Assessing the Impact of Policy Changes in the Icelandic Cod Fishery using a Hybrid Simulation Model

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Abstract: Most of the Icelandic cod is caught in bottom trawlers or longliners. These two fishing methods are fundamentally different and have different economic, environmental and even social effects. In this paper we present a hybrid-simulation framework to assess the impact of changing the ratio between cod quota allocated to vessels with longlines and vessels with bottom trawls. It makes use of conventional bio-economic models, discrete event modelling and provides a framework for simulating life cycle assessment (LCA) for a cod fishery. The model was constructed in AnyLogic and consists of two models, a system dynamics model describing the biological aspect of the fishery and a discrete event model for fishing activities.

1 INTRODUCTION

1.1 Icelandic Cod Fisheries

Historically, the seafood sector has been the single most important industry in the Icelandic economy with cod fishery as its backbone. Even though other industries have been growing larger during the years, the seafood industry is still considered the most important one. National accounts show that in the year 2011, exported seafood accounted for more than 40% of total exports, with cod explaining more than 12% (Iceland, 2013a). Figure 1 shows value of exported seafood as a percentage of total exports. Moreover, it has been estimated that the contribution of the fisheries sector and related industries, or the so called fisheries cluster, to the GDP in the year 2010 is 26% (Sigfusson et al., 2013).

In the 1980's, recruitments of cod began to reduce drastically while at the same time fishing effort remained higher than recommended by the Marine Research Institute. Stock levels of cod reached a critical level and to contain the situation a harvest control rule was developed to determine total allowable catch (TAC). In 1984, a comprehensive system of individual transferable quotas (ITQ) was introduced. In the beginning, quota was allocated

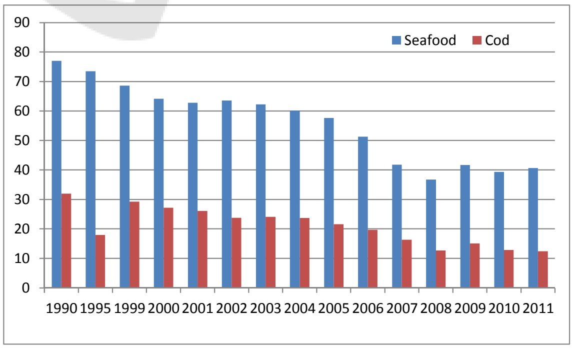

Figure 1: Ratio of seafood of total value of exports and ratio of cod in total value of seafood in during 1990-2011.

based on vessel's previous catch records. The ITQ system resulted in an improved economic efficiency of the fisheries as well as biological viability (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).

The Icelandic government has defined objectives with its fisheries management system which are to promote conservation and efficient utilisation of the exploitable marine stocks of the Icelandic fishing banks and thereby ensure stable employment and

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settlement throughout the country (Ministry of Fisheries and Agriculture, 2006).

1.2 Purpose of Study

Considering the aforementioned objectives, new policies for managing the fisheries have to be assessed in the three dimensions of sustainability; economic, environmental and social. In this paper we present a hybrid-simulation framework to assess the impact of changing the ratio between cod quota allocated to vessels with longlines and bottom trawls. It makes use of conventional bio-economic models, discrete event modelling (DES) and provides a framework for simulating life cycle assessment (LCA) for a cod fishery. The model was constructed in AnyLogic and consists of two models; a system dynamics model describing the biological aspect of the fishery and a discrete event model for fishing activities.

1.3 Fisheries Models

Most simulation research in fisheries management is based on continuous multi-parameter models. Tools that have been used previously for assisting in fisheries management are for example the multi-parameter models FLR (Fisheries Library for R) and EcoSim. The FLR framework is a development effort directed towards the evaluation of fisheries management strategies (Kell et al., 2007). Ecopath with EcoSim (EwE) is an ecosystem modelling software suite that allows for spatial and temporal modelling for exploring impact and placement of protected areas and policy assessment. It is probably the best known ecosystem model and has been applied widely in fisheries around the world.

