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Methods for Environmental and Economic Accounting for the Exploitation of Wild Fish Stocks and Their Applications to the Case of Icelandic Fisheries

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Abstract. The paper discusses methods for estimating the value of commercially exploited fish stocks and the cost of exploiting them. Methods which are recommended in the System of National Accounting (SNA) satellite system and the System for Integrated Environmental and Economic Accounting (SEEA) and relevant for this task are discussed. The paper questions the relevance of some of these methods. It argues for the integration of economic accounting for wild fish stocks with estimation of efficient management of them. Using biological and economic data makes it possible to produce consistent estimates of the value of fish stocks and the cost of exploiting them. These estimates are useful for national accounting and for guiding management of fisheries. This method allows estimation of the cost of inefficiency of fisheries management besides estimation of the cost of depletion. The different methods are illustrated using data on commercial fisheries in Iceland and the fish stocks that they exploit. It is shown that even if all methods are based on market valuation and use only objective data they lead to very different outcomes.

Key words: commercial fisheries, cost of exploitation, environmental national accounting, Icelandic fisheries, value of fish stocks

JEL classifications: M41, Q20, Q22

1. Introduction

Until recently the System of National Accounting (SNA), which is used for compiling the national accounts in most countries, recommended that changes in the volume and the value of natural assets, such as wild fish stocks, should be excluded from the accounts. In the case of wild fish stocks there were two main reasons. Firstly, nobody really controlled the exploitation of wild fish stocks; and secondly, biological knowledge of these stocks used to be quite limited. There are still cases where both reasons are valid. However, for many fish stocks, neither is valid today.

The UN Conference on Environment and Development held in Rio de Janeiro in 1992 recognised the need to include environmental assets in the national accounts and recommended that this should be done in all member states at the earliest date.[1] The revised version of the SNA, which was adopted in 1993, has a section on integrated environmental-economic satellite accounts. In these accounts expenditures that are directly related to environmental protection activities (e.g. expenditures aimed at reducing harmful effects of emissions and waste from industries and the cost of managing environmental protection) should be included. These costs do not result in additional goods or services but merely prevent deterioration of the environment and a decrease in the well being of people. They should therefore be treated as intermediary goods and subtracted from the estimated value of production of relevant industries.[2]

System of National Accounting 1993 also introduces refinements into the cost, capital and valuation concepts of the central framework that deals with natural assets.[3] It is recommended that physical accounts, and if possible also monetary accounts, should be constructed for those natural assets that could be classified as economic assets. The complete accounts would show the physical size of the assets and their monetary value at the end of each year and estimates of the growth of the resource and its exploitation during the year. The accounts for these natural assets should be added to the asset accounts of the national accounts. The depletion of the natural assets due to exploitation should be valued and recorded in the satellite account together with other environmental costs. In the satellite account the Net Domestic Product (NDP) should be adjusted for environmental protection costs and depletion costs to give the Environmentally adjusted Domestic Product (EDP).

In this paper we will focus on estimations of the value of fish stocks and the cost of exploiting them. As far as we are aware there exist some pilot studies (see below) discussing such estimations, but in no case have such estimations been included in the official national accounts.

Until quite recently most ocean fisheries were open-access fisheries. Economic theory explains that under open access, the economic value of the natural asset is zero in equilibrium. There are many examples of stocks being fished down to near-extinction under open access. It is obviously important to collect biological and ecological information about these fish stocks. It is also possible to use some methods discussed in this paper to estimate the cost of over-exploitation under open access. However, the main aim of this paper is to discuss and develop methods that can be used to estimate the value of fish stocks and the cost of exploiting them, in cases where the stocks are managed by an authority which has a clear judicial mandate to do so.

The introduction of the 200-mile EEZ for many coastal states around 1980 and the establishment of regional management bodies have created a legal framework for establishing management of the exploitation of many fish stocks. Around the same time some states started to introduce regulations on investment in fisheries, quotas and effort limitations, and other methods for restricting effort and catches. Nonetheless, the actual control over the exploitation of many fish stocks is very limited. Besides the judicial side of the control and the difficulties of policing compliance with official regulations, the control over fish stocks is also limited by lack of biological and ecological knowledge. Including a fish stock in the national accounts requires biological knowledge of the stock that allows reasonably good predictions of future benefits from its exploitation.

It should be noted that in the best of cases the annual growth of a wild fish stock is far less predictable than that of a stock of cattle, or a stock of salmon in aquaculture. In many instances the growth of a wild fish stock in a given period of time is so uncertain that accounting for it may not seem worthwhile. However, if the stock has to be managed anyway to prevent over-exploitation, it seems reasonable that some form of accounting for it is valuable. In such cases very uncertain accounting information should be preferred to no accounting information.

This paper discusses national accounting for commercially exploited fish stocks. It ignores the value that these stocks have because of other uses (recreational fishing, nature watching and other enjoyment of nature). In most cases the value that these stocks have for commercial fishing is the most important part of their total value.

The paper uses data from the Icelandic fisheries to estimate the value of fish stocks and the cost of exploiting them. Different recognised accounting methods are used. It is shown that the different methods – all based on market valuations and using objective data – lead to very different estimates.

Where the right to fish from a stock has been organised into a marketable property right that has a market price, it is possible to estimate the value of fish stocks in the same way as the value of buildings and cultivated land by using the market prices. This is possible in the case of all important fish stocks in Icelandic waters as they are managed with Individual Transferable Quotas (ITQs). Since 1991 the fisheries management system in Iceland has allowed trade in the quota asset (quota shares), i.e. the right to receive a certain percentage of the annual total quota each year.

Estimates of the value of fish stocks, using market prices of quota shares, provide valuable information. However, they do not make alternative methods of accounting redundant. There are several reasons for this. The most important is that the prices of quota shares reflect the efficiency of the fisheries management (or the fishermen's estimation of it). For this reason fisheries management needs other methods of accounting in order to assess its efficiency. It should also be noted that even if the quota shares in Iceland have many characteristics of property rights they do not have the same legal status and the same constitutional guarantees as the right of the farmer to his land or his cattle.[4] For these reasons the prices of quota shares might be below the expected present value of future rents from exploiting the fish stock. On the other hand, it has been pointed out that if there is excess capacity, the prices of quota shares might overestimate the expected present value of long-run (full-cost) rents as the quota prices might reflect the short-run rents where a number of cost items are sunk (see Danielsson 2002).

When the market price of an asset is not available, or deemed unreliable, the asset's value should be estimated on the basis of direct estimations of the present value of future rent that can be earned from its utilisation.[5] When such methods are used for estimating the value of individual fish stocks they frequently encounter the problem that many fisheries are multi-species fisheries. And in cases where the fisheries are single-species fisheries, fishermen frequently take part in more than one fishery in the accounting period (usually a year). In such cases it is possible to use complicated (but still often very imprecise) statistical procedures to estimate the rent from fishing for the different species. However, accounting should avoid complicated statistical procedures. To do so, it will be proposed below that the lease prices of quotas should be used to estimate relative profitability of fishing for the different species. Economic theory predicts that these prices reflect the (short-run) marginal rents (profits) of fishing for the different species. This makes it possible to make simple estimations of the rent from fishing for the different species in Icelandic waters. Fairly free trade in annual quotas and an active market for lease quotas in Iceland provides reliable data for these estimations.

