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Economic Indicators for a Marine Ecosystem

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1 Introduction

The aims of Defineit is to produce tools necessary to determine the economically optimal level of exploitation of European marine ecosystems, while ensuring that the pressure exerted on the stocks is biologically sustainable (Definiet, 2009, p. 5). An aim of the project is therefore to develop resource indicators by combine for example economic and biology into indicators that relates directly to the benefit of the society (Definiet, 2009, p. 6). The objective of this paper is develop indicators for use in responsive management as tool for improving the benefit the marine ecosystem provide society. Other work package in the project will produce ecosystem and multi-species models, while cost and price information is collected as an other task. Present report therefore depart from the existence of a biological model as well as net price information, based hereupon indicators suitable for responsive management are developed.

Many previous developed economic indicators for fishing focus on the output and efficiency of the fleet (e.g. Accadia and Spagnolo, 2006; Hoff et al., 2009). In this paper a different approach is taken: We focus on the marine ecosystem as a capital and ask: "Is this capital of the right composition and size?" Tradition has that capital theoretic approaches shall find the optimal composition and size of the system, and the control path to this, that is: how to get there (e.g. Clark and Munro, 1975). As we in this paper is only try to improve the capital, the ambition is more modest than optimal control. However, it is the idea to develop indicators useful in a world where management decision is made through negotiations with many stake holders, the knowledge of the ecosystem is updated regularly and the decision makers time horizon is limited. Therefore it is indicators that test if the state of the ecosystem can be improved, from an economic point of view, that has focus in present work. The key stone for the indicators will be the value of the ecosystem. The value in it self is not of any special interest, it is the potential improvement in value created by management decisions that is of interests. In section 2 a method to calculate the value of the ecosystem is developed, and test in a simple model by letting a management taking decision on yearly basis. In section 3 the value of ecosystem is used to develop indicators that describe the state of the ecosystem, and therefore implicit evaluates the past management that created present state. The indicators can, however, be used to improve the management as well, as they specific point to where improvement can be made. Finally, in section

4, a retrospective indicator is developed, an indicator that can evaluate, for example, last years management as a whole.

2 Value of ecosystem

In the following it is expected that there exits a model of the ecosystem able to predict the future amount of fish given a fishery. The fish in the model are stratified into for example spices, size or age. The strata are numbered with i and the stock of fish is a vector $\boldsymbol{x}$ with element x_i. The removable from the sea, harvest and discard, is y_i collected in the vector $\boldsymbol{y}$. The ecosystem model can then be described as

$$\frac{\mathrm{d}x_i}{\mathrm{d}t} = f_i(\boldsymbol{x}, \ldots) - y_i \tag{1}$$

where $f_i(\boldsymbol{x}, \ldots)$ is the predicted growth and "$\ldots$" represents external factors, that will be disregarded below.

The first indicator to be considered is the value of the ecosystem. The value of the ecosystem is not of any interest by it self (unless the ecosystem is up for sale), however, if a set of different management actions is available and have to be compared, the execution of each actions will lead to different expected state of the ecosystem. To value the different management actions, the difference in the value of the final states of the ecosystem has to be accounted for; to do this there is a need for valuation of the ecosystem. The purpose of the valuation of the ecosystem is then to tell the difference in value between state of the ecosystem relative close to each other in the space of $\boldsymbol{x}$.

Valuation of natural resources was formalized by Faustmann (1849) and (in modern continues notation) defined as:

$$\mathbb{C} = \int_0^\infty \mathrm{e}^{-\delta t} u(t)\, \mathrm{d}t$$

where $u(t)$ is the utility derived from the resource at time t and δ is the discount rate. The integral sums the discounted net benefit from the resource from now into infinity and is then the true value of the resource as a capital, it is therefore referred to as capital value. If it is the capital value from a social point of view, the discount rate δ will be the social discount rate, and u will be the utility for the society.

If the ecosystem is represented by the model (1) the harvest can be written as

$$\boldsymbol{y}(t) = \boldsymbol{f}(\boldsymbol{x}(t)) - \dot{\boldsymbol{x}}(t) \tag{2}$$

If the direct benefit is a function of the harvest, the utility function can be written as

$$u(t) = u(\boldsymbol{x}(t), \dot{\boldsymbol{x}}(t))$$

Formulated like this the utility is a function of the stock $\boldsymbol{x}$ and how the stock will develop in time $\dot{\boldsymbol{x}}$. What management will decide on is how the development in stock $\dot{\boldsymbol{x}}$ has to be. The capital value will then be

$$\mathbb{C} = \int_0^\infty \mathrm{e}^{-\delta t} u(\boldsymbol{x}, \dot{\boldsymbol{x}}) \,\mathrm{d}t \tag{3}$$

In the definition of capital value as written in (3), the capital can develop in all directions and give at lot of different values of capital value. These differences will, however, not value the capital $\boldsymbol{x}$ *per se*, but is rather a valuation of the rules for how $\dot{\boldsymbol{x}}$ shall be set. The situation where $\dot{\boldsymbol{x}} = \mathbf{0}$ is a special situation: Here the capital is constant and the use of the resource is, as natural capital is constant, per definition sustainable in economic sens. In present work the situation of stationery capital, that is $\dot{\boldsymbol{x}} = \mathbf{0}$, is seen as the ideal benchmark for evaluation of the system.

