fish610.080 EAFM Tools: Atlantis

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April 7, 2018

Acknowledgements

This tutorial was developed as a part of the EU H2020 project MINOUW.

This project has received funding from the European Commission's Horizon 2020 Research and Innovation Programme under Grant Agreement No. 634495 for the project Science, Technology, and Society Initiative to minimize Unwanted Catches in European Fisheries (MINOUW).

`http://minouw-project.eu/`

Contents

1 Introduction to Atlantis

1.1 About Atlantis

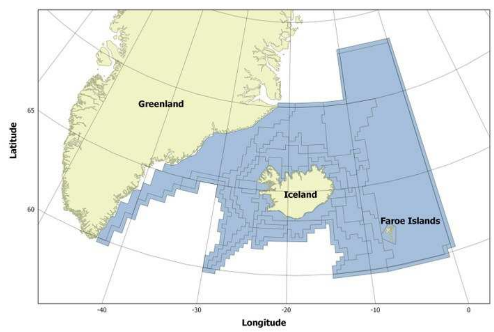
Atlantis is a modeling framework that can be used to construct ecosystem models for various marine and fresh water ecosystem. It has for example been used to model the ecosystem of: Icelandic waters, Lake Victoria, the California current and the waters of south east Australia. The Atlantis model simulates the entire ecosystem and can contain up to six modeling components: 1) oceanographic model component, 2) biological component, 3) fisheries model with multiple fleets, 4) sampling and assessment model, 5) management model, and 6) socio-ecological model. It is a deterministic model which means that if the parameters values and the initial conditions are the same the model will produce the same results. The model tracks energy flow (nitrogen) in the system. The initial source of nitrogen is set in the water and in the functional groups. Nitrogen can be added to the system with e.g. river inputs and atmospheric deposition. Nitrogen is lost e.g. to sediments and atmosphere, and by denitrification. A detailed description of framework can be found in the user guide (Az).

In this tutorial the first three model components of the Atlantis modeling framework will be described using examples from the Icelandic Atlantis model.

2 Oceanography Model

2.1 The model domain

The modeled area is divide up in spatial boxes. Factors considered when the area is split into boxes are e.g. bathymetry, hydrography, and species distribution. Each box is then further split into vertical layers. In the Icelandic Atlantis model the 1,600,000 km2 area was split into 53 boxes: 2 land boxes (Iceland and Faroe Islands), 36 active boxes (where the biology model is active) and 15 boundary boxes (to buffer water fluxes to and from the modeled area). Each box had one sediment layer and up to six water column layer (0-50m, 50-150m, 150-300m, 300-600m, 600-1000m, 1000m+), depending on the depth of the box.



The modeled are of Icelandic waters and the division into 53 spatial boxes.

2.2 Oceanography

Water fluxes, salinity and temperature need to be calculated for each box and layer for each day for the whole simulated period. A full model run for the Icelandic model is from 1948-2012, i.e. 65 years. The oceanographic data were taken from a hydrodynamic model (Logemann 2013), water fluxes were calculated for each box and layer and a forcing time-series created to imitate the water currents in the area from 1948-2012. The same was done for salinity and temperature. The water fluxes control the distribution of nutrient and plankton groups in the system.

3 Biological Model

3.1 Functional groups

There can be a number of functional groups, each modeled as a different type, e.g. vertebrates, invertebrates, primary producers, bacteria, and detritus. How the vertebrates are modeled depend also on if they are fish, shark, mammals, birds or reptiles. The invertebrates are also modeled differently for infaunal, epibenthic and water column invertebrates. The same is for the primary producers but they can be either epibenthic or not and the bacteria is either in the sediment or in the water column. There are three detritus groups: carrion which contains discards, labile detritus and refractory detritus.

There are 52 functional groups in the Icelandic model: 20 fish groups (8 represented at a species level), 5 mammals, 1 seabird group, 16 invertebrates, 5 primary producers, 2 bacteria and 3 detritus groups.

Vertebrates can have up to ten age-classes each with multiple cohorts. A vertebrate with maximum age 30 would have ten age-classes and 3 cohorts in each age class. A vertebrate with maximum age 6 would have 6 age-class each with one cohort. The model tracks number per cohort within an age-class and the weight of the age-class. The weight is divided into reserve weight (soft tissues) and structural weight (bones). When the vertebrate dies the reserved weight goes into the labile detritus groups and the structural weight into the refractory detritus group. The invertebrates can also have age-structure but are usually modeled as aggregated biomass pools with no explicit are structure.