Assuming no additional information, the best forecast of future rent is the last period's rent (or the average of the rent during some recent periods). Using this, and assuming some rate of interest, the present value method can be used to estimate the value of the fish stocks.

If no information is available on the future prospects of the stock, the biological and economic control over it is rather poor. Even if the biological information is often uncertain there are many cases where it can be used to improve the estimates of future rents and therefore of the value of the stock. It will be shown for the case of the Icelandic cod stock that biological and bio-economic relationships can have very large influence on the estimates of the present value of expected future rents.

In those cases where bio-economic relationships are included the estimated value of the fish stock provides valuable economic information to the managers of the fisheries. Such economic accounting for managed fish stocks requires collaboration with biological researchers and even with managers of the stocks. The main contribution of this paper is to show how a simple bio-economic model can be used to forecast future rents from exploiting fish stocks. It is suggested that the value of the stocks should be estimated as the present value of the rents earned by implementing the optimal harvest rule. This way of calculating the value of the fish stock is not only the most correct one from the point of view of economic theory, it also makes it possible to obtain estimations of the cost of exploiting the stock that are consistent with estimates of its value. It also provides relevant information for the managers of the fisheries.

To illustrate the accounting methods proposed in this paper, a simple bio-economic model for the Icelandic cod stock is constructed and an optimal quota rule is estimated. It is suggested that this simple model is able to provide relevant estimates and that more complicated models and more accurate methods of estimating the optimal quota rule do not lead to significantly different results.

The paper is organised so that Section 2 discusses estimations of the value of fish stocks using data on the prices of quota shares and presents estimates of the value of the important fish stocks in Icelandic waters using this method. Section 3 discusses estimations of rents from fishing for the different species. Estimates are presented of rents from fishing for most of the species managed with quotas in Icelandic waters. The lease prices are used to estimate rents from fishing for individual species from aggregating accounting data. Estimates of the value of the fish stocks, using these estimates of the rents and assuming no additional information available to predict future rents, are also presented.

Section 4 discusses the use of a bio-economic model for estimating the value of a fish stock using an estimate of an optimal harvest rule for this stock. It also provides estimations of the value of the Icelandic cod stock using this model. Section 5 discusses estimations of the costs of exploiting fish stocks using economic and biological data. It provides estimates of the cost of depletion for the Icelandic cod stock using the maintenance cost method recommended in the SEEA. It also provides estimates of the cost of exploitation as the change in the value of the stock. The latter estimates are consistent with those of the value of the fish stock. In this section it is also argued that because of the large variations in the growth of fish stocks, depletion and cost of exploitation should be estimated on the basis of what is expected when the fisheries management decisions are made. Unexpected variations in the growth of the fish stock should then be recorded as "Other changes in volume of assets". Section 6 discusses the cost of sub-optimal exploitation of fish stocks, a concept that is not included in the SEEA. Section 7 gives complete environmental and economic accounts for the Icelandic cod stock at current and fixed prices for the period 1992–2000, using estimates from Sections 4–6. Section 8 presents the conclusions.

2. Estimates Using Prices of Quota Shares

In 1984 an ITQ system was introduced for most of the important species in the Icelandic fisheries. The law defines the concept of quota shares for each species, which determine the percentage of the annual total quota for the species that should be allocated to a vessel each year. The original quota shares of each vessel were decided in 1984 on the basis of catch history.

Before 1991, trade in annual (lease) quotas was relatively free while trade in quota shares was not allowed, except when they were sold together with a vessel. During this time the value of the quota shares was reflected in the price of the vessels.[6] It should be noted, however, that before 1991 the fisheries management laws specified a date when they would cease to be effective and there were no guarantees that the individual rights in the given law would be respected in the next law. The present law, which has been in force since 1991, does not specify a date when it ceases to be effective.

In 1991, free trade in quota shares was allowed. The quota shares define the access rights of the quota holders. If the quotas are used for commercial fishing the price of these quota shares reflects the sum of discounted expected profits from fishing the quota that the quota shares entitles the holder to each year. The price of the quota shares should therefore reflect the value that the fish stock has for commercial fisheries, i.e. the asset value of the fish stock. As mentioned in the introduction above it should though be noted that because the profitability of the fishery depends on the quality of the fisheries management so does the price of the quota shares. The legal status of the quota shares and the existence of excess capacity in the fishery will also affect the price of quota shares.

Table I shows the value of all access rights for the main stocks in Icelandic waters valued at the end-of-year prices of the quota shares.

It should be noted that for some of these species (capelin, herring, offshore shrimp, plaice) all access rights are in the form of ITQs, while for other species a significant part of the total catch is taken by vessels outside the main ITQ system. Most important is that from 1994 some 14% of the Total Allowable Catch (TAC) for cod was allocated to vessels outside the main ITQ system, mainly to vessels below 6 GRT that use only hand-line and/or long-line. Foreign vessels take a small catch. The value of these access rights can be estimated from the excess prices that vessels holding licences for these fisheries fetch in the market compared to the prices of comparable vessels that do not have such licences.[7] A somewhat easier method was used for compiling Table I where it was assumed that the share of the total catch allocated to those fishermen who had access rights outside the main ITQ system, in a given year, would remain the same for all future periods. The value of this share was then estimated using the prices of quota shares in the main ITQ system.[8]

Table I shows that the price of quota shares rose very rapidly during the period 1994–1997, especially the price of quota shares for cod, shrimp and herring. Part of the reason was that the estimated size of these stocks increased considerably. Table VII in Section 7 below shows however, that in the case of cod there were considerable over-estimations of its size during

Table I. Asset values of all access rights, valued at the end-of-year prices of quota shares

	1994	1995	1996	1997	1998	1999
Cod	32.2	62.0	86.3	131.8	131.2	134.2
Haddock	4.2	5.8	8.8	12.1	13.2	15.7
Saithe	3.6	3.4	3.4	5.3	6.4	7.8
Redfish	6.2	10.4	15.0	20.8	22.1	21.5
Catfish			1.5	2.2	2.2	2.3
Greenland halibut	4.4	3.0	3.0	4.8	4.6	4.8
Plaice	1.4	1.5	1.6	1.7	2.5	2.9
Shrimp	6.5	21.4	24.0	33.0	25.7	19.5
Nephrops	1.2	1.0	0.9	1.0	1.2	1.4
Herring	1.4	3.5	8.0	8.8	8.2	7.6
Capelin	5.5	6.0	15.0	19.0	22.8	26.5
Total	66.5	117.9	167.5	240.4	239.9	244.1

Unit: billion Icelandic Kronas (ISK). The exchange rate of the USD was around 70 ISK

1997–1999. Table II in the following section shows that changes in the profitability of these fisheries may have played some role in increasing the price of quota shares for shrimp and herring. A contributing explanation, suggested in NEI (1999), is that the agents' expectations concerning future lifetime and stability of the ITQ system gradually increased. Danielsson (2002) argues against this explanation.