2.1 Stationery Capital

With a situation where capital is constant $\dot{\boldsymbol{x}} = \mathbf{0}$ as benchmark, the system can be examined by a analyze known as Stationery Rate of Return on Capital (Weitzman, 2003). The analyze can examine if it is possibly to make improvements by changing the capital level, where the improvements is measured by the value of capital.

If a small change Δx_i of the capital at strata i is made, the immediate benefit is $\Delta x_i \frac{\partial u(\boldsymbol{x},\mathbf{0})}{\partial \dot{x}_i}$ while the long term consequence can be summaries as $\Delta x_i \left.\frac{\partial \mathbb{C}}{\partial x_i}\right|_{\dot{\boldsymbol{x}}=\mathbf{0}}$. The analyze of stationery capital can then be summarized as the marginal net benefit from a change in x_i

$$\mathbb{B}_i = \frac{\partial u(\boldsymbol{x}, \mathbf{0})}{\partial \dot{x}_i} + \left.\frac{\partial \mathbb{C}}{\partial x_i}\right|_{\dot{\boldsymbol{x}}=\mathbf{0}} \tag{4}$$

If $\mathbb{B}_i$ is positive the value of the marginal harvest fish in strata i is more valuable in the sea as capital compared with harvested, and *vice versa*. If $\mathbb{B}_i = 0$ for all i the system is in a stationery point, in the sense of calculus, that may be optimal. For a interpretation of (4) remember that in the model (1) $\mathrm{d}x_i$ is equivalent with - $\mathrm{d}y_i$ — the harvest y_i has the same decline as the increase in capital $\dot{x}_i$. The first part is then minus the marginal utility of a fish i when harvest, and the second part is the change in capital value if the marginal fish i is left in the sea, under a stationary capital. The last part is then the opportunity value of the fish. If V_i is the marginal net value

$$\mathbb{B}_i = -V_i + \zeta_i \tag{5}$$

$$\text{Where: } \zeta_i = \left. \frac{\partial \mathbb{C}}{\partial x_i} \right|_{\dot{\boldsymbol{x}}=\mathbf{0}} \tag{6}$$

The stationery capital analyze above seems strait forward, however, in many biological models it will not make sens to have constant capital $\dot{\boldsymbol{x}} = \mathbf{0}$ because there will be some growth $f_i(\boldsymbol{x})$ where it is not reasonable to harvest. This may be because the size of the fish is to small, because it is not a commercial fished species, or it may not be profitable to fish it. This can be summarized in the social net value V_i being negative. To apply an analyze, equivalent to the stationery capital analyze, to models where it is not economic reasonable to fish on all strata, the concept of stationery capital has to be approximated with a pseudo stationery capital, that is, at situation as closes to a static system that is economical reasonable. Economic reasonable will be only to exploit fish from strata with positive net value: Only if $V_i \geq 0$ is the strata i exploited. The pseudo stationery capital is then defined as a situation where

$$i \text{ under exploitation} \Longrightarrow \frac{\mathrm{d}x_i}{\mathrm{d}t} = 0$$

alternatively the pseudo steady capital is defined as

$$y_i = \begin{cases} f_i(\boldsymbol{x}) & \text{if } V_i \geq 0 \\ 0 & \text{else} \end{cases} \tag{7}$$

The value of the ecosystem can then be defined as:

$$\mathbb{C} = \left. \int_0^\infty u(t)\, \mathrm{e}^{-\delta t}\, \mathrm{d}t \right|_{\frac{\mathrm{d}x_i}{\mathrm{d}t} = 0\ \forall\ i \text{ under exploitation}} \tag{8}$$

This paper first examines if this definition of capital value of the ecosystem under a pseudo stationery capital can be used as guardian to improve the capital level, and what kind of indicators can be developed base on this definition.

The stationery capital analyze is not an optimization tool, the analyze examines if improvement can be made given the new state is stationery as well. This may lead to a optimal capital level if all strata has a $\mathbb{B}_i = 0$. However, if optimum is not with stationery capital, it will not be examined and found by the analyze. Further a state where $\mathbb{B} = \mathbf{0}$ is only a indication of a stationery situation, it may be a saddle point, a local minimum or a local maximum. The situation of local minimum or saddle points can be identified and avoided by examine points in the space close to $\boldsymbol{x}$, however, a local maximum can be hard too identify as not a global maximum.

An alternative to stationery capital analyze is optimal control analyze. Here the optimal $\dot{\boldsymbol{x}}(t)$ is found from now into infinity. The analyze can be highly complicated and solution for more complicated system as three coupled differential equations (Flaaten, 1988) and in single species cohort model (Botsford, 1981; Tahvonen, 2009) is not accomplished. The models used in the Defineit project, multi-species cohort model and multi-species sized based models, are at present beyond the capacity of the methods to solve the optimal control problem. Further, the validity of the biological and economic models is confined to subset of state space where data is available; but optimal control path can only be found in models where the validity of the model can be expected in the entire state space. If the model available do not have the global validity, adaptive management by gradually improving the capital level with in the validity of the models may be the best option.