Table 1: The 26 vertebrate groups in the model.

Group Code	Group name
FCD	Cod
FHA	Haddock
FSA	Saithe
FRF	Redfish
FGH	Greenland Halibut
FFF	Flatfish
FHE	Herring
FCA	Capelin
FMI	Blue whiting
FMA	Mackerel
FOC	Other codfish
FDC	Demersal commercial
FDF	Other demersal
FDL	Long lived demersal
FMP	Large pelagic fish
FBP	Small pelagic fish
SSD	Small sharks
SSH	Large shark
SSR	Skates
SB	Seabirds
PIN	Pinniped
WMW	Minke Whale
WHB	Baleen whales
WHT	Large tooth whales
WTO	Small tooth whales

Table 2: Invertebrates, primary producers, bacteria and detritus groups in the model.

Group code	Group name
CEP	Cephalopoda
PWN	Shrimp
ZM	Mesozooplankton
ZS	Microzooplankton
ZL	Macrozooplankton
ZG	Gelatinous zooplankton
BML	Megazoobenthos
LOB	Lobster
SCA	Scallop
QUA	Quahog
CUC	Cucumbers
BD	Deposit Feeder
BFF	Other Filter feeders
BG	Benthic grazer
BC	Benthic Carnivore
BO	Meiobenthos
PL	Diatom
PS	Pico-Phytoplankton
MA	Macroalgae
SG	Seagrass
DF	Dinoflagellates
PB	Pelag Bacteria
BB	Sediment Bacteria
DL	Labile detritus
DR	Refractory detritus
DC	Carrion (discards)

3.2 Reproduction

The reproduction of the vertebrate groups can be modeled with number of different function in the Atlantis model. It can e.g. be modeled as constant per adult, with the Beverton-Holt function or with the Ricker function. In the Icelandic Atlantis model the reproduction of fish groups were modeled with the Beverton-Holt function but the recruitment of the mammals and seabird groups were modeled as constant per adult.

The time of spawning and recruitment is set. At time of spawning the spawning biomass is calculated and the numbers of recruitment. If the ratio between reserve and structural weight is under a certain value (i.e. the group is starving) there will be no reproduction. The groups lose a certain proportion (usually 25-40%) of their biomass at the time of spawning. The larval life stage is to modeled and the recruitment comes into the model at a time set which can be months after the spawning time. The time of recruitment is also the time when aging into older age classes takes place.

3.3 Predation and consumption

The consumption rate of predators is usually modeled with Holling type I-II in the Atlantis model. In the Icelandic Atlantis model the consumption rate (CR_{ij}) of predator j on prey i is modeled with Hollig type II as follows:

$$CR_{ij} = \frac{C_j \cdot a_{ij} \cdot B_i}{1 + \frac{C_j}{mum_j}[\sum_{k=1}^{n} a_{kj} \cdot B_k \cdot E_{kj}]} \tag{1}$$

where mum_j is the maximum growth rate and C_j is the clearance rate of predator j. The ratio between the mum and the C controls how steep the consumption curve is (Figure). The B_i is the biomass of prey i, a_{ij} is the availability of that prey to predator j, and the E_{ij} is the assimilation rate of prey i for predator j. The assimilation rate was set to 0.8 which means that 80% of what the predator eats it can use for growth. The availability parameter (a_{ij}) is tuned to adjust the diet composition of each predator. The availability of each prey is also affected by the gape limitation of the predator. A gape limitation is set in the model so that the prey has to fit into the mouth of the predator. This is usually set so that the prey can not be larger than 40% of the predator weight. This is though often different for sharks and tooth whale that can prey on individual larger than themselves. The predator and prey also need to overlap spatially so the predator can feed on the prey.

3.4 Growth

The growth functions of the functional groups depends on their group type.

The growth of the primary producers depend on their growth rate and is limited by nutrients, light and space.

The growth of invertebrates modeled as biomass pools depends on their growth, (i.e. the proportion of their consumption that can be used for growth), respiration, what is lost because of predation or other mortality.

