Iceland Atlantis Report (DRAFT)

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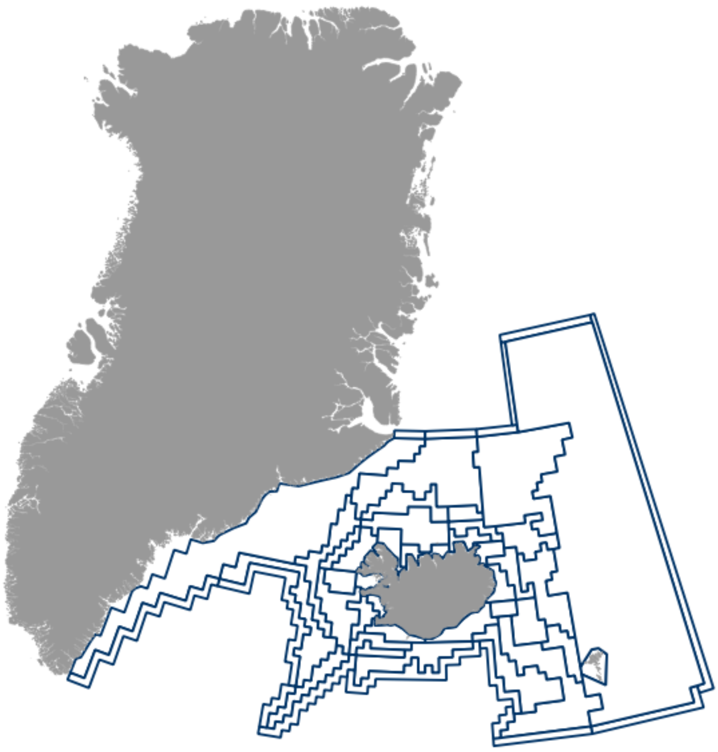
Math mode disabled while drafting

Setting up the Modelling Domain

Atlantis requires a special spatial file format. This is termed a *bgm* file (box geometry file). The *bgm* file defines the geometry (i.e. bathmetry) used in the Atlantis model. The *bgm* file stores the spatial information in *x* and *y* terms rather than latitude and longitude. Information about the projection (used in the visualization of the spatial data and for determining the day length), number of boxes, number of dynamic faces, maximum depth, vertical mixing and horizontal transport scalars, whether a box is a boundary box (i.e. is it dynamic, meaning does it border the open ocean) and the spatial layout of the boxes and the faces (e.g. area, location of vertices, depth of box) are specified in the *bgm* file.

For the Icelandic Atlantis model, data provided by the Marine Research Institute (MRI) in Reykjavík contained in the *reitmapping.tsv* and the `R` `geo` package were used to develop the modelling domain. The subdivisions used are described in Anonymous (2004)[1]. The subdivisions were exported from `R` to `QGIS` where they were modified to not overlap with Iceland, Greenland, and the Faroe Islands and boundary boxes were added around the subdivisions. The boundary boxes, generally, buffer the active model area by 1/2 degree longitude and 1/4 degree latitude. These boundary boxes were selected to be make the interpolation of the hydrography data easier. The modelling domain of the Iceland Atlantis model is shown below.



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Comparing the figure with the Figure 9.7 in Anonymous (2004), the location and, generally, uniform width of the boundary box around the subdivisions is easily discernible.

On the CSIRO wiki, there are various tools to help generate a *bgm* file. In particular the `bgmeriser.jar` tool was used after the shapefile was cleaned in `QGIS` and `GRASS`. The projection used was ISN93/Lambert 1993, which corresponds to the following `proj4` format:

```
+proj=lcc +lat_1=64.25 +lat_2=65.75
+lat_0=65 +lon_0=-19 +x_0=500000
+y_0=500000 +ellps=GRS80
+towgs84=0,0,0,0,0,0,0 +units=m +no_defs
```

The maximum depth for each box in the modelling domain was calculated using data provided in `geo::gbdypi`. The depths of the boxes ranged from 100m to 3800m. Iceland and the Faroe Islands, while included in the modelling domain, were assigned a depth of 0 in the model in order to avoid having islands in the model

For the Icelandic Atlantis model, the water column was split up into at most six water column layers: 0 - 50 m, 50 - 150 m, 150 - 300 m, 300 - 600m, 600 - 1000m, 1000m+ with one sediment layer. The size of these layers was selected after consultation with researchers at MRI and these layers are similar to depth layers reported Atlantis models (Link, Fulton, & Gamble, 2010[2]; Savina, Fulton, Condie, Forrest, Scandol, & Astles, 2008[3]).

Biological Submodel

Functional Groups

Pinnepids

The pinnepid group (PIN) consists of the two breeding Icelandic seal species: grey seal, *Halichoerus grypus*, and the common (or harbour) seal, *Phoca vitulina*. Data for the grey seal come largely from Hauksson (2007a)[4] and Hauksson (2007b)[5]. Data on abundance and basic biology can be found in Hauksson (2007a) and data on von-Bertalanffy and weight-allometric growth parameters can be found in Hauksson (2007b). Grey seals breed between the middle of September to early November in colones along the southeast and northwest coasts. During other times of the year, grey seals are found throughout Iceland but are at higher densities off the west, northwest, and southeast coasts (Hauksson, 2007a). Grey seals were estimated to number around 4000 to 5000 in the 1960s, 8,000 to 11,500 in 1982, and 4,100 to 5,900 in 2002 (Hauksson, 2007a). Changes in population size appear to be associated with an increase of breeding land as people moved from the countryside in the 60s and the recent declines appears to be associated with increased fishing (Hauksson, 2007a).

Information on harbour seals come from Hauksson & Einarsson (2010)[6].

Ocean Quahog (*Arctica islandica*)

Information on ocean quahog comes from Thorarinsdottir & Einarsson (1996)[7], Thorarinsdottir & Jacobson (2005)[8], the Icelandic Ministry of Fisheries[9], and NOAA[10].The ocean quahog is a long-lived (up to 400 years) bivalve occupying depths of 4 meters down to approximately 400 meters with depths up to 256 meters reported for Iceland (Thorarinsdottir & Einarsson, 1996). The majority of the catches in Iceland are reported between 5 and 50 meters (Thorarinsdottir & Jacobson, 2005). They inhabit soft, sandy soil where they are endobenthic and filter-feed on phytoplankton and detritus. They typically avoid gravel areas and have very slow recruitment. Males may mature as early as 10 years (49 mm shell length) and females may mature as early as 13 years (44 mm shell length) (citation in Thorarinsdottir & Jacobson, 2005). Spawning in Iceland peaks between June - July but occurs all year round (citation in Thorarinsdottir & Jacobson, 2005). Larvae are planktonic for 4 - 6 weeks and settlement peaks off Iceland during August. Recruitment has occurred every year since 2002 in Icleand but recruitment appears to peak every 20 years (citation in Thorarinsdottir & Jacobson, 2005). They are a cold-water invertebrate (could be affected by global warming?) and can tolerate temperates up to 12 celsius in Iceland (Thorarinsdottir & Jacobson, 2005).

According to the Icelandic Ministry of Fisheries, the stock size of ocean quahog in Icelandic waters is estimated at over 1 million tons with mean densities of 3.0 (+/- 0.3 SE), 2.8 (+/- 0.6 SE), and 4.2 (+/- 0.5 SE) kg/m^2 in the north-west, north, and east regions of Iceland (Thorarinsdottir & Einarsson, 1996).

Norway Lobster (*Nephrops norvegicus*)

All information on Norway lobster, *Nephrops norvegicus*, come from Pampoulie et al. (2010)[11], Eiriksson (1999)[12], the Icelandic Ministry of Fisheries, and personal communcations with staff at MRI in Reykjavík. Norway lobster are found exclusively in the south of Iceland at depths ranging from 100 - 300 meters (Eiriksson, 1999) preferring ocean temperatures of 6 - 9 celsius. They prefer soft bottom substrates (such as clay or sand), are endobenthic and feed on small benthic animals. They typically do not range more than 100 meters and there does not appear to be different genetic populations (Pampoulie et al. 2010)[@10].

Initial biomass estimates and spatial distribution comes from Jónas Jónasson at the MRI. Biomass in 1968 was used for Norway lobster, which was roughly the virgin biomass. This value was 30,940 tons and was distributed to **Atlantis** boxes proportionate to their reported landings.

Iceland Scallop (*Chlamys islandica*)

The initial biomass for Iceland scallop was distributed to the Brieðafjorður region of the **Atlantis** model (i.e. box 31). This biomass was 100,000 tons.

Initial conditions for tracers with little or no data

For tracers with no data, e.g. pelagic bacteria, sediment bacteria, sediment silica, seagrass, etc, initial conditions were taken from Savina et al. (2008)'s model. These tracers were updated after running **Atlantis**.

Equations

Conversions

Tons to Nitrogen (invertebrates)

The following `R` function was used to convert tons to either mg N/m^3 (invertebrates occurring in the water column) or mg N/m^2 (epibenthic and endobenthic invertebrates).

```
tons_mgN <- function(tons, unit){
mgN <- (tons * 1e9) / 20 / 5.7 / unit
return(mgN)
}
```

Where *unit* is either the area of the box or the volume of a layer.

Recruitment

The typical Beverton-Holt recruitment model can be expressed as:

$$R = \frac{\alpha S}{1 + \frac{S}{K}}$$

Where α is the maximum number of recruits per individual and K is the spawning stock biomass at which recruitment is 1/2 maximum.

In **Atlantis**, however, α represents the maximum number of recruits produced (units: individuals) and β represents the spawning stock biomass at which recruitment is 1/2 maximum (units: mg N).

$$R = \frac{\alpha S}{\beta + S}$$

Now if we let **Atlantis's** α and β be represented as $\tilde{\alpha}$ and $\tilde{\beta}$ and set $\tilde{\alpha} = \alpha K$ and $\tilde{\beta} = K$, respectively, then we can derive the typical formulation of the Beverton-Holt equation:

$$\frac{\tilde{\alpha} S}{\tilde{\beta} + S} = \frac{\alpha K S}{K + S} = \frac{\alpha S}{1 + S/K}$$

Therefore, we see that **Atlantis's** α is really αK (i.e. R_∞) and β is really K.

For cod, haddock, and saithe recruitment was initially calculated using MRI's recruitment and spawning stock biomass data. This data is available on their website in the *summary.csv* files for each of these species, respectively.

Rate of Change Equations

Primary Producers

Primary producers are modelled as biomass pools (mg N/m^3) in each spatial box.

Rate of change for water column *w* for primary producer *PP* is:

$$\frac{d(PP_w)}{dt} = G_{PP_w} - M_{lys,PP} - M_{lin} - M_{quad} - \sum_{j=predators} P_{PP,j}$$

$$G_{PX} = \mu_{PP} * \delta_{irr} * \delta_{nut} * \delta_{space} * PX$$

G_{PP} is the growth rate for *PP*; $M_{lys,PP}$ is the loss of *PP* due to lysis; M_{lin} and M_{quad} are loss due to linear (density-independent) and quadratic (density-dependent) mortality not treated in the model, respectively; $P_{PP,i}$ are the losses of *PP* to predation by species *i*; μ_{PP} is the maximum growth rate; δ_{irr} is the light limitation; δ_{nut} is nutrient limitation; and δ_{space} is space limitation.

Invertebrates

Invertebrates are measured either per-area (e.g. epibenthic and endobenthic species) (mg N/m^2) or per-volume (e.g. zooplankton) (mg N/m^3).

Rate of change for a standard invertebrate consumer *SCI* is:

$$\frac{d(SCI)}{dt} = G_{SCI} - M_{linSCI} - M_{quadSCI} - \sum_{j=predator} P_{SCI,j} - F_{SCI}$$

$$G_{SCI} = \left(\epsilon_{SCI} * \sum_{i=prey} P_{i,SCI} + P_{DL,SCI} * \epsilon_{SCI,DL} + P_{DR,SCI} * \epsilon_{SCI,DR} \right) * \delta_{space} * \delta_{O_2}$$

G_{SCI} is the growth rate for *SCI*; M_{linSCI} and $M_{quadSCI}$ are again unexplained density-independent and density-dependent mortaility whose purposes are to set a reasonable carrying capacity in **Atlantis**; $P_{SCI,j}$ is depredation of *SCI* by predator *j*; F_{SCI} is fishing on the group (if applicable); ϵ_{SCI} is the growth efficiency of *SCI* when feeding on living prey; $\epsilon_{SCI,DL}$ and $\epsilon_{SCI,DR}$ are the efficiencies when eating on labile and refractory detritus; δ_{space} is space limitation; and δ_{O_2} is oxygen limitation.

Vertebrates

Vertebrates are tracked in age-groups in **Atlantis** by abundance, structural weight (bones and hard tissue, mg N/m^3), and reserve weight (soft tissue, mg N/m^3).

Rate of change for a vertebrate group *V* is:

$$\frac{d(V_{i,s})}{dt} = G_{V_{i,s}}$$

$$\frac{d(V_{i,r})}{dt} = G_{V_{i,r}}$$

$$\frac{d(V_{i,d})}{dt} = T_{im,V_i} - T_{em,V_i} - M_{linV,i} - M_{quadV,i} - \sum_{j=predator} P_{V,j} - F_{V_i}$$

Subscript *i* refers to age group *i*; *s* for structural weight; *i* for reserve weight; *d* for density; T_{im,V_i} and T_{em,V_i} represent movement of vertebrates into and out of the polygon. Growth for vertebrates is calculated the same way as for invertebrates with the exception that it is done for each age group and not as biomass pools.

Nitrogen

Water column ammonia and nitrate concentrations are governed by uptake by autotrophs, excretion by consumers, nitrification, and denitification.

Rates of change for ammonia and nitrate are:

$$\frac{d(NH_3)}{dt} = -\sum$$

SHOULD FINISH THIS LATER BUT THE CRUMMY NOTATION KILLS ME :(

References

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