2.2 Responsive Management and Test

To test if the definition (8) can be used to improve the capital level and in the end achieve economical optimal exploitation, the definition (8) is in this section tested in a responsive management. The management have a limited time horizon of one year, that is, the responsive management will set the harvest for only one year at a time. The harvest will be set by maximizing the present value of next years harvest plus the value of the

Table 1: Parameters in the test model. After Ragozin and Brown (1985)

Parameter	Value	Unit
a	0.36	year^{-1}
b	0.88×10^{-8}	$\text{ton}^{-1}\text{year}^{-1}$
c	0.35	year^{-1}
d	0.35×10^{-8}	$\text{ton}^{-1}\text{year}^{-1}$
α	0.35×10^{-8}	$\text{ton}^{-1}\text{year}^{-1}$
β	0.12×10^{-8}	$\text{ton}^{-1}\text{year}^{-1}$
δ	0.05	year^{-1}
p	1	$\$\,\text{ton}^{-1}$
q	10^7	\$

system at the end of the year:

$$\begin{aligned} \text{Objective: } & \max_{\boldsymbol{y}} \left(\int_0^1 \boldsymbol{y} \cdot \boldsymbol{V} \, \mathrm{e}^{-\delta t} \, \mathrm{d}t + \mathrm{e}^{-\delta} \mathbb{C}_1 \right) \\ \text{st: } & \boldsymbol{x}(0) = \boldsymbol{x}_0 \\ & \frac{\mathrm{d}x_i}{\mathrm{d}t} = f_i(\boldsymbol{x}, \ldots) - y_i \end{aligned} \tag{9}$$

where $\mathbb{C}_1$ is the value of the system at year 1 calculated by (8)

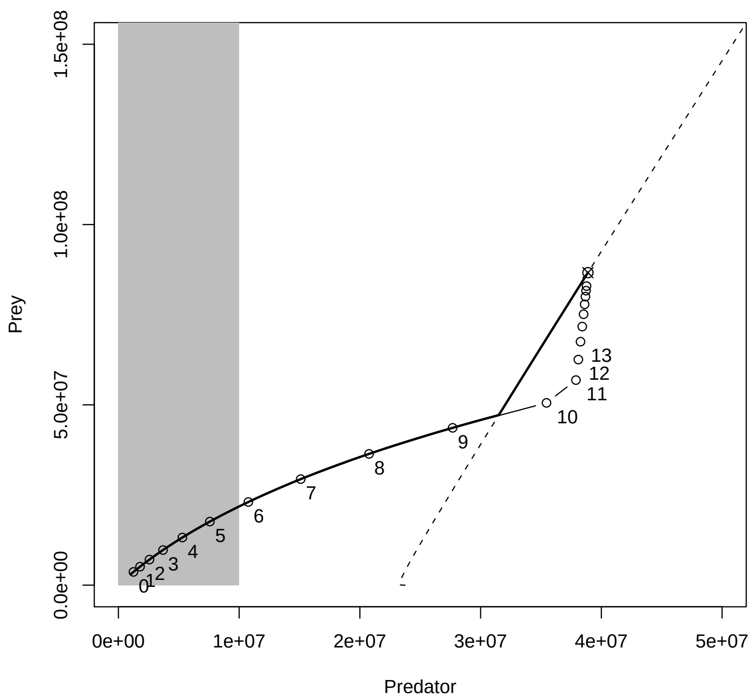
The benchmark when testing the responsive management is Optimal Control Theory (Clark and Munro, 1975). The responsive management is therefore applied to a model where the optimal path is known and the results can be compared. A predator–prey model of the Lotka–Volterra type is used.

$$\begin{aligned} f_1 &= x_1 \left(a - b x_1 + \alpha x_2 \right) \\ f_2 &= x_2 \left(c - d x_1 - \beta x_2 \right) \end{aligned}$$

The predator stock is x_1 and the prey stock is x_2. If there is fishery on both species this type of model is relative simple, however, if the fishery is limited to the predator

$$\boldsymbol{y} = \begin{pmatrix} y_1 \\ 0 \end{pmatrix}$$

Figure 1: Predator prey diagram. The diagram gives the optimal state of the predator and prey system with the point $\otimes$. The dash line indicates the singular path according to the optimal control; to the left of the line the optimal control is zero harvest and to right it is maximum possibly harvest. The bold line indicates a optimal control path from the point marked 0 towards the $\otimes$ point. The line and points marked with numbers indicates the path of a responsive management only looking one year ahead. The numbers indicates years. The gray area indicates where the net value of the predator is negative.



the model poses a lag effect because only x_1 can be kept constant in the calculations in (8). The net value function is:

$$\boldsymbol{V} = \begin{pmatrix} p - \frac{q}{x_1} \\ 0 \end{pmatrix} \tag{10}$$

The model and parameters follows Ragozin and Brown (1985) and are given in Table 1. Ragozin and Brown solved the optimal control problem and discuss the value of the not commercial prey in form of the shadow price. With this formulation of the value function (10), the optimal control solution is a bang-bang solution: Only along a singular path the harvest has to be differentiated. To the left of the singular path (that is for smaller x_1) the optimal control is $y_1 = 0$ and to the right of the singular path the optimal harvest is the maximum possibly with the available fishing capital. Bellow a discount rate at $\delta = 0.05$, as used in Ragozin and Brown (1985), is adopted. This is only for compare with Ragozin and Brown's calculations, not a general acceptance of this rate.

