cost of enforcement function, $C(e)$
4. The enforcement response function, $q = Q(e,f,x,q^*)$. This may be derived from the other data.
5. The current level of biomass, $x(0)$.
6. The penalty parameter, f
7. The rate of discount, r
8. The various prices entering the cost and benefit functions

Step 2. The enforcement rule or harvesting rule that should be employed should be the best guess of future policy. As mentioned, these rules may evolve over time or shift at one.

Step 3. This is straight forward prediction.

Step 4. This requires the calculation of the expression:

$$V(x(0), r, f, q^*) = \int_0^{\infty} [B(Q(E(x; r, f, q^*), x; f, q^*), x) - C(E(x; r, f, q^*))] \cdot e^{-rt} dt.$$

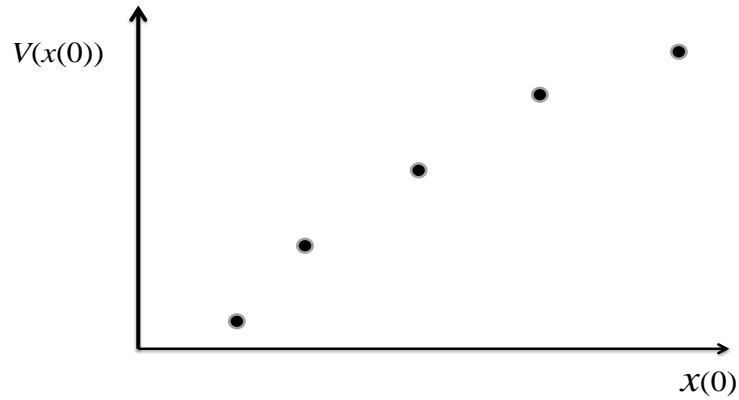
Subject to: $\dot{x} = G(x) - Q(E(x; r, f, q^*), x; f, q^*)$, $x(0)$ given.

which is a considerable task. However, the advantage is that this only needs to be done once for each $x(0)$ selected. Although, of course, if some of the data, such as prices change, it may be deemed worthwhile to redo the calculations. One of the initial biomass points selected should be the optimal equilibrium whose value function is comparatively easy to calculate

For five different initial biomass levels, this exercise will generate a value function scatter diagram as illustrated in Figure 2

Figure 2

Examples of value function levels

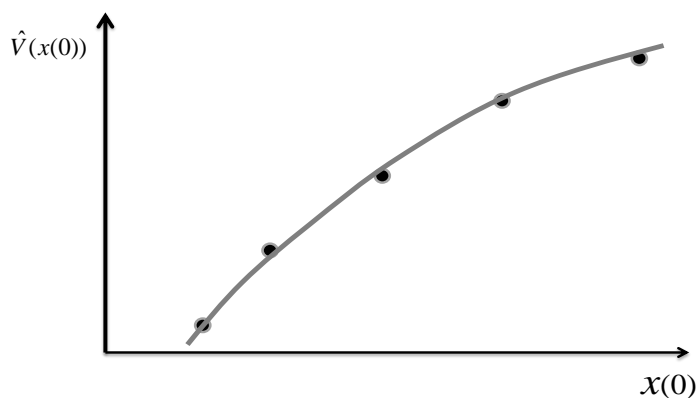


It is worth noting that environmental concerns can easily be included in the fishery value function by adding a term such $\Psi(x)$ which is strictly positive and increasing in biomass, x .

Step 5. The fit to the value function data points will usually be satisfactory with a simple functional form such as $\hat{V} = \alpha \cdot \ln(x(0) + \beta)$ or a simple polynomial noting that the value function should be non-decreasing in biomass. The outcome will be as illustrated in Figure 3

Figure 3

A fitted value function



Let us refer to this estimated value function as

$$\hat{V}(x(0); r, f, q^*)$$

Step 6. Given the estimated value function, it is easy to calculate the shadow value of biomass as either the first derivative of the estimated value function:

$$\lambda = \frac{\partial \hat{V}(x(0); r, f, q^*)}{\partial x(0)}$$

Or, if this derivative is not available, the approximation:

$$\lambda = \frac{\hat{V}(\bar{x}(0) + \varepsilon; r, f, q^*) - \hat{V}(\bar{x}(0); r, f, q^*)}{\varepsilon}.$$

There are several important advantages to the approach to estimating the shadow value of biomass described above.

- (1) The first and most important advantage is that it is perfectly feasible and, compared to solving the dynamic maximization problem in full, quite trivial.
- (2) The second great advantage is that it is theoretically consistent. Thus, if the enforcement feed-back rule is in fact optimal, then this method of determining the shadow value of biomass will lead to enforcement effort that actually replicates the enforcement feed-back rule.⁴
- (3) The third advantage is that this process is informationally accumulative. Thus, as an increasing number of value function points are calculated over time with different values of the exogenous variables f , q^* , r and so on, the data basis for estimating a more complete value function including parameters for these varying parameters as well as different biomass levels is generated. Thus, pretty soon, it will be possible to calculate the response of the shadow value of biomass to these parameters as well.

6. Calculations of shadow values: A simple numerical example

What follows is a very simple example of calculation of shadow values on the assumption that data points for the value function have been calculated. It is of course possible to compute a numerical example from the scratch (the basic bioeconomic model), but that is considerably more work.

Let there be four estimates of the value function as follows:

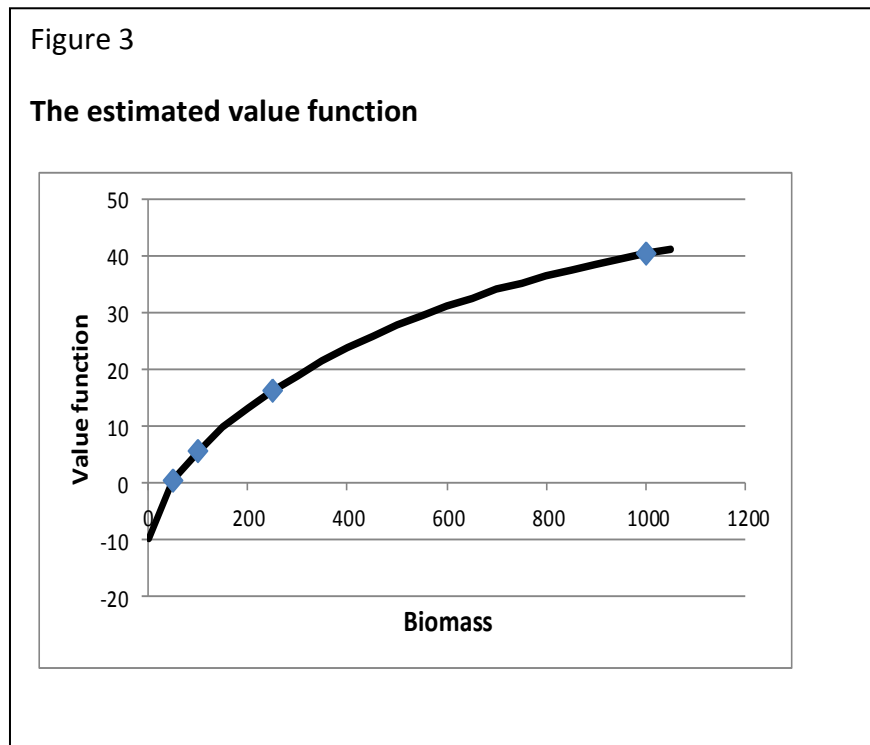
⁴ I believe I can prove this mathematically, but the proof is outside the scope of this study.

Biomass	Value
50	0,38
100	5,60
250	16,27
1000	40,51

A polynomial equation that fits these points exactly is:

$$\hat{V}(x(0)) = x(0)^{0.6} - 0.0001 \cdot x(0)^{1.7} - 10.$$

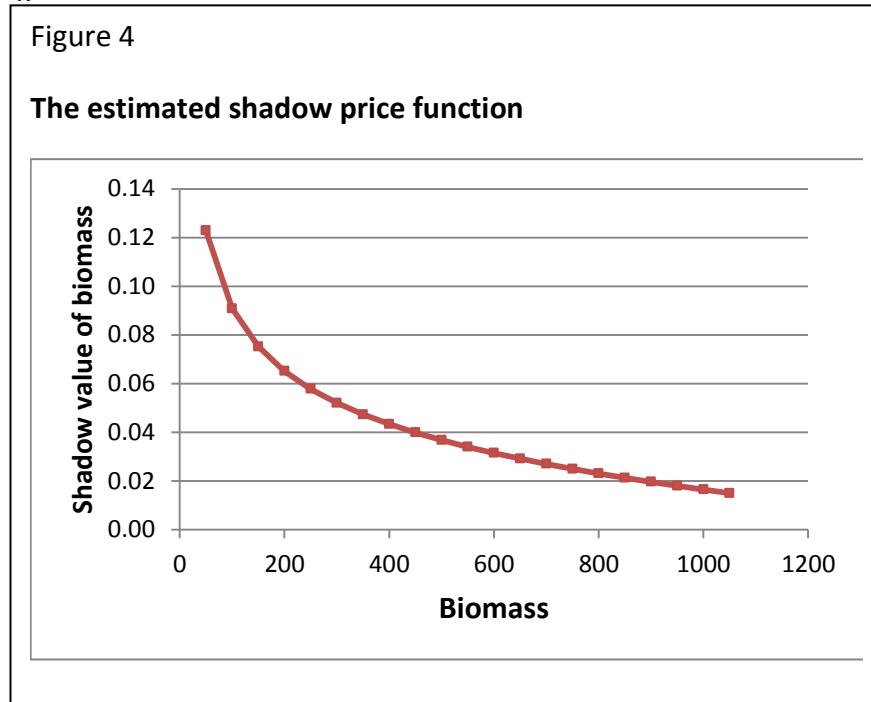
This yields the estimated value function graph:



It immediately follows that the shadow value of biomass at different levels of biomass is estimated by the expression (see section 4):

$$\lambda = \frac{\partial \hat{V}(x(0); r, f, q^*)}{\partial x(0)} = 0.6 \cdot x(0)^{-0.4} - 0.00017 \cdot x(0)^{0.7}.$$

So, for any level of initial biomass the shadow value can be easily calculated by simply plugging the biomass into this equation. The graph of the shadow value is illustrated in Figure 4.



As already mentioned, it is of course possible to derive the value function and the associated shadow values for any specified bio-economic enforcement model, provided the other data mentioned in chapter 4 are also provided. Depending on the complexity of the model, this may be significant work, however. The main reason is that it involves the calculation of an integral over time. The advantage is that only a few value function points have to be calculated.