3. Present Value Method Using Recent Rents

If it is not possible to estimate the value of an asset from its market price, the SNA recommends that the value is estimated as the present value of expected future profits (rents).[9] If it is prohibited to trade the permanent access rights to the fish stocks, there is no alternative to using such methods. However, as discussed in the introduction, there are also reasons to use this method when data on the asset prices of access rights are readily available.

One of the main problems facing a statistician estimating the value of individual fish stocks is that fisheries are rarely single-species fisheries and even when they are the available accounting data from the fishing firms show revenue and cost of fishing for many species. In fisheries managed with ITQs it can be reasonably expected that the lease prices of quotas indicate the relative marginal variable rents from fishing for the different species. This can be used to estimate the relative profitability of fishing for the different species. To make these estimations, data were collected on revenues and costs for 5–7 main segments of the Icelandic fishing fleet (the number varies between years depending on availability of data), together with the composition of their catches and the average landing prices and average lease prices of quotas for the different species for the years 1992–2000.[10] The costs of each segment were divided crudely into perfectly fixed and perfectly variable costs, and the cost of fishing for individual species estimated by assuming that for each segment the revenue minus variable cost is distributed over the fishing for different species in the same proportions as the lease value of the quotas used for the fishing. As the accounting data did not distinguish between fishing in the main ITQ system and outside it, this method was also used for estimating the variable cost of fishing for the different species by vessels outside the main ITQ system. For the species that are not included in the ITQ system, and those where there is insufficient data on quota prices, cost of fishing was assumed proportional to the species' share in the revenue. The fixed cost of fishing for a species was assumed proportional to the species' share in the revenue.[11] This method gave the estimates shown in Table II.

The profit (rent) in Table II is estimated from accounting data except for the cost of capital.[12] The cost of managing the fishery, biological research and policing the management system has not been subtracted. Some (relatively small) subsidies have not been subtracted either and some (relatively small) special taxes on fishing in Iceland have not been added. This is in accordance

Table II. Rent in million Icelandic Kronas (ISK) estimated from survey data

	1992	1993	1994	1995	1996	1997	1998	1999	2000
Cod	1,605	2,883	4,008	3,792	2,111	1,978	4,742	5,697	4,826
Haddock	−301	−716	−1,461	−1,163	−1,203	−653	−841	−536	−99
Saithe	116	−296	−527	−642	−505	−447	−231	−63	67
Redfish	495	487	−25	218	438	−36	460	324	397
Catfish					−245	−222	−245	−169	−120
Greenland halibut	391	678	−259	−1,012	−975	−439	166	252	407
Plaice	12	−134	−186	−194	−263	−309	−143	−88	24
Herring		−33	493	841	1,183	627	49	1	47
Capelin		−504	−565	−804	−295	312		−1,174	−1,023
Nephrops			−24	−32	−62	−40	−31	−56	−68
Shrimp	−1,017	−909	−728	1,271	1,462	−54	−948	−905	−523
Other	331	214	54	210	350	−528	137	−474	−332
Total	1,630	1,670	783	2,484	1,997	188	3,116	2,809	3,603

All revenues and costs related to trade in quotas are excluded.

with recommendations for national accounting. In the case of Iceland the management costs are also relatively small, around 3%.[13] Note also that these costs have been paid for by the state and do not affect the prices of quota shares presented in Table I. Ignoring these costs when estimating the value of a fish stock in Tables III and IV makes these calculations consistent with the calculations that vessel-owners make when estimating demand price for the quota shares for this stock.

However, it should also be noted that some parts of these costs are relevant for the management of fisheries. When deciding on the optimal fisheries management it is the profit after subtraction of management cost that matters. These costs should therefore be included in accounting that is intended for management purposes.

If nothing further is known about future profitability of the exploitation of these stocks (and there is no special reason to expect that the present exploitation is not sustainable), the best estimate of future profits is the profit in the preceding period(s). In this case the present value of rent for infinite number of future periods is equal to the annual rent divided by an appropriate rate of interest.[14] Table III shows the results from such estimations using an interest rate of 8%.[15] The average interest rate on government bonds was marginally above 5% during this period. It can be argued that the large uncertainty associated with many fish stocks would require a somewhat higher rate of interest to be used for calculating the present value of future rents from fisheries.

Table III. Asset values in billion Icelandic Kronas (ISK)

	1992	1993	1994	1995	1996	1997	1998	1999	2000
Cod	20.1	36.0	50.1	47.4	26.4	24.7	59.3	71.2	60.3
Haddock	0	0	0	0	0	0	0	0	0
Saith	1.5	0	0	0	0	0	0	0	0.8
Redfish	6.2	6.1	0	2.7	5.5	0	5.7	4.1	5.0
Catfish					0	0	0	0	0
Greenland halibut	4.9	8.5	0	0	0	0	2.1	3.1	5.1
Plaice	0.1	0	0	0	0	0	0	0	0.3
Herring		0		10.5	14.8	7.8	0.6	0.0	0.6
Capelin		0	0	0	0	3.9		0	0
Nephrops			0	0	0	0	0	0	0
Shrimp	0	0	0	15.9	18.3	0	0	0	0
Other	4.1	2.7	0.7	2.6	4.4	0	1.7	0	0
Total	36.9	53.3	50.8	79.1	69.4	36.4	69.4	78.4	72.1

Many entries in Table II are negative. In Table III the asset values have been set to zero in these cases. The reason is that one would expect that an asset that can be disposed of without cost has a non-negative asset value. The figures in Table I show that the market value of the access rights is never negative. Negative asset values in Table III might therefore simply reflect some errors in the estimations.

The asset values in Table III are based only on the rent in the fisheries in the same year. The estimations use the average prices of outputs and inputs during the year. If this method is applied it is probably better to use average rent during recent years to even out short-run fluctuations in the rent.

Comparing asset values in Tables I and III shows that in almost all cases the asset values in the former table are much higher than in the latter. In some cases this can be explained by the fact that the estimations in Table III didn't take into account expectations about future growth of the stocks and how this growth might affect the profitability of the fishery as catches and the cost of fishing will change. The next sections will discuss methods to estimate the effects of future growth of the Icelandic cod stock on the asset value of this stock.

4. Present Value Method Using a Bio-Economic Model

Using biological and economic data to improve the forecasts of future profits (rents) requires some bio-economic modelling. If the managers of the fisheries use such models to device the optimal rule for deciding the TACs[16] this rule can be used to forecast future rents based on the optimal exploitation. Otherwise, those responsible for the accounts have to make their own estimates of the optimal exploitation.

The Marine Research Institute (MRI) in Iceland has developed a biological model of the cod stock in Icelandic waters. The MRI uses a Beverton and Holt cohort model and a Ricker recruitment function to simulate long-run effects of exploitation strategies. The MRI includes the cod stock together with shrimp and capelin in a multi-species model.[17] These multi-species considerations will be ignored in this paper. To simplify the calculations further the MRI model is approximated by a logistic growth function:[18]

$$G_\tau = g(S_\tau) = r \cdot S_\tau(1 - S_\tau/K), \qquad (1)$$

where G_τ is the growth of the stock in year τ, S_τ is the size of the stock by the beginning of year τ and g is a concave function. With $r = 0.5242$ and $K = 2,720,000$ tonnes the logistic growth function gives the same maximum sustainable yield of 356,000 tonnes when the fishable stock is 1,360,000 tonnes as the MRI model.