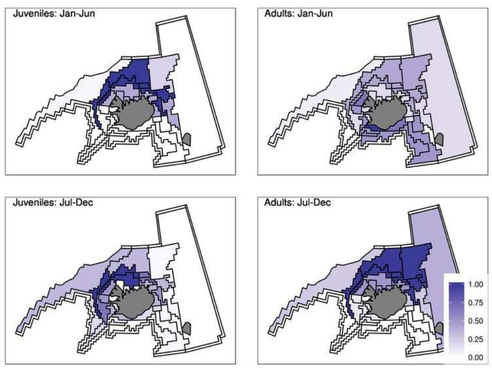
The growth for age structured groups (vertebrates) is divided between the reserve and structural weight. What affects individual growth of vertebrates are the growth, respiration, and weight lost due to spawning. The the model also tracks the number of individuals of the vertebrates. the changes in numbers depend on recruitment and ageing into the next age group. It also depends on predation mortality and other mortalities.

3.5 Mortality

Mortality can be modeled in many different ways and this also depends on the type of the functional group. Predation mortality is modeled with the consumption function, e.g. Holling type II. Additional mortalities that the model is not able to catch can be modeled with linear and quadratic mortalities. Linear mortality is a constant proportion that dies but quadratic mortality is density dependent, i.e. it increases as the density of the group increases.

3.6 Movement and migration

The modeled area is divided into spatial boxes and into vertical layers. The groups can have different spatial and vertical distribution which can be allowed to change from one season to the next. The distribution can also be different between juveniles and adults. The groups can also have migratory behavior and can migrate in and out of the model area.



Density of juvenile and adult capelin by spatial boxes and two seasons.

3.7 Initial conditions

Initial conditions need to be set before the model can simulate the ecosystem. The Icelandic Atlantis model starts in 1948 and the initial conditions are therefore set for that year. The initial condition include total numbers and individual weight for each age-class of each vertebrate group and total biomass for groups not with an age structure (invertebrates, primary producer, etc.). The model also requires initial condition of the nutrient concentrations (N, Si and O_2) in the ocean.

4 Fisheries Model

4.1 Fishing mortality

Fishing mortality can be produced by three different ways in the Atlantis model: 1) with time-series of biomass that should be removed from the system, 2) with proportion that should be harvest, and 3) with a dynamic fisheries model. Method 2 is used in the Atlantis model for Icelandic waters and will be described in this section.

Fishing mortality is set as the proportion harvested each day and is the same all days and in all spatial boxes and layers unless optional management parameters are used, such as seasonal or spatial closures. The biomass harvested ($Y_{a,g,f,t,b}$) for each age-class a of group g by fleet f at time t in box b is as follows:

$$Y_{a,g,f,t,b} = HR_{g,f} + B_{a,g,t,b} + sel_{a,g,f} + mpa_{f,b} + brok_f \tag{2}$$

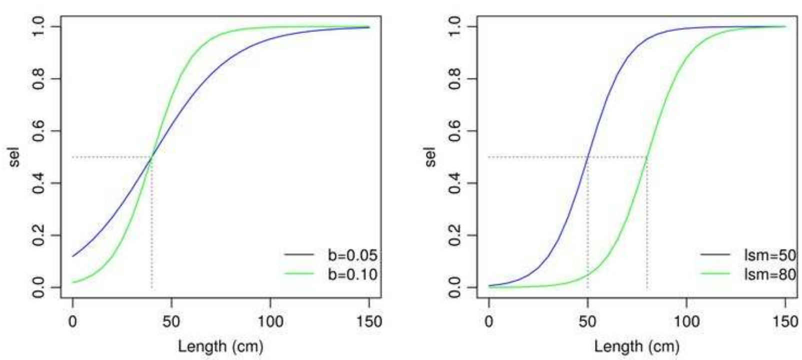
where HR is the proportion harvested per day, B is the biomass of the harvested group, sel is the selectivity which is from 0 to 1, and mpa and $brok$ are optional management parameters for closures and harvest rules, respectively. The fishing mortality (HR) and selectivity (sel) can be allowed to vary with time.