References

- COBECOS. 2009. Final Report. The EU project Costs and Benefits of Control Strategies. DG XIV. Bruxelles.
- Dixit, A. 1990. Optimization in Economic Theory. 2nd. Edition. Oxford University Press.
- Dorfmann, R. 1969. An Economic Interpretation of Optimal Control Theory. *American Economic Review* 59, pp. 817-31.
- Kamien, M.I. and N.L. Schwartz. 1981. Dynamic Optimization. The Calculus of Variations and Optimal Control in Economics and Management. North Holland. Amsterdam.
- Pontryagin, L.S, V.S. Boltyanski, R.V. Gramkeldize and E.F. Mishchenko. 1962. The Mathematical Theory of Optimal Processes. Wiley, New York.
- Sandal, L, Arnaon, R, S. Steinshamn and N. Vestergaard. 2004. Optimal Feedback Controls: Comparative Evaluations of the Cod Fisheries of Denmark, Iceland and Norway. *American Journal of Agricultural Economics* 86, 2:531-542.

PART 3 Extension of the theory to include administrative and newer control tools.

On January 13, 2012, I contracted with the Swedish Agency for Marine and Water Management (SwAM) to assist in a pilot study for applying the COBECOS fisheries enforcement methodology. This report constitutes a partial fulfilment of my obligations under this contract, namely item 3.d of the contract.

Reykjavik 1. May 2012



Ragnar Arnason

1. Introduction

The fundamental COBECOS enforcement theory (COBECOS 2009) is quite general. The basic theory can accommodate a wide range of management controls and enforcement tools. However, to incorporate specific enforcement tools in the basic theoretical structure in a proper way is not always straight forward. This paper attempts to explain further how this can be done. More specifically, it considers certain novel types of enforcement tools; VMS (vessel monitoring system), ERS (electronic recording and reporting system) and ACC (administrative cross checks). Also, due to a special request, it says a few words about the enforcement of discarding rules.

The paper is organized as follows. The general COBECOS theory of multiple management controls and enforcement tools is laid out in section 2. In section 3, the application of this theory to VMS, ERS, ACC is discussed and explained. Section 4 deals specifically with the enforcement of discarding restrictions.

2. Multiple enforcement tools

In this section the basic COBECOS enforcement theory is extended to include (i) multiple fisheries activities — not just the volume of harvest, (ii) multiple management controls (targets) — not just landings and (iii) multiple enforcement tools — not just enforcement of landings. As will become apparent, the basic theory extends in a straight-forward manner in this respect.

2.1 Fishers' actions

Let all possible fishers' actions (including fishing time, search time, crew size, gear type, location etc.) be represented by the vector \mathbf{s} .

Harvests are produced by:

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

where x is biomass. It is convenient to refer to the $(l+1)$ vector (\mathbf{s}, q) supposed to be $(1 \times l)$ as the vector of possible fisheries actions.

With general fisheries actions, instead of just harvests, there may be some impacts on the biomass growth function. For instance mesh size, timing of fishing and fishing areas may influence the growth of the biomass. A general modelling of this is:

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

where $G(\mathbf{x}, \mathbf{s})$ 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, $G_{s_i}(\mathbf{s})$, is identically zero.

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

$$(1) \quad B(\mathbf{s}, x) = p \cdot Q(\mathbf{s}, x) - C(\mathbf{s}),$$

where p refers to the price of landings and $C(\mathbf{s})$ to the cost of fishers' actions.

2.2 Management controls

Fisheries managers may want to control any or all possible fishers' actions. For instance, they may want to restrict harvests, q , (or landings) or they may want to control fishing time and areas, reduce discards and so on. In general they can impose restrictions on any fishers' actions, i.e. the vector \mathbf{s} , as well as the harvest, q . We refer to these management restrictions as a management controls.

To be worthwhile fisheries management controls must either alter components of fishers' private benefit functions or the biological constraint. Any other controls are irrelevant to how the fishery is conducted. Clearly, the maximum number of management controls is equal to the dimension of fishers' actions, i.e. $I+1$ in this case. In practice only a few of these actions will actually be controlled.

It should be noted that fisheries managers may also want to alter the effective landings price or costs by taxation (positive or negative). This is a type of fisheries management and, as other management controls, requires enforcement. This is ignored in the current formulation, but could be included.

2.3 Enforcement tools

Enforcement tools are all the methods enforcement authorities can use to increase adherence to the management controls. There is a great number of possible enforcement tools. Let all possible fisheries enforcement tools (including dock side monitoring, airplane hours, number of on-board observers, number of inspections, VMS, ERS etc.) be represented by an $(1 \times J)$ vector. Moreover, let the effort along all these tools be represented by the $(1 \times J)$ vector \mathbf{e} .

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

$$CE(\mathbf{e}).$$

2.3 Penalties

Penalties for violating management controls are given by the vector, \mathbf{f} . Clearly the dimensionality of this vector equals the number of different management controls. More precisely this vector can be written as:

$$\mathbf{f}=(f_1, f_2, \dots, f_{l+1}).$$

If there are no constraints on some possible fishers' action, j , say, the corresponding penalty will be identically zero, $f_j \equiv 0$. Needless to say, in most enforcement situations, most of the elements in the \mathbf{f} vector will be zero.

Note that, instead of being parameters as above, the penalties may actually be functions, e.g. of the extent of the violation.

2.4 Probability of penalty

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

$$\boldsymbol{\pi}(\mathbf{e}) = (\pi_1(\mathbf{e}), \pi_2(\mathbf{e}), \dots, \pi_{l+1}(\mathbf{e})).$$

Note that in principle all probabilities of penalty depend on all the enforcement efforts. This is because e.g. a landing's observer may detect fishing gear violation and so on. In accordance with the vector of fishers' action in section 2.1, the last item in this vector represent the probability of suffering a penalty for violating harvesting restrictions.

2.5 Private behaviour

Given the above specifications the private (or fishers') maximization problem may be expressed as:

$$(I) \quad \underset{s}{Max} \ B(Q(s, x), x) - \sum_{i=1}^l f_i \cdot \pi_i(\mathbf{e}) \cdot (s_i - s^*) - f_q \cdot \pi_q(\mathbf{e}) \cdot (Q(s, x) - q^*).$$

In this formulation starred, $'^*$, variables refer to the allowable levels of fisheries actions. The simplification that all management controls are represented as an upper bound on the respective fishers' actions is not necessary. A more general formulation is to write this as some function of the action and the management control, $\Gamma(s_i, s_i^*)$, say. For that formulation we may rewrite (I) as :

$$(Ib) \quad \underset{s}{Max} \ B(Q(s, x), x) - \sum_{i=1}^l f_i \cdot \pi_i(\mathbf{e}) \cdot \Gamma(s_i, s_i^*) - f_q \cdot \pi_q(\mathbf{e}) \cdot \Gamma(Q(s, x), q^*)$$

The solution to this private maximization problem may be written as the $(1 \times l + 1)$ vector function (more generally correspondence):

$$(2) \quad (S(e; f, x, s^*, q^*), Q(S(e; f, x, s^*, q^*), x)).$$

Equation (2) is the enforcement response function in the multiple management control, multiple enforcement tool case. It defines how the various fishers' actions depend on the vector of enforcement effort, e , biomass, x , and management controls, (s^*, q^*) .

2.6 Social optimization

The social maximization problem is:

$$(II) \quad \underset{e}{Max} \quad B(Q(S(e, f, x, s^*, q^*), x), x) + \lambda \cdot (G(x, S(e, f, x, s^*, q^*)) - Q(S(e, f, x, s^*, q^*), x)) - CE(e)$$

Apart from the generalizations there is one important difference between this social problem and the one in the basic COBECOS theory (COBECOS 2009). This is the inclusion of fishers' action in the biomass growth function. This is because some of the fisher's actions e.g. fishing gear choice, area-time choices and size selectivity may affect biomass growth.

The necessary conditions for solving this problem are informative:

$$(3) \quad \sum_{i=1}^I [B_{s_i} + \lambda \cdot (G_{s_i} - Q_{s_i})] \cdot \frac{\partial s_i}{\partial e_j} - CE_{e_j} \leq 0, \quad e_j \geq 0,$$

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

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

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

Expression (3) defines the optimal enforcement effort level and therefore also the optimal mix of all possible enforcement tools. The principle is that the enforcement effort for all tools that are used should at a level where it produces the same marginal benefits, namely zero. The level of effort for other tools must equal zero.

Obviously, to work out the solution corresponding to (3) requires knowledge of (i) the private benefit function, (ii) the cost of enforcement function, (iii) the probability of penalty function, (iv) the penalty structure as well as the management restrictions for all possible fishers' actions. With that knowledge in hand, the private maximizing

solution in equation (2) can be derived and subsequently the expression for optimal enforcement effort mix given in (3).

3. Specific enforcement tools

In this section we will consider certain specific enforcement tools suggested by SwAM and how they can be modeled within the basic COBECOS fisheries enforcement theory. In all cases we assume that there are two management controls (i) a catch constraint, q^* and (ii) an area constraint, a^* . We also assume that in addition of the specific enforcement tools considered, there are some other tools employed such as dockside monitoring, at-sea monitoring, observer monitoring and so on. In the interest of simplifying the notation, we represent these jointly by one enforcement effort variable, e . For ease of understanding, we will present these examples along the lines set out in the theory in section 2.

3.1 VMS

VMS makes it easier to establish the location of the fishing vessel at all times as well as some other aspects of its behaviour.

Enforcement model components:

<i>Fishers' actions:</i>	Area choice, a ; harvest level, q and fisheries inputs, z . Represent this by the vector (a, q, z) .
<i>Fishers' benefits:</i>	$B(q, x)$. This assumes that the actions a and z do not affect benefits directly but only through q and x . This is for simplicity of exposition only. More generally the benefit function would be $B(q, x, a, z)$.
<i>Harvest function:</i>	The level of harvest depends on fisheries inputs, area choice and the level of biomass; $q = Q(z, a, x)$
<i>Biomass growth:</i>	$G(x, a) - q$
<i>Management controls:</i>	Area restrictions and catch restrictions, (a^*, q^*) .
<i>Enforcement tools:</i>	General enforcement and VMS. The effort on each is represented by the vector (e, e_{VMS}) .
<i>Cost of enforcement:</i>	$C(e, e_{VMS})$
<i>Penalties:</i>	Penalties for harvest violations, f_q , and area violations f_a .
<i>Probability of penalty:</i>	$\pi_q(e, e_{VMS})$ and $\pi_a(e, e_{VMS})$.