Let the harvest function for exploiting the stock be

$$H_\tau = h(S_\tau, E_\tau) = \kappa \cdot E_\tau(S_\tau)^\gamma, \tag{2}$$

where H_τ is the volume of catch, h is a differentiable function increasing in both arguments and $E_\tau(= \kappa^{-1}H_\tau(S_\tau)^{-\gamma})$ is the volume of effort, while κ and γ are parameters. Here γ is set equal to 0.8.[19] The estimates of the value of the stock are very sensitive to the value of γ.

The cost of harvesting in period τ is

$$C_\tau = C(H_\tau, S_\tau) = cE_\tau = c\kappa^{-1}H_\tau(S_\tau)^{-\gamma}, \tag{3}$$

where C is a differentiable function increasing in the first argument and decreasing in the second. The cost per unit of effort is assumed constant (c) in the present period. In forecasting future costs, the cost per unit of effort is assumed equal to the cost per unit of effort in the present period. These assumptions ignore that shares are used to remunerate labour and capital in fishing in Iceland. In a competitive labour market the parameters of the share contracts would change so that the wage rate in fishing is always equal to the wage rate in an alternative employment, allowing for differences in risk and other characteristics of the different types of labour. If the market is not sufficiently competitive, the fishermen will receive a share of the rent in the future. The part of the total rent received by the fishermen in this case is included in the calculations of the value of the stock below. In this case it may also be necessary, when estimating the cost of fishing, to take into account that a part of the actual wages of fishermen may be rent.

It should be noted that Equations (2) and (3) do not take into account the problem of non-malleability of capital or the time required for new investments. It is very difficult to model these phenomena realistically. Some considerations of these phenomena will be included below through restrictions on permissible quota rules.

A general objective function for the management of the fishery in period t is

$$\sum_{\tau=t}^{\infty} \beta^{(\tau-t)} u(H_\tau, E_\tau), \tag{4}$$

where u is a function giving the net benefits from the fishery and β is the discount factor. The optimisation problem for the managers is to choose a harvesting strategy that maximises the expression in Equation (4) subject to the constraint in Equation (1). If most of the fish is sold in foreign markets it is reasonable to set net benefits equal to profits,

$$u(H_\tau, E_\tau) = \pi(H_\tau, S_\tau) = p_\tau H_\tau - C(S_\tau, H_\tau), \tag{5}$$

where p_τ is the price of the harvest in period τ. This price is usually a function of the supply of fish, H_τ. It is assumed below that Icelandic cod faces demand with constant price elasticity (ε) of 10.[20] This elasticity is used to predict all future prices, as it is assumed that no other information on future prices is available.

If demand for the harvest from the fishery is not perfectly elastic, a fisheries management arrangement that uses Equation (5) to determine the optimal harvest is functioning as the organiser of a cartel for the fishermen. In most countries fisheries managers should therefore not use Equation (5) but a formula which considers the interests of consumers as well as producers. This can be done by setting net benefits equal to the estimated sum of profits and consumer surpluses, i.e.

$$u(H_\tau, E_\tau) = \int_0^{H_\tau} p(\omega)\mathrm{d}\omega - C(S_\tau, H_\tau). \tag{6}$$

A condition for maximisation of the objective function in Equation (4) with the net benefit function in Equation (6) and subject to Equation (1) is that price equals the (direct and indirect) marginal cost of catching an additional unit of harvest. Fisheries management that used this objective function would therefore do for the fishing industry what economic theory predicts that perfect competition and freedom of entry does for most other industries. Weitzman's (1976) results concerning the welfare significance of the national accounts are valid in this case.

Solving the problem of maximising the objective function in Equation (4) gives the optimal harvest (H_τ^*) in each period of time. It is well known that linear models give bang–bang solutions, i.e. if the stock is below its optimal level all fishing should be stopped until the stock has reached it again, and when the stock is above its optimal level it should be fished down to the optimal level as fast as possible. (See Clark 1990, p. 93.) Nearly linear models such as the one above give solutions that are close to the bang–bang solution. There are several common-sense objections to these solutions, mostly based on various fixed and sunk costs associated with actual fishing and ignored in simple bio-economic models: fixed cost in fishing capital, in training of fishermen and in marketing of fish products. It is very difficult to model these costs realistically. However, it is known that if this were possible the model would give an optimal harvest rule that is much smoother than the bang–bang solution. It is therefore reasonable to postulate some smooth functional form for the harvest rule and choose its parameters so that it is optimal in a given model. A simple form for such a smooth harvest rule is

$$H_\tau^* = \alpha \cdot H_{\tau-1} + (1-\alpha) \cdot \lambda \cdot S_\tau, \tag{7}$$

where $0 \leq \alpha \leq 1$. If α is positive, it functions as a smoothing parameter reducing the variability of catch levels. Even if the harvest rule in Equation (7) is not optimal in the model in this section it is reasonable to expect that with an appropriate choice of parameters,[21] the loss in terms of smaller present value of profits (rents) is fairly small. Ideally, the value of α should be based on considerations concerning adjustment costs and sunk costs, including social costs, uncertainty and aversion to risk and fluctuations. As these factors have not been modelled realistically α is simply set equal to 0.5.

If λ is set equal to H^*/S^* where S^* and $H^* = g(S^*)$ are the long-run optimal values for the stock and the harvest, the harvest rule in Equation (7) directs the stock size and the harvest levels to the equilibrium (S^*, H^*) in most cases when $0 \leq \alpha \leq 1$. Exceptions must be made, however, for cases where the stock may decline or even collapse because the initial harvest is very large and α close to 1, while the initial size of the stock is low. In cases like those discussed in this paper where there is no danger that Equation (7) leads to a decline in the stock Equation (7) is a reasonable approximation of an optimal harvest rule and it is sufficient to estimate S^* and $H^* = g(S^*)$ to obtain an estimate of λ.