The system has with a social discount rate $\delta = 0.05$ the optimal stock state of $\boldsymbol{x} = (38\,888\,146, 86\,666\,922)$ as the $\otimes$ point in the Figure 1 and the singular path as the dash line. To the left of this line the optimal control is $y_1 = 0$ and to the right the harvest shall be maximum with the available fishing capital. The point of departure for the benchmark is a point with very low stock $\boldsymbol{x} = (1\,040\,370, 3\,101\,652)$. Form this point the optimal approach is $y_1 = 0$ for around $9\frac{1}{2}$ years as illustrated by the bold line in Figure 1, and then along the singular path towards the $\otimes$ point.

When successive applying the responsive method for one year at a time, the responsive management will follow the line with $\circ$ points in Figure 1. The points indicate the start of a year and the numbers give the time in years.

In the diagram it is seen that responsive management with one year planing of harvest follows the optimal path for the nine first years. In these nine years neither of the approaches will harvest. After the zero harvest period the responsive management is, compared with the optimal path, a little to slow to pick up the fishery. But, after year 12 the responsive management follows a path directly approaching the optimal point $\otimes$. The net present value of the responsive management is 97% of the net present value of the optimal path.

In the Table 2 the first 25 years of the responsive management is summarized. The first column indicate the year where management decide on

Table 2: Data from the responsive management. First column is the time in years, second column indicates if net value of a harvest is positive, third column gives the responsive management harvest relative to the sustainable harvest. Column 4–6 gives indicators of the state of the system under the assumption of sustainable yield; fourth column gives the net social benefit, fifth column gives the implicit discount rate and the sixth gives the indicator rate w. When net value is negative the implicit discount rate and w is not defined hence a — is given in the columns.

year	$V_1 > 0$	y_1/f_1	$\mathbb{B}_1$	ρ_1	w_1
0	FALSE	0.0000	20.1753	—	—
1	FALSE	0.0000	17.7409	—	—
2	FALSE	0.0000	15.9564	—	—
3	FALSE	0.0000	14.5563	—	—
4	FALSE	0.0000	13.3260	—	—
5	FALSE	0.0000	12.0783	—	—
6	TRUE	0.0000	10.6407	4.8371	7.5590
7	TRUE	0.0000	8.8588	0.9199	1.3613
8	TRUE	0.0000	6.6251	0.4913	0.6891
9	TRUE	0.0000	3.9317	0.2693	0.3578
10	TRUE	0.6959	0.9194	0.0965	0.1140
11	TRUE	0.9767	0.0406	0.0521	0.0528
12	TRUE	0.9806	0.0408	0.0523	0.0528
13	TRUE	0.9855	0.0335	0.0520	0.0523
14	TRUE	0.9892	0.0273	0.0517	0.0518
15	TRUE	0.9920	0.0221	0.0515	0.0515
16	TRUE	0.9941	0.0180	0.0512	0.0512
17	TRUE	0.9956	0.0147	0.0510	0.0510
18	TRUE	0.9968	0.0121	0.0508	0.0508
19	TRUE	0.9976	0.0102	0.0508	0.0507
20	TRUE	0.9982	0.0087	0.0507	0.0506
21	TRUE	0.9987	0.0076	0.0506	0.0505
22	TRUE	0.9990	0.0068	0.0505	0.0505
23	TRUE	0.9993	0.0061	0.0505	0.0504
24	TRUE	0.9995	0.0057	0.0504	0.0504

next years harvest. Next column indicates if the net value of fishery is positive. If this is FALSE there is no need to do more calculation, any fishery will yield negative rent. If it is positive the objective 9 is maximized and in the third column the ratio between next years harvest and the $f_1(\boldsymbol{x})$ is given. The harvest is 0 until year 10 where there is a harvest of 70% of f_1. Next year the harvest is increased to 98% of f_1 and thereafter slowly increasing, however, the stock of x_1 continues to increase as all ratio y_1/f_1 is below 1. The three next columns are discussed in later section.

2.3 Discussion

The above test of using (8) for valuing the ecosystem illustrate the usefulness of the concept capital value under a pseudo stationery capital. The consequences of a management action, here deciding on next years harvest, can easily be done in a relative simple manner. The other alternative will be to use the net present value given a optimal control path in the future. The later have three problems: 1) The biological models may not be solvable by optimal control method, 2) it implicit assumes a commitment from management to plan into infinity and follow the optimal control path, and 3) the net present value of the optimal path is partly valuing the control path that there is no commitment for (point 2). The definition of the capital value used here assumes only a commitment of sustainability, and values the state of the system as it is.