Private maximization:

The problem is:

$$\text{Max}_{z,a} B(Q(z,a,x),x) - f_q \cdot \pi_q(e,e_{VMS}) \cdot (Q(z,a,x) - q^*) - f_a \cdot \pi_a(e,e_{VMS}) \cdot (a - a^*)$$

Note that the difference $(a - a^*)$ must be interpreted as some measure of area violation.

The necessary conditions are:

$$B_Q \cdot Q_z - f_q \cdot \pi_q(e,e_{VMS}) \cdot Q_z = 0, \text{ if } z > 0,$$

$$B_Q \cdot Q_a - f_q \cdot \pi_q(e,e_{VMS}) \cdot Q_a - f_a \cdot \pi_a(e,e_{VMS}) = 0, \text{ if } a > 0.$$

Solving these equations produces the enforcement response equations:

$$z = Z(e,e_{VMS},x,f_q,f_a,q^*,a^*),$$

$$a = A(e,e_{VMS},x,f_q,f_a,q^*,a^*).$$

Optimal enforcement

$$\begin{aligned} \text{Max}_{e,e_{VMS}} & B(Q(Z(e,e_{VMS},x,f_q,f_a,q^*,a^*),A(e,e_{VMS},x,f_q,f_a,q^*,a^*),x),x) \\ & + \lambda \cdot (G(x,A(e,e_{VMS},x,f_q,f_a,q^*,a^*),x)) - Q(Z(e,e_{VMS},x,f_q,f_a,q^*,a^*),A(e,e_{VMS},x,f_q,f_a,q^*,a^*),x)) \\ & - CE(e,e_{VMS}) \end{aligned}$$

This maximization problem may seem more complicated than it actually is. Remember that for the maximization only the enforcement efforts e and e_{VMS} are actually variable.

Application: What needs to be done?

The above tell us what needs to be done in addition to the standard COBECOS work. The following functions need to be estimated.

- (1) A harvesting function, $Q(z,a,x)$, including area choices needs to be empirically estimated.
- (2) The impact of area choice on the biomass growth function, $G(x,a)$, needs to be estimated.
- (3) A joint cost function including both enforcement efforts, $C(e,e_{VMS})$, needs to be estimated.

- (4) The two joint probability of penalty functions, $\pi_q(e, e_{VMS})$ and $\pi_a(e, e_{VMS})$, need to be estimated.

The parameters, a^* and f_a need to be established just as q^* and f_q .

Apart from this, the application of the theory proceeds in the usual way. Maximization procedures will be more complicated than in the single enforcement effort case but eminently feasible.

3.2 ERS

ERS can contribute to the enforcement of many fisheries management controls. In our example it can contribute to both catch and area restrictions in the same qualitative way as the VMS discussed above. It follows that to apply the COBECOS enforcement theory will proceed in exactly the same way as that described for the VMS above. All that needs to be done is to replace the acronym VMS with ERS

Note that the harvesting function, $Q(z, a, x)$ and the biomass growth function, $G(x, a)$, which only depend on fishers' actions and not on the enforcement tools, do not need to be re-estimated. The probability of penalty functions, $\pi_q(e, e_{ERS})$ and $\pi_a(e, e_{ERS})$ will be different and may well be more difficult to assess.

3.3 ACC

ACC (administrative cross checks) consist of comparing reports from various stages of the harvesting (including log-books), landings, processing, distributional and marketing process in order to detect deviations indicative of violations. This process can contribute to the enforcement of actual catches and several other fishers' actions that are subject to controls. Thus, from an analytical and empirical perspective ACC works in a similar way to ERS or VMS. However, for the sake of illustration let us consider the case where there is only one management control, the volume of harvest, q , and ACC contributes to the enforcement of this.

Enforcement model components:

- Fisheries actions:* Area choice, a ; harvest level, q and fisheries inputs, z . Represent this by the vector (a, q, z) .
- Harvest function:* The level of harvest depends on fisheries inputs, area choice and the level of biomass; $q=Q(z, a, x)$
- Biomass growth:* $G(x, a)-q$
- Management controls:* In this case only catch restrictions, q^* .

Enforcement tools: General enforcement and ACC. The effort on each is represented by the vector (e, e_{ACC}) .

Cost of enforcement: $C(e, e_{ACC})$

Penalties: Penalties for harvest violations, f_q .

Probability of penalty: $\pi_q(e, e_{ACC})$.

Private maximization:

The problem is:

$$\text{Max}_{z,a} B(Q(z, a, x), x) - f_q \cdot \pi_q(e, e_{ACC}) \cdot (Q(z, a, x) - q^*)$$

The necessary conditions are:

$$B_Q \cdot Q_z - f_q \cdot \pi_q(e, e_{ACC}) \cdot Q_z = 0, \text{ if } z > 0,$$

$$B_Q \cdot Q_a - f_q \cdot \pi_q(e, e_{ACC}) \cdot Q_a = 0, \text{ if } a > 0.$$

Solving these equations produces the enforcement response equations:

$$z = Z(e, e_{ACC}, x, f_q, q^*),$$

$$a = A(e, e_{ACC}, x, f_q, q^*).$$

Optimal enforcement

$$\begin{aligned} \text{Max}_{e, e_{ACC}} & B(Q(Z(e, e_{ACC}, x, f_q, q^*), A(e, e_{ACC}, x, f_q, q^*), x), x) \\ & + \lambda \cdot (G(x, A(e, e_{ACC}, x, f_q, q^*), x)) - Q(Z(e, e_{ACC}, x, f_q, q^*), A(e, e_{ACC}, x, f_q, q^*), x) \\ & - CE(e, e_{ACC}) \end{aligned}$$

4. Enforcing discarding restrictions.

Fisheries management often aims at reducing or eliminating discards. To do so obviously requires enforcement.

The rationale for reducing discards is not always very clear (Arnason 1994). Discarding obviously benefits the fishers; otherwise it wouldn't occur. This may be detrimental to society for several reasons. First, discarding may distort catch statistics, which often only count landings: Second, discarding of catches may be distressing to a part of the population. Third, discarding may be caused by other restrictions such as individual catch quotas and therefore be socially inefficient while privately beneficial.

The following describes the essential steps in constructing a discarding (and landings) enforcement model.

Enforcement model components:

- Fishers' actions:* Harvest level, q and discarding, d . Represent this by the vector (q, d) .
- Fishers' benefits:* Discarding in general affects fishers' benefit function. First it must be subtracted from catches which generally reduces benefits. However, if the cost of bringing the discarded catch to shore exceeds the price, discarding is directly beneficial. This would be the case if it happens under no particular fisheries management (Arnason, 1994). Therefore, in general, the benefit function should be written as $B(q, d, x)$.
- Harvest function:* Since in this formulation harvest is assumed to be the fishers' decision variable a harvesting function is not needed.
- Biomass growth:* $G(x, a) - q$
- Management controls:* Catch and discarding restrictions, (q^*, d^*) . Note that d^* may be zero.
- Enforcement tools:* General enforcement and discarding enforcement. Enforcement of discarding restrictions may be effected in many ways with which we do not have to be concerned here. The effort on each enforcement tool is represented by the vector (e, e_d) .
- Cost of enforcement:* $C(e, e_d)$
- Penalties:* Penalties for harvest violations, f_q , and for discarding f_d .
- Probability of penalty:* $\pi_q(e, e_d)$ and $\pi_d(e, e_d)$.
- Social benefits:* $B(q, d, x) - CD(d) - C(e, e_d) + \lambda \cdot (G(x) - q)$, where $CD(d)$ is the social cost of discarding e.g. because it distresses the general population.

Private maximization:

The fishers' problem is:

$$\text{Max}_{z, d} B(q, d, x) - f_q \cdot \pi_q(e, e_d) \cdot (q - d - q^*) - f_d \cdot \pi_d(e, e_d) \cdot (d - d^*)$$

Note that this formulation of the private problem assumes that discards cannot be verified (or penalized) as catches.⁵ It follows that for the fishers discarding has double benefits. It affects the benefit function directly and it reduces expected penalties for excessive catches.

The necessary conditions for solving this problem are:

$$B_q - f_q \cdot \pi_q(e, e_d) = 0, \text{ if } q > 0,$$

$$B_d + f_q \cdot \pi_q(e, e_d) - f_d \cdot \pi_d(e, e_d) = 0, \text{ if } d > 0.$$

In the 2nd necessary condition, note the additional benefits from discarding in terms of reduced marginal penalties, $f_q \cdot \pi_q(e, e_d)$.

Solving these equations produces the enforcement response equations:

$$q = Q(e, e_d, x, f_q, f_d, q^*, d^*),$$

$$d = D(e, e_d, x, f_q, f_d, q^*, d^*).$$

Optimal enforcement

$$\begin{aligned} \text{Max}_{e, e_d} \quad & B(Q(e, e_d, x, f_q, f_d, q^*, d^*), D(e, e_d, x, f_q, f_d, q^*, d^*), x) - CD(D(e, e_d, x, f_q, f_d, q^*, d^*)) - C(e, e_d) \\ & + \lambda \cdot (G(x) - Q(e, e_d, x, f_q, f_d, q^*, d^*)) \end{aligned}$$

How to apply

To apply the above theory the following functions need to be estimated.

- (5) Fishers' private benefit function including discards.
- (6) A joint cost function including both enforcement efforts, $C(e, e_d)$.
- (7) The two joint probability of penalty functions, $\pi_q(e, e_d)$ and $\pi_d(e, e_d)$.
- (8) The social cost of discarding function $CD(d)$. This, if not identically equal to zero, may be difficult to estimate very precisely.

In addition, the parameters, d^* and f_d as well as q^* and f_q need to be established.

⁵ This assumption can of course be dropped and the modelling generalized.

Apart from this, the application of the theory proceeds in the usual way.

References

- COBECOS. 2009. Final Report. The EU project Costs and Benefits of Control Strategies. DG XIV. Bruxelles.
- Arnason, R. 1994. On Catch Discarding in Fisheries. *Marine Resource Economics* 9:189-207.

Swedish Agency for Marine and Water Management (SwAM)
Gothenburg (Sweden)

Swedish COBECOS Pilot Study

Deliverable 3

Software & Simulations

Project Responsible: Jenny Nord

29/11/2013

Disclaimer

This report has been prepared under contract ICEEF Service Contract Nr. 257233 by the Swedish Agency for Marine and Water Management (SwAM), Gothenburg (Sweden). It does not necessarily reflect the view of the European Commission and in no way anticipates the Commission's future policy in this area.