If the managers aim at maximising present value of future profits, and the rate of interest is i, the value of the optimal stock (S^*) can be obtained by solving the equation

$$i = \frac{\partial g}{\partial S} - \frac{\partial C/\partial S}{(1 - 1/\varepsilon)p(g(S)) - \partial C/\partial H}\ , \tag{8}$$

while if the managers aim at maximising welfare by maximising the present value of the sum of profits and consumer surpluses, S^* can be obtained by solving the equation[22]

$$i = \frac{\partial g}{\partial S} - \frac{\partial C/\partial S}{p(g(S)) - \partial C/\partial H}\ . \tag{9}$$

If the objective is to maximise welfare, estimations of the optimal values give a stock size of around 1500 thousand tonnes and a harvest of around 350 thousand tonnes, implying a value of λ around 23%. This value is used below.[23]

If $V_t(S_t)$ is the value of the stock when its size is S_t at the beginning of year t, then the present value method gives that

$$V_t(S_t) \sum_{\tau=t}^{\infty} \beta^{(\tau-t)} \left[p_\tau H_\tau^* - C(S_\tau^*, H_\tau^*)\right], \tag{10}$$

where $S_t^* = S_t$ and $S_\tau^* = S_{\tau-1}^* + g(S_{\tau-1}^*) - H_{\tau-1}^*$ for $\tau = t+1, t+2, \ldots$

To illustrate this method it will be used to estimate the value of the Icelandic cod stock. To make the model applicable to Icelandic conditions it is necessary to make certain assumptions concerning time. The accounting data refer to the calendar year while the quotas are set for the quota year, which starts on September 1st and ends on August 31st in most cases.[24] The estimation of the size of the cod stock is made during the first half of each year and based on data on catches landed before the end of the preceding year and on research fishing during March of the present year. The estimates below refer to the calendar year and would be exact if the TACs were decided for the calendar year on the basis of stock estimates obtained during the first half of the year.

Given λ (and α) it is possible to use Equation (7) to forecast optimal catches. Future prices are forecasted assuming the own price elasticity to be 10. The cost is forecasted using Equation (3) (and Equation (2)) and assuming that the unit price of effort is constant. The data on the prices and costs each year are reported in Appendix II. Given these forecasts, Equation (10) can be used to calculate the value of the stock. Table IV shows the size of the Icelandic cod stock as it was estimated at the time $(S_{t|t})$[25]. The second row shows the value of the stock at the beginning of the year valued at current prices $(V_t(S_{t|t}))$. The last row shows the value of the stock at constant 1992 prices $(V_{1992}(S_{t|t}))$.

The estimates in Table IV are much higher than the estimates of the value of the cod stock in Table III. In most cases they are also higher than the estimates of the value of the cod stock in Table I.

The estimates in Table IV depend on the time of the estimation and what is known at that time about future growth of the stock and the future rents of the fisheries exploiting the stock. Estimates of the values of some assets at a given point in time are frequently made some time later. For this reason it has been allowed here that the estimates of the value of the stock at a given point in time use information about the price and cost of fishing for cod in the first year after this point in time.

The estimates use only information about the profit (rent) in the cod fisheries in the first year. The rents in all later years are based on predictions.

Table IV. The size of the fishable cod stock (cohorts from the age of four), as estimated at the time and its value at current and constant (1992) prices

	1992	1993	1994	1995	1996	1997	1998	1999	2000
Fishable biomass	640	630	590	560	675	889	975	1,031	756
Value of stock									
At current prices	128	150	171	174	139	113	138	142	165
At 1992 prices	128	127	122	118	132	152	159	163	141

Units: ′000 tonnes and billion Icelandic Kronas (ISK).

Table V. Depletion cost for Icelandic cod using different methods, 1992–2000

	1992	1993	1994	1995	1996	1997	1998	1999	2000
Annual rent approach (maintenance cost)									
Depletion cost I	0.1	0.5	0.7	−2.6	−2.5	−0.8	−1.1	6.1	3.7
Depletion cost II	0.1	0.0	−1.4	−1.4	−1.0	−1.1	−1.7	−1.7	−1.1
Change in asset value approach									
Depletion cost III	1.2	4.8	3.8	−12.1	−16.7	−4.7	−3.4	20.0	19.2
Depletion cost IV	1.4	−0.2	−7.3	−7.0	−7.2	−6.9	−5.1	−4.4	−4.5

Unit: billion Icelandic Kronas (ISK).

The MRI's estimates of the size of the fishable stock of cod, by the end of each year, become available in May/June in the subsequent year.

It is possible to use the model above to estimate the value of the Icelandic cod stock at different points in time, using data on unit price and cost per unit of effort in a specific year. In this way it is possible to estimate the fixed-price value of the stock. The bottom row in Table IV shows the value of the stock as it is estimated using prices and costs in 1992 and the estimates from the MRI of the size of the fishable stock by the beginning of each year.

5. Cost of Depletion

The SEEA advocates the use of the maintenance cost method for estimating the cost of depletion of fish stocks.[26] According to this method the cost of fishing in excess of the growth of the stock is equal to the rents foregone if the catch is equal to its growth.

Here depletion is the actual decline in the stock. This is reasonable if the decline in the stock is predictable and well estimated at the time when the cost of it is estimated. However, in the case of most fish stocks the actual growth in a given year is very uncertain. For this reason the same optimal decision will be associated with high depletion costs if the growth of the stock happens to be small, while it will be associated with low (or negative) depletion cost if the growth of the stock happens to be large. In fisheries management the regulations (TACs, days at sea, number of licences) have to be decided before the fishing starts. This means that these regulations have to be decided before the growth of the fish stock in the period is known. In such cases it seems reasonable to use the expected (i.e. normal) growth of the stock in the estimation of the cost of depletion. In this case, other changes in the actual stock are recorded as "Other changes in volume of assets". This is in accordance with the practice in accounting for the cost of using fixed capital. Depreciation is the cost associated with the normal use of a durable asset while the costs associated with accidents are recorded as "Other changes in volume of assets".

It should be noted that the estimate of the actual depletion of the stock in a given year, made by the end of the year, is also highly uncertain. In cases where Virtual Population Analysis (VPA) is used, the estimate of the actual depletion in a given year is gradually improved during several subsequent years. When the VPA is used the difference between the estimated stock size at the beginning and the end of the year $(S_{t+1|t+1} - S_{t|t})$ is not the same as the estimate of the change in the stock size made at the end of the year $(S_{t+1|t+1} - S_{t|t+1})$. The reason is that the estimate of the size of the stock at the beginning of year t will be revised in the estimation made at the end-of-year t (beginning of year $t+1$), using the additional information that has been collected during the year on the cohorts in the stock by the beginning of year t.

The SNA and SEEA advocate that wild fish stocks that are exploited by commercial fisheries should be recorded as "economic assets". This means that the stock of these natural assets should be estimated and included in the value of economic assets. It also means that efforts should be made to estimate the cost of depletion and this cost should be subtracted from the NDP to give the EDP in the satellite account. But wild fish stocks should also be recorded as "non-produced natural assets" because control over the growth process is insufficient for recording them as "produced assets" together with buildings, machines, cattle stocks and stocks of farmed fish. For this reason increase in wild fish stocks should not be recorded in the same way as decrease (depletion) and the value of the increase in the fish stocks (negative depletion) should not be used in estimations of EDP.[27] In this paper, these recommendations are ignored, and increase and decrease in the fish stocks are treated symmetrically. If decreases in the fish stock because of excessive fishing are parts of the productive process of managed fisheries, increases due to limitations in the catches should also be recorded as part of this same process. Other changes in the fish stock, or its biological potential, due to errors in the estimations or changes in the environment, should be recorded as "Other changes in volume of assets" and should not affect the estimation of the EDP.