The test is preformed on a relative simple model. The difference in present value of around 3% is acceptable and probably far below the error originating from the dispersion in the biological and economic model. The test show that the pseudo stationery capital valuation do not lead to substantial lose in present value and therefore acceptable, however, this only apply for the specific model. The cost function used above is linear, leading to the bang-bang solution of the optimal path. A more realistic cost function can be used with some modification in the definition of pseudo stationery capital (7). With increasing marginal harvest cost, the rule will be either to harvest as much as is profitable or f_i, which ever is smallest:

$$y_i = \max\left(0, \min\left(f_i(\boldsymbol{x}),\, y_i|_{V_i(y_i)=0}\right)\right)$$

3 Ecosystem State Indicators

With background in the definition (8) of the value of the ecosystem under pseudo stationery capital, indicators that test the state of single strata i are developed in the following paragraphs. The basic idea is that it is the state of each strata that is valuated, and the indicators examines if this state can be improvement.

3.1 Net social benefit

The first indicator to be discussed is the net social benefit of increasing the capital x_i, already defined in (5). The only difference difference from (5) is that the opportunity cost is measured as the partial deviate of the capital value under a pseudo stationery capital

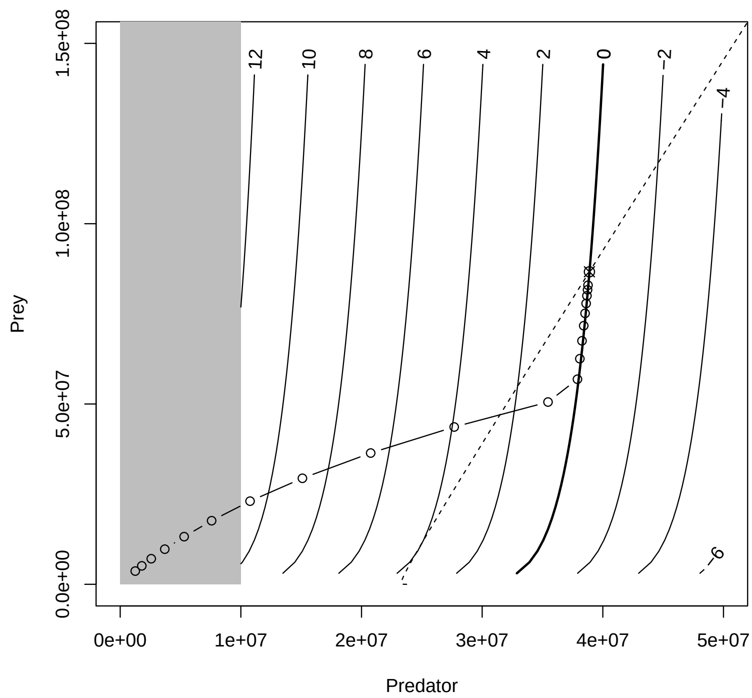
$$\mathbb{B}_i = \zeta_i - V_i \tag{11}$$

$$\text{Where: } \zeta_i = \frac{\partial \mathbb{C}}{\partial x_i} \tag{12}$$

$$\text{and } \mathbb{C} \text{ is mesured by (8)} \tag{13}$$

In Table (2) the fourth column marked $\mathbb{B}_1$ indicates the marginal net social benefit of increasing the stock of x_i. The values are all positive, indicating that the harvest has to be lower than growth f_1. The values are, compared with the price of 1, large in the start, decreasing around year 10 to small values, corresponding to when the fishery starts. The $\mathbb{B}$ is not confined to be calculate along a specific path, but can be calculated for the entire space of possibly states of $\boldsymbol{x}$. I Figure 2 $\mathbb{B}_1$ is given for the predator prey space. As the 0 contour line is not following the optimal path in the figure (the dash line), the figure illustrates the difference between optimal control where a path is found, and the responsive management based on the pseudo stationery capital approach, where only improvement in the capital level is sought. However policies based on the $\mathbb{B}_1$ in the figure will lead towards better utilization of the resource, and in this case towards the global optimum.

Figure 2: $\mathbb{B}_1$ contours i the state space. The bold line is the $\mathbb{B}_1 = 0$ contour, to the right of the zero contour $\mathbb{B}_1$ is negative $-2, -4, -6, \ldots$ and to the left positive $2, 4, 6$.



3.2 Implicit discount rate

The marginal net social benefit indicates by it's sign whether x_i should be increased or decreased, however, the magnitude of $\mathbb{B}_1$ may be of little interest as it depends on the specific net price of fish in the strata. Here the return on the investment of a marginal increase of x_i may be more appropriated. The rate of return on an investment is the discount rate that make the investment decision indifferent. In a social context that is when net social benefit is zero. The rate of return can then be found as:

$$\rho_i = \rho \Big|_{\mathbb{B}_i(\rho) = 0}$$

In the calculation of $\mathbb{B}_i$ only the calculation of opportunity cost involves discounting so