Preface

According to the Swedish COBECOS pilot study contractual obligations, the Final Report should be accompanied by the software implementation along with feedback on simulations, and should be made available as a deliverable (D3) upon final completion of the Tender (month 18). The following report and annexes constitute the fulfilment of this obligation.

Gothenburg 29 November 2013

For the contractor in the Swedish COBECOS Pilot Study,

Jenny Nord and Malin Hultgren

Table of Contents

1. Background.....	51
2. Software implementation	53
3. Simulations	58

1. Background

Following up lessons learnt from EU funded (FP6) research project COBECOS (<https://cobecos.jrc.ec.europa.eu/>), where JRC was scientific coordinator, the main objective of the current study is the pilot implementation of the COBECOS theory and software in the specific context of two Swedish fisheries managed and enforced by the Swedish Agency for Marine and Water Management (SwAM).

The FP6 project COBECOS estimated the cost of EU fisheries enforcement to be between 150 and 600 Million Euro. Making enforcement more effective can result in significant social and economic benefits of the order of tens of millions of Euro. Furthermore, the FP6 COBECOS project resulted in the awareness that a number of pilot implementations of COBECOS are still needed before developing validated operational-grade tools that could then be used by EU fisheries enforcement and control agencies for their daily work. In fact, each enforcement situation has its own particular features that must be accounted for in the application of the COBECOS enforcement theory and software, and pilots are necessary to help understand these particularities. The most striking outcome of COBECOS was that 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 analyzed.

Under the contract IPSC/2011/04/07/NC-Service Cntr. 257233, the COBECOS theory is applied to two relatively simple fisheries, managed and enforced by the Swedish fisheries enforcement authorities, namely, the Swedish cod trawl fishery in the Baltic Sea (single-species) and the demersal trawl fishery in Kattegat and Skagerrak (multi-species). SwAM :

- ✓ provided a general description of the two trawl fisheries: their fisheries management systems, their fisheries enforcement systems and the costs and effectiveness of the enforcement.
- ✓ compiled time series (2009-2011) of quantitative/qualitative data on variables crucial for estimation of theoretical relationships, such as:
 - private and social benefit function of fishing (bio-economic modeling data)
 - cost of enforcement function (enforcement costs and enforcement effort data)
 - probability of penalty function (sanctions over number of violations)
 - penalty schedule (usually specified in regulations).
- ✓ provided a bio-economic model (necessary for the private benefit function and the stock dynamics) for the aforementioned fisheries.
- ✓ provided short-cut methods to obtain approximately correct values of the shadow value of fish stocks (i.e. the value of leaving one unit of the stock behind; allowing it to grow spawn and reproduce), an important concept in optimal fisheries management and fisheries enforcement.

SwAM by pulling together all the above information (Deliverables 1 & 2), provided necessary services allowing JRC to run simulations based on the existing

COBECOS software. Following these simulations, JRC extended and improved the current COBECOS software producing a user friendly version easy to exercise by any non-IT skilled stakeholder. This new implementation incorporated administrative controls, which are becoming increasingly important as well as any other cost effective mean to conduct fisheries controls. The FP6 project COBECOS failed to deal with them in the past analyses.

Feedback on interpretation of the results of simulations by JRC ("what if" scenarios) was provided by SwAM, so that the most effective means of control (both in terms of cost as well as compliance) will be identified by the Swedish authorities for potential future control and enforcement schemes. At this final stage, the software can be considered an operational tool for control and enforcement agencies.

2. Software Implementation

The whole implementation was developed in R (www.r-project.org) which is available as Free Software under the terms of the Free Software Foundation's GNU General Public License in source code form. It is platform independent, compiling and running on a wide variety of UNIX platforms and similar systems (including FreeBSD and Linux), Windows and MacOS.

The version used in this study was R version 2.15.3 - 2013/03/01 (R Core Team, 2013) ran inside RStudio (RStudio, 2013) a developer environment for R. A graphical representation of the implementation can be visualized in figure 1.

The software package developed uses input fisheries data of bio-economic nature as well as control and enforcement data. Through a user-friendly Graphical User Interface it outputs optimal levels of control at the lower costs, so that to obtain higher benefits from the fishery for the society.

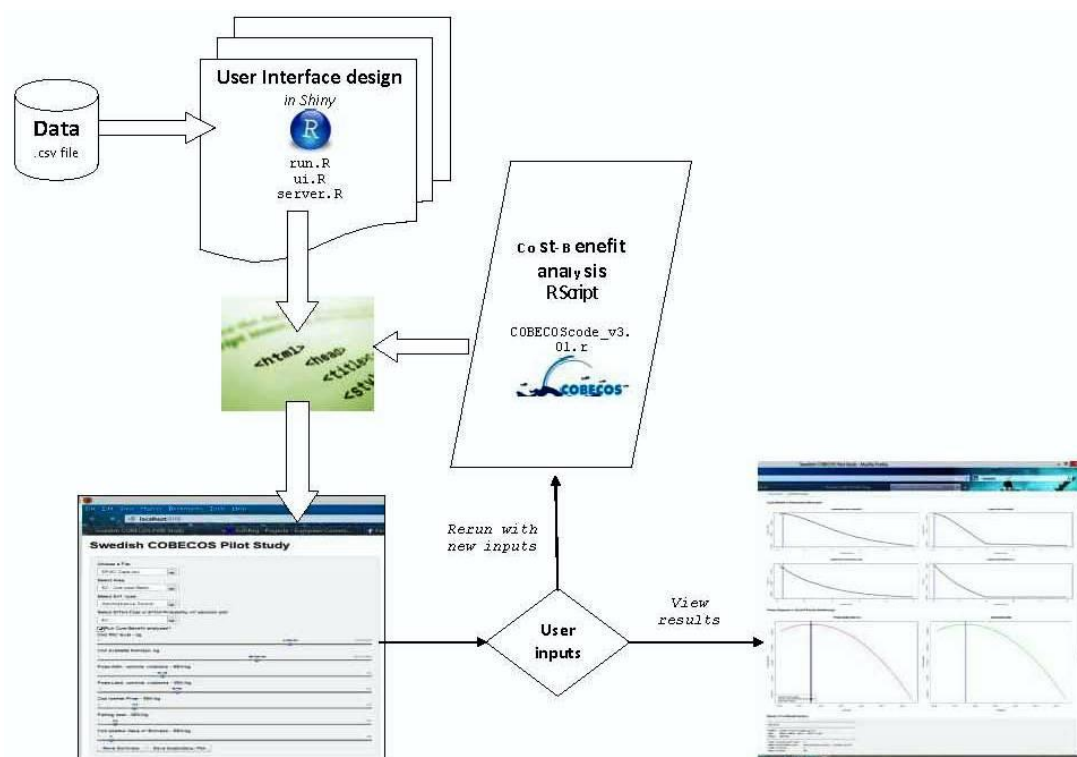


Figure 1. Flow chart of the current implementation

Data

Required data types include:

- bio-economic nature data
 - stock size,
 - catch,
 - catch limits-TACs,
 - market prices,
 - operational costs
- Control and enforcement data
 - control effort,
 - enforcement cost,
 - number of infringements,
 - penalty levels

User interface

The user interface (UI) was developed using innovative 'Shiny' package in RStudio (version 0.1.0 - 28/7/2012 - <http://www.rstudio.com/shiny/>) which allows to turn analyses previously running solely under R into interactive web applications without developing HTML or Java applications. Although Shiny package itself is designed to run locally (current implementation) it can also be deployed over the web if needed.

Three R scripts are responsible for delivering the user interface:

- run.R (calls ui.R and server.R and translates R into HTML pages)
- ui.R (definition of the user interface design; renders server.R outputs)
- server.R (read data inputs; main R coding and analyses; call COBECOS script)

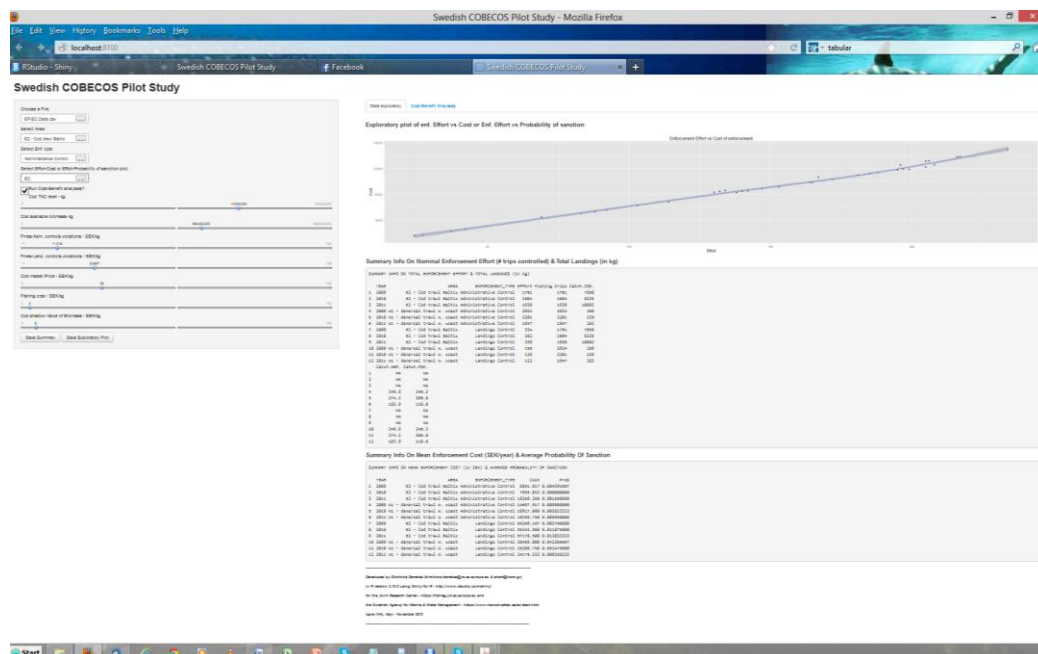
The UI consists of a sidebar on the left in which user can select initial inputs and adjust levels of input parameters:

- Basic inputs
 - data file to read
 - case study to analyse
- Input for Exploratory plots
 - Enforcement type under consideration
 - Enforcement effort vs Probability of sanction plot (EP plot)
 - Enforcement effort vs Cost of enforcement plot (EC plot)
- Adjust initial inputs of some parameters
 - TAC levels
 - Available stock biomass
 - Administrative control Fine level
 - Landings control Fine level
 - Market price of fish
 - Fishing costs
 - Shadow value of biomass for the exploited stock