These definitions of cost will now be used to estimate the cost of exploiting the Icelandic cod stock in the period 1992–2000. Table V shows estimations of maintenance cost for Icelandic cod stock. Depletion cost I is the cost of depletion estimated using the maintenance cost method and the actual change in the estimated stock size, i.e.

$$\text{Maintenance cost} = \text{Rent pr. }'000\text{ tonnes} \times (S_{t+1|t+1} - S_{t|t}). \quad (11)$$

Depletion cost II is the cost of depletion estimated using the maintenance cost method and the forecasted growth in the stock and actual catch, i.e.

$$\text{Maintenance cost} = \text{Rent pr. }'000\text{ tonnes} \times (S_{t+1|t} - S_{t|t}). \quad (12)$$

In 1992 the two maintenance cost estimates give almost the same result because the actual change in the estimated stock size is almost the same as the forecasted change estimated by the beginning of 1992. In 1994 the change in the estimated stock size is much smaller than predicted. In spite of a large decrease in the catch Depletion cost I is positive in 1994. Depletion cost II, on the other hand, estimates negative depletion cost (i.e. investment in the stock). In 1995 and 1996, the actual change in the estimated size of the cod stock was quite large compared to the expected change, making Depletion cost I estimates show much higher investment in the stock than Depletion cost II. In 1999 and 2000 this was the other way around.

The estimates of the cost of exploitation, obtained using the maintenance cost method, are not logically connected with any estimates of the value of fish stocks. To derive estimates of the cost of using an asset, which are consistent with the estimates of the value of the asset, the cost must be estimated as the decrease in the asset's (fixed-price) value. By using the model in the preceding section it is possible to estimate the depletion costs for the Icelandic cod stock using this method. The depletion cost can be estimated on the basis of the forecasted change in the value of the stock,

$$\mathrm{Cost}_t^d = V_t(S_{t|t}) - V_t(S_{t+1|t}). \tag{13}$$

Depletion cost IV in Table V shows the estimated depletion cost for exploiting the Icelandic cod stock in 1992–2000 using Equation (13). Depletion cost III in Table V is the difference between the value of the stock at the beginning of the year and the value of the stock, estimated by the end-of-year t (i.e. $V_t(S_{t|t}) - V_t(S_{t+1|t+1})$).

Because the Icelandic cod stock was in a depleted state during the years under consideration in Table V, Depletion cost III and IV are much higher than Depletion cost I and II. When the stock is above its optimal size the maintenance cost method gives higher depletion costs than methods using the estimated value of the stock.

Table V shows that there can be large differences between the estimates of depletion costs using the forecasted change in the stock and those using the actual change in the estimated stock size.

6. Inefficiency Cost

Depletion cost is associated with a decrease, or an increase, in the volume of the asset. If the volume of the asset remains the same, i.e. if it is managed sustainably, there is no depletion cost. Both methods discussed in the preceding section give that result. But a renewable resource like a fish stock can be sustainably managed, but still far from optimally managed. If a fish stock is in a seriously depleted state and kept there through sustainable catches, it is inefficiently managed. The depletion cost would be zero in this case, but the cost of the inefficient management is obviously considerable. It is possible to use the model in Section 4 above to calculate the cost of this inefficiency.

Let $H^*_{t|t}$ be the optimal harvest in period t and let $S^*_{t+1|t}$ be the forecasted size of the stock by the beginning of period $t+1$ if the catch in period t is $H^*_{t|t}$, i.e.

$$S^*_{t+1|t} = S_{t|t} + g(S_{t|t}) - H^*_{t|t} \tag{14}$$

In this case, the optimal income (rent plus capital gain/loss from the change in the value of the stock) from exploiting the stock is

$$R_t^{\text{opt}} = \pi_t(H^*_{t|t}) + V_t(S^*_{t+1|t}) - V_t(S_{t|t}). \tag{15}$$

Equation (10) gives that

$$V_t(S_{t|t}) = \pi_t(H^*_{t|t}) + \beta \cdot V_t(S^*_{t+1|t}). \tag{16}$$

Using Equation (16) to substitute for $V_t(S^*_{t+1|t})$ in Equation (15) gives that

$$R_t^{\text{opt}} = i \cdot \lfloor V_t(S_{t|t}) - \pi_t(H^*_{t|t}) \rfloor. \tag{15$'$}$$

The expected income from the actual harvest is

$$R_t^{\text{act}} = \pi_t(H_{t|t}) + V_t(S_{t+1|t}) - V_t(S_{t|t}) = \pi_t(H_{t|t}) - \text{Cost}_t^d. \tag{17}$$

The difference between the forecasted optimal income and the expected actual income measures the inefficiency cost of sub-optimal (usually excessive) harvest levels

$$\text{Cost}_t^{\text{ie}} = R_t^{\text{opt}} - R_t^{\text{act}} = i\lfloor V_t(S_{t|t}) - \pi_t(H^*_{t|t}) \rfloor - \pi_t(H_{t|t}) + \text{Cost}_t^d. \tag{18}$$

The SNA records the actual rent in fishing as part of the annual production, i.e. $\pi_t(H_{t|t})$, but the part of the rent which consists of a decrease or an increase in the value of the environmental asset $(V(S_{t|t}) - V_t(S_{t+1|t}) = \text{Cost}_t^d)$ is not included. This omission should be corrected in the environmentally adjusted satellite accounts. Neither the SNA nor the environmentally adjusted satellite accounts are supposed to record the inefficiency cost, $\text{Cost}_t^{\text{ie}}$. Frequently, this cost is very important, as shown in Table VI.

The depletion cost can be positive or negative, depending on whether the stock is forecasted to decrease or increase, given the harvest over the period. The inefficiency cost, on the other hand, would be positive in most cases. It should be noted, however, that when optimal management is defined in terms of maximisation of the sum of discounted profits and consumer surpluses, the actual harvest strategy may yield higher income to the producers than the optimal strategy. In such cases $\text{Cost}_t^{\text{ie}}$ becomes negative as the producers' income is above its optimal level while the consumer surplus is below its optimal level.

According to the definition above there is some inefficiency cost if the catch in the present period is not optimal. This means that there are costs associated with the under-utilisation of a natural resource. A special case

Table VI. Estimations of depletion and inefficiency cost for the Icelandic cod stock

	1992	1993	1994	1995	1996	1997	1998	1999	2000
Stock size	640	630	590	560	675	889	975	1,031	756
Catch									
Actual catch	268	252	179	169	182	203	243	260	235
Optimal catch	228	206	194	154	162	193	214	240	217
Rent (net profit)									
Actual rent	1.6	2.9	4.0	3.8	2.1	2.0	4.8	5.7	4.9
Rent from opt. Catch	1.4	2.4	4.4	3.5	1.9	1.9	4.2	5.3	4.5
Depletion cost (IV)	1.4	−0.2	−7.3	−7.0	−7.2	−6.9	−5.1	−4.4	−4.5
Inefficiency cost	7.2	8.7	2.0	2.9	1.7	0.0	0.9	0.8	3.5

Unit: thousand tonnes and billion Icelandic Kronas (ISK).

would be if the natural resource were not exploited at all. If the authorities ban all commercial exploitation of a natural asset, which could be profitably exploited, this policy has a cost (inefficiency cost), which is equal to the income foregone by not exploiting it.

