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TROPHIC MODELLING AS A TOOL TO EVALUATE AND MANAGE ICELAND'S MULTISPECIES FISHERIES

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ABSTRACT

The main purpose of this project is primarily to attempt, for the first time, to detail a steady-state model of tropic interactions and organic matter transfer in the Icelandic fisheries, using user-friendly software, ECOPATH (version 4 alphas). The rationale behind this is to present to the Icelanders an optional tool for the evaluation and management of multispecies fisheries such as the Icelandic fisheries. Ecopath is user friendly in a number of important features: (i) use of a "generalized linear inverse" matrix routine allowing the system of linear equations used to estimate model parameters to over- or slightly underdetermine; (ii) estimation of (almost) any set of unknowns and not only of biomasses; (iii) explicit consideration of respiratory, ejective and excretory losses (with default provided for inputs) and of the detritus pathways; (iv) estimation of numerous derived quantities on species groups or a whole-system basis, such as gross and net efficiencies, tropic levels, food electivity, pathways and cycles involving any groups and "ascendancy" *sensu* R. E. Ulanowicz.

The model presented was based mainly on published data and personal communications from staff of Marine Research Institute. It was structured around commercially important fish groups and shrimp with a top predator (i.e. *Gadus morhua* L.) evaluated at 1.3 $t.km^{-2}$. Biomass estimates obtained for other fish were considered very reasonable and comparable with estimates from analytical tools used in Iceland. The results of mixed tropic impacts, trophic aggregation, and other network analyses are presented. The input data and results are expressed on area basis and thus cover the total marine fisheries waters of Iceland. The period modeled here is 1997 and 1998.

Key words: Tropic model, Ecosystem, Fisheries management, single species, multispecies, tropic interactions, Icelandic fisheries.

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1 BACKGROUND AND JUSTIFICATION

1.1 Geography and Location

Iceland covers an area of 103,000 km^2. Off its coasts, out to a depth of 200 m, is a continental shelf with a total area of 115,000 km^2 but is 216,000 km^2 at 50 nautical miles equidistant from the baseline, rising to 750,000 km^2 at the 200-mile economic zone (Malmberg, 1991). Beyond the continental shelf limit are submarine ridges and the deep ocean.

The country is situated at a point were fronts of cold and warm ocean currents meet. Iceland is located atop several submarine ridges which define the limits of the various areas of the ocean around it. The ridges form a barrier against the three main ocean currents: the warm Irminger currents or *Gulf-stream* from the south, the cold *East-Greenland Current* and the *East-Icelandic Current* (Figure 1). These include the ridge which runs from Greenland to the British Isles, through Iceland and the Faroe Islands. This is an old area of volcanic activity from the tertiary period. It is also the so-called Mid-Atlantic Ridge, a rift system and scene of current volcanic activity joined by crystal drift, which divides the Atlantic Ocean into a western and eastern basin.

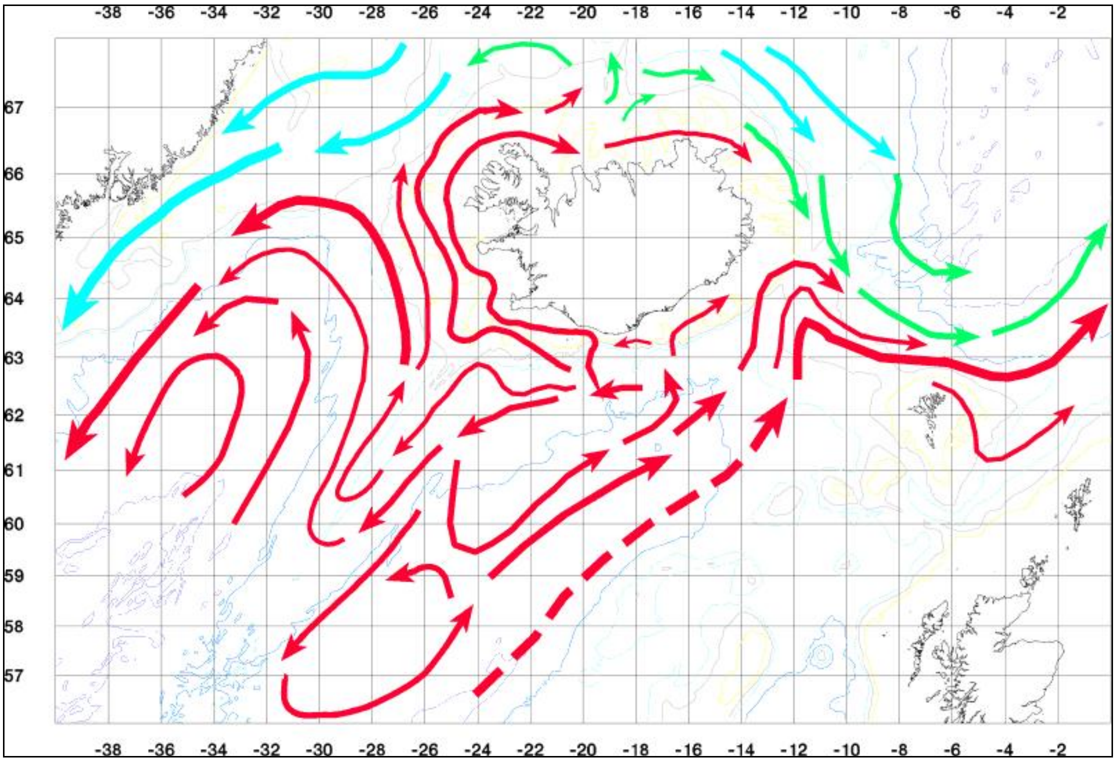

Figure 1. Shows circulation and ocean fronts in Icelandic waters derived from satellite tracked drifters. (Valdimarsson, H. and Malmberg, S.A. 1998).

The Greenland-Scotland Ridge forms a barrier against the main ocean currents around Iceland and to the south is the warm Irminger Current which is a branch of the North

Atlantic Current with a temperature range of 6-8°C. The cold East-Greenland and East Icelandic Current (1-2°C) prevail in the north. There are also deep and bottom currents in the sea around Iceland, principally the overflow of deep cold water from the Nordic Seas and the Arctic Ocean south over the submarine ridges into the North Atlantic.

1.2 The Mixing Effects

The impact of water currents with the submarine ridges, and vice versa, causes a mixing in the sea, an upwelling in the continental slopes and anti-clockwise mixing around Iceland. This phenomenon facilitates the transportation of dissolved oxygen through to the deep waters and the movement of nutrients upwards to the surface layers (Malmberg, 1991). These conditions, coupled with a fairly extensive continental shelf and the rays of the sun, form an ideal environment for the recruitment and growth of marine life, the basis for the existence of rich fishing grounds around Iceland and all human life within the country.

The hydrographic conditions in Icelandic waters are also reflected in the atmospheric or climatic conditions in and over the country and the surrounding seas, mainly through the Iceland Low and Greenland High. These conditions in sea and air have their impact on biological conditions, expressed through the food chain in the waters including recruitment and catches of commercial fishes.

1.3 Fisheries Research

The waters around Iceland, fed by the warm Gulf Stream from the south, offer exceptional conditions for fish stocks to thrive. Since understanding of the marine ecosystem is the foundation of sensible and sustainable harvesting of these resources, a key role has been assigned to marine research. Such research is the basis on which effective fisheries management can be implemented and the system that has been developed in Iceland today aims to harvest the stocks in the most responsible manner, in order to ensure and maintain maximum long-term productivity of all marine resources.

Fisheries have been important to the Icelandic nation ever since the country was settled in the ninth and tenth centuries. Today, fisheries are responsible for some 75% of Iceland's total revenues from goods exports (around 5% of the world's total fishing exports), and yield 55% of all national foreign currency earnings. During this present century, Iceland has developed from a poor agricultural nation into a modern technological society whose foundation is based on productive marine fisheries. History has shown that the cod (*Gadus morhua)* has been the most important commercial fish species. Table 1 summarizes decadal trend in catches by fish species. The value reported in this table represent only landed catches by each species and do not include catches that are discarded out at sea.

Table 1. Historical catch data in nearest '000 tons of major commercial species (from MRI report for 1997/98).

Year\Species	Cod	Haddock	Saithe	Redfish	G. Halibut	Herring	Capelin	Nephrop	N.Shrimp
1905	92								
1915	136								
1925	332								
1935	402								
1945	216								
1950	350	67	73	126					
1955	538	65	48	110		54		0.2	0.4
1965	394	99	60	114	7	763	50	4	1
1975	371	46	88	71	24	33	460	2	5
1985	325	51	57	92	32	49	1000	2	25
1995	169	61	49	90	36	300	746	1	84
1997	204	44	37	73	30	285	2	1	82

1.4 Fisheries Resources Management

After having acquired control of the territorial sea, the Icelanders took upon themselves the responsibility of seeing that the nation's fish stocks are exploited in a rational and sustainable manner. The first step in this direction was effort limitations, primarily focused on limiting the number of vessels and fishing days. These measures however, did not achieve the protection objectives they were intended to secure but rather led to inefficient use of effort and over-investment. The Icelanders as a nation that depends upon the existence, growth and development of the fish stocks could not be satisfied with a system that produced such results.

Icelanders thus looked for other fisheries management strategies, and in doing so have broken new grounds in fisheries management. Iceland is believed to be the first country to adopt a system of fisheries management based primarily on individual transferable quota shares (ITQs) which are totally transferable and divisible (Ministry of Fisheries). The ITQs allocated to fishing vessels aggregate to the total allowable catch (TAC) for a given year, which is decided on after scientists had conducted stock analyses and have made their recommendations on safe harvest levels. This quota system had the twin objectives of limiting the total catch and encouraging more efficient fishing operations, through the transfer of fishing rights among vessels and more rapid reduction of the fishing fleet.

The ITQ system is based on estimates of fishable biomass of individual species that would be available for uptake during the next fishing season. As fish survival and mortality rates are a result of many complex factors involving tropic relationships, abiotic and biotic environmental factors, etc., the understanding of how a given ecosystem functions needs a quantitative model of the interactions between its components.

The emerging consensus among fisheries scientists and managers of aquatic resources is that management and monitoring of fisheries resources should move from a single-species approach to that of an ecosystem approach, to appreciate the dynamics and inter-relationships in aquatic ecosystems. The acknowledgement of the present fishing effort and discarding practices only buttressed the apparent need for modification of fisheries management policies for biological and economically sustainable yield of fisheries resources. Despite the new awareness, the dynamics of, and interactions between, the various components of ecosystem are complex and it is difficulty to build adequate models for realistic scientific advice policies.

Although several tools (conceptual and analytical) have been in use for a considerable period of time, three of these tools have gained some grounds but none has received general acceptance; (i) multispecies virtual population analysis (MSVPA, Sparre, 1991), (ii) simpler differential equation models for biomass dynamics (Larkin and Gazey, 1982) and, (iii) bioenergetics modeling to assess impacts of changing predation regimes, mainly in freshwater ecosystems (Stewart *et al*., 1981; Kitchell *et al*., 1994, 1996). No further descriptions of these tools will be attempted here and readers are therefore referred to cite materials. In 1984, Polovina developed a simpler tool (Ecopath) for analyzing tropic interactions in a fisheries resource which was further developed by Christensen and Pauly (1992a, 1992b, 1995). Ecopath has since been widely applied to aquatic ecosystems (fisheries resource systems, aquaculture ponds and natural systems; see contributions in Christensen and Pauly, 1993), and recently also to farming systems (Dalsgaard *et al.*, 1995).

1.5 Mass-balance Models

As a mass-balance model, Ecopath has the distinct advantag that it is straightforward to parameterize and calculate, thus making it possible to standardize and to check the mutual compatibility of a set of estimates related to the ecology of single species (e.g., Jarre *et al*. 1991). Although adding dynamics to the interactions that would allow proceeding beyond modest ecosystem perturbations remains problematic, mass-balance models give a comprehensive overview of interactions in a given scenario and in situations where data requirements of more elaborate approaches are not met. Moreover, they force fishery scientists to include all ecosystem compartments relevant to fish production, rather than limiting their focus to species of major commercial interest, directing all other predation to a nebulous pool of “other food” as practiced in MSVPA (Jarre, 1998). Note that while the authors of Ecopath (Polovina 1984, Christensen and Pauly, 1992) initially emphasized the steady-state nature of the models described by Ecopath, equilibrium is not necessary for a mass-balance model to be constructed: thus, the equation of the system can include a biomass accumulation term, reflecting a change.

2 THE OBJECTIVE OF THE PROJECT

The purpose of this project is to attempt, for the first time, to integrate the inter-relationships between various species groups and fishery, using a balanced, steady-state model (Ecopath, version 4 alpha) in the Icelandic fisheries. Up to recently, Icelandic fisheries management was based on, and, evolved around a core species, the "Icelandic Cod", hence overlooking fish community structure and tropic relationships. An attempt will also be made to introduce alongside Ecopath a simulation approach (Ecosim, a module of Ecopath) which utilizes assessment results of Ecopath to construct dynamic ecosystem model to simulate and analyze changing equilibrium.

3 MATERIALS AND METHODS

The trophic community structure is analyzed with the Ecopath 4a model, see previous note. Populations and their interdependencies are described by deterministic linear equations. Characteristics of the Ecopath model are discussed elsewhere (Polovina 1984; Christensen and Pauly 1992a, 1992b). Basically, the approach is to model an ecosystem using a system of simultaneous linear equations (one for each species or group of species). The basic Ecopath equation (Christensen and Pauly 1992b) describes a steady-state ecosystem where the utilized production of each compartment corresponds to the consumption by all predators plus all exports as follows:

$$B_i.(P_i/B_i)-\sum_j B_j.(Q_j/B_j).DC_{ji}-(P_i/B_i)(1-EE_i)-EX_I- B_{acc} = 0 \quad (1)$$

where

P_i = total production ($t.km^{-2}yr^{-1}$) of group (i) over a time period considered
B_i = biomass ($t.km^{-2}yr^{-1}$) of groups(i);
P_i/B_i = production/biomass ratio ($year^{-1}$) of group (i), which under steady-state conditions, is equal to instantaneous coefficient of total mortality Z (Allen 1971)
EE_i = ecotrophic efficiency is the part production that goes to predation, catches and exports to other systems;
B_j = biomass of predator (j);
Q_j/B_j = consumption/biomass ratio ($year^{-1}$) of predator(j);
DC_{ji} = is the fraction of prey group (i) by weight in the average diet of predator (j);
EX_i = is the sum of fisheries catches of group (i) plus considered emigration to adjacent waters($t.km^{-2}yr^{-1}$); and
B_{acc} = Biomass accumulation here assumed zero.

The model requires that at least three out of the four input parameters (B, P/B, Q/B and EE) be previously known for each compartment. One of the most important features of the model is that it is based upon a series of simultaneous equations linked through the data provided by the predator-prey matrix.

Since Ecopath provides only a static picture of ecosystem tropic structure (Walters *et al,* 1997), Ecosim, a module of Ecopath is an approach which uses results of Ecopath assessments to construct dynamic ecosystem models, as systems of coupled differential equations can be used for dynamic simulation and analysis of changing equilibrium.

Ecosim uses the linear equations that describe trophic fluxes in mass-balance, equilibrium assessments (such as in Ecopath approach) and re-expressed them as differential equations defining trophic interactions as dynamic relationships varying with biomasses and harvest regimes. The Ecosim routine is incorporated in the well-documented ECOPATH software so as to enable a wide range of potential users to conduct fisheries policy analyses that explicitly account for ecosystem trophic interactions, without requiring the users to engage in complex modeling or information gathering much beyond that required for Ecopath (Walters *et al*, 1997). While the Ecosim predictions can be expected to fail under fishing regimes very different from those leading to the Ecopath input data, Ecosim will at least indicate likely directions of biomass change in various trophic groups under experimental policies aimed at improving overall ecosystem management (Walters *et al*, 1997).

3.1 The Key System Component and Key Data in Ecopath With EcoSim Model

The biota of the study area were in the present model grouped in 21 key groups (system components) defined from the available biomass and commercial importance. The economically most important species are demersal fish, such as cod (*Gadus morhua* L.), redfish (*Sebastes marinus* L.), haddock (*Melagrammus aeglefinus* L.) and saithe (*Pollachius virens* L.) as well as pelagic species where capelin (*Mallotus villosus* M) and herring (*Clupea harengus* L.) are by far the most important (Jonsson, 1983). Prawns (*Pandulus borealis* L.) have in recent times developed into the second most important species in terms of economic value.

It would be observed that economically most important fish species formed individual species groups while the rest are grouped according to their ecological or taxonomical relations. This enables species specific information relative to the ecosystem to be generated as required. Tables 2 and 3 show various system components and input data/parameters of the model. The group’s zooplankton and benthos included all species of macro-, meio- and micro fauna as well as bacterial loops. The Nekton group contains all other organisms that are capable of swimming against water currents. No information was available to provide a finer classification of these groups.

Table 2. Parameters used to describe the Icelandic Fisheries ecosystem model, 1997. An explanation of each parameter (except for GE) used in this model is given in section 3.2. in the report. GE, gross efficiency is the ratio between production and consumption. Key: () indicates values estimated assuming mass balance, * indicates values assumed after reviewing models involving similar groups and ecosystems e.g. of the North Sea, West Greenland shrimp grounds (Pedersen, 1994). EE = 0.95 for some groups are qualified guessestimates.

Group Name	Catches ($tkm.^2y.^1$)	Biomass ($tkm.^2y.^1$)	P/B $y.^1$	Q/B $y.^1$	EE	GE (P/Q)
Marine Mammals	0.00	1.745	0.010	5.000	(0.017)	(0.002)
Seabirds	0.00	0.017	0.010	35.000	(0.588)	(0.000)
Cod	0.27	1.300	0.410	3.100*	(0.894)	(0.132)
Juvenile Cod	0.00	(1.331)	0.350	3.100*	0.950	(0.113)
Haddock	0.06	0.200	0.798	3.800*	(0.975)	(0.210)
Saithe	0.05	0.213	0.686	3.300*	(0.875)	(0.208)
Redfish	0.12	2.133	0.350	4.500*	(0.942)	(0.078)
Greenland Halibut	0.04	0.153	0.618	3.500*	(0.739)	(0.171)
Other Flatfish	0.04	(0.841)	0.300	3.600*	0.950	(0.083)
Other Dem. Fish	0.03	(1.277)	0.450	3.000*	0.950	(0.150)
Herring	0.09	(0.800)	(0.700)	4.600*	(0.949)	(0.152)
Capelin	1.67	2.692	1.950	7.000*	(0.941)	(0.270)
Other Pelagics	0.03	(6.244)	0.585	4.500*	0.947	(0.130)
Nephrops	0.00	0.013	0.370	2.000*	(0.333)	(0.185)
Northern Shrimps	0.08	(1.550)	1.020	6.000*	0.956	(0.170)
Molluscs	0.02	(0.731)	0.200	6.000*	0.950	(0.033)
Benthos	0.00	(15.757)	3.000	10.000*	0.950	(0.300)
Nekton	0.00	(8.040)	.600	3.500*	0.950	(0.171)
Zooplankton	-	30.000	5.000	20.000*	(0.555)	(0.250)
Phytoplankton	-	162.667	50.000	-	(0.079)	-
Detritus	-	200.000	-	-	(0.013)	-

Table 3. Diet composition matrix for the Icelandic Fisheries ecosystem model, 1997.

Prey\Predator	1	2	3	4	5	6	7	8	9	10
1 Marine Mammals	-	-	-	-	-	-	-	-	-	-
2 Seabirds	-	-	-	-	-	-	-	-	-	-
3 Cod	0.020	-	-	-	-	-	-	0.020	-	0.005
4 Juvenile Cod	0.010	-	0.040	-	-	0.001	0.005	0.030	0.010	0.025
5 Haddock	0.008	-	0.005	-	-	0.010	-	-	-	-
6 Saithe	0.003	-	0.013	-	-	-	-	-	-	-
7 Redfish	0.010	-	0.052	-	0.003	0.010	-	0.040	0.060	0.020
8 Greenland Halibut		-	0.005	-		-	-	-	-	-
9 Other Flatfish	0.010	-	0.027	-	0.007	0.002	-	-	-	-
10 Other Dem. Fish	0.050	-	0.020	-	-	-	-	-	-	0.002
11 Herring	-	0.005	0.005	-	-	0.001	-	-	-	-
12 Capelin	0.120	0.387	0.270	-	0.100	0.290	0.030	0.080	0.037	0.037
13 Other Pelagics	0.020	0.014	0.052	-	-	0.001	0.020	0.060	-	-
14 Nephrops	-	-		-	-	-	-	-	-	-
15 Northern Shrimps	0.010	-	0.111	0.150	0.035	-	0.013	0.040	0.033	0.033
16 Molluscs	-	-	-	-	-	-	-	-	-	0.030
17 Benthos	0.059	0.417	0.110	0.410	0.532	0.080	0.150	0.050	0.500	0.458
18 Nekton	0.180	0.040	0.085	0.070	0.013	0.260	0.040	0.250	0.200	0.200
19 Zooplankton	0.500	0.077	0.205	0.270	0.310	0.344	0.742	0.130	0.040	0.040
20 Phytoplankton	-	-	-	0.100	-	-	-	-	-	-
21 Detritus	-	0.060	-	-	-	0.001	-	0.300	0.120	0.120
Total	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

Table 4. (Cont. of table 3). Diet composition matrix for the Icelandic Fisheries ecosystem model, 1997.

Prey\Predator	11	12	13	14	15	16	17	18	19
11 Herring	-	-	-	-	-	-	-	0.015	-
12 Capelin	-	-	-	-	-	-	-	0.001	-
13 Other Pelagics	-	-	-	-	-	-	-	0.100	-
14 Nephrops	-	-	-	-	-	-	-	-	-
15 Northern Shrimps	-	-	-	-	-	-	-	-	-
16 Molluscs	-	-	-	-	-	-	-	-	-
17 Benthos	-	-	-	0.300	0.300	0.350	0.200	0.034	-
18 Nekton	-	-	-			0.150	-	-	-
19 Zooplankton	0.900	0.900	0.800	0.500	0.550	0.300	-	0.850	-
20 Phytoplankton	0.100	0.100	0.200	0.050	0.050		0.200	-	1.000
21 Detritus	-	-	-	0.150	0.100	0.200	0.600	-	-
Total	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

3.2 Parametrization and Source of Data

Steady-state models are less data hungry than simulation models. At the same time, steady-state models are very useful for making summaries of available data and trophic flows in a system (Christensen and Pauly 1993). Most importantly, these models help identify gaps in one's knowledge about an ecosystem. Together, this makes steady-state models a good starting point for ecosystem modeling (Christensen and Pauly, 1993). Although this model requires very limited data, certain requirements must be met. It is normal that one of the parameters B_i, P/B_i, Q/B_i or EE_i may be unknown and in special cases that Q/B_i may be unknown in addition to one of the parameters mentioned above. Below are attempts to briefly explain these input parameters and their data sources.

3.2.1 Biomass (B)

The biomass estimates and catches used here are obtained from the 1998/99 annual report on the state of marine stocks in Icelandic Waters by the MRI, Sigurjónsson and Víkingsson 1997 contribution to NAFO/ICES symposium on the Role of Marine Mammals in the Ecosystem, Lilliendahl and Solmundsson, 1997 estimate of summer food consumption of six bird species in Iceland and personal correspondence from individuals working on particular species or group of species in the Marine Research Institute. Although there exists a lot of data in the institute on limited number of species (important commercial species) there are also serious data gaps for most species. These data gaps on some groups or system components are explained by the inclination towards management of Icelandic fisheries resources based on single species which led to strong data requirements in all the more important time series data for VPA analysis. Biomass estimates used here are for fishable stocks only, see the 1998/99 report.

In this model biomass of a group was assumed to be constant for the period (1997) covered by the model and that an average biomass can be used as representative of the biomass of each group. A biomass accumulation term could have been to the left-hand term of equation (1), had this assumption not be met (see above). The units used are $t.km^{-2}year^{-1}$ as given in Table 2.

3.2.2 PB - the production/biomass ratio

Production/biomass (P/B) ratio and total mortality (Z) were shown by Allen (1971) to be identical, under steady-state, when von Bertalanffy growth and exponential mortality are assumed (Christensen and Pauly, 1992). One of the assumptions for Z = P/B can be Von Bertalanffy growth and constant mortality across ages. To approximate this assumption one may need to base Z on F+M where F is a population weighted average over all ages. Thus, P/B is taken as Z for the major fish species of Iceland, i.e., Ratios for Cod, Haddock, Saithe, Greenland Halibut, Herring and Capelin were taken from the State of the Marine Stock report for 1998/99, MRI. The rest were either from sources mentioned in the biomass section or qualified guess estimates following review of literature or other published models of similar species and ecosystems. In instances where data was available, Z was calculated.

3.2.3 QB - the consumption/biomass ratio

The consumption parameter expresses the intake of food by a group over the time period considered and it is entered as consumption over biomass ratio, (QB). Most QB estimated values were assumed after reviewing models involving similar groups and ecosystems e.g. the North Sea (Christensen 1995) and West Greenland shrimp grounds (Pedersen, 1994). Attention is also drawn to sources quoted above. But where total consumption and biomass of species group, exist, QB was calculated e.g., whales.

3.2.4 EE - the ecotrophic efficiency

Ecotrophic efficiency (EE) is used here to express the proportion of the production for any group that is utilized for predation, catches or biomass accumulation in the system. This parameter, scaled between 0 to 1 is difficult to estimate and can for most groups be expected to be closer to 1 than to 0 (Christensen, 1995). The EE is linked to the non-predation mortality, M0, $EE_i = 1-(M0_i / P_i)$. EE = 0.95 was assumed for some groups as a qualified guess, assuming M0 to be low.

3.2.5 DC - Diet Composition

Diet composition (DC) is the average composition of the food of each consumer organism on a weight basis. The diet composition of the groups were obtained from published literature such as the feeding habits of demersal fish species in Icelandic waters (Palsson, 1983, Sjávarnytjar við Ísland Gunnarsson, *et al*., 1998), Cetaceans and Seabirds reports mentioned earlier in the report and from other models cited here. It should be mentioned also that more quantitative work on feeding habits of Icelandic marine fauna need to be carried out.

4 RESULTS AND DISCUSSION

The prevalent fish stock management strategy employed in Iceland is single species oriented and more or less centered and evolved around key fish species; cod, haddock, saithe and others as already mentioned in this report. As the saying goes, “no fish is an island”. It is therefore pertinent to look beyond single species management tools to ensure the sustainability of fisheries in the long term. This pilot project was initiated to examine the use of a mass balance steady-state model which incorporates fish community structure to come up with trophic relations in the Icelandic fisheries.

The primary purpose of this paper is to discuss results obtained from the Icelandic fisheries model to show that steady-state models are less data hungry than VPA analysis, and the Ecopath model can be used as a management tool in the Icelandic fisheries. Although the input parameter data are scanty or available in qualitative form the model does produce reasonable results. Figure 1 below gives a graphical presentation of a food web of the Icelandic fisheries system. Here all groups are balanced, i.e., input equals output.

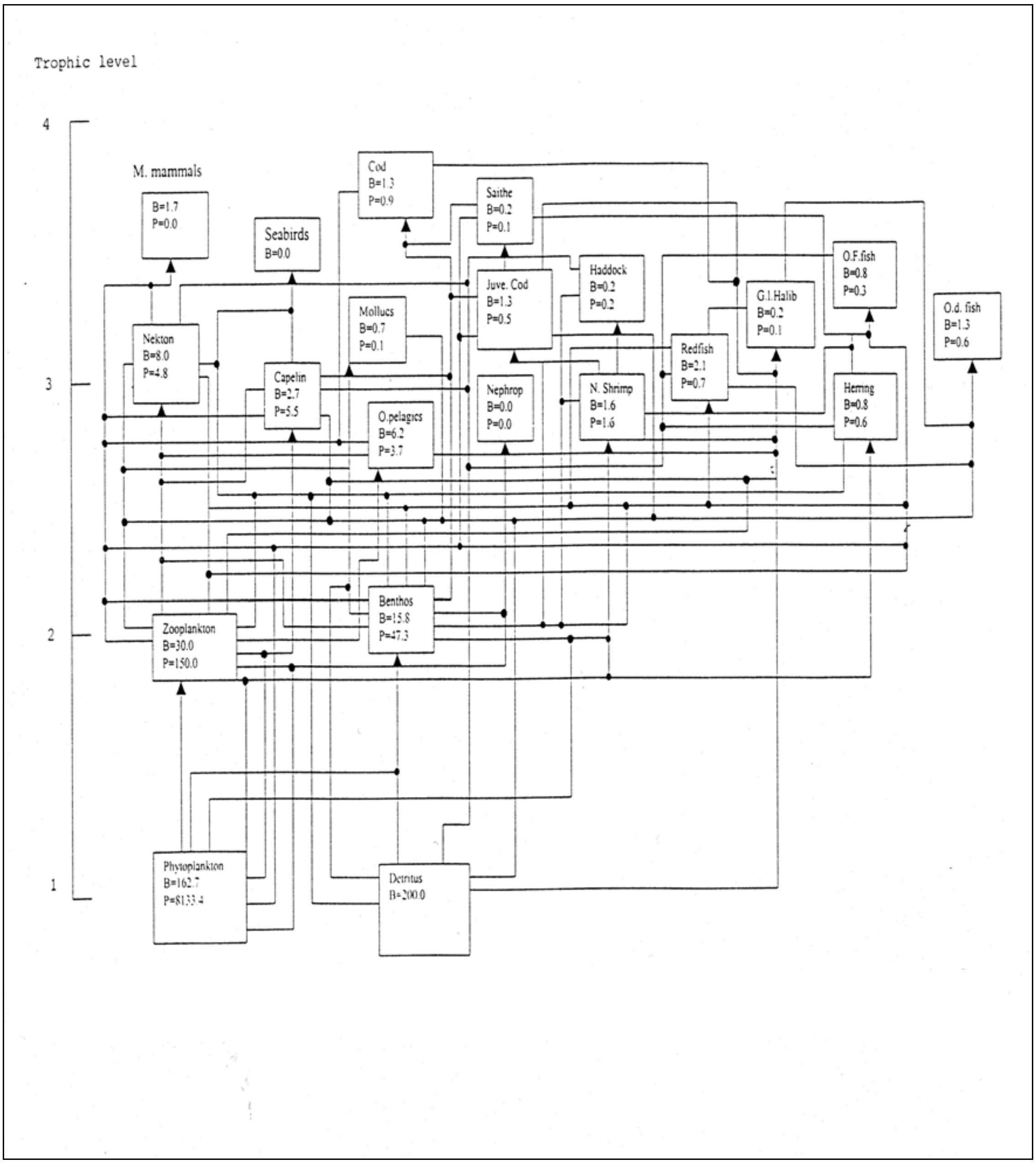

Figure 2. A network of trophic interactions in the Icelandic Sea in 1997. The boxes are arranged on the y-axis after trophic levels. The model groups are balanced so that input equals output. Flows exiting a group do so from the top or sides of a box, while flows enter at the bottom.

4.1 Parameter Estimates

The groups used in the model are given in Table 2. Input values relative to catch, biomass, P/B and Q/B ratios, and ecotrophic efficiency together with values estimated when the model assumed a balanced state are also given. All groups (key components) are balanced so that input equals output and hence express the inter-relationship among the species and the fishery in the Icelandic fisheries system. Biomass estimates and P/B ratios excluding those estimated by the model came from resources survey reports of the MRI. The original input values of biomass and P/B ratios for the herring group obtained from the above report were, on assuming a balanced state, increased from 0.58 $t.km^{-2}$ and 0.35 to 0.8 $t.km^{-2}$ and 0.7 respectively. This may be due to an underestimation of these parameters by the analytical method(s) used by MRI. A 0.95 estimate of ecotrophic efficiency (EE) was assumed and inputted for groups as necessary. It is reasonable to assume that most of the production in an exploited system will be predated upon or fished. This assumption, though, may not be true for top predators with little or no fishing and predation pressure. The apex predator, cod, in the model endures quite a considerable fishing pressure and significant predation in the early stages of life.

Here a separate group for juvenile cod was modeled due to the cannibalistic behavior of the adult cod (Bogstad, *et al*, 1994). The model biomass estimate for the juvenile cod group is 1.331 $t.km^{-2}$ and 1.550 $t.km^{-2}$ for northern shrimps.

A close look at the gross food conversion efficiency (GE), which for any group is the ratio between its total production and total food consumption revealed that the GE value for capelin was slightly high as this ratio for most vertebrates ranges from 0.05 to 0.25 (Christensen, 1995). The high GE can be probably attributed to a low consumption estimate. Apart from this observation, parameter input values used here seem reasonable and hence led to an easily balanced model.

4.2 Prey-Predator Matrix

A prey-predator matrix was constructed on the basis of the relative food item proportions within stomach of groups shown in Table 3 and 4. Food habit studies carried out in the Icelandic fisheries area are mainly qualitative in nature while for some groups, no feeding studies had ever been conducted. The deficit in data on feeding habits has been addressed here by using diet composition of similar species studied in similar ecosystems and adjusting them to fit the model. Basically, once the initial diet vectors were determined, the approach consisted in adjusting these vectors in order to satisfy the pre-established limits on EE and other model inputs. In most cases minor adjustments of the order of 0.025% to 0.05% were applied to satisfy model requirements.

4.3 Trophic Transfer Efficiency

Since Lindeman (1942), it has often been assumed that tropic transfer efficiencies in ecosystems vary around 10%, so that one-tenth of the energy that enters a trophic level is transferred to the next trophic level; and that the tropic transfer efficiency gradually decreases on the higher trophic levels due to increased respiration (Lindeman 1942; Burns 1989).

Using the trophic aggregation routine in Ecopath (Christensen and Pauly 1992a) based on Ulanowicz (1995), the flows in a system can be distributed by trophic levels and the transfer efficiencies can be estimated. The tropic transfer efficiency of the Icelandic system shows higher transfer efficiencies at lower trophic level (3, 4) as seen in Figure 2. The average trophic transfer level of the system was estimated at 9.72 which are close to the commonly used 10% rule.

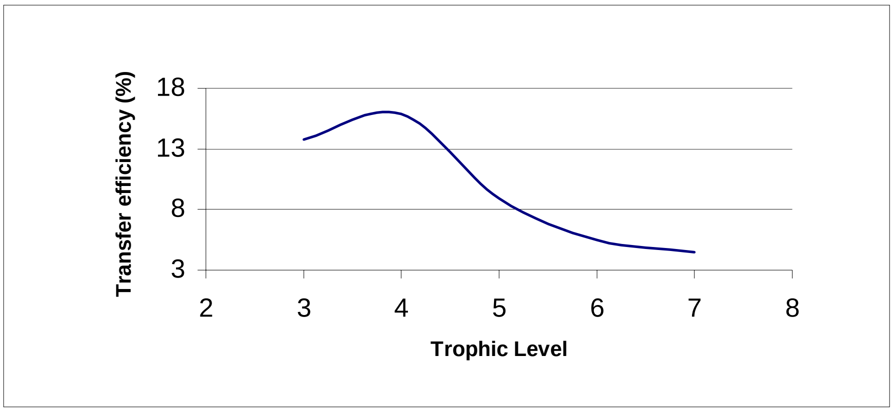

Figure 3. The trophic transfer efficiency in the Icelandic system. Mean = 9.72

4.4 Primary Production Required to Sustain Consumption and catches

Table 5 gives the primary production required to sustain consumption of various groups in the Icelandic ecosystem. The total primary production and detritus available in the system are 639.7 and 7739.9 $t.km^{-2}-yr^{-1}$ respectively. It could be observed that only 880.57 $t.km^{-2}-yr^{-1}$ was consumed by all the model groups. All the groups except benthos and zooplankton (whose PPR/Con. ratios amounted to 1) consumed less than the production.

Table 5. Estimates of primary production and detritus required to sustain consumption and catch ($t.km^{-2}.yr^{-1}$) in the Icelandic ecosystem, arranged in descending ecological cost.

Group	PPR	Con	PPR	Catch	E.cost
Cod	106.7	4.0	54.5	0.3	26.5
Marine Mammals	216.6	8.7	3.7	0.0	24.8
Greenland Halibut	10.4	0.5	4.5	0.0	19.4
Other Dem. Fish	68.5	3.8	3.5	0.0	17.9
Other flatfishes	49.1	3.0	7.2	0.0	16.2
Saithe	11.2	0.7	3.8	0.1	15.9
Molluscs	36.2	4.4	5.9	0.0	8.3
Juvenile Cod	33.7	4.1	0.3	0.0	8.2
Seabirds	4.5	0.6	2.6	0.0	7.4
Haddock	5.1	0.8	1.9	0.1	6.8
Nekton	183.0	28.1	0.2	0.0	6.5
Redfish	61.5	9.6	9.7	0.1	6.4
Herring	13.6	3.7	2.1	0.1	3.7
Capelin	49.8	13.5	15.8	1.7	3.7
Other Pelagics	95.5	28.1	0.7	0.0	3.4
Northern Shrimps	31.2	9.3	1.7	0.1	3.4
Nephrops	0.1	0.0	0.0	0.0	3.2
Benthos	157.5	157.5	0.0	0.0	1.0
Zooplankton	600.0	600.0	0.0	0.0	1.0
Total	1734.2	880.6	118.0	2.5	183.7

The primary production and detritus required to sustain the consumption of each of the groups in the system and the catches were quantified by Ecopath 4a (Table 5). The model calculated total primary production required to sustain catches to be 118.0 $t.km^{-2}$, of which 54.5 $t.km^{-2}$ and 15.8 $t.km^{-2}$ were required by cod and capelin respectively. The catch of 1997 required only 1.41% of the available primary productivity. The efficiency of the fishery which is calculated as a ratio of the sum of all catches and total primary production is 0.0003. (Table 9). Various authors have collected the ratio between primary production and (potential) fishery catches (see Polovina and Marten, 1982). The global rated average efficiency of fisheries is about 0.0002 (Christensen and Pauly 1992).

In Table 5, the groups are arranged in the order of ecological cost ratio. It gives more details on ecological cost to maintain different groups in the system. This ratio is presented here as a measure of the “food web price” for having a group in an ecosystem, and as such it is a measure related to the ´emergy´ concept of Odum

(1988). Emergy expresses how much solar energy equivalents a flow in a system represents. Cod is observed to be the most costly group to have in the Icelandic system with 26.5 points followed by marine mammals with 24.80.

4.5 Trophic Aggregation

Apart from being able to calculate group-specific fractional trophic levels as suggested by Odum and Heald (1975), a routine has been included in Ecopath which aggregate the entire system into discrete trophic levels *sensu* Lindeman (1942). In order to clearly show the trophic structure of the Icelandic fisheries system the flows in this system were aggregated in discrete trophic levels using the method suggested by Ulanowicz (1995). Table 5 shows the results produced by the trophic aggregation routine in Ecopath. The results shows that the most important group in trophic level II is benthos, on trophic level III it is the nekton, other pelagic and capelin that dominate while marine mammals and cod dominate trophic level IV. Table 5 also shows the trophic levels of the group sorted in descending order. Cod is seen to top the league among the fish group, as expected.

Table 6. Absolute flows (t.km^{-2}yr^{-1}) by discrete trophic levels (I to VI). The groups are sorted according to their trophic levels (TL). Total flows (t.km^{-2}yr^{-1}) and biomasses (t.km^{-2}yr^{-1}) trophic level is presented. The total biomasses excludes detritus.

TL	Group Name	I	II	III	IV	V	VI	VII
3.72	Cod	-	-	1.540	2.320	0.162	0.008	0.000
3.60	Saithe	-	0.000	0.319	0.364	0.019	0.000	0.000
3.50	Marine Mammals	-	-	5.093	3.208	0.403	0.020	0.000
3.45	Seabirds	-	0.036	0.323	0.242	0.002	-	-
3.37	Other flatfishes	-	0.363	1.664	0.919	0.080	0.001	0.000
3.28	Haddock	-	-	0.652	0.105	0.003	0.000	0.000
3.26	Greenland Halibut	-	0.164	0.114	0.239	0.018	0.000	0.000
3.26	Other Dem. Fish	-	0.385	2.660	0.701	0.081	0.003	-
3.22	Juvenile Cod	-	0.413	2.899	0.788	0.027	-	-
3.14	Redfish	-	-	8.653	0.900	0.045	0.000	-
3.10	Nekton	-	-	25.484	2.656	-	-	-
3.05	Molluscs	-	0.877	2.851	0.596	0.062	-	-
2.93	Northern Shrimps	-	1.395	7.906	-	-	-	-
2.90	Herring	-	0.368	3.312	-	-	-	-
2.90	Capelin	-	1.346	12.114	-	-	-	-
2.88	Nephrops	-	0.005	0.021	-	-	-	-
2.80	Other Pelagics	-	5.620	22.480	-	-	-	-
2.25	Benthos	-	157.52 3	-	-	-	-	-
2.00	Zooplankton	-	600.00	-	-	-	-	-
1.00	Phytoplankton	133.351	-	-	-	-	-	-
1.00	Detritus	739.936	-	-	-	-	-	-
	Total flow by TL	873.290	768.49 6	98.085	13.037	0.904	0.033	0.000
	Tot. Biomass by TL	162.667	48.142	23.255	3.406	0.223	0.008	0.000

4.6 Mortality Coefficients

One output of the model is mortality coefficients (Table 6). The total mortalities (Zyr^{-1}) input to the model are based on those calculated by MRI staff using VPA methods. But where mortalities are absent the model gives estimates (Table 2). The Z of all groups is divided into its various constituents, e.g., mortality due to fishing, predation and others. For example, a weighted total mortality of 0.410 for fishable cod stock was fed into the model and the following breakdown was obtained: mortality due to fishing was 0.209, 0.157 and 0.044 were due to predation and other mortality respectively. Contrary to what some people believe, mortality exerted on most commercially important groups by fishing is lower than that due to other mortality; the estimates of natural mortality coefficients are generally higher compared to fishing mortality coefficient (Pedersen, 1994; see also table 6). According to Pedersen (1994) high natural mortality shows how difficult it is to obtain precise estimates of indices of abundance for fish and shrimps using an analytical approach such as VPA. This also affirms the need for ecosystem approach management of multispecies fisheries.

Since this is a steady-state model, fishing mortality is calculated as catch/biomass ratio where catch is a rate (e.g., t km-^{2}year-^{1}), the biomass lacks the time dimension, (e.g., is expressed as t km-^{2}). Thus the fishing mortality is an instantaneous rate, (e.g., year-1) (Christensen and Pauly, 1992). Fishing mortality of cod that produces an equilibrium state in the system is estimated at 21% of the biomass which is comparable to the 25 % set by the MRI. It is thought that although the target was 25% the actual rate of fishing was 21% of the cod stock. Fishing mortality rates that produce an equilibrium state in the Icelandic system are given in Table 7.

Table 7. Mortality Coefficients for Icelandic Fisheries ecosystem model groups (all units are in year^{-1})

Group Name	Prod./Biom.(Z)	Fishing mort.	Predat. Mort.	Other mort.
Marine Mammals	0.010	0.000	0.000	0.010
Seabirds	0.010	0.006	0.000	0.004
Cod	0.410	0.209	0.157	0.044
Juvenile Cod	0.350	0.003	0.330	0.018
Haddock	0.789	0.293	0.485	0.020
Saithe	0.686	0.231	0.369	0.086
Redfish	0.350	0.055	0.275	0.020
Greenland Halibut	0.618	0.261	0.182	0.157
Other Flatfish	0.300	0.044	0.241	0.015
Other Dem. Fish	0.450	0.023	0.405	0.023
Herring	0.700	0.107	0.557	0.036
Capelin	1.950	0.619	1.215	0.115
Other Pelagics	0.585	0.004	0.553	0.031
Nephrops	0.370	0.123	0.000	0.247
Northern Shrimps	1.020	0.054	0.920	0.045
Molluscs	0.200	0.033	0.157	0.010
Benthos	3.000	0.000	2.850	0.150
Nekton	0.600	0.000	0.570	0.030
Zooplankton	5.000	0.000	2.775	2.225
Phytoplankton	50.000	0.000	3.933	46.067

In addition, the Ecopath 4a model provides important information (Table 8) that may allow one to establish the status of an ecosystem in terms of maturity and to compare different systems (see Christensen and Pauly 1992a). The total system throughput is equal to the sum of all flows (consumption, exports, respiratory flows and flows into the detritus) within an ecosystem.

Table 8. Basic Parameter Estimates Statistics

Parameter	Value	Units
Sum of all consumption	881	t.km^2.year
Sum of all exports	7645	t.km^2.year
Sum of all respiratory flows	488	t.km^2.year
Sum of all flows into detritus	7740	t.km^2.year
Total system throughput	16754	t.km^2.year
Sum of all production	8350	t.km^2.year
Mean trophic level of the catch	3.04	-
Gross efficiency (catch/net p.p.)	0.0003	-
Calculated net primary production	8133.4	-
Total primary production/total respiration	16.7	-
Net system production	7645	t.km^2.year
Total primary production/total biomass	34.2	-
Total biomass/total throughput	0.014	-
Total biomass (excluding detritus)	237.7	t.km^2
Total catches	2.5	t.km^2.year
Connectance index	0.298	-
System omnivory index	0.208	-

4.7 Mixed Trophic Impact

Ecopath incorporates a routine based on the method of an approach developed by Ulanowicz and Pauccia (1990). This approach was first used in ecology by Hannon (1973) and Hannon and Joiries (1989) to assess the impact of any group in a system on all other groups. Mixed trophic impact routine assesses the direct and indirect effect that changes in the biomass of a group will have on the biomass of the other groups. From the mixed trophic impact analysis presented in Figure 4, it can be seen that the lower trophic level planktonic groups have higher impact on other groups of the ecosystem. The relatively small negative impact observed in the exploited groups can be seen as a result of a system that evolved over a long time. The fishing effort too has remarkably little or no negative impact on the same groups. The only harvested groups negatively impacted by fishing are cod, haddock, and saithe and Greenland halibut. These groups happen to be the most highly targeted fish species in Iceland.

Generally, fish predators impact each other negatively as confirmed by Figure 4. Also from Figure 4, it is observed that capelin and northern shrimp impact positively on the cod group. The cod have a positive impact on molluscs. This could be because adult cod preys on other demersal fish (sea catfish and others) which prey on molluscs. The juvenile cod have registered a negative impact on northern shrimps but as mentioned earlier, only slightly. Both capelin and northern shrimp have a positive impact on cod.

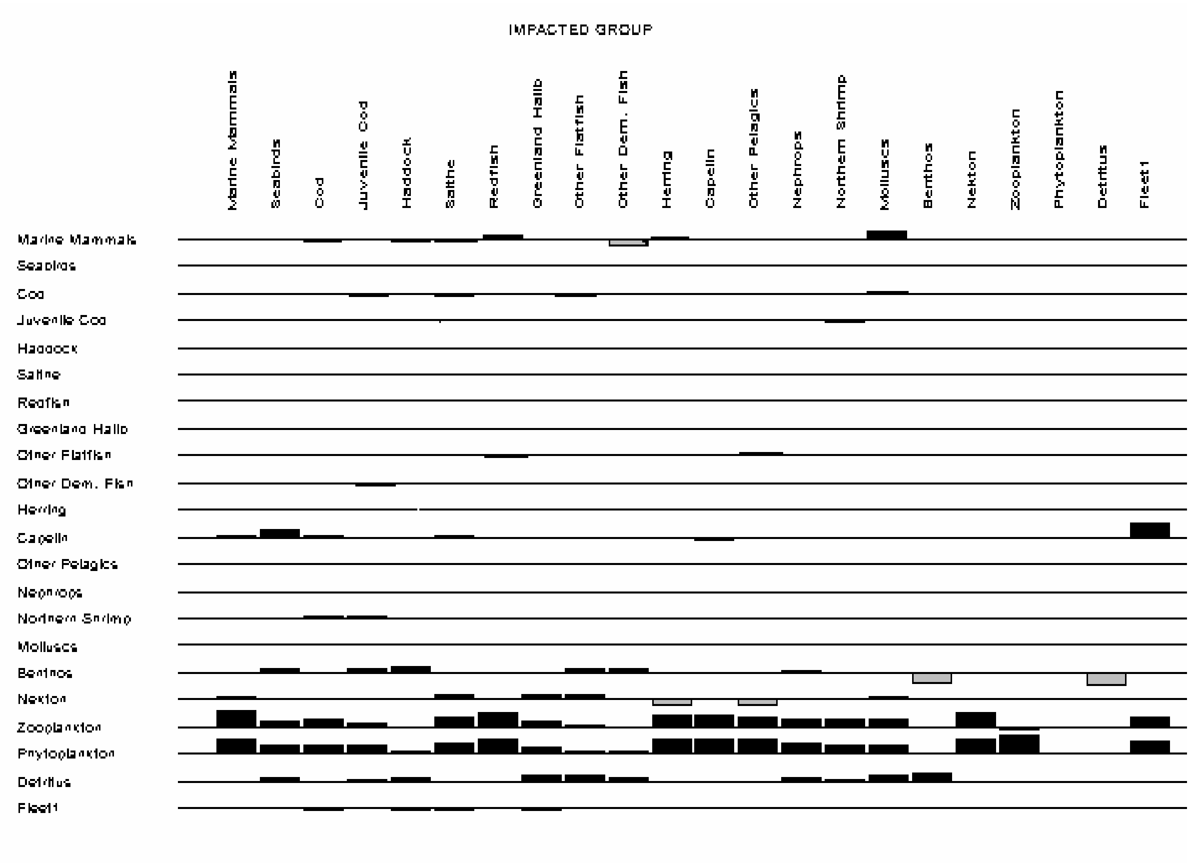

Figure 4. Mixed trophic impacts in the 1997 Icelandic system. The bars quantify the direct and indirect trophic impacts that the groups on the left have on those on the top. The impacts are relative but comparable among groups.

According to Christensen (1995), the mixed trophic impact can be seen as a simple sensitivity analysis because it gives an idea of how important the different groups in the system are for the trophic dynamics, and therefore where gains from improved parameter estimation can be expected.

4.8 Fishing Mortality and Biomass Change

As an indication of what could be achieved with Ecosim, a series of selected simulations involving some major model groups were conducted and the results are here presented. The results are relative and thus only point to the direction of biomass change and also indicate the groups likely to be affected by such changes. Figure 4 for an example of Ecosim simulation, biomass over time. In the simulation processes, fishing rates were varied to appreciate their impact on the fisheries as a whole or on the individuals. Included in the Ecosim output are fishing mortality (F.M) at which the simulated group are at equilibrium and the F.M. at which these groups are likely to collapse within the simulated time period, 10 years.

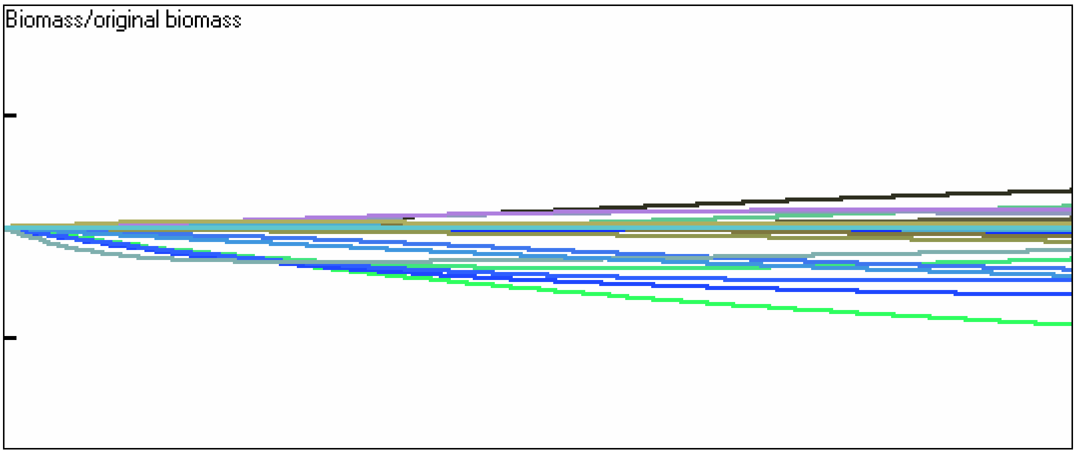

Figure 5. Shows an example of a 10 year simulation using Ecosim (adult cod is worst affected in this example)

Figure 5 shows the effect of different fishing rates or regimes applied to the Icelandic fisheries as a unit. The entire ecosystem was seen to equilibrate at F.R 1 but when F.R. 0.5, 1.5 and 2.0 were applied their effect on various groups were clearly visible as graphically presented below, (Figure 4). Only major or commercially important groups are shown in the graph.

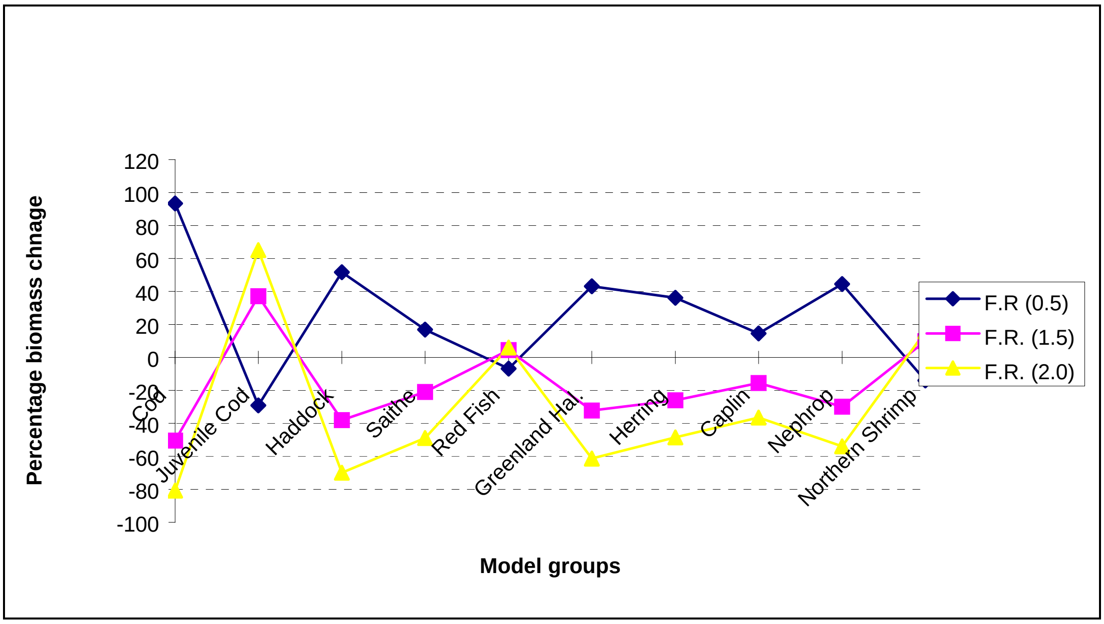

Figure 6. Simulated effect of fishing rate on Icelandic fisheries biomass and possible impact on model groups.

Ecosim is able to show fishing rates likely to cause the collapse of some major groups within the simulated time period (Table 9). Other major groups are seen to persist beyond the 10 year period under those fishing rates.

Table 9. F.M at which the

tabulated groups are likely to collapse

Group	F.M.
Cod	1.8
Haddock	2.2
Greenland Hal.	2.7
Herring	2.8
Nephrop	2.1

4.9 Individual Selected Model Groups

4.9.1 Cod Group

The cod group is seen to have equilibrated at F.M 0.21 $year^{-1}$. The effect of F.M 0.105 $year^{-1}$, 0.315 $year^{-1}$ and 0.42 $year^{-1}$ respectively on cod group was simulated and the resulted effects of these fishing regimes are shown in Figure 6. It was clear from the simulation exercise that when the cod on selected groups experiences a change in biomass other groups in the system respond accordingly confirming the assertion made earlier that "no fish is an island". According to the simulation results the cod group is likely to collapse at F.M. 0.42 within the simulated period.

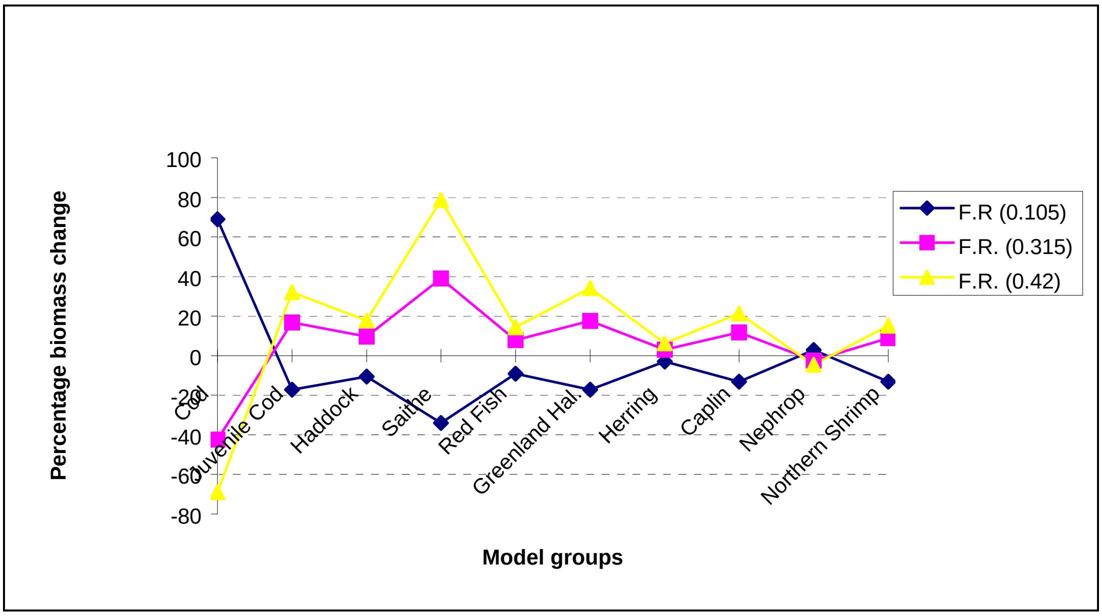

Figure 7. Simulated effect of F.M on cod group biomass and possible impact on other model groups.

4.9.2 Haddock Group

For the haddock group, the major change is on the biomass of the group itself with little or no impact on other major groups, see Figure 7 for details. The haddock group is at equilibrium with a fishing rate of 0.29 $year^{-1}$.

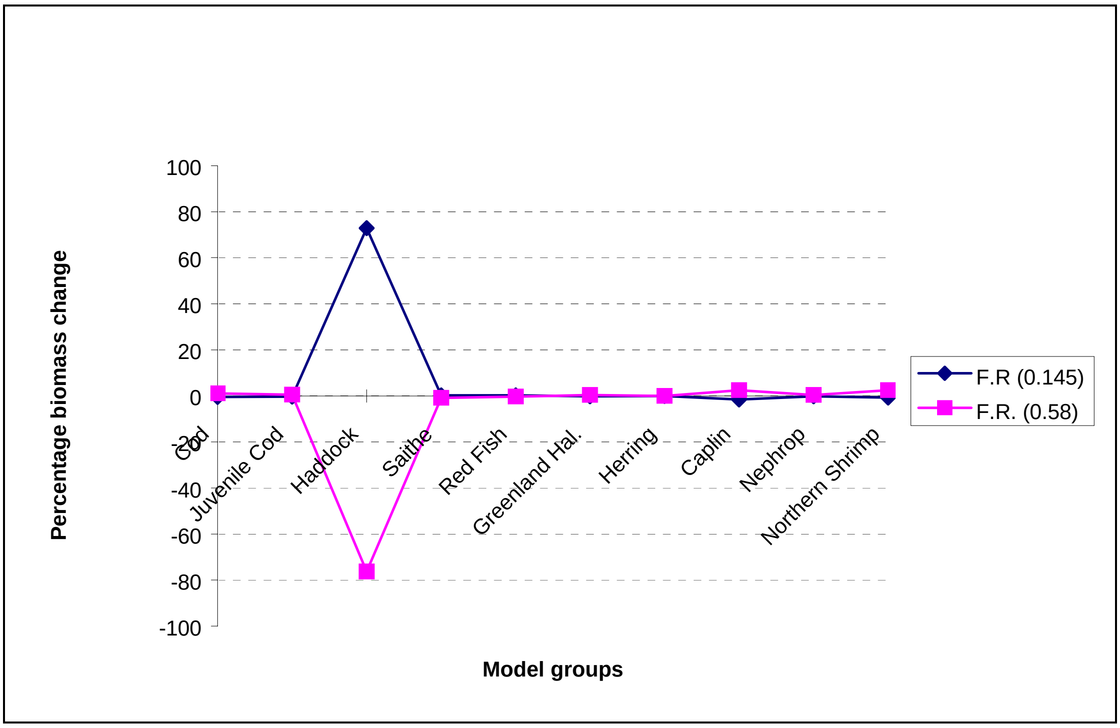

Figure 8. Simulated effect of F.M. on the haddock biomass and possible impact on other model groups

4.9.3 Northern Shrimp

No significant impact is observed on any of the major model groups when F.R. of 0.025 is applied on northern shrimp and only cod and juvenile cod groups are significantly impacted on by F.R. of 0.1. This is not surprising as both groups are major predators of northern shrimp. Table 10 gives the extent of this effect on the impacted groups. The likelihood of northern shrimp collapsing within the 10 year period is remote under these fishing regimes. Note the equilibrium F.R. on northern shrimp is estimated at 0.05.

Table 10. Shows groups affected by F.R. 0.1 on northern shrimp

Group	F.M. (0.1)
Cod	-1.9
Juvenile cod	-2.6
Northern Shrimp	-13.5

4.9.4 Capelin

Capelin is one of the major forage groups in the Icelandic system. Fishing rates applied on capelin are observed to have impact on major groups of the model (Figure 8). The estimated equilibrium F.R. is 0.62.

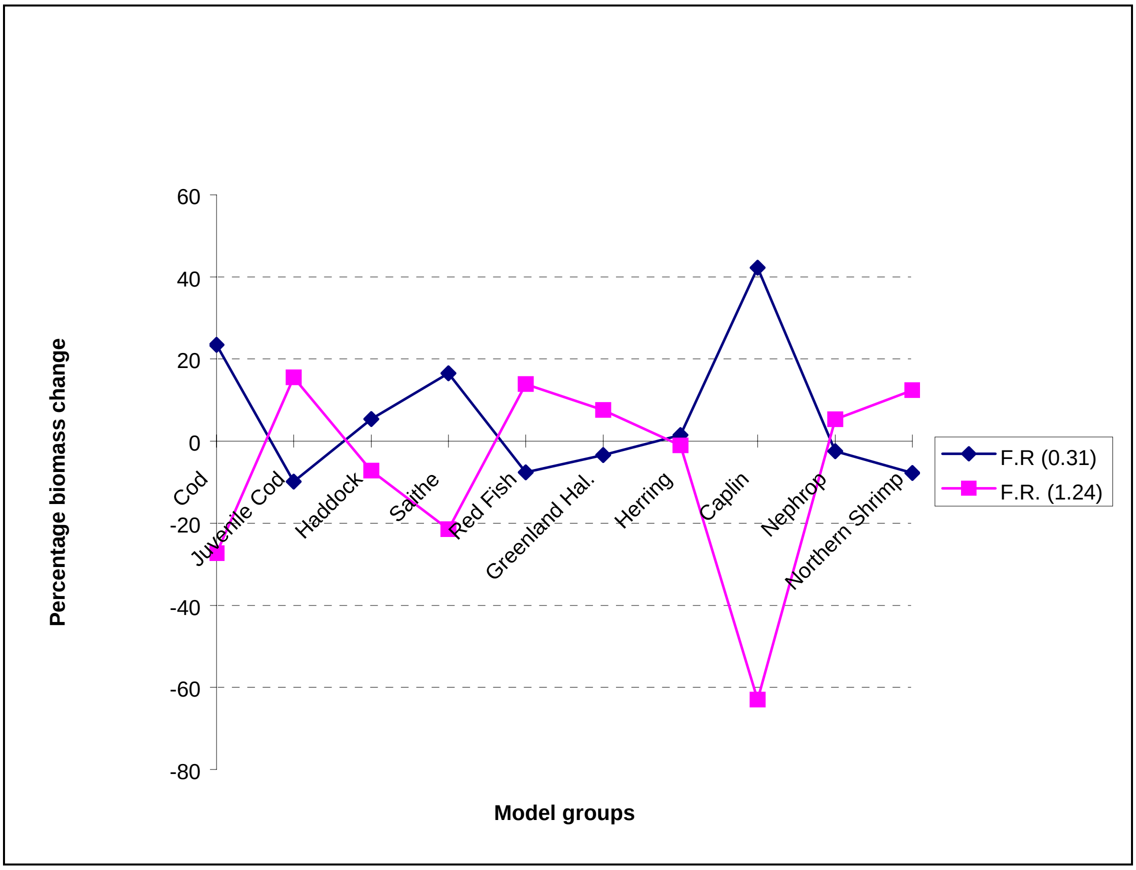

Figure 9. Simulated effect of F.R. on capelin biomass and possible impact on other model groups

5 CONCLUSION

The primary purpose of this report was to evaluate the trophic interactions and organic matter transfer in the Icelandic fisheries system using ECOPATH 4a. In spite of lack of parameter estimates for some groups, the Ecopath 4a model was reasonably balanced. The results obtained from this model were found to be reasonable and comparable with estimates obtained by other models used as fisheries management tools in Iceland. However, the seasonal shifts in the ecosystems were not considered. It is recommended, therefore, that the next modeling attempts focus on producing separate models for the different seasons where seasonal shifts and migratory patterns could be accounted for, using the seasonal version of Ecopath presently being developed at the Fisheries centre, University of British Columbia (see www.ecoparth.org)

The limited availability of parameter estimates of some groups including the main invertebrates groups of the Icelandic fisheries on an annual basis reflects a need for process-oriented studies aimed at producing such estimates. It is recommended that more analysis of feeding habits of most groups be done.

It is therefore hoped that the rationale presented in this report will help establish the potential of steady-state modeling as a tool to improve understanding of the ecosystems and hence stimulate future ecological studies in fisheries waters of Iceland.

From the selected simulations carried out in this report it is fitting to recommend further investigation into the use of the Ecosim routine incorporated in Ecopath as a valuable tool for the design of ecosystem-scale adaptive management experiments.

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