The main panel hosts two panels (as tabs):

- Data Exploratory tab (Fig. 2)
 - The user can view the scatter-plots of EP or EC plots and identify the underlying relationships between Effort-Probability and Effort-Cost.
 - Summary info table of enforcement effort and landings (aggregated by Year, Area, Enforcement type)
 - Summary info on mean enforcement Cost & average probability of sanction (aggregated by Year, Area, Enforcement type)
- Cost-Benefit Analyses tab (Fig. 3)
 - Social Benefit vs Enforcement effort plots
 - Fishery Response vs Social & Private Benefits plots
 - Detailed results of Cost-Benefit Analysis in tabular format
 - 2D level plot of Probability of detection vs enforcement control effort & Effort vs Cost relationship plots

Figure 2. View of the Data Exploratory tab in the main panel



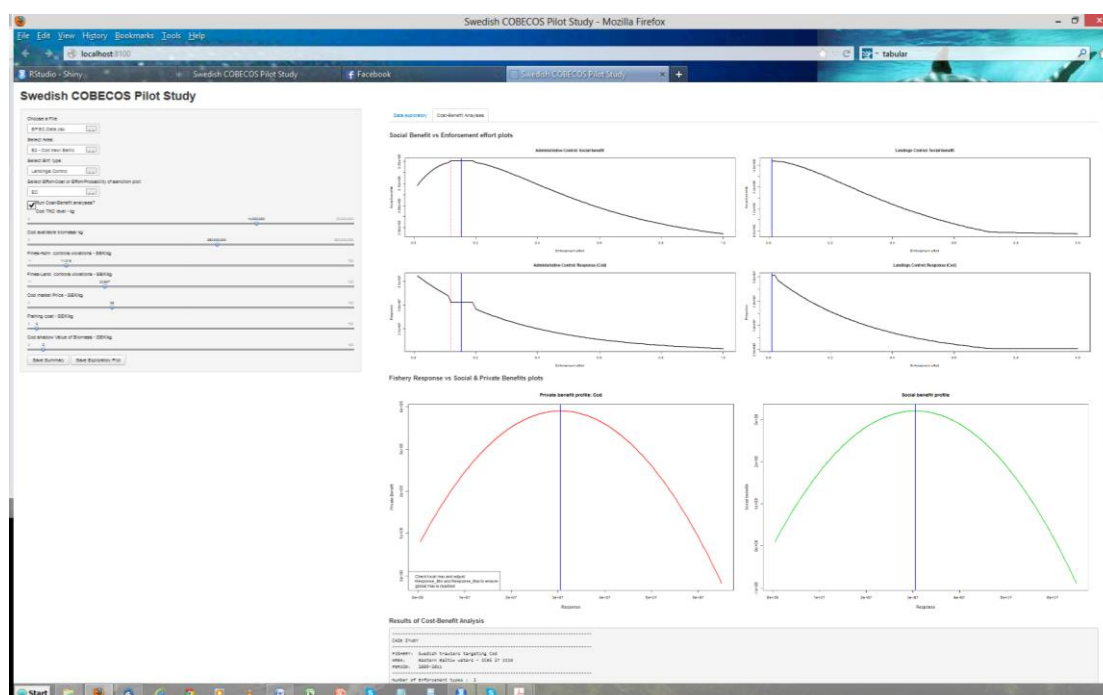


Figure 3.View of the Cost-Benefit Analyses tab in the main panel

Cost-Benefit analyses

All cost-benefit optimization analyses are based largely on the script developed for COBECOS FP6 project by Charles Edwards and Tom Carruthers and specifically the latest version v.2.11 - June 2009.

Private Benefit and Social Objective functions were revised and the COBECOS script was updated to be used in the Swedish fisheries assigned a version number of v.3.01. The key functional aspects of the COBECOS approach are listed below:

1. Defines the functional form of private and social benefit functions
 - Default functional forms exist but users are encouraged to specify their own
2. Evaluates the private and social benefits at user defined levels of enforcement effort
 - User defines a vector of enforcement effort (that can be 'real world' or hypothetical)
 - Returns the social and private benefits at these effort levels given the Effort-Cost and Effort-Probability relationships
 - Plots the marginal social benefit(s) across enforcement level(s)
 - Returns the predicted level of catch
3. Evaluates the private and social benefits at optimal levels of enforcement effort.
 - Optimisation routines select enforcement effort(s) to maximise the social benefit
 - Returns the social and private benefits at these effort levels given the Effort-Cost and Effort-Probability relationships

- Plots the marginal benefits across enforcement level
 - Returns the predicted level of catch
4. 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 Effort-Cost and Effort-Probability relationships
 - Either or both types of uncertainty can be included
 - Enforcement levels can be optimised or set to user defined levels

The corresponding aforementioned functional relationships have been described in detail within Deliverable 2 of this report.

3. Simulations

Initially the models were fed with the inputs provided by SwAM, which actually depict the current situation regarding:

- stock status,
- harvest rates,
- enforcement effort,
- enforcement costs and
- probability of been sanctioned

After viewing the outputs and comparing optimized levels against current ones some potential changes were investigated by Case Study.

In general, 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.

Case study 2E

Initial values used as input

Parameter	Admin. Controls value	Landing controls value	Reference
Current enforcement effort	1.0	0.174	SwAM Deliv.1
Investigated min enforcement effort	0.01	0.01	
Investigated max enforcement effort	1.0	1.0	
Parameter	Value		Reference
Fishery Response	8,721,900 kg		SwAM Deliv.1
Min_Response investigated	500,000 kg		
Max_Response investigated	65,000,000 kg		
Cod TAC	14,000,000 kg		EC COM 1088/2012
Cod Biomass	290,000,000 kg		SwAM Deliv.1
Fines (Admin. Control)	0.0011 SEK/kg		SwAM Deliv.1
Fines (Landings Control)	0.0014 SEK/kg		SwAM Deliv.1
Fishing cost	6.2 SEK/kg		SwAM Deliv.1
Cod market price	13.5 SEK/kg		SwAM Deliv.1
Cod Shadow value of biomass	5.0 SEK/kg		

Current status

FISHERY: Swedish trawlers targeting Cod
AREA: Eastern Baltic waters - ICES 27 IIId
PERIOD: 2009-2011

Number of Enforcement types: 2
Names of Enforcement types: Administrative Control - Landings Control
Number of Stocks: 1
Names of Stocks: Cod

Current enforcement effort by enf. type (stand.):	1	0.174
Investigated Min enforcement effort by enf. type:	0.01	0.01
Investigated Max enforcement effort by enf. type:	1	1
Optimized enforcement effort by enf. type:	0.011	0.01
Total enforc. costs by enf. type (SEK/year):	108308	4314258
Effort optimized enforc. costs by enf.type(SEK):	1132	247945
Probability of violation by enforcement type:	0.0324	0.0311
Current fine levels by enforcement type (SEK/kg):	0.22	0.11

Current TAC for Cod(kg):	1.4e+07
Current available biomass for Cod (kg):	2.9e+08
Current fishery response (Cod landings - kg) :	8721900
Model output fishery response (Cod landings - kg):	9056927
Investigated Min response level (Cod landings - kg):	5e+05
Investigated Max response level (Cod landings - kg):	6.5e+07

Current fishing costs (SEK/kg) :	6.5
Current Cod market price of landings (SEK/kg):	13.5
Estimated shadow value of biomass of Cod stock (SEK/kg):	5

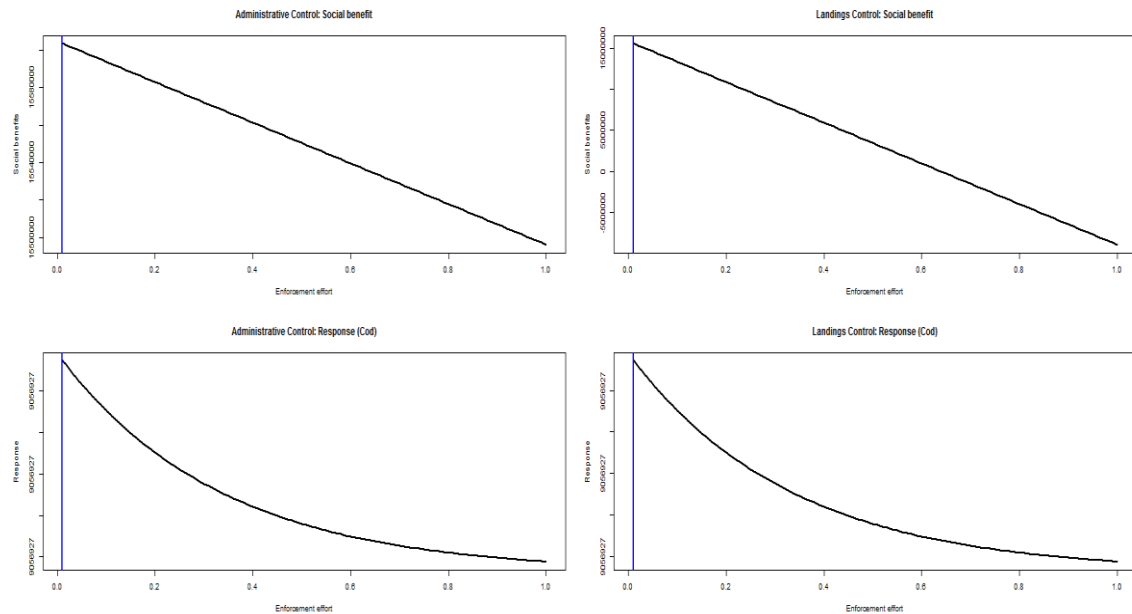
Estimated Social Benefit (SEK) : **15603450**
Estimated Private Benefit (SEK) : **61140308**

* SEK = Swedish kroner

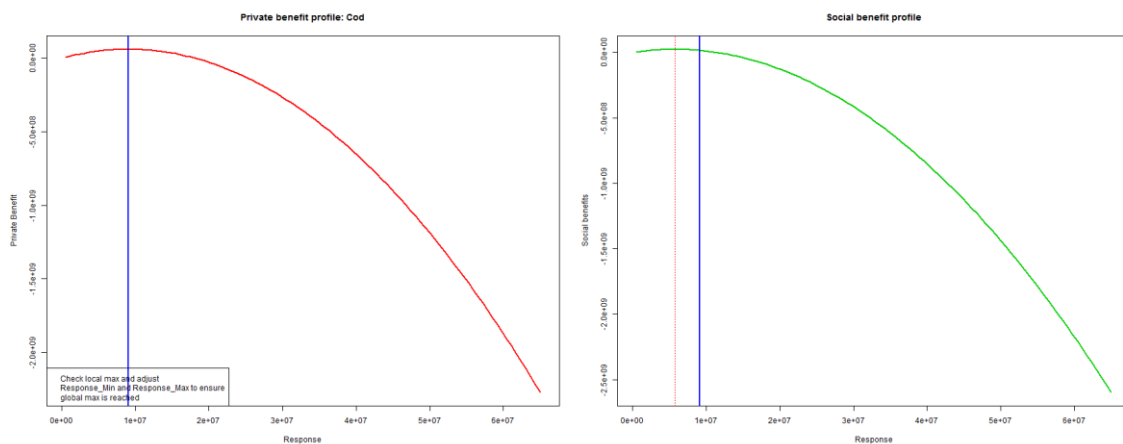
Graph indications throughout the text

A dotted red line indicates the level of the predictor variable (X-axis) at which the response variable (Y axis) reaches a global maximum. A solid blue line indicates the optimal level suggested by the model outputs.