7. Complete Accounts for Icelandic Cod

It is now possible to set up the complete account for the Icelandic cod stock. Table VII shows the physical accounts for the Icelandic cod stock. Note that an extra row, showing depletion (= forecasted growth − catch), has been included.

The bottom row in Table VII shows the size of the cod stock at the beginning of the respective year as estimated by the MRI in 2001. These estimates are not used in the calculations of the environmental accounts for the Icelandic cod stock but have been included to indicate the size of the estimation error. It should be noted that the estimation errors in 1998–2000 are far above the average during the last 25 years.

Table VIII shows the monetary accounts for the Icelandic cod stock for the period 1992–2000. The closing stock and the holding gain/losses[28] were not available for 2000.

The top row in Table VIII shows the value of the stock at the beginning of the year valued at current prices. These figures were also reported in Table IV above. The second row shows the depletion cost based on estimated change in the value of the stock. These costs were reported as Depletion cost IV in Tables V and VI. The closing stock (as estimated by the beginning of the following year) at the previous year's prices is estimated using the method discussed in Section 4 above. "Other changes in volume of assets" is then a balance item to ensure that the accounts add up. The estimate of the value of

Table VII. Physical accounts for the Icelandic cod stock (fishable stock 4+)

	1992	1993	1994	1995	1996	1997	1998	1999	2000
Opening stock	640	630	590	560	675	889	975	1,031	756
+ Forecasted growth	257	254	242	233	266	314	328	336	286
−Catch	−268	−252	−179	−169	−182	−203	−243	−260	−235
(= Depletion)	−11	2	63	64	84	111	85	76	51
+ Other changes in vol.	1	−42	−93	51	130	−25	−29	−351	−230
= Closing stock	630	590	560	675	889	975	1,031	756	577
Opening stock as estimated in 2001	547	580	577	553	672	786	710	709	527

Unit: thousand of tonnes.

the closing stock, at the following year's prices, gives the closing stock. The difference between this estimate and the "Closing stock at previous year's prices" is holding gain/losses. The inefficiency cost shown in Table VIII is not part of the accounts. National account data on GDP and on fixed capital in fishing at current prices for the period 1992–2000 is shown for comparison. Table VIII shows that the asset value of the Icelandic cod stock is roughly twice the size of the asset value of the fixed capital in fishing for all commercial species in Icelandic waters.

Table VIII. Monetary accounts for the Icelandic cod stock

	1992	1993	1994	1995	1996	1997	1998	1999	2000
Opening stock	128	150	171	174	139	113	138	142	165
−Depletion cost	1	0	−7	−7	−7	−7	−5	−4	−4
−Other changes in volume of assets	0	−5	−11	5	10	−2	−2	−24	−24
= Closing stock at prev. year's prices	127	145	167	186	156	117	141	122	145
+ Holding gain/loss	23	26	7	−47	−43	20	1	42	
= Closing stock	150	171	174	139	113	138	142	165	
Inefficiency cost	7	9	2	3	2	0	1	1	3
Fixed capital in fishing	71	74	79	76	79	76	75	73	72
GDP	400	412	439	451	484	524	579	623	672

Unit: billion Icelandic Kronas (ISK).

The depletion cost and the inefficiency cost in Table VIII can be compared to the GDP. The depletion costs were largest in 1994 and 1995 when they amounted to 1.5% of the GDP. There was no depletion cost in 1993. This means that the rate of growth of the EDP in 1994 was 1.5% lower than that of the GDP. The inefficiency cost was highest in 1992 and 1993 when it amounted to roughly 2% of GDP. This figure indicates how much good fisheries management could have contributed in these years.

Table VIII shows that "Other changes in volume of assets" are large compared to depletion costs. This gives a measure of the degree of control that can be exerted over the growth of the Icelandic cod stock.

In this paper all estimates of the value of the cod stock are based on the price and unit cost of effort in only one year. The large decline in the value of the cod stock in 1995 and 1996 is caused by a sharp decline in the profitability of the cod fisheries and reflected in the accounts by large holding losses. It may seem more realistic to use the average price and the average unit cost of effort during recent years to forecast future profits (rents). The resulting estimates would then be smoother than those in Table VIII.

8. Conclusions

In this paper we have discussed different methods for estimating the value of wild fish stocks exploited by commercial fisheries, and the cost of exploiting them. Data on Icelandic fisheries and fish stocks in Icelandic waters have been used to illustrate the different methods. Data on the prices of quota shares have been used to estimate the value of fish stocks managed with ITQs. Data on the lease prices of quota shares have also been used to estimate from aggregate data the rents from fishing for each species.

It was shown above for the case of the Icelandic cod stock that ignoring the effect of changes in the stock size on future rents from the fishery may lead to very inefficient estimates of the value of stock. (Cf. the estimates for the value of the cod stock in Tables III and IV above.) It was therefore strongly recommended that wherever the necessary data are available the value of fish stocks should be estimated using a simple bio-economic model to forecast future rents from the fishery.

The fisheries economics literature explains that the value of a fish stock is equal to the present value of expected future rent from the optimal exploitation, i.e. the exploition which maximises the present value of expected future profits. However, using this in practical estimations for the national accounts has not been proposed before. It is also the first time that it has been proposed to link fisheries management and national accounting in the manner discussed in the paper. As most fish stocks have to be managed, some estimation of the optimal management has to be made. The paper argues that these estimations should be used in the national accounts.

Because of the need to manage the exploitation of fish stocks, this kind of bio-economic modelling is necessary even in cases where it is possible to use alternative methods for estimating their value. For instance, if the asset prices of access rights are given in a market, as is the case with prices of quota shares in Iceland, these data should be collected as they contain important information. However, these data would not make estimations using the method discussed in Section 4 above redundant. The latter estimates would still be needed for fisheries management. This can be compared to the estimations of the value of a firm that can be obtained both from the stock market and from the firm's asset accounts. As in estimations of the value of fish stocks, the difference between these two estimates of the value of the firm is sometimes quite large. Nonetheless, both provide valuable information about the firm.

The concept of maintenance cost recommended by the SEEA (1993) was discussed. It was proposed that, if possible, depletion cost should be estimated as the change in the value of the fish stock. These estimates of depletion cost are consistent with those of the value of the stock.

It was also pointed out that in some cases estimates of depletion cost do not give proper estimates of the cost of inefficient fisheries management. If decisions on total catch (or total effort) are such that the stock is kept sustainable on a level far below its optimal level the depletion cost is zero but the cost of this inefficient management can be substantial. In this case the estimates of inefficiency cost discussed above would give proper estimates of the costs of exploitation caused by the actual fisheries management, or the lack thereof. As far as we are aware the concept of inefficiency cost has not been discussed or estimated before.

A further drawback of the discussion of the maintenance cost in the SEEA is that it ignores the large variations in annual growth rates of fish stocks. This uncertainty makes estimation of the cost of depletion on the basis of the annual difference between the growth of the stock and the harvest quite unreasonable. Instead, depletion cost should be based on estimations of the average, or expected, growth in a fish stock. Other changes in the value of a fish stock should then be recorded as "Other changes in volume". This would be similar to the use of depreciation to estimate the "ordinary" cost of using fixed capital and the use of "Other changes in value of assets" when there are large unexpected changes in the value of an asset.