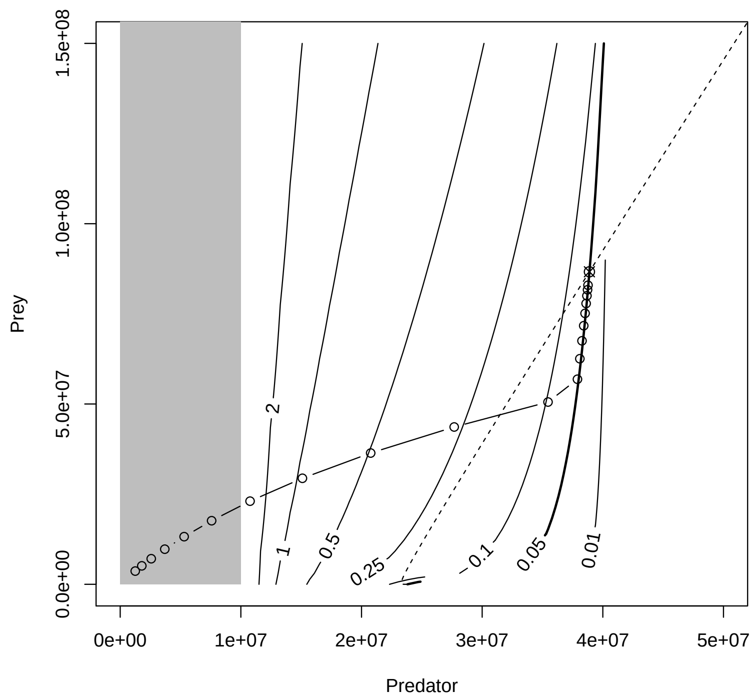
$$\begin{aligned} \rho_i &= \rho \Big|_{\zeta_i(\rho) = V_i} \\ &= \rho \Big|_{\frac{\partial \int_0^\infty u(t)\, \mathrm{e}^{-\rho t}\, \mathrm{d}t}{\partial x_i} = V_i} \end{aligned} \tag{14}$$

As the state of the ecosystem is a result of previous management actions, the rate of return ρ_i reveals the implicit time preference of the managers. It can then also be perceived as the implicit discount rate. The implicit discount rate is not defined if the signs of ζ_i and V_i are not the same or one is zero, this can happen in an under utilized system where ζ_i can be negative for all ρ, in a subsidized system where V_i can be negative, or in the case where y_i is discarded. In the discard case V_i can be zero, but may be positive due to reduced cost of catching the target fish. If the implicit discount rate is compared with the social discount rate the following rule can be applied

If	$\zeta_i < 0$	Decrease x_i
If	$\rho_i < \delta$	Decrease x_i
If	$\rho_i > \delta$	Increase x_i
If	$V_i \leq 0$	Increase x_i

In Table 2 the fifth column marked ρ_1 indicates the implicit discount rate of removing one fish more than keeping the stock constant. The values are not defined when the net value is negative. After year 6, when the net prise gets positive, values are all higher than the social discount rate. This indicating that investment in the resource is a good idea, that is, harvest has to be lower than growth. The implicit discount rates are, compared with the used social discount rate, large in the start and decreasing around year 10 to values comparable with social discount rate. The implicit discount rate is not confined calculated to a specific path but can be calculated for the entire space of possibly states of $\boldsymbol{x}$. I Figure 3 the implicit discount rate is given for the predator prey space. As the 0.05 contour line is not following the optimal path in the figure (the dash line), the figure illustrates the difference between optimal control where a path is found, and the pseudo stationery

Figure 3: Implicit discount rate contour in state space. The bold line indicates $\rho = 0.05$, to the right is a 0.01 contour and to the left $0.1, 0.25, 0.5, 1$ and 2 contours.



capital approach, where improvement in the capital level is sought. The 0.05 contour line corresponds to the $\mathbb{B}_1 = 0$ line in Figure 2.

3.3 Indicator rate

If it was possibly to have a total stationery capital, the capital value can be reduced to

$$\begin{aligned} \mathbb{C} &= \int_0^\infty \mathrm{e}^{-\delta t} u(\boldsymbol{x}, \mathbf{0}) \, \mathrm{d}t \\ &= \delta^{-1} u(\boldsymbol{x}, \mathbf{0}) \end{aligned}$$

The shadow price can then be found as

$$\zeta_i = \frac{\partial \mathbb{C}}{\partial x_i} = \delta^{-1} \frac{\partial u(\boldsymbol{x}, \mathbf{0})}{\partial x_i}$$

The rate of return defined in (14) is then

$$\begin{aligned} \rho_i &= \frac{\frac{\partial u(\boldsymbol{x}, \mathbf{0})}{\partial x_i}}{V_i} \\ &= \delta \frac{\zeta_i}{V_i} \end{aligned}$$

The implicit discount rate found in this way is only valid for a true stationery capital. With a pseudo stationery capital the same approach can be used to make an approximation for the implicit discount rate referred to as an indicator rate

