Introduction to length based stock assessment

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Today:

1. Introduction on lengh-based assesments
2. A brief overview of Gadget
3. Case study: Red Seabream
4. Case study: Icelandic Ling

What next...

The story so far

You have seen varying degree of complexity in stock assement models:

- **Stock production models**:
  - Conceptually very simple.
  - light in terms of data requirements, only requires biomass and catch series.
  - Insensitive to species characteristics such as age composition, species interaction or environmental drivers
  - Typically the stock dynamics are modeled as

$$B_{t+1} = B_t + rB_t\left(1 - \frac{B_t}{K}\right) - C_t$$

  - Indices (e.g. survey or CPUE) are modelled as

$$U_t = qB_t$$

  - And the objective function is simply:

$$\sum_t (U_t - \hat{U}_t)^2$$

    where $\hat{U}_t$ is the observed index
  - Problems can occur when the data lack contrast i.e. one-way trends in catch and index timeseries or there are trends in catchability

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The story so far

- **Age–based models**:
  - Closer to reality, can distinguish between slow and fast growing species.
  - On the surface they require little data, however obtaining catch at age involves either a lot of otolith reading (ie bunch of data) or some intermediary modelling.
  - Typically the stock is modeled as

$$N_{a,t} = N_{a-1,t}e^{-Z_{a,t}}$$

    where $Z_{a,t} = M_{a,t} + F_{a,t}$
  - Fleet selection sometimes set up as independent of time (separable)
  - Recruitment ($N_{a_0,t}$) can be estimated as a free variable or as a function of SSB

- Indices (e.g. survey or CPUE) are modelled as

$$U_{a,t} = q_a N_{a,t}$$

- Catches are modelled via the Baranov catch equation

$$C_{a,t} = \frac{F_{a,t}}{F_{a,t} + M_{a,t}}(1 - e^{-(F+M)})N_{a,t}$$

- And the objective function is

$$\sum_{a,t}(U_{a,t} - \widehat{U_{a,t}})^2 + w\sum_{a,t}(C_{a,t} - \widehat{C_{a,t}})^2$$

  where $\hat{U}$ and $\hat{C}$ are the observed index and catch respectively.
- Problems with this approach are in general related to the lack of reliable data on age

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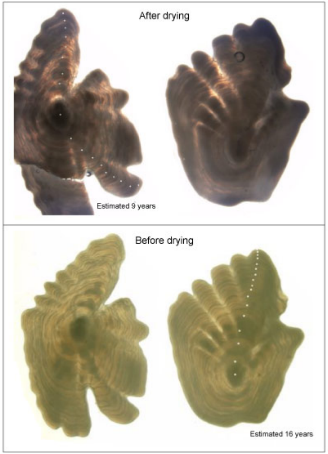
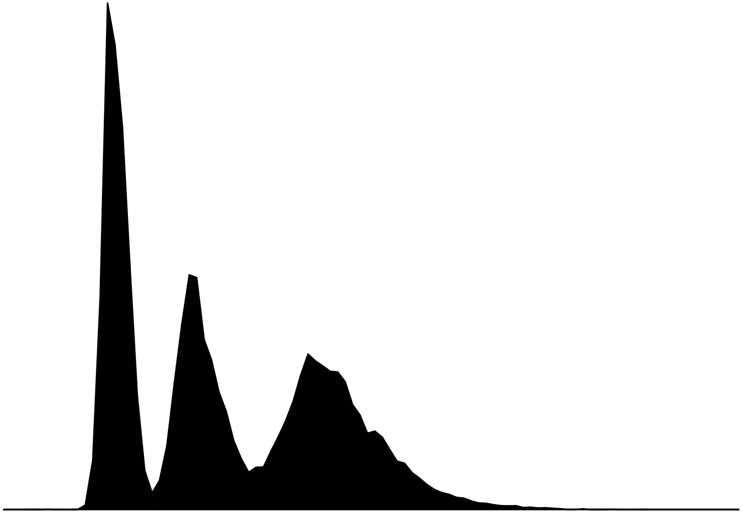
Aging problems

Some species are problematic:

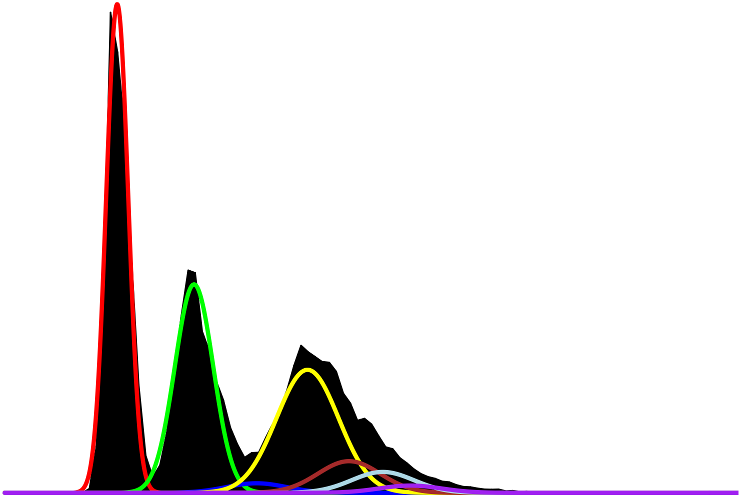
- No hard parts that collect year rings.
- Even if otoliths exist there are uncertainties in reading them



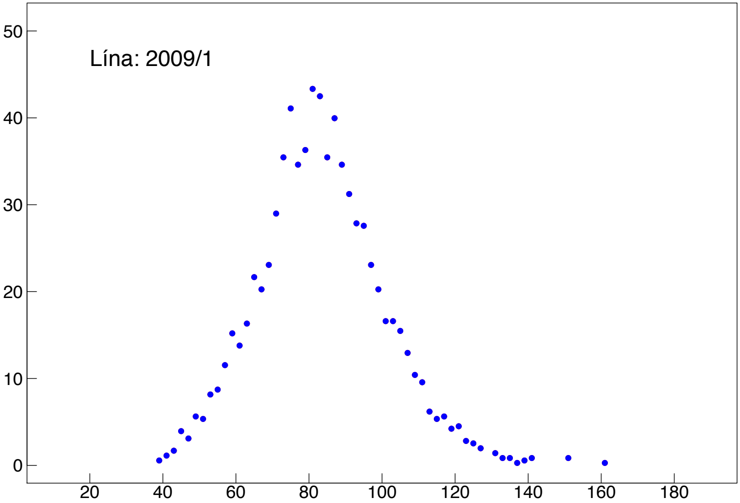
Age inferred



Age inferred



Age inferred?



Length–based assesments

- Model the data at the level of (slightly aggregated) data. Size of input data can be very large
- Combines the ad-hoc-ery of the determination of catch at age with the model itself
- Conceptually more complicated, but the processes are modelled in the correct currency
  - Fleet catches by size instead of age
  - Growth in length/weight
- The objective function now includes compositional data from a multitude of sources (e.g. catch proportion of different fleets, maturity stages and diet data)

- $$l^{\mathrm{T}} = \sum_g w_{gf}^{\mathrm{SI}} l_{g,S}^{\mathrm{SI}} + \sum_{f \in \{S,T,G,L\}} \left(w_f^{\mathrm{LD}} l_f^{\mathrm{LD}} + w_f^{\mathrm{AL}} l_f^{\mathrm{AL}} \right) + w^{\mathrm{M}} l^{\mathrm{M}} \tag{1}$$

- Various frameworks developed for the purposes of stock assessment:
  - SS3: `http://nft.nefsc.noaa.gov/Stock_Synthesis_3.htm`
  - **Gadget**: `https://github.com/hafro/gadget`
  - casal2: `https://github.com/NIWAFisheriesModelling/CASAL2`

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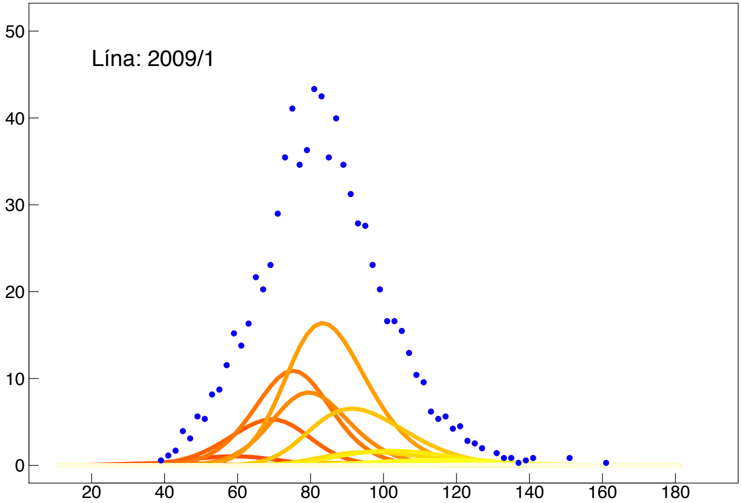
Age inferred



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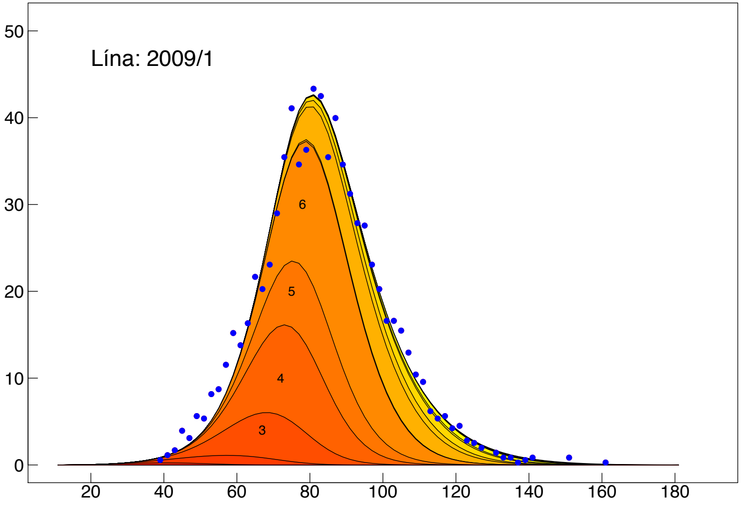
Age inferred



What next...

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What is Gadget?

- shorthand for: **"Globally applicable Area Disaggregated General Ecosystem Toolbox"**
- Gadget contains a highly congurable ecosystem simulator that emulates the interaction between **substocks**, representing either parts of the same species or separate species, living in one or more **areas**
- It is a forward simulator where the simulation takes place in a set number of years
- It allows for the simulation of (irregular sized) timesteps within those years to allow for the emulation of various cyclical process such as spawning or stock migrations
- Any process can be parametrised by the user, both for use estimation and/or scenario analysis

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The framework

The Gadget framework essentially consists of three components:

- an ecosystem simulator
- a likelihood function that takes the output (from the ecosystem simulator) and compares the data,
- a function minimizer (optimization routines to find the best set of the model parameters values)

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Gadget models

- The fundamental block in Gadget is the **substock**, an entity that is homogeneous with respect to various processes
- For each substock the number of fish at a certain length and age is stored
- The substocks live in an **area**, or areas, where they optionally migrate to and from
- Harvesting of the substocks is defined through **fleets** that fish according to effort (or quota) and use selection functions (either length or age based but more on that later)
- The state of the ecosystem that is simulated in Gadget is observed through the substock abundance, consumption and harvest

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Illustration of a model

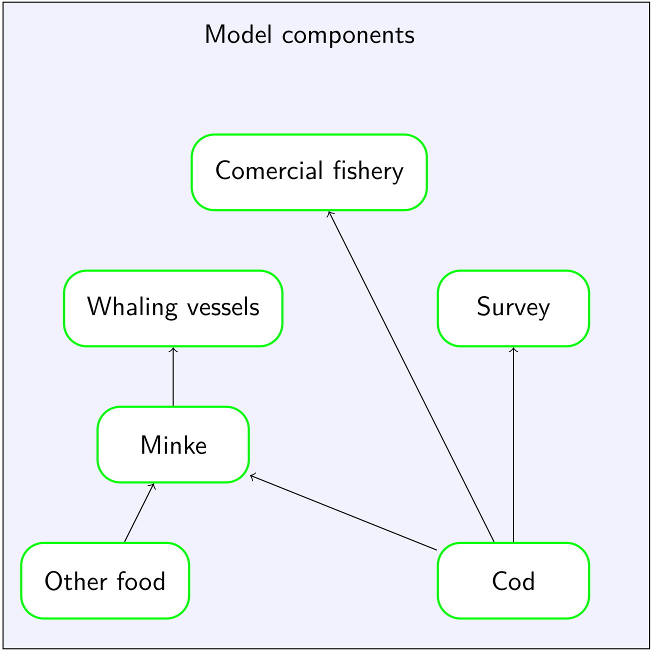

Illustration of a model

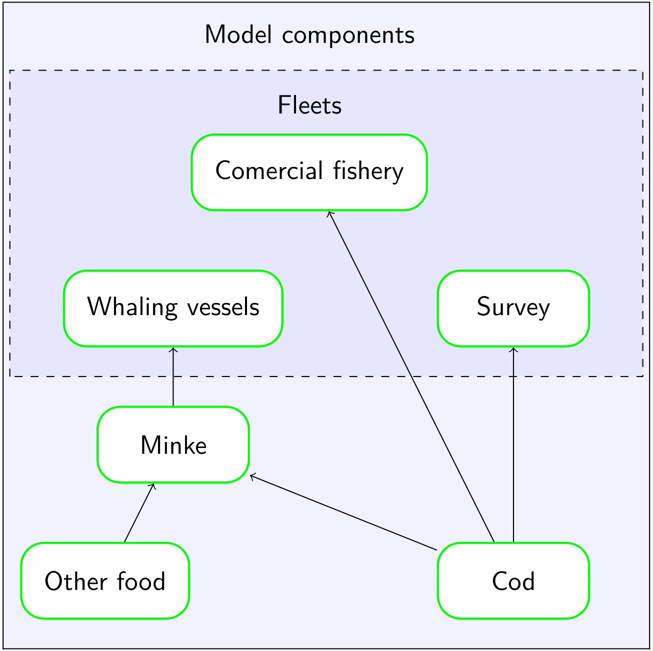

Illustration of a model

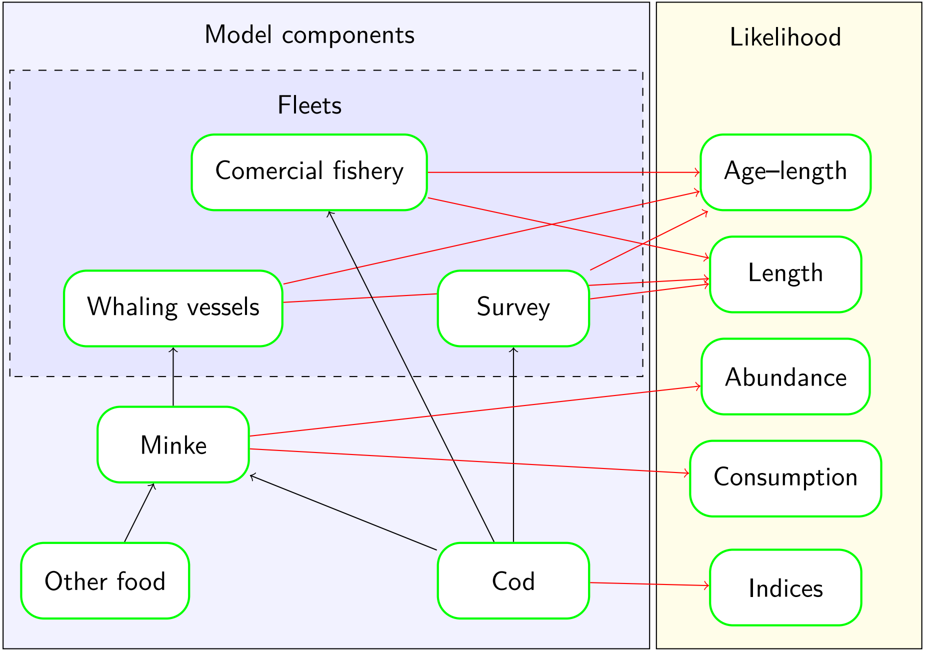