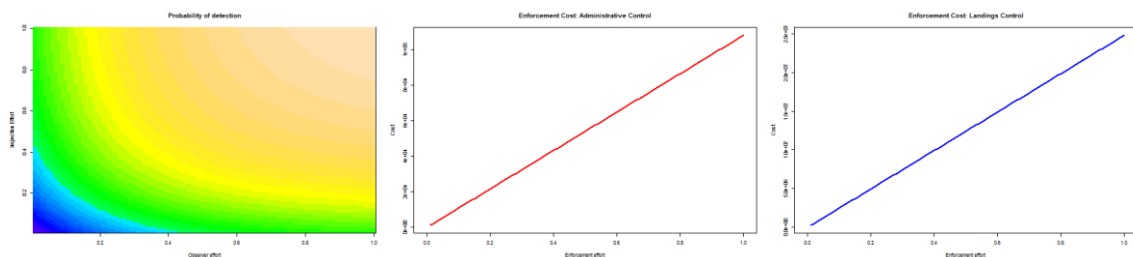
Social Benefit and response vs Enforcement effort plots



Fishery Response vs Social & Private Benefits plots



2D level plot of Probability of detection against enforcement control effort - Effort-Cost relationship plots



Exploratory plots confirmed a linear relationship for the Enforcement effort - Cost of enforcement relationship, while Enforcement effort - Probability of sanction was nowhere close to any established functional relationship. As a result the default bilinear equation of $Prob = a*Effort_1 + b*Effort_2 + c*Effort_1*Effort_2$ was used.

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. The very low number of violations suggests that the fishery is either 'compliant' or control is ineffective to detect infringements. As a result, optimized effort of control suggests that the current levels are not contributing to the overall social benefit more than if these levels would be lowered 10-fold for landings controls (from 0.174 down to 0.01) and 90-fold for the Administrative controls (from 1.0 to 0.011). [Note: effort is standardized between 0-1; 1 indicating 100% control, 0 absence of control]. Additionally the quite high TAC (14,000 tons) compared to the much lower current response (8,721 tons) suggests that a higher response, lower than the TAC, will not contribute negatively to the social benefit, while it will increase private benefit. Most likely this is an effect of the current market price of Cod (13.5 SEK/kg), being twice that of the fishing costs (6.5 SEK/kg), and the selected (low?) shadow value of biomass (5 SEK/kg).

Simulations-Scenarios

All the plausible combinations of the 7 'adjustable' parameters (TAC, Biomass, Administrative control fines, Landings control fines, market price, fishing costs, shadow value of biomass) taken 1, 2..., 7 at a time are given by the formula for combinations in the table below:

$$\binom{n}{r} = \frac{n!}{r!(n-r)!}, \text{ where } n! = n(n-1)(n-2) \dots 1$$

$\binom{7}{1}=7$
$\binom{7}{2}=21$
$\binom{7}{3}=35$
$\binom{7}{4}=35$
$\binom{7}{5}=21$
$\binom{7}{6}=7$
$\binom{7}{7}=1$
Total: 127

So, there are at least 127 different potential scenarios, without changing the default values of the aforementioned 7 variables. Taking into account changes in the default values of these 7 parameters, we end up with an infinite number of scenarios, an exercise left to the users to investigate.

Scenario 1

Investigate the following changes in the fishery:

- increase fishing costs by 25% (due to a future fuel price hike)
- increase market price by 25% (to compensate for rising fishing costs)
- increase of average fine to ~1 SEK/kg for both enforcement types (increasing fishing cost will amplify the incentives of fishers to infringe)
- Increase the shadow value of biomass to the level of market price

FISHERY: Swedish trawlers targeting Cod
AREA: Eastern Baltic waters - ICES 27 IIId
PERIOD: 2009-2011

Number of Enforcement types : 2
Names of Enforcement types : Administrative Control - Landings Control
Number of Stocks: 1
Names of Stocks: Cod

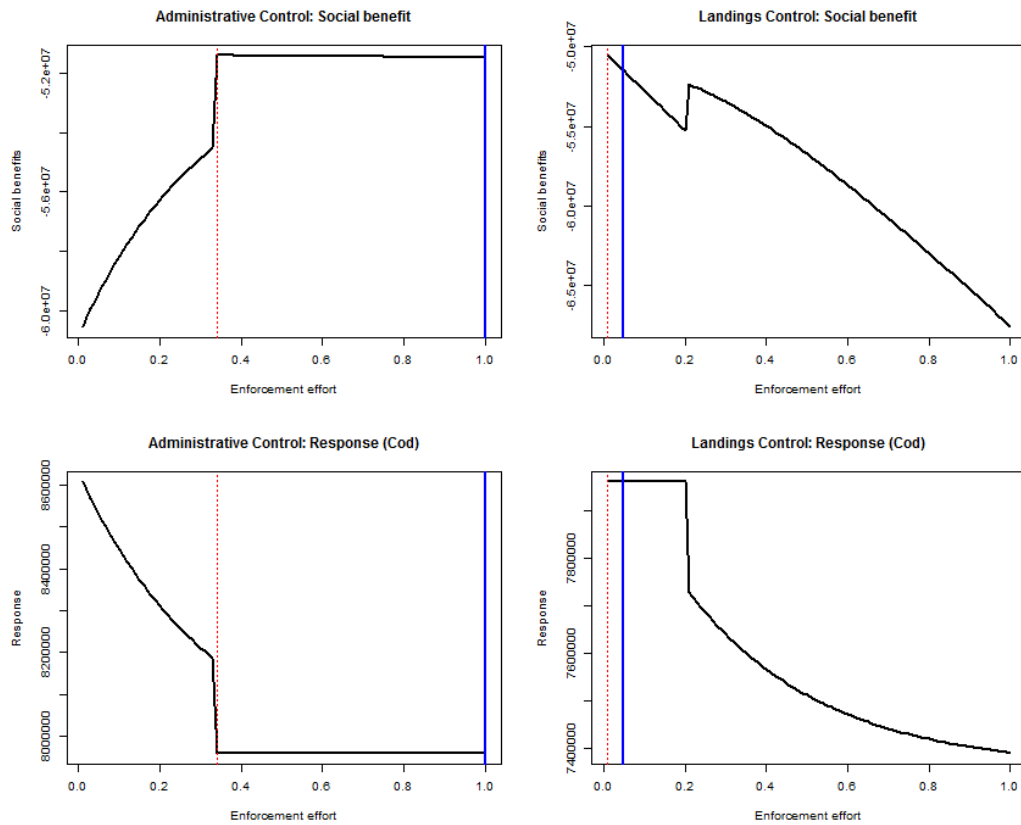
Current enforcement effort by enf. type (standardized 0-1): 1 0.174
Investigated Min enforcement effort by enf. type : 0.01 0.01
Investigated Max enforcement effort by enf. type : 1 1
Optimized enforcement effort by enf. type (stand. 0-1): 1 0.0482
Total enforcement costs by enf. type (SEK/year): 108308 4314258
Optimized costs of enforcement by enforc. type(SEK): 108308 1196873
Probability of violation by enforcement type : 1 0.1418812
Current fine levels by enforcement type (SEK/kg) : 1.222 1.222

Current TAC for Cod(kg): 1.4e+07
Current available biomass for Cod (kg): 2.9e+08
Current fishery response (Cod landings - kg) : 8721900
Model output fishery response (Cod landings - kg): 7961246
Investigated Min response level (Cod landings - kg): 5e+05
Investigated Max response level (Cod landings - kg): 6.5e+07

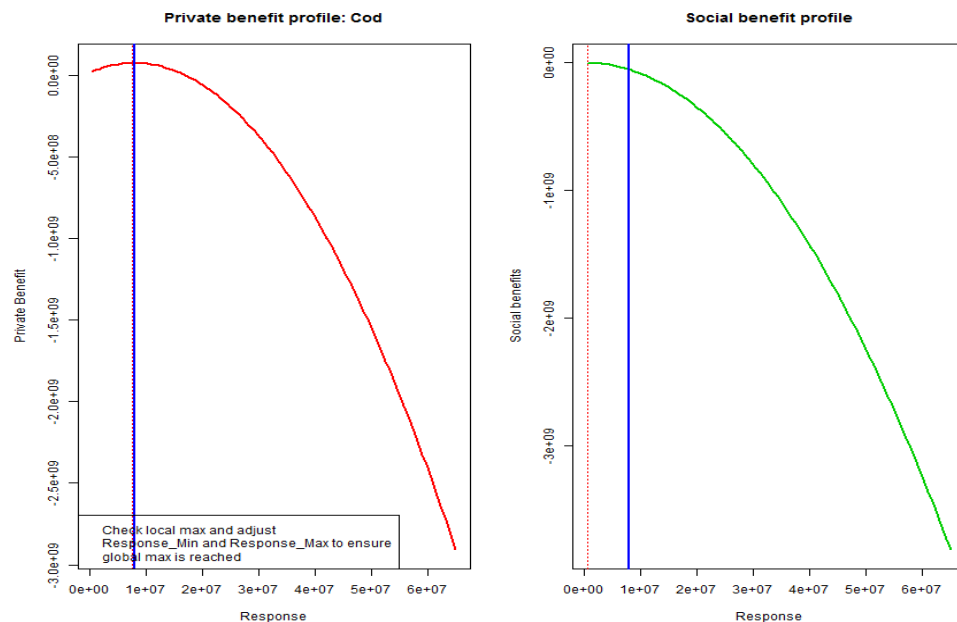
Current fishing costs (SEK/kg) : 8
Current Cod market price of landings (SEK/kg): 16
Estimated shadow value of biomass of Cod stock (SEK/kg): 15

Estimated Social Benefit (SEK) : **-51479375**
Estimated Private Benefit (SEK) : **77670845**

Social Benefit and response vs Enforcement effort plots



Fishery Response vs Social & Private Benefits plots



In this scenario, (fuel price increase, market price increase, fine increase to >1 SEK/kg, shadow value of biomass ~ market value) the suggested optimal enforcement levels are quite close to the current ones, although still lower for the landings control. Increased fishing costs were compensated by an increase in market price, and although fishers reduced fishing effort and corresponding landings by circa 10% (from 8700 tons down to 7900 tons) the private benefit of the fleet remained more or less unaffected, even increasing by ~20% (from 61 million SEK to 77 million SEK).