$$w_i = \delta \frac{\zeta_i}{V_i}$$

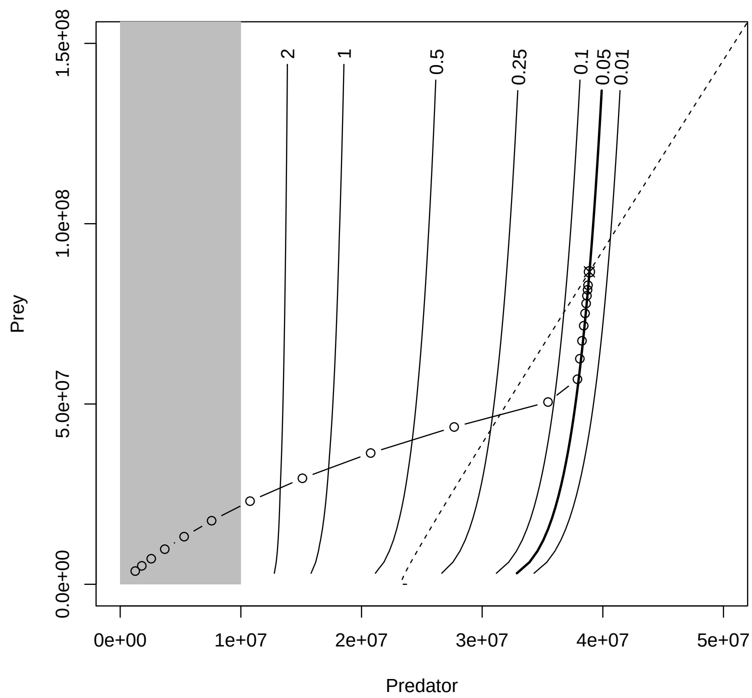
This indicator rate will give an approximation of the return on a investment by increasing stock i.

In Table 2 the sixth column marked w_1 gives the the indicator rate. The values are all comparable to the implicit discount rate, especially when close to the social discount rate. I Figure 3 the implicit discount rate is given for the predator prey space. The figure shows that the contours have the shape of the $\mathbb{B}_1$ in Figure 2. The indicator rate is actually the shadow price scaled relative to the net value and scaled according to the discount rate. Thus the indicator rate w gives the same information as the $\mathbb{B}$ but scaled to gives values that can be interpreted as approximation of implicit discount rates.

3.4 Discussion of state indicators

The value of the shadow price, an hence the $\mathbb{B}$, as defined in present paper, is not the same as the values found in optimal control theory. For example, at start of year 7, the opportunity value of predator $\zeta_1 = 9.20$ and of prey $\zeta_2 = 0.14$ while the shadow value found in optimal control theory is $\lambda_1 = 0.70$ and $\lambda_2 = 0.57$. This difference is because the optimal control

Figure 4: Indicator rate contours in state space. The bold line indicates $\rho = 0.05$, to the right is a 0.01 contour and to the left $0.1, 0.25, 0.5, 1$ and 2 contours.



has a commitment from the management to follow optimal path in the future, while the opportunity values have a commitment of pseudo stationery capital. Thus the opportunity cost ζ calculated as in (11) gives the improvement of the capitalized rent if the stock is increased with one more ton, given a pseudo stationery capital. The shadow value λ gives the value of one more ton given an optimal control in the future. Hence, like the the net present value, the λ is partly valuing future control. If management do not have the commitment of optimal control, there seems to be little reason to expect that in the calculations, if management, on the other hand, do have a commitment for the future management, this can be incorporated in the model and typically shadow prices will be smaller if management do have a long-term commitment of improving net benefit.

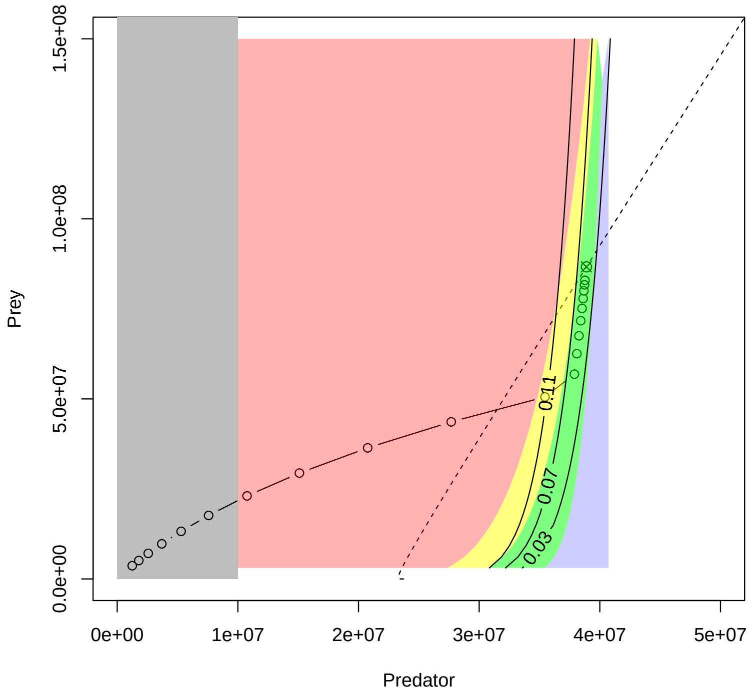
The developed indicators is indicators for the state of the ecosystem as a capital. They indicate if the value of the system can be improved. As such they do only indicate if next years harvest ought to be above, at, or below the sustainable harvest. There is a tradition of developing indicators into traffic signals: if they are good they are green, if they are bad they are red, if they are yellow they are approaching the good. The marginal net social benefit $\mathbb{B}$ is not good for traffic signal, because the magnitude of the $\mathbb{B}$ is depending on the value of the fish. The implicit discount rate ρ is better as it can be compared with the social discount rate δ directly. In Figure 5 the state space is green between implicit discount rate 0.03 $\text{year}^{-1}$and 0.07 year^{-1}, yellow between implicit discount rate 0.07 $\text{year}^{-1}$and 0.11 year^{-1}, and red above 0.11 year^{-1}. In the model used here it seems that a harvest of zero in the red zone, a harvest of around 50% of sustainable harvest in the yellow zone and close to sustainable harvest in the green zone is appropriate.