4.2 Selectivity

The fishing mortality (proportion harvested) depends on the selectivity of the fleet (fishing gear). The selectivity can be modeled in few different ways in Atlantis. It can be set as being different between juveniles and adults or it can be modeled with curves (logistic, normal or bimodal curves). In the model for Icelandic waters the selectivity was modeled with the logistic curve which is defined as follows:

$$sel_{a,g,f} = \frac{1}{1 + exp(-b \cdot (le_{a,g} - lsm))} \tag{3}$$

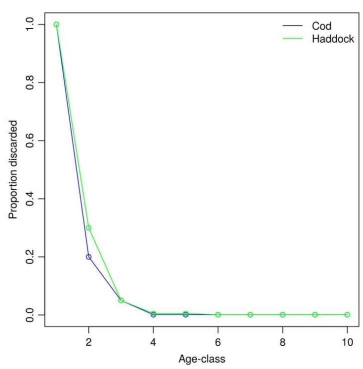
where $sel_{a,g,f}$ is the selectivity (0-1) for age-class a of group g for fleet f. The b and lsm are parameters where lsm is length of fish which has selectivity of of 0.5 and b is the steepness of the curve. The $le_{a,g}$ is the length of fish in age-class a of group g.



Selectivity with different parameters.

4.3 Discards

Discards can be modeled in various ways in Atlantis: 1) it can be modeled as a constant per group, 2) constant per age-class of a group, 3) size based. Also, management and marketing can affect discarding if those model components are included.
In the model for Icelandic waters discarding is modeled as constant proportion per age-class. Only two groups are modeled with discards, cod and haddock.



5 Economic Indicators

5.1 Calculating economic indicators

The economic indicators: revenue, cost and profit can be calculated from the model. A different method is used for demersal and pelagic species because oil use in demersal fisheries are mainly because of trawling (60

Economic indicators for demersal species

Economic indicators where calculated for five demersal species (cod, haddock, saithe, redfish and Greenland halibut) in the Atlantis model for Icelandic waters.

The price was taken as the average for the year 2012. The price depend on the weight of the demersal fish except for Greenland halibut.

The cost of harvesting per ton is assumed to be a function of the total biomass, i.e. as the biomass increases the cost of harvesting per ton decreases. The change in biomass is based on the biomass in the status quo scenario in the year 2012. The function is in a power of 0.8 which make it not linear, i.e. if the biomass is doubled the cost does not decrease by 50

$$C_{s,i,t} = 44,800 \cdot \left(\frac{B_{s,1,2012}}{B_{s,i,t}}\right)^{0.8} \tag{4}$$

where $C_{s,i,t}$ is the cost of harvesting one ton of species s in scenario i at year t. The $B_{s,1,2012}$ is total biomass of species s in the status quo scenario in 2012.

The profit ($Profit_{s,i,t}$) for each species s at scenario i at year t is then calculated as:

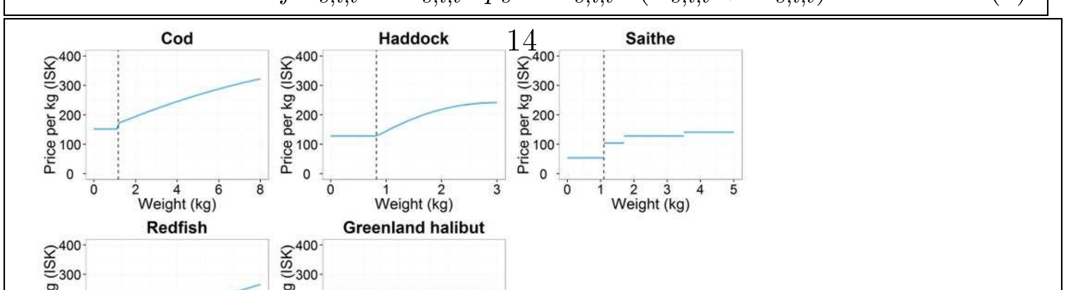
$$Profit_{s,i,t} = \sum_{w}(L_{w,s,i,t} \cdot p_{w,s}) - C_{s,i,t} \sum_{w}(L_{w,s,i,t} + D_{w,s,i,t}) \tag{5}$$

where $L_{w,s,i,t}$ and $D_{w,s,i,t}$ is the landings and discards of a certain weight group w of species s in scenario i at year t and $p_{w,s}$ is the price for that group.

