A system dynamics approach to assess the impact of policy changes in the Icelandic demersal fishery

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Abstract

Seafood is of great importance in the Icelandic economy and in 2010 the fisheries sector and related industries contributed 26% to GDP. The main stocks in Icelandic waters are controlled with individual transferable quotas. Permanent quota shares in the Icelandic demersal fisheries are allocated into two segments the so-called large ITQ-system that applies to all species and all vessels are eligible in the system which accounts for approximately 83% of total demersal catchers. The other segment, which is the case study presented in this paper, is the small boat hook system with vessels smaller than 15 gross tons and use longline or hand line as fishing gear and accounts for about 15% of total catchers. In this paper we show how the system dynamics approach is used to model an simulate changes in the management of the fisheries and the impact of these changes on chosen performance indicators.

Key words

System Dynamics, Fisheries Modeling, Fisheries Management, Using R for System Dynamics

1 Introduction

1.1 The Icelandic demersal fisheries

During the centuries, seafood has been the most important industry in Iceland's economy. With other industries growing larger, the seafood industry is still the most important one and has played an important role in the recovery of Icelandic economy after the financial crisis hit in 2008. National accounts show that exported seafood accounted for more than 40% of total export in 2011, whereof cod was 12% (Statistics Iceland 2013). Figure 1 shows the value of exported seafood as a percentage of total exports. Recent study furthermore shows that a contribution of 26% of Iceland's GDP in 2010 came from the fisheries sector or related industries, i.e. the fisheries cluster (Sigfusson, Arnason, and Morrissey 2013).

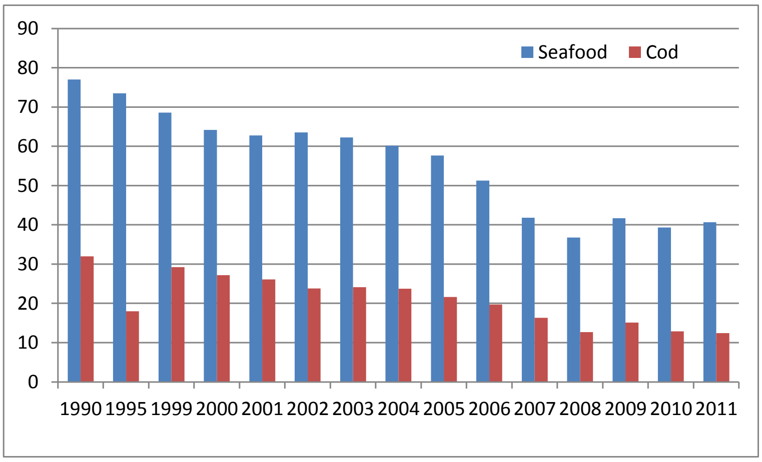

Figure 1: Ratio of seafood of total value of exports and ratio of cod in total value of seafood in during 1990-2011.

The Icelandic government has defined objectives with its fisheries management system which are to promote conservation and efficient utilization of the exploitable marine stocks of the Icelandic fishing banks and thereby ensure stable employment and settlement throughout the country (Minstry of Fisheries and Agriculture 2006). The management of the Icelandic fisheries has however been an intensive political debate ever since Icelanders gained control of their 200 miles Exclusive Economic Zone. In 1983 a new approach was taken, when effort limitations, which had been in force since 1973 were dropped and individual quotas (IQs), were adopted. The system was then made transferable (ITQs) in 1991. The new management system was based on each vessel's catch performance from 1981–1983. The first year of allocating IQs was 1984. The present comprehensive fisheries management system is still based on that allocation.

Stock levels of the main demersal target species have fluctuated during the years. In the 1980's and 1990's, stock levels of cod reached a critical level but with the ITQ system and the development of a harvest control rule (HCR) in 1995 to determine the total allowable catch, the situation was contained and now the stock is becoming quite strong. The haddock stock has historically been around 150 thousand tons except for exceptionally large year classes in 2003-2010. The saithe stock decreased significantly in the 90's, but has recuperated since then and is in stable condition (Icelandic Marine

Research Institute 2012). Figure 2 shows the levels of fishable stock of the three target species in the Icelandic demersal fisheries.

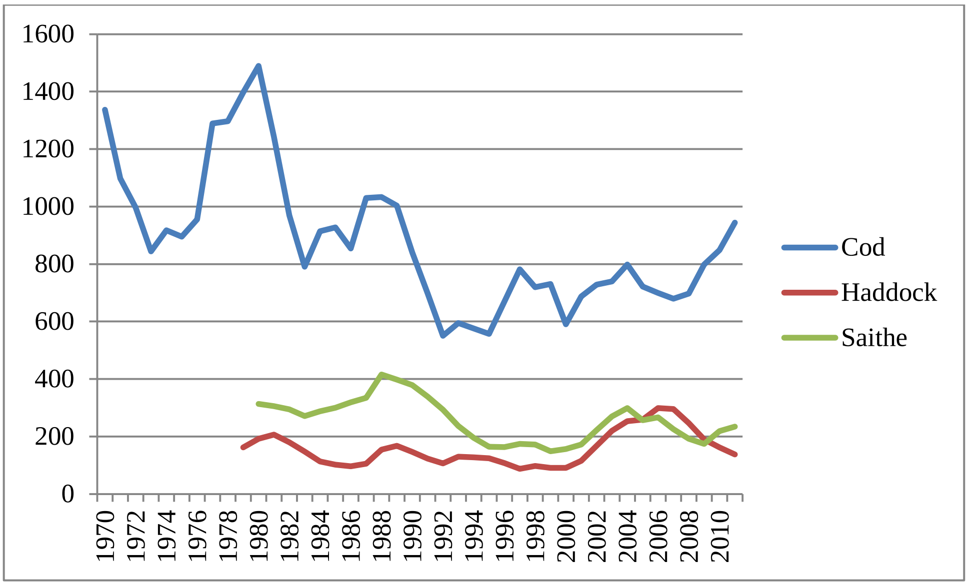

Figure 2: Fishable stock of cod, haddock and saithe in Icelandic waters (thousand tons).

The ITQ system resulted in an improved economic efficiency of the fisheries as well as biological viability as figure 1 displays (Arnason 1993, Arnason 2006). The merits of the quota system have however been heavily debated since its establishment due to the consolidation of quotas and the effect it has had on fisheries communities short of quota (Eythorsson 2000).

Regardless of whether the quota system is responsible for regional development in Iceland or not, it is clear that new policies for managing the fisheries have to be assessed in the three dimensions of sustainability; economic, environmental and social. In this paper we will show how the system dynamics approach can contribute to this by applying it to the case a management plan for small vessels within the Icelandic demersal fisheries.

1.2 System Dynamics and fisheries modeling

System Dynamics (SD) is a good tool for creating holistic models and understanding how things affect one another. Dudley (2008) has demonstrated the benefits of using SD for modeling fisheries and represented a framework that can be adapted to most fisheries. A number of system dynamics models in fisheries exist. A SD model of individual transferable quota system was constructed in order to differentiate ITQ from total allowable catch effects and identify areas where policy changes and management improvements may be most effective (Garrity 2011). Other SD models include a model for the management of the Manila clam, a shellfish fishery in the Bay of Arcachon in France (Bald et al. 2009) a model of the management of the gooseneck barnacle in the marine reserve of Gaztelugtxe in Northern Spain (Bald, Borja, and Muxika 2006) and a SD model of the Barents Sea capelin (Yndestad 2002).

Finally, a hybrid model combining SD and agent based modeling has been constructed for understanding competition and cooperation between fishers (Bendor, Scheffran, and Hannon 2009).

2 Purpose of research: The case study

Permanent quota shares in the Icelandic demersal fisheries are allocated into two segments; the so-called large ITQ-system that applies to all species and all vessels are eligible in the system which accounts for approximately 83% of total demersal catchers. The other segment, which is the case study presented in this paper, is the small boat hook system where only vessels smaller than 15 gross tons and use longline or hand line as fishing gear and accounts for about 15% of total catchers.

The proposed policy change under assessment involves re-distribution of quotas. The new plan proposes that a larger share of the total allowable catch of the target species is to be allocated to the fleet segment, partly through permanent quota shares and partly through a quota bank where only vessels from the fleet segment can bid on quota. The species that are under consideration are cod, haddock, saithe, golden redfish and catfish. The management plan was assessed in terms of chosen indicators that are measurable performance objectives based on the management goals of the resource management system. Table 1 shows the indicators used for the assessment of the new policy.

Table 1: The performance indicators defined for the management plan

Number of indicator	Description of indicator
1	Spawning stock biomass of cod, the proportion of the fish population that is able to reproduce.
2	Spawning stock biomass of haddock, the proportion of the fish population that is able to reproduce.
3	Spawning stock biomass of saithe, the proportion of the fish population that is able to reproduce.
4	Fishing mortality of golden redfish, or the ratio catch/fishable biomass.
5	Fishing mortality of golden redfish, or the ratio catch/fishable biomass.
6	EBITDA of the fleet segment, earnings before tax, depreciation and amortization.

In the next chapter, a model that describes the fishery and includes the indicators in table 1 will be presented.

2.1 A causal loop diagram

All the indicators in table 1 are measurable and can be expressed mathematically. Fisheries are however complex systems with many stakeholders with different interest and dynamics of fisheries are affected by many external factors. To get a comprehensive overview of a fisheries management system, a causal loop diagram (CLD) can be extremely useful, especially to be able to analyze the softer elements within the system. CLDs are used to display the behavior of cause and effect from systems standpoint and figure 3 shows such a diagram for our case. The diagram consists of nodes representing variables connected together. The relationship between these variables is represented by arrows which are labeled either positive or negative.

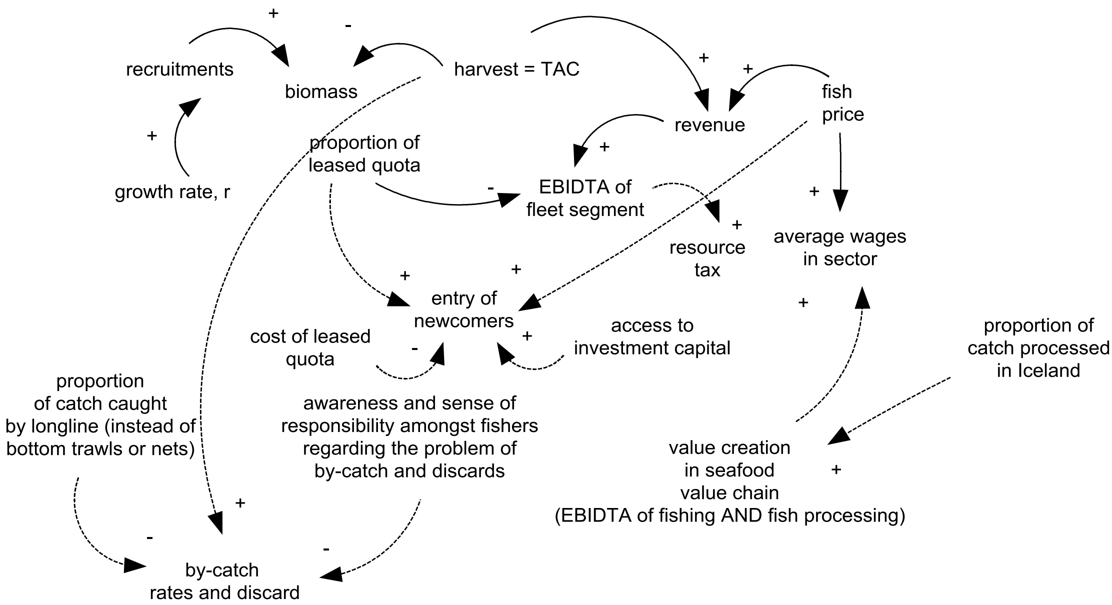

Figure 3: A causal loop diagram for the case study of the policy changes in the small boat hook system. Relationships represented by dashed lines are based on speculations rather than strong data-supported evidence.

3 Model equations

The model consisted of two sub-models, a population dynamics model, describing the growth in natural biomass of the five species and an economic sub-model. The model equations were then implemented in R which provided just the needed flexibility and support when working with large data sets such as the one containing vessel data.

3.1 Population dynamics

A simple biological model was applied to describe the biomass of the five species. It accounts for no age-structure and the population dynamics are described with a logistic function (Clark 1985):

$$x_{(t+1)} - x_t = rx_t\left(1 - \frac{x_t}{K}\right) - h_t \qquad (1)$$

where x_t is the biomass of fish at year t, r is the intrinsic growth, K the carrying capacity and h the harvest at year t. The simulation can be run multiple times with different values of growth rate. It is assumed that harvest, or total allowable catch (TAC) is determined with harvest control rules:

$$h_{t+1} = Fx_{t+1} = TAC_{t+1} = \frac{aX_t + TAC_t}{2} \quad (2)$$

where *F* is fishing mortality and *a* is harvest rate. Spawning stock biomass (SSB) is assumed to be a certain ratio, r_{SSB} of biomass:

$$SSB_t = r_{SSB} x_t \quad (3)$$

where r_{SSB} is a uniformly distributed random variable on an interval which is obtained from analysis of SSB data from the Icelandic Marine Research Institute.

3.2 Economic model

EBIDTA was derived from numbers from operating accounts of fishing companies within the fleet segment, collected by Statistics Iceland. The operating accounts are categorized by vessel size. EBITDA are earnings before tax, amortisation and depreciation. Revenue was calculated for each vessel in the hook and line system using information about quota allocation from the Directorate of Fisheries which gives information on how much quota each vessels get from the total allowable catch (Directorate of Fisheries, 2012), obtained from equation (2). Revenue for the coastal fisheries fleet was however not calculated per vessel basis, but scaled over a whole fleet. Cost was assumed as a proportion of revenue, denoted *costRev,* and these parameters were obtained from operational accounts from 1997-2011 collected by Statistics Iceland (Statistics Iceland 2013b). Oil cost was regarded as a separate variable.

$$EBITDA_t = Revenue_t - cost_t \quad (4)$$

$$Revenue_t = \sum_{i}^{species} r_{pq} p_{i,t} catch_{i,t} + r_{lq}(p_{it} - p_{lq}) catch_{i,t} \quad (5)$$

$$cost_t = \sum_{j}^{vessel\ types} costRev_{oil,j} + costRev_{other.j} revenue_{j,t} \quad (6)$$

Revenue and cost are summed up for each species, denoted i, r_{pq} is the ratio of permanent quota shares and r_{lq} is the ratio of leased quota. These parameters differ from the current management plan and the proposed plan. The total cost for each year was summed over vessel types, denoted j.

Fish price was forecasted with exponential smoothing using the *forecast* library in *R* (Hyndman 2013) Figure 4 shows an example of how cod price is predicted. Cost (and oil cost) as a proportion of revenue was assumed a fixed parameter in the simulation runs but running a sensitivity analysis for example oil cost might be insightful. Same applies to fish price fluctuations.

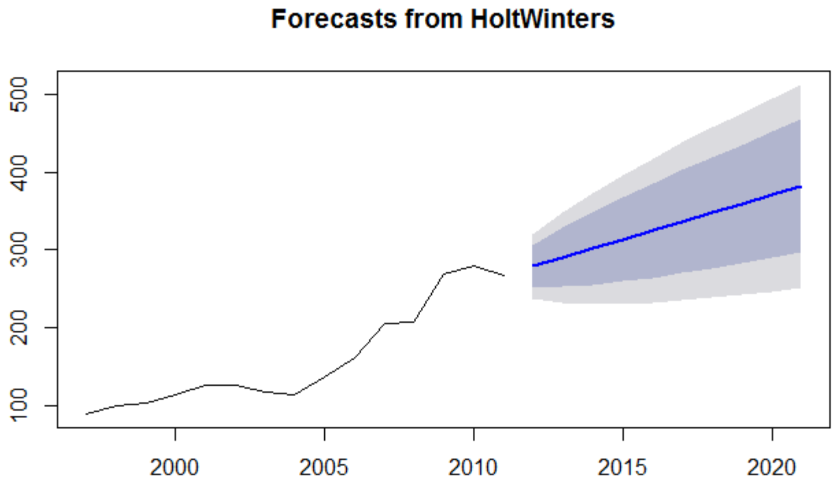

Figure 4: Predicted cod price over the next ten years. The light area represents 95% confidence interval and the darker area 80% confidence interval.

4 Model validation

By simulating a representation of the current management plan used for the fishery, the model was validated and it was confirmed that it describes the reality fairly well. Biological models were validated with catch numbers dating back as long as to 1955. Naturally, the economic calculations were somewhat simplified but they were validated against 2011 operational data, and using 2011 catch numbers, the model produced similar economic results.

5 Results and discussions

Running simulations for 10 years, the indicators shown in figure 5 were obtained. They show the simulated results (black lines) plotted with the defined minimum negative outcome. For cod, haddock and saithe these are estimates for spawning stock biomass while for the golden redfish and catfish the performance index is fishing mortality. So in the graphs representing spawning stock biomass we do not want the spawning stock biomass to fall below the red lines whereas fishing mortality should not be higher than the fishing mortality represented by the red lines. These results are directly dependent on which value is chosen for harvest rate, and in all the species we are well below the defined biological limits except for the catfish which jumps slightly over the desired fishing mortality in the last simulated year. It would be of interest to do some further sensitivity analysis for some of the model parameters, such as growth parameters and harvest rate.

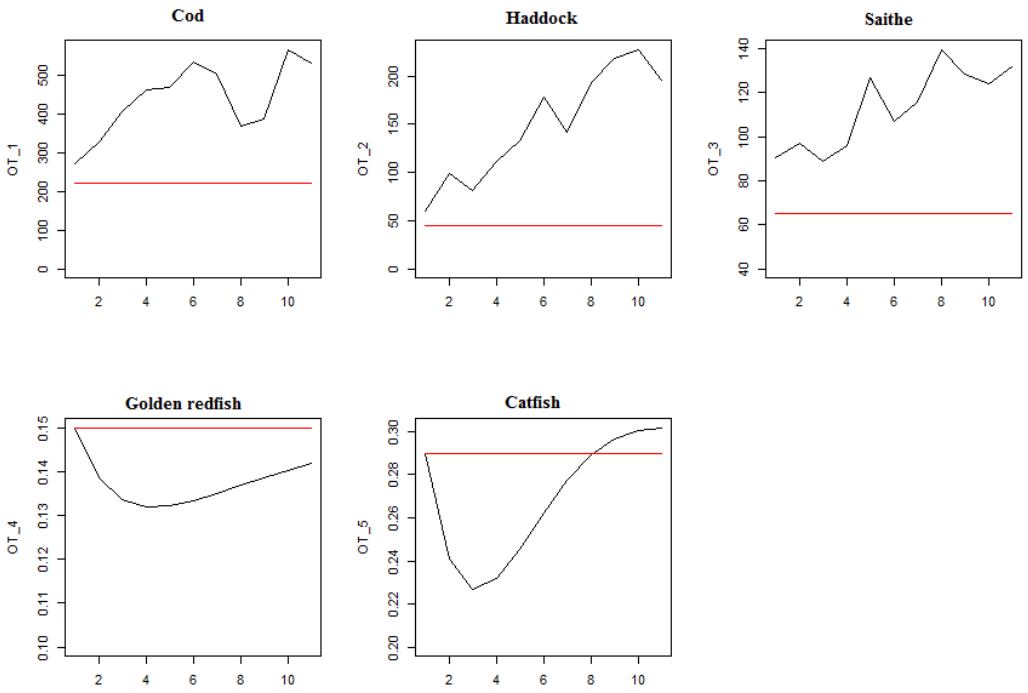

Figure 5: Results for the biological performance indicators for the five species in the model. **For** cod, haddock and saithe these are estimates for spawning stock biomass while for the golden redfish and catfish the performance index is fishing mortality.

Table 2 shows the results in terms of the economic performance indicators. The change will lead to a decreased EBITDA since cost of leasing quota will directly affect the EBIDTA calculations. Leasing quota instead of buying might however have positive effects on the total profit and financial statement position of companies as now there is less need for lending money for buying permanent quota shares, resulting decreased interest cost.

Table 2: The EBITDA obtained from simulation results. All values are in million Icelandic kronas

Current	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
3650 Mkr	1774 Mkr	1515 Mkr	1637 Mkr	1834 Mkr	2073 Mkr	2331 Mkr	2589 Mkr	2833 Mkr	3055 Mkr	3253 Mkr

6 Conclusions

Using R for system dynamics offers great flexibility and is a good platform for large data sets manipulation. The task of assessing the impact of the system in terms of the defined performance indicators was successfully solved with simulation. Creating a causal loop diagram was however very complementary to the analysis of the system as it allows for analysis of more qualitative factors as well as external factors that are hard to include in a simulation model. The study presented in this paper allows for some interesting future work such as adding dynamics for quota trade and lease.

Acknowledgements
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