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Notes

1. UN (1993), resolution 1, annex II, §8.42.
2. See SEEA (1993), pp. 41–53.
3. SNA (1993), Chap. XXI, sect. D. In the same year the UN Department for Economic and Social Information and Policy Analysis, Statistical Division, published a handbook on national accounting describing a System for 'Integrated Environmental and Economic Accounting' (SEEA 1993). In 2000 this agency, together with the UN Environmental Programme, published 'Integrated Environmental and Economic Accounting – An Operational Manual' (UN 2000). In 2004 UN Department of Economic and Social Affairs, UN Statistics Division and FAO published a handbook of national accounting for Integrated Environmental and Economic Accounting for Fisheries (FAO 2004).
4. This is also the case in most other countries where ITQs have been introduced.
5. See SNA (1993), §2.69.
6. For further information about the Icelandic ITQ system see Arnason (1995) and Danielsson (2002).
7. Flaaten et al. (1995) used this method to estimate the value of access rights in Norway.
8. Table I contains two species that are shared by Iceland and other countries. The exploitation of capelin is regulated by an agreement between the governments of Iceland, Greenland and Norway. The figures for the value of capelin in Table I are estimated from the value of the quotas of Icelandic vessels. The Greenland halibut stock is exploited by vessels from Iceland, Greenland and Faroe Islands without any agreement. The Icelandic government decides quotas for Icelandic vessels fishing out of this stock. The figures for the value of this stock in Table I are estimated from the value of the Icelandic quota rights.
9. See SNA (1993), §3.75. The paragraph also contains the following warning: "Although this method is theoretically entirely justified, it is not generally recommended since it involves many assumptions and as a consequence the outcomes are highly speculative".

   In this paper the cost functions are such that there is no difference between profit and rent and these two terms will be used interchangeably. In general the optimal policy maximises the sum of discounted profits but not necessarily the sum of discounted rents, but the value of the asset is the discounted sum of the rents from the policy that maximises the sum of discounted profits.
10. Most of these data have been published in Concerted Action (1999). Most of the data on the quota prices used in the calculations are published in NEI (1999).
11. The formulas are given in Appendix I below.
12. For each type of fixed capital depreciation and interest cost is estimated as the annuity of a sum equal to the replacement value and repayable for a period equal to the expected lifetime. The interest on the working capital is estimated using the market rate of interest for these loans.
13. See Arnason (2003).
14. In a pilot study, Statistics Norway has used this method for estimating the value of fish stocks (or fisheries) in Norway. See Hass and Sørensen (1998). This method is also used by Flåm (1993) and Kjelby (1993). Flåm (1993) assumes that "all stocks are in equilibrium, giving maximum sustainable catch" (p. 1), while Kjelby (1993) gives the value of the cod fisheries as the stocks were exploited at the time. She then goes on to estimate their value if the stocks were exploited at the Maximum Sustainable Yield.

15. This valuation does not account for the value of the access rights that foreign vessels have in the Icelandic EEZ. The error caused by this omission is in most cases zero and in all cases less than 0.5%.
16. Or for deciding the total effort if fisheries are managed with effort limitations.
17. This model is described in Danielsson et al. (1997).
18. A good discussion of the logistic growth function and other functions in the model in this section can be found in Clark (1990).
19. Danielsson et al. (1997) used $\gamma = 0.7$ based on the study by Helgason and Kenward (1985). In Danielsson (2000) γ is estimated 0.8 on the basis of survey data for 1985–2000.
20. This number is an approximation of the elasticity used in Danielsson et al. (1997).
21. Simple rules like Equation (7) derive their justifications from the fact that profits and rents (and the sum of their present values) are usually fairly flat functions of the relevant variables in a large area around the optimal solution. In simple deterministic models the difference in the present value of profits (rents), when the quotas follow the optimal adjustment path (i.e. when catches are reduced to zero without cost) while the stock increases from half of the optimal level to the optimal level, compared to when the quotas follow the simple catch rule in Equation (7), is around 5%. This difference becomes smaller when the stock is closer to the optimum level S^*.
22. Clark (1990), pp. 138–139 and 145 derives Equation (9) for the case where $C(H, S) = c(S) \cdot H$. Equations (8) and (9) can be derived using the same arguments.
23. See Danielsson (2000). If the objective is to maximise profits the optimal stock is slightly larger, the optimal harvest slightly smaller and the value of λ around 22%. This number is very close to 22%, which was the ratio advocated by the Governmental Working Group on the Rational Exploitation of Fish Stocks. See Vinnuhópur um nýtingu fiskistofna (1994), p. 2. After receiving this report the Icelandic government decided on a catch rule for cod where the TAC for the next quota year should be 25% of the estimated size of the fishable stock. This has been interpreted as 25% of the average of the estimated size of the stock by the beginning of the year and the forecasted size of the stock a year later.
24. Two important exceptions are capelin and herring.
25. Below $X_{t_1|t_0}$ indicates the value of the variable X at time t_1 as it is estimated at time t_0.
26. See, SEEA, 1993, pp. 19–20 (§58) and p. 94 (§265).
27. See SNA (1993), p. 268 (§12.26)
28. I.e. the effect of changes in prices of outputs and inputs.

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Appendix I

Let $p_{i,j}$ be the average price of species i fetched by vessels in vessel group j and let $q_{i,j}$ be the quantity sold. Let further ρ_i be the average lease price of the quota for species i and let vc_j and fc_j be variable cost and fixed cost respectively in vessel group j. Estimated profit (rent) in vessel group j from catching species i is then

$$\pi_{i,j} = \left(\sum_i p_{i,j}\, q_{i,j} - vc_j \right) \frac{\rho_{i,j}\, q_{i,j}}{\sum_i \rho_{i,j}\, q_{i,j} - fc_j \frac{p_{i,j} q_{i,j}}{\sum_i p_{i,j} q_{i,j}}} \tag{A.I1}$$

And

$$\pi_i = \sum_j \pi_{i,j} \tag{A.I2}$$

gives the estimates of profits from fishing for each species reported in Table II in Section 3 above.

Appendix II

Table A.II. Basic data for cod fisheries in Iceland

	Harvest ('000 tonnes)	Price (ISK/kg)	Revenue (Million ISK)	Cost (Million ISK)	Rent (Million ISK)
1992	267.8	74.68	19,997	18,393	1,605
1993	252.0	77.03	19,410	16,527	2,883
1994	178.8	100.54	17,977	13,969	4,008
1995	169.4	97.66	16,546	12,754	3,792
1996	181.7	74.64	13,559	11,448	2,111
1997	203.2	74.94	15,224	13,247	1,978
1998	242.6	89.19	21,640	16,898	4,742
1999	260.1	103.11	26,815	21,118	5,697
2000	235.2	109.04	25,646	20,820	4,826

ISK – Icelandic Kronas.