The implicit discount rate involves root finding and the indicator rate w is introduced to ease calculations. If the Table 2 is examined the implicit discount rate and w are very close, especially when approaching the social discount rate. In Figure 5 the contours of w is drawn for the same value as used for the implicit discount rate: 0.03, 0.07 and 0.11. As the figure illustrates the w is a very good approximation for ρ.

4 Retrospective indicators

As the valuation method in (8) can be used for planing, it can as well be used for retrospective evaluation of management of, for example, the last year. To set up accounting for the year both income, change in capital and opportunity cost of capital has to be included. The actual net rent to society is $\mathbf{V} \cdot \mathbf{y}$, and the value of the ecosystem have changed from $\mathbb{C}_{-1}$ to $\mathbb{C}_0$. The opportunity cost of the capital value $\mathbb{C}_{-1}$ is expected return if used in other part of the society, that is $\delta\mathbb{C}_{-1}$. This is also the value of the output from the ecosystem that can be expected if the ecosystem is unchanged between the periods. Both the net income and the opportunity cost of capital are flows and have to be integrated and discounted to get

Figure 5: Traffic light system applied to the implicit discount rate. The state space is colored green with $\rho \in [0.01, 0.07]$, yellow for $\rho \in [0.07, 0.11]$ and red for $\rho > 0.11$, corresponding to a social discount rate $\delta = 0.05$, The black line are indicator rate w contours for $0.01, 0.07$ and 0.11



the result of the year:

$$\begin{aligned}\Pi &= \int_{-1}^{0} \mathrm{e}^{-\delta t} \left(\mathbf{V} \cdot \mathbf{y} - \delta \mathbb{C}_{-1}\right) \mathrm{d}t + \mathbb{C}_0 - \mathbb{C}_{-1} \\ &= \int_{-1}^{0} \mathrm{e}^{-\delta t} \mathbf{V} \cdot \mathbf{y} \, \mathrm{d}t + \mathbb{C}_0 - \mathrm{e}^{\delta} \mathbb{C}_{-1}\end{aligned}$$

This result Π evaluates if there is generated extra welfare from the resource or the resource is used for shortsighted purpose. The result can always be done better and as compare the optimal harvest patten for last year can be found:

$$\begin{aligned}\overset{\star}{\boldsymbol{y}} &= \underset{\boldsymbol{y}}{\operatorname{argmax}} \int_{-1}^{0} \mathrm{e}^{-\delta t}\mathbf{V}\cdot\mathbf{y}\,\mathrm{d}t + \mathbb{C}_{0|\boldsymbol{y}} \\ \text{st: } & \boldsymbol{x}(-1) = \boldsymbol{x}_{-1} \\ & \frac{\mathrm{d}x_i}{\mathrm{d}t} = f_i(\boldsymbol{x},\ldots) - y_i\end{aligned}$$

And the optimal result of the year can be found as

$$\overset{\star}{\Pi} = \int_{-1}^{0} \mathrm{e}^{-\delta t}\mathbf{V}\cdot\overset{\star}{\boldsymbol{y}}\,\mathrm{d}t + \mathbb{C}_{0|\overset{\star}{\boldsymbol{y}}} - \mathrm{e}^{\delta}\mathbb{C}_{-1}$$

The difference between the two will indicate a forgone earning to society

$$\text{Forgone earning} = \overset{\star}{\Pi} - \Pi$$

It will be impossibly to archive zero in forgone earning, but a large value will indicate a mall preforming management.

The ratio between the two results

$$\pi = \frac{\Pi}{\overset{\star}{\Pi}}$$

may be a better indicator of the preforms of the management the last year. It will be impossibly to archive 100%, and how good it is possibly to preform is dependent on the accuracy of the models and other available information. I will until tested in models and management suggest:

Green	if	$\pi > 75\%$
Yellow	if	$75\% > \pi > 50\%$
Red	if	$50\% > \pi$

5 Conclusion

Valuing the marine ecosystem under a pseudo stationery capital (8) gives the possibility for responsive management, for example, in cases where the validity of the biological and economic model is confined to a subset of state space. The responsive management can also be is also be useful if the time horizon of the managers is limited, as illustrated in section 2.2.

As the indicators $\mathbb{B}_i$, ρ_i and w_i evaluates the state of the system, they implicit evaluates the management that created this state. If an overall indicator of management is needed an retrospective indicator is suggested: The preferment indicator π. π gives the ration between the actual result and the the result under best management.

In this report a simple model has been used for tests. This, however, proves not the appropriateness in real world situations. For this the method has to be applied to the complex model of the real world. It is the authors' hope that these indicators can be shown useful and be included in ICES' stock assessment reports and in STECF's impact analyse.

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