Assigning a higher value to the shadow value of biomass resulted in a great loss in social benefit, indicating that a valuable future resource was harvested for the sake of an ephemeral private benefit. The increase of enforcement effort costs had an insignificant contribution to the overall negative social benefit, since this was driven by the increased shadow value of biomass.

Case study 1W

Initial values used as input

Parameter	Admin. Controls value	Landing controls value	Reference
Current enforcement effort	1.0	0.068	SwAM Deliv.1
Investigated min enforcement effort	0.01	0.01	
Investigated max enforcement effort	1.0	1.0	
Parameter	Value	Reference	
Fishery Response (Cod)	264,122 kg	SwAM Deliv.1	
Fishery Response (Nephrops)	269,325 kg	SwAM Deliv.1	
Fishery Response (Pollack)	220,980 kg	SwAM Deliv.1	
Min_Response investigated (Cod)	1,000 kg		
Min_Response investigated (Nephrops)	1,000 kg		
Min_Response investigated (Pollack)	1,000 kg		
Max_Response investigated (Cod)	800,000 kg		
Max_Response investigated (Nephrops)	7,000,000 kg		
Max_Response investigated (Pollack)	600,000 kg		
Cod TAC	607,000 kg	EC COM 1088/2012	
Nephrops TAC	6,000,000 kg	ICES (2012)	
Pollack TAC	8,000,000 kg	ICES (2012) - No TAC	
Cod Biomass	6,070,000 kg	Assuming a 10% harvest rate - based on ICES (2012)	
Nephrops biomass	136,000,000 kg	ICES (2012)	
Pollack biomass	7,900,000 kg	Assuming a 5% harvest rate - based on ICES (2012)	
Fines (Admin. Control)	0.22 SEK/kg	SwAM Deliv.1	
Fines (Landings Control)	0.11 SEK/kg	SwAM Deliv.1	
Fishing cost	12.0 SEK/kg	SwAM Deliv.1	
Cod market price	13.5 SEK/kg	SwAM Deliv.1	
Nephrops market price	89.5 SEK/kg	SwAM Deliv.1	
Pollack market price	13.5 SEK/kg	SwAM Deliv.1	
Cod Shadow value of biomass	5.0 SEK/kg		
Nephrops Shadow value of biomass	30.0 SEK/kg		
Pollack Shadow value of biomass	5.0 SEK/kg		

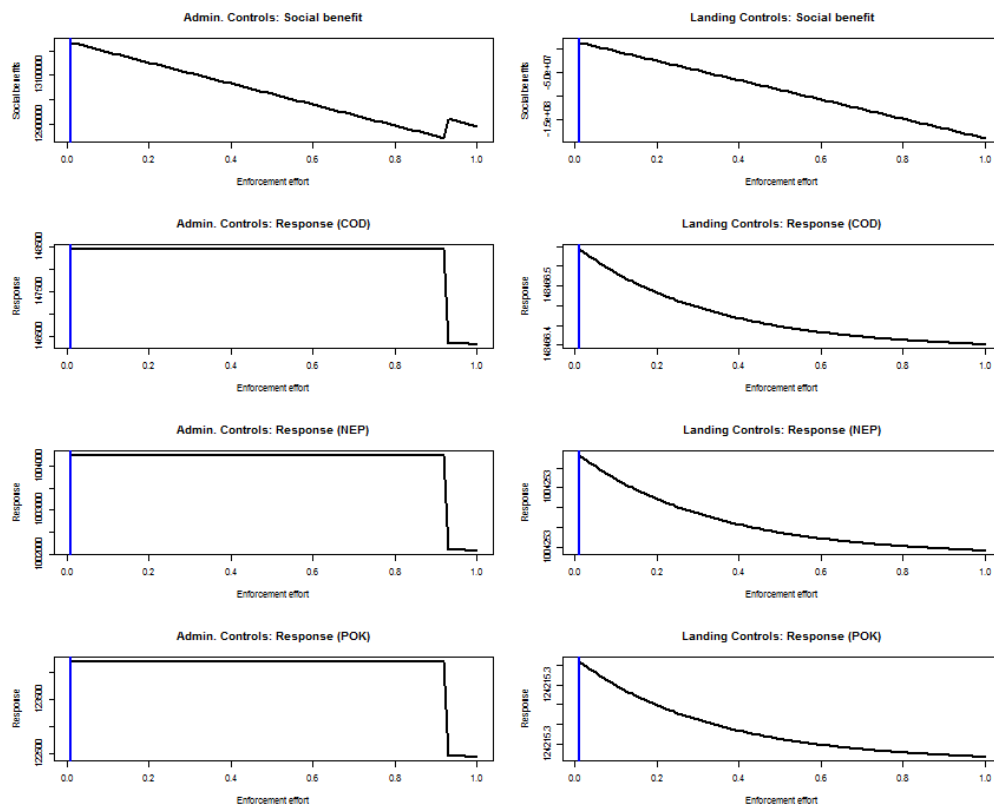
Current status

FISHERY: Demersal trawlers
AREA: Swedish western coast - Kattegat-Skagerrak - ICES 27 IIIa
PERIOD: 2009-2011

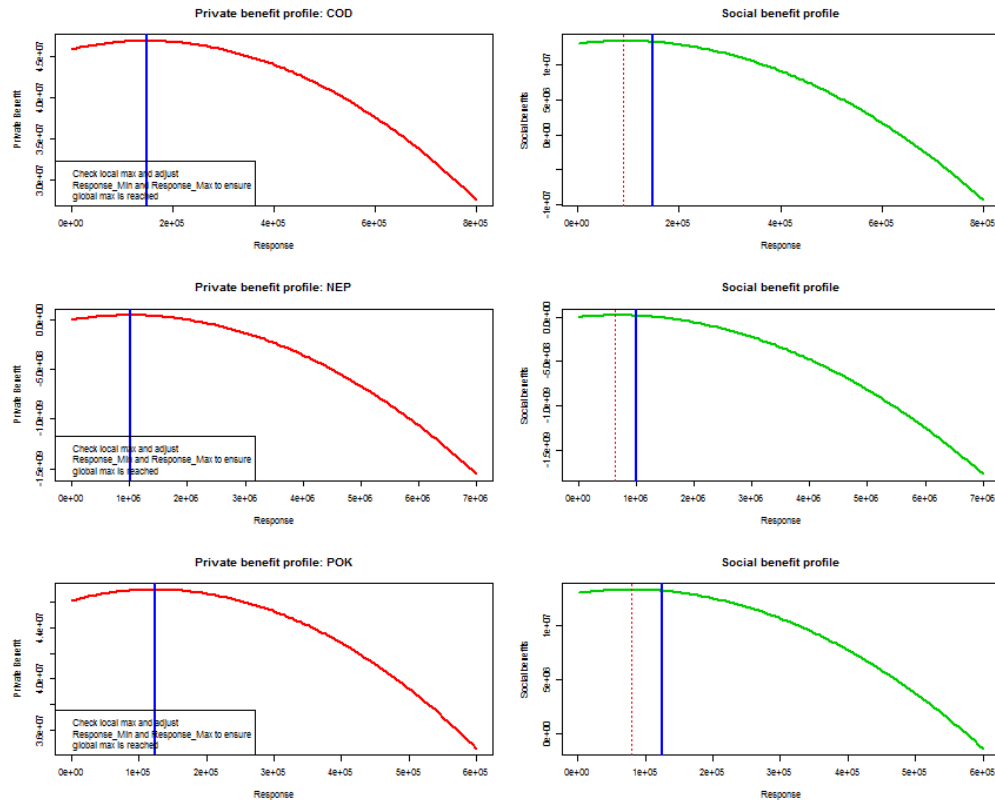
Number of Enforcement types : 2
Names of Enforcement types : Admin. Controls - Landing Controls
Number of Stocks: 3
Names of Stocks: COD NEP POK

Current enforcement effort by enf. type:	1.0	0.068	
Investigated Min enforcement effort by enf. type:	0.01	0.01	
Investigated Max enforcement effort by enf. type :	1	1	
Optimized enforcement effort by enf. type:	0.01	0.01	
Total enforc. costs by enf. type (SEK/year):	143898	4664255	
Effort optimized costs by enforc. type (SEK):	1438.9	685920	
Probability of violation by enforcement type:	0.0311	0.0311	
Current fine levels by enforcement type (SEK/kg):	0.22	0.11	
Current TAC for Cod-Nephrops-Pollack(kg):	6e+05	6e+06	8e+06
Current biomass for Cod-Nephrops-Pollack (kg):	6100000	1.36e+08	8e+06
Current response for Cod-Nephrops-Pollack (kg):	264122	269325	220980
Model output response for Cod-Nephrops-Pollack(kg):	148466	1004253	124215
Investigated Min response for Cod-Nephrops-Pollack:	1000	1000	1000
Investigated Max response for Cod-Nephrops-Pollack:	8e+05	7e+06	6e+05
Current fishing costs for Cod-Nephrops-Pollack (SEK/kg):	12	12	12
Current market price for Cod-Nephrops-Pollack (SEK/kg):	13.5	89.5	13.5
Estimated shadow val. biomass Cod-Nephrops-Pollack(SEK/kg):	5	30	5
Estimated Social Benefit (SEK) :	13233802		
Estimated Private Benefit (SEK) :	46911199		

Social Benefit and response vs Enforcement effort plots



Fishery Response vs Social & Private Benefits plots



Once again 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. Optimized effort of control suggests that the current levels are not contributing to the overall social benefit more than if these levels would be lowered 7-fold for landings controls (from 0.068 down to 0.01) and 90-fold for the Administrative controls (from 1.0 to 0.011). [Note: effort is standardized between 0-1; 1 indicating 100% control, 0 absence of control].

Additionally the quite high TACs (6,000 tons) for Nephrops and the high levels of available biomass (136,000 tons) suggest that a higher response, almost 4-fold (1,000 tons), will not contribute negatively to the social benefit, while it will increase private benefit. Once more this is probably an effect of the current market price of Nephrops (89.5 SEK/kg), being 7-times that of the fishing costs (12.0 SEK/kg), and the selected (low?) shadow value of biomass (30 SEK/kg).

Scenario 1

Investigate the following changes in the fishery:

- increase fishing costs by 25% (due to a future fuel price hike)
- increase market price by 20% for cod and pollack-not nephrops (to compensate for rising fishing costs)
- increase of average fine to ~1 SEK/kg for both enforcement types (increasing fishing cost will amplify the incentives of fishers to infringe)
- Increase the shadow value of biomass to the level of market price
- Lower Nephrops TAC to 1,000 tons

FISHERY: Demersal trawlers

AREA: Swedish western coast - Kattegat-Skagerrak - ICES 27 IIIa

PERIOD: 2009-2011

Number of Enforcement types : 2

Names of Enforcement types : Admin. Controls - Landing Controls

Number of Stocks: 3

Names of Stocks: COD NEP POK

Current enforcement effort by enf. type (stand. 0-1): 1 0.068

Investigated Min enforcement effort by enf. type : 0.01 0.01

Investigated Max enforcement effort by enf. type : 1 1

Optimized enforcement effort by enf. type (stand. 0-1): 0.577 0.01

Enforc. costs in current effort by enf. type (SEK/year): 143898 4664256

Optimized total costs of enforc. by enforc. type (SEK): 83132 685920

Probability of violation by enforcement type: 0.8664 0.0311

Fine levels for violations by enforcement type (SEK/kg): 0.8 0.8

Current TAC for Cod-Nephrops-Pollack(kg): 6e+05 1e+06 8e+06

Current biomass for Cod-Nephrops-Pollack (kg): 6100000 1.36e+08 8e+06

Current response for Cod-Nephrops-Pollack (land/kg): 264122 269325 220980

Model response for Cod-Nephrops-Pollack (land/kg): 1433477 797040 123616

Investigated Min response for Cod-Neph.-Pollack (land/kg): 1000 1000 1000

Investigated Max response for Cod-Neph.-Pollack (land/kg): 8e+05 7e+06 6e+05

Current fishing costs for Cod-Nephrops-Pollack (SEK/kg): 15 15 15

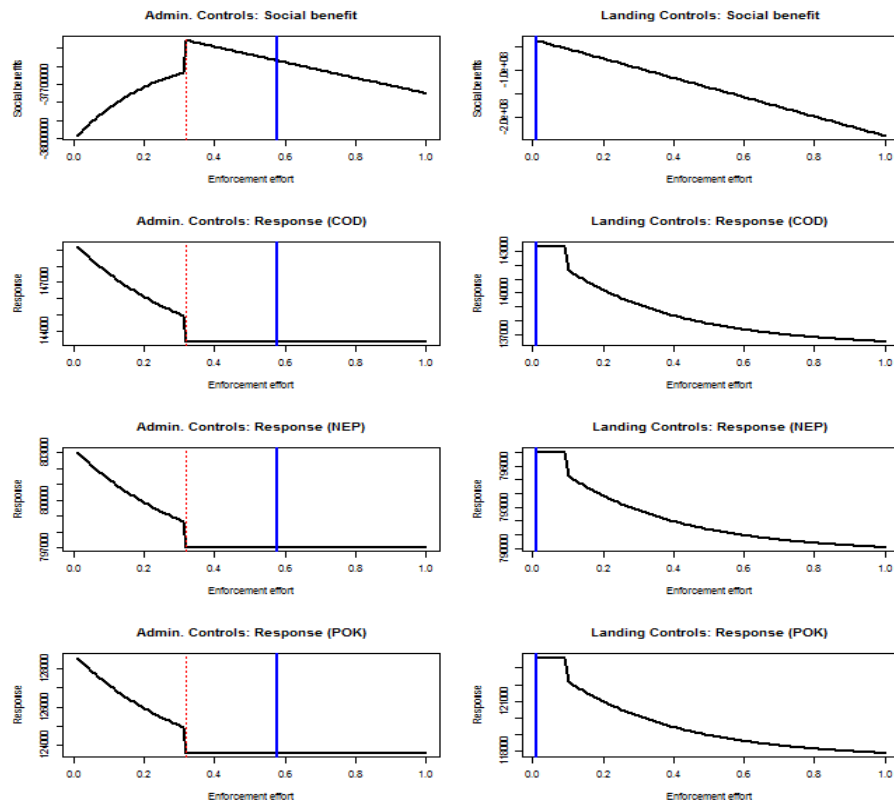
Current market price of landings for Cod-Neph.-Pollack (SEK/kg): 17 89.5 17.5

Estimated shadow value of biomass for Cod-Neph.-Pollack (SEK/kg): 13 88 13

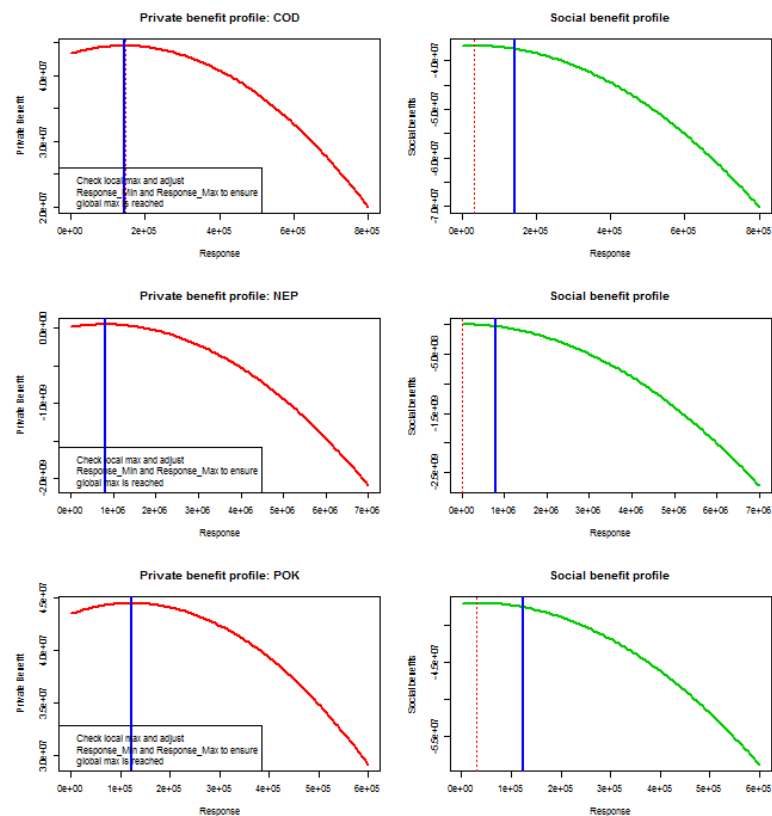
Estimated Social Benefit (SEK) : **-37567574**

Estimated Private Benefit (SEK) : **44478571**

Social Benefit and response vs Enforcement effort plots



Fishery Response vs Social & Private Benefits plots



In this scenario, (fuel price increase, market price increase, fine increase to >1 SEK/kg, shadow value of biomass ~ market value, lower Nephrops TAC) the suggested optimal enforcement levels are lower than the current ones, 2-fold for administrative controls and 7-fold for the landings control.

Increased fishing costs were compensated by an increase in market price, and fishers relocated their fishing effort and corresponding landings towards Nephrops by reducing cod and pollack landings by circa 50% and doubling Nephrops landings, however keeping it still lower than the TAC. As a result the private benefit of the fleet remained more or less unaffected.

Assigning a higher value to the shadow value of biomass resulted in a great loss in social benefit, indicating that a valuable future resource was harvested for the sake of an ephemeral private benefit. The increase of enforcement effort costs had an insignificant contribution to the overall negative social benefit.

4. Conclusions

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.

In this study, 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 selected fisheries.

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. 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.

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. The latter was the case for both case studies analysed herein and it was obvious that the current level of overall fines imposed is low. This can be attributed to: (i) the low average fine per violation; (ii) the high compliance, resulting in few violations detected or (iii) the very low efficiency of control means.

Some criticism

Simulations outcomes 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.

Epilogue

One of the deliverables of the project has been the production of a fully functioning software. This open source user friendly software allows the user to investigate the costs and the benefits of enforcement tools of various 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.

As shown in practice, it can be implemented in the following ways:

- as a learning/training tool for fisheries enforcement and control agencies that need better understanding of the principles of efficient enforcement;
- as a rough design tool for exploring better enforcement systems;
- as a guidance for budgeting decisions to argue for increased enforcement budgets on the basis of cost efficiency.

References

European Commission, 2012. COUNCIL REGULATION (EU) No 1088/2012 of 20 November 2012 fixing for 2013 the fishing opportunities for certain fish stocks and groups of fish stocks applicable in the Baltic Sea.

ICES, 2012. Report of the Working Group on the Assessment of Demersal Stocks in the North Sea and Skagerrak (WGNSSK), 27 April - 3 May 2012, ICES Headquarters, Copenhagen. ICES CM 2012/ACOM: 13. 1346 pp.

R Core Team (2013). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL <http://www.R-project.org/>

RStudio (2013). RStudio: Integrated development environment for R (Version 0.97.318) [Computer software]. Boston, MA. Retrieved Nov 20, 2013. Available from <http://www.rstudio.org/>

European Commission

EUR 26406 – Joint Research Centre – Institute for the Protection and Security of the Citizen

Title: Swedish COBECOS Pilot Study. Costs and Benefits of Control Strategies in selected Swedish fisheries. Final Report

Author(s): Jenny Nord, Malin Hultgren (SwAM); Jann Martinsohn, Dimitrios Damalas (JRC)

Luxembourg: Publications Office of the European Union

2013 – 75 pp. – 21.0 x 29.7 cm

EUR – Scientific and Technical Research series – JRC87034

ISSN: 1831-9424

ISBN: 978-92-79-35002-3

Catalogue Number: LB-NA-26406-EN-N

DOI : 10.2788/51025

As the Commission's in-house science service, the Joint Research Centre's mission is to provide EU policies with independent, evidence-based scientific and technical support throughout the whole policy cycle. Working in close cooperation with policy Directorates-General, the JRC addresses key societal challenges while stimulating innovation through developing new standards, methods and tools, and sharing and transferring its know-how to the Member States and international community.