Economic indicators for pelagic species

Economic indicators where calculated for four pelagic species (capelin, herring, blue whiting and mackerel) in the Atlantis model for Icelandic waters. For the pelagic species, the cost does not depend on the biomass and the price does not depend on the weight of the fish. The profit is defined as:

$$Profit_{s,i,t} = L_{s,i,t} \cdot p_s - C_{s,i,t} \cdot (L_{s,i,t} + D_{s,i,t}) \tag{6}$$



6 VizAtlantis

6.1 About VizAtlantis

VizAtlantis is a tool to visualize fisheries scenarios from the Atlantis model and can be found here https://mfdb.rhi.hi.is/shiny/VizAtlantis/
The tool shows simulations the ecosystem of Icelandic waters from 1948 to 2012. It can be used to visualize how the ecosystem had evolved if different management had been in place. Scenarios with different fishing mortality, selectivity, or discarding can be observed and compared.

6.2 The scenarios

Fishing mortality:
F0.50 = F1 decreased by 50F0.75 = F1 decreased by 25F1 = Historical fishing mortality.
F1.25 = F1 increased by 25F1.5 = F1 increased by 50F2 = F1 doubled.
F5 = 5 times F1.

Selectivity:
sel1 = Historical selectivity (L0.5 = 87cm).
dec1 = Lower selectivity for juveniles (L0.5 = 90cm).
dec2 = Lower selectivity for juveniles (L0.5 = 93cm).
inc1 = Higher selectivity for juveniles (L0.5 = 84cm).
inc2 = Higher selectivity for juveniles (L0.5 = 80cm).

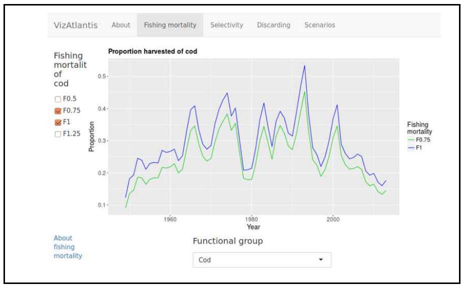
Discarding:
HD = Historical discarding
LO = Landing obligation with 100MD = More discarding, HD doubled.

6.3 How it works

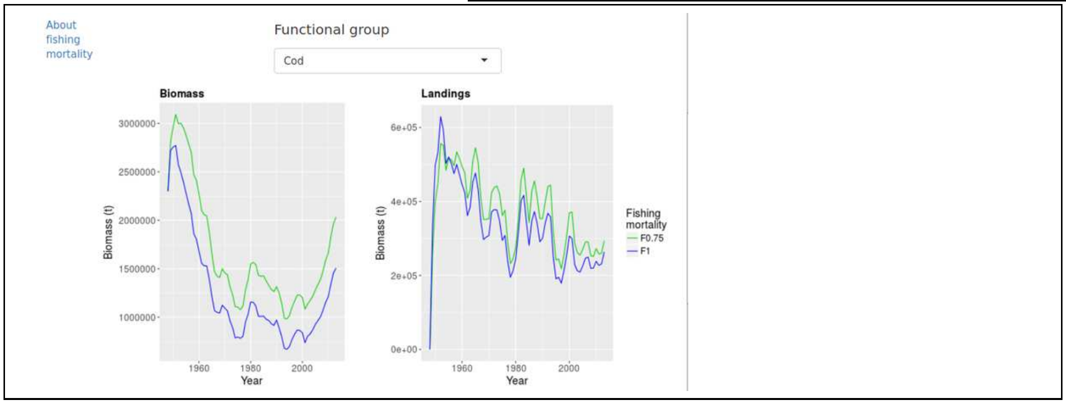
The tool has five tabs: About, Fishing mortality, Selectivity, Discarding and Scenarios. The About tab has short description of the tool and the model. The Fhising mortality tab shows scenarios where different fishing pressure is applied to one group (cod). In the Selectivity tab the effect of changed selectivity can be observed. The effects of discarding can be visualized in the discarding tab, and in the Scenarios tab a mix of fishing mortality, selectivity and discarding scenarios can be observed.

Fishing mortality

You can chose different fishing mortality of cod in the tick boxes. Here the historical fishing mortality (F1) is chosen and where it has been decreased by 25



Below are plots that show how biomass and landings have char
the simulated period. From the drop down list you can chose a
tional groups that are in the model and see what effect the sc
on those groups. If you scroll further down you see plots with
statistics, such as the discard rate by weight and by numbers
biomass and numbers discarded of the chosen functional group.
plots with economic indicators: revenue, profit, total cost and c
harvested.
There are also link that you can follow to get explanation on f
how fishing mortality work in Atlantis or how economic ind
calculated.



6.4 Fisheries in Icelandic waters

Background

Fisheries have been very important for the Icelandic economy for decades and in 2014 one million metric ton was harvested and the fisheries contributed 8.3

In 1976 days-at-sea were reduced to try to limit the catch of the over-exploited cod stock but without success. In 1975 the quota system was introduced for pelagic stocks and in 1984 for the cod and other demersal species but the management was also partly effort based. This still did not result in complete control of the total landings as they kept going over the recommended. Individual transferable quota (ITQ) system was implemented for all fisheries in 1990 with minor exemptions. This resulted in better control over the total landings and made the fisheries more economically efficient. A discard ban was first put into action in 1977 for six demersal species and in 1996 a discard ban was carried out for all fish species. The Icelandic fisheries management systems includes measures to prevent discarding such as ITQ related measures, gear restrictions and closed areas but despite these efforts discarding still exists in Icelandic waters.

Regulations to reduce incentives for discards

Discarding in Iceland did most likely not start until at the end of the 19th century when fishing with trawlers began. In the beginning of the 20th century there were no rules about the fisheries but in 1937 a law of minimum length of landed fish and minimum mess size was executed. These regulations probably led to increased discards of fish smaller than the minimum size. Ban on discard was first put into action in Iceland in 1977 when discards of cod and haddock and four other demersal species was prohibited. The discard banned evolved and in 1986 a discard ban was enforced for all fish that was in the quota system and ten years later it applied to all fish species.

ITQ systems can lead to increased rate of discarding. Fishermen aim for the most profitable catch and the ITQ system encourages high-grading, i.e. discarding of small and less valuable fish for larger one, as the catch size is limited. The system also encourages fishermen to discard by-catch species they do not hold quota for. The fisheries management system in Iceland has evolved to reduce the act of illegal discarding by allowing for flexibility within the ITQ system. It is allowed to exceed the quota for species but quota for other species that the vessel holds are then reduced accordingly. This regulation comes with restrictions such as the total quota exceeded can be no more than 5

With the enforcement of the discard ban the regulations on minimum landing size was changed to minimum legal size. In the beginning all catch under the minimum legal size was confiscated by the government but to discourage discards these regulations have been changed and fish under the minimum legal size is no longer confiscated but will only account to 50

The fisheries management system in Iceland allows for temporal real-time

7 ForAtlantis

7.1 About ForAtlantis

This is a tool to visualize fisheries scenarios from the Atlantis model. The fisheries scenarios are for different: 1) fishing mortality, 2) selectivity, and 3) discarding scenarios. These scenarios can be explored by clicking the tabs above. The first graph on each page shows what has been changed in the scenario chosen in the checkboxes. Fisheries scenarios can be chosen for different harvested group and the effects observed for each functional group. This tool shows how the model simulates the Icelandic ecosystem from 1948-2012 and forecasts different fisheries scenarios from 2013-2043

7.2 The scenarios

Fishing mortality:
F0.50 = F1 decreased by 50F0.75 = F1 decreased by 25F1 = Status quo (fishing mortality as in 2012).
F1.25 = F1 increased by 25F1.5 = F1 increased by 50F2 = F1 doubled.

Selectivity:
sel1 = Status quo selectivity (L0.5 = 87cm).
dec1 = Lower selectivity for juveniles (L0.5 = 90cm).
dec2 = Lower selectivity for juveniles (L0.5 = 93cm).
inc1 = Higher selectivity for juveniles (L0.5 = 84cm).
inc2 = Higher selectivity for juveniles (L0.5 = 80cm).

Discarding:
SQ = Status quo discarding.
LO = Landing obligation with 100MD2 = More discarding, 2x SQ.
MD4 = More discarding, 4x SQ.