Atlantis (Fulton et al., 2011) is a modelling framework developed to evaluate ecosystem based management strategies. It consists of a number of different linked modules: biophysical, industry and socioeconomic, monitoring and assessment.

Many other modelling frameworks exist including Gadget (Begley, 2004) and BEMMFISH (Arnason, R. and Koholka, 2003).

Most of these modelling frameworks allow for great details in the biological aspect of fisheries modelling but may lack overview in the three aforementioned dimensions of sustainability. The need for holistic modelling in fisheries has been emphasized (Dudley, 2008). 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 modelling 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 et al., 2006) and a SD model of the Barents Sea capelin (Yndestad, 2002).

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

1.4 Combining DES and LCA

Life Cycle Assessment (LCA) standardized by ISO 14040:2006 and 14044:2006 (Finnveden et al., 2009) is by far the most commonly used analysis method for evaluation of environmental footprint. LCA, however, holds drawbacks, which reduce its preciseness and limit its value for producing reliable results. The main associated problems with traditional LCA analyses are (Reap J. et al., 2003)

- Use lumped parameters and site-independent models.
- Static in nature and disregard the dynamic behaviour of industrial and ecological systems.
- Focuses only on environmental considerations, not economic or social aspects.

Hence, it can be beneficial to complement LCA with other analysis tools, in order to effectively combine environmental and economic analysis. An example of such a combination is discrete event simulation (DES) and LCA. Various different examples of successful LCA-DES combinations have been carried out and presented before (Thiede et al., 2011), (Heilala, J. et al., 2009), (Solding, P. et al, 2009); (Wohlgemuth et al., 2006).

2 BOTTOM TRAWLERS VS. LONGLINERS

Nowadays most of the Icelandic cod is captured in bottom trawls or with longlines. Use of gillnets used to be more widespread than of longlines but that has

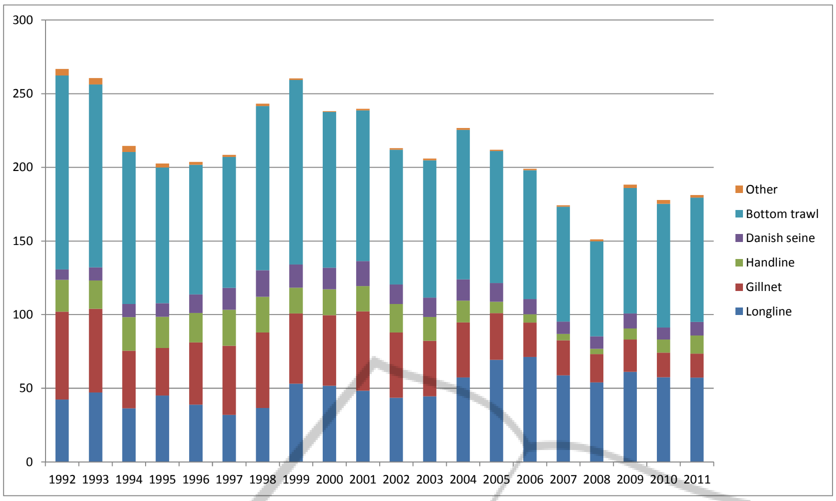

Figure 2: Total landings (thousand tonnes) of cod by fishing gear 1993-2011.

changed as figure 2 confirms. In 2011 46% of the total allowable catch for cod was captured with bottom trawls and 32% with longlines (Iceland, 2013a), so around 78% of the total allowable catch is under consideration in this study.

Bottom trawls and longlines are very different fishing gears and have different economic and environmental impacts, and potentially social impacts which are harder to quantify and measure

Economic Impact

Data from operating accounts of fishing companies collected by Statistics Iceland reveal that the larger vessels are more economically viable (Iceland, 2013b). During the years 2002-2007, the operation of smaller vessels was unstable, partly due to external factors such as high interest rates and strong exchange rate of the Icelandic krona (Agnarsson, 2012).

Environmental Impact

When comparing bottom trawls and longliners in terms of minimising environmental impact, the longliner is a far better choice. In 2009, a life cycle assessment was applied to compare the environmental impact made when producing 1 kg of frozen cod caught with a bottom trawl on the one hand and a long line on the other. The conclusion from that study was that a trawled cod has a higher impact within all categories assessed such as climate change, respiratory organics/inorganics, eco-toxicity, acidification and fossil fuel (Guttormsd, 2009).

It has been reported that the distribution of corals around Iceland began to decline when bottom trawling was initiated (Institute, 2004). The biggest drawback of longlines however are danger to marine animals such as sea birds that get stuck in the hooks of the longlines (Valdemarsen and Suuronen, 2003).

3 THE MODEL

A hybrid simulation model of the Icelandic cod fishery was constructed to assess the difference between the two fishing gears. The model consists of a System Dynamics model that describes the growth of the cod stock. Fishing activities were simulated with a Discrete Event model. Figure 3 shows a diagram of the model. The discrete event model simulates fishing trips of four different vessel types. Before a vessel starts a trip, it sends a query to the SD model to see if there is still catch quota available. If the total allowable catch is reached, no further fishing trips are planned until the TAC is updated for the following fishing year.

One of the key assumptions made in the model is that every year, the vessels reach their catch quota. This is a valid assumption as the system holds a lot of fishing capacity and there is a demand for catch quotas and landing records confirm that they are always met (Marine Research Institute, 2004).

3.1 A System Dynamics Model

The SD model describes the dynamics of the biological stock and provides the total allowable catch.

Natural Biomass Growth Function

A simple biological model was applied to describe the biomass of cod. It accounts for no age-structure and the population dynamics are described

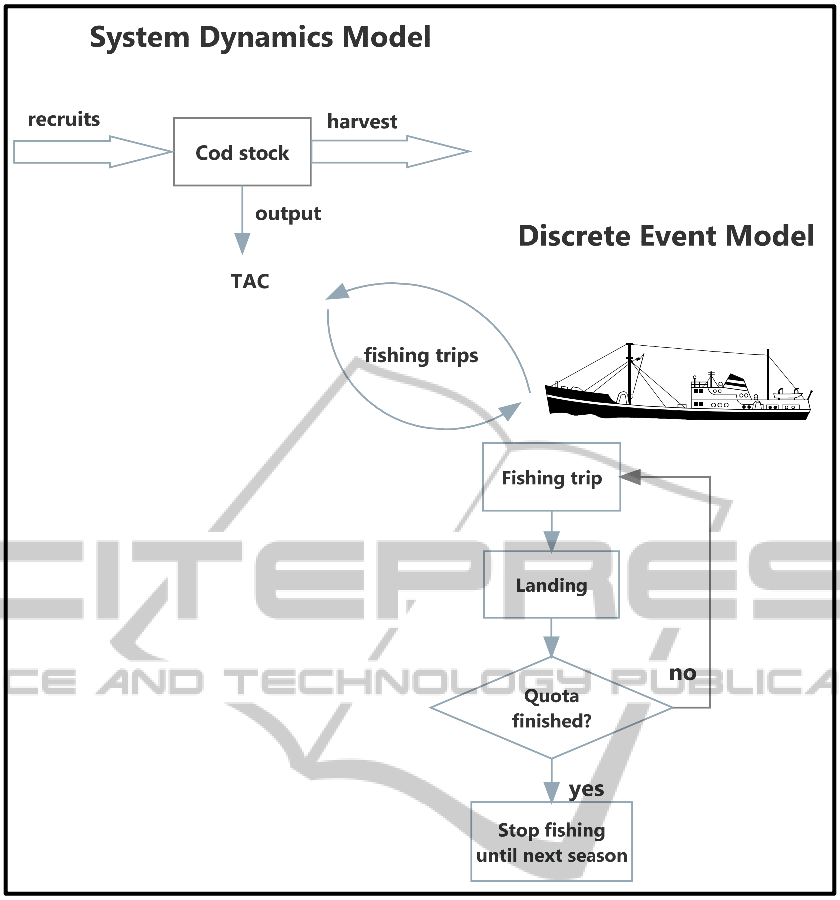

Figure 3: A diagram describing the hybrid-simulation model and the interaction between the SD model and the DE model.

with a logistic function (Clark, 1985):

$$\dot{x} = rx(1 - \frac{x}{K}) \tag{1}$$

Were x is the stock size of the fishable cod, K, is the carrying capacity and r the intrinsic growth rate of the stock.

Total Allowable Catch

The total allowable catch at a year $y+1$ is determined with the following harvest control rule:

$$TAC_{y+1} = \frac{aB_{4+,y} + TAC_y}{2} \tag{2}$$

where a represents harvest rate, and $B_{4+,y}$ is the fishable biomass at year $y+1$, which consists of cod large enough to be caught (Ministri of Fisheries and Agriculture, 2010).

3.2 Discrete Event Model

The discrete event model simulates fishing trips of three different types of longliners and a bottom trawler. Ideally the model would make use of information from logbooks and use data on trip basis, information such as duration of trip, distance sailed, and amount of catch and oil consumption as an input. In this study only public data on quota allocation and landings were used and scaled over the whole fishing fleet under consideration.

The model outputs are catch numbers, economic performance and CO_2 equivalences.

Catch numbers for each vessel are estimated with data over quota allocations published by the Directorate of Fisheries (Directorate of Fisheries 2012).

Economic Impact

Economic performance is measured by multiplying revenue with the ratio of net profit and revenue but this information is available from Statistics Iceland for different vessel types (see equation 3). Figure 4 shows the economic performance of the four different vessels during 2006-2011. This shows clearly how unstable the operating results have been for the small vessels. Average numbers dating back to 1997 were used in the model.

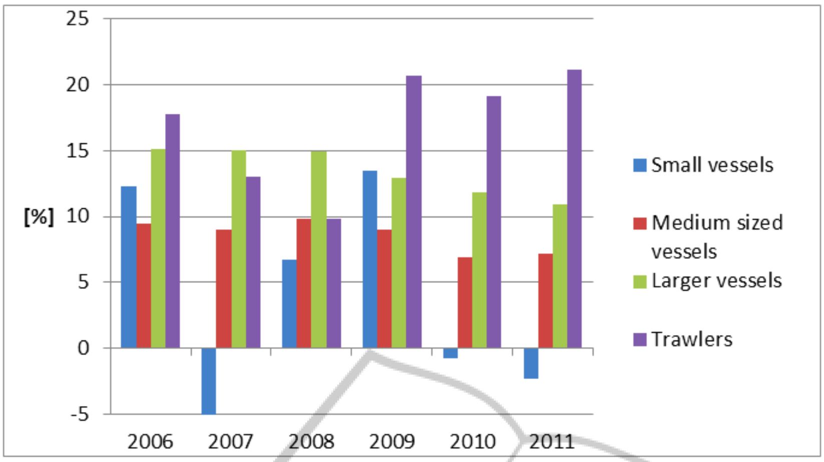

Figure 4: Profits as a ratio of total revenue by vessel type.

$$Profit = Value\ of\ fish \cdot Catch \cdot \frac{Profit}{Net\ revenue} \quad (3)$$

Environmental Impact
The environmental impact of each of the fishing gear was measured in CO_2 equivalences and based on results from an LCA carried out in 2009. That study showed that a one kilo of trawled cod had a 5.14 kg CO_2 equivalence while a long lined cod added up to 1.58 kg CO_2 eq (Guttormsd., 2009). In the same study, it was revealed that the hot spot in the life cycle of cod is the fishing phase.

Social Impact
It is not an easy task to simulate social impact of changing management policies. In this study the only social factor taken into account are number of jobs on each vessel. It might also be relevant to take jobs on-shore into account since many of the longliners do not have baiting machines on-board and thus create jobs on land.

3.3 Model Validation

The model was validated using available historical data as an input.

Biological growth
Stock assessment data from the Icelandic Marine Research Institute was fitted to the logistic model (equation 1) with a linear regression. With 57 data points, the following fit was obtained:

Table 1: Results from fitting stock data to a logistic model with linear regression.

	Parameter	t-statistic
r	0.4700	6.6559
K	2654.44	2.5561

These results are not far from results obtained by (Arnason et al., 1993). Moreover, running the model with historical catch data as an input, results are shown in figures 5 and 6.

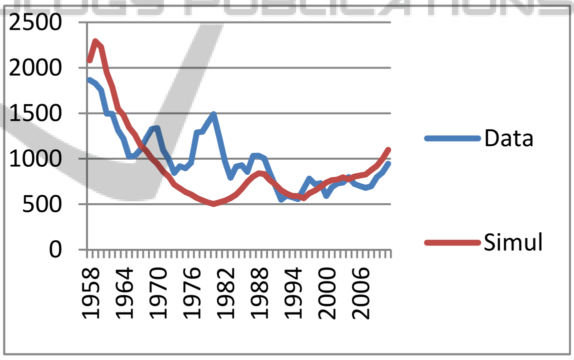

Figure 5: Comparison of output from model simulations and actual stock assessment data for fishable biomass.

There we compare our results from simulation runs with data from 1955. The model gives good results in comparison with data from the mid-eighties until present times which is the period when the demersal stocks of Iceland have been controlled under a quota management scheme and the cod stock has been quite stable. The model however does not account very well for the fluctuations in the stock due to overfishing in the years before the ITQs were imposed. These fluctuations are very visible in the graphs where there is a large gap between the blue and the red line. This we find acceptable as in the foreseeable future, the stock will without a doubt continue to be controlled with catch quotas, and thus maintain its equilibrium.

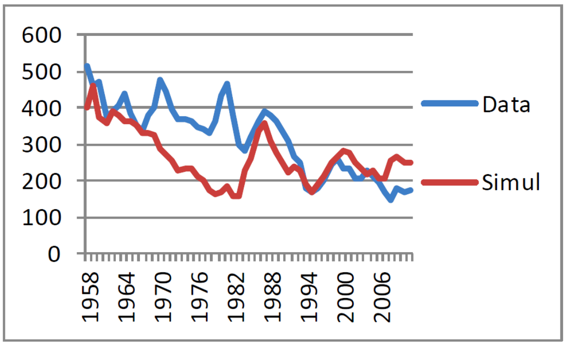

Figure 6: Comparison of output from model simulations and actual stock assessment data for landings.

Other results such as number of jobs, economic performance and number of vessels were compared to current numbers for validation purpose when running the model with actual harvest rates from historical data.

4 RESULTS

The main objective of the study was to use simulation to determine the optimal ratio of quota allocated to trawlers versus longliners with the multi-objective aim of maximising profit and number of jobs while minimising environmental impact. The model was run multiple times over ten years for different values of *q* which determines division between quota allocated to bottom trawlers and longliners. Figure 7 shows the results from these runs. The results are displayed in such a way that for each category, each value is displayed as a proportion of the best possible outcome.

The best possible economic outcome is obtained when the entire quota is allocated to bottom trawlers whereas the best environmental outcome is at the opposite end, where the entire quota is allocated to longliners. The dashed line in figure 7 shows the current allocation policy, which leans towards maximizing profitability rather than minimizing environmental impact. If the policy were to lean more towards the intersection of the economic and environmental components, we would get the best possible outcome, assuming that the two components have the same importance. The model does not take into account jobs in baiting that are created on-shore because of long liners.

By expanding the model boundaries, we are likely to see even more positive effects of long liners and a sharper contrast between longliners and bottom trawlers in terms of social aspects. This also leads to a more distribution of wealth which surely would be accounted for as a positive social

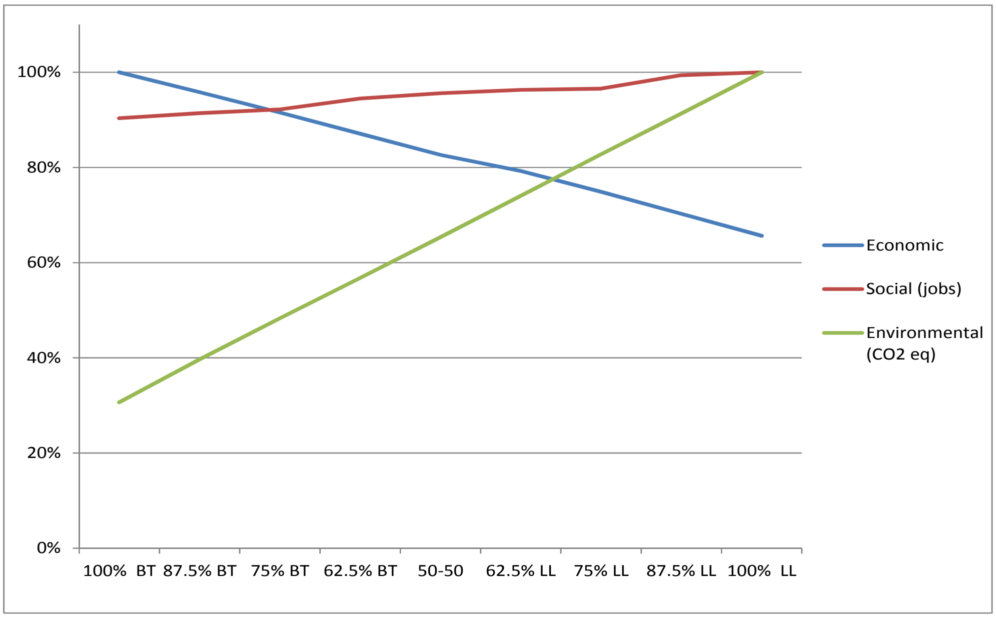

Figure 7: Main results from running simulations with different quota allocations. To the far left we display the case where the entire quota under consideration is allocated to bottom trawlers and the far right shows the opposite case with the entire quota allocated to long liners.

5 DISCUSSION AND FUTURE RESEARCH

In this paper we have presented the first steps in combining a SD and a DE model resulting in a holistic model of a system while looking at parts of it in more detail. In this study, we used publicly accessible data on landings and quota allocations, which were scaled over the whole fleet under consideration. The output of this work is a simple model which can be improved by adding more system details. Next step is to add more species but the model is easily scalable in terms of number of species. Another obvious step to make in terms of improving the analysis is to expand the system boundaries, for instance to include jobs throughout the whole value chain.

We present a simulation framework which makes it possible to combine LCA data with a hybrid DES-SD model. Using logbook data, as an input to the DE model, the fishing phase could be modelled in more detail but the fishing phase is the part of the life cycle of cod which has the most negative environmental impact due to fossil fuel consumption. With data from logbooks and more detailed operational data, the model could be more realistic and used for further scenario evaluation on quota allocation. In terms of future research, it would be possible to model agent based vessels for finding company operations revenue and equilibrium based on different quota allocations. Such a model could be used to identify opportunities to minimise environmental impact and reduce cost by simulating alternative fishing routs for the vessels.

6 CONCLUSIONS

To conclude, the findings made from the combined SD DE model shows and confirm the results in terms of clarification of economic and environmental impact of longliners versus bottom trawlers. The model also shows a need for a larger more complete modelling approach including logbooks from the vessels for increasing accuracy on catch and redirection of traffic to minimize cost and environmental impact while maintaining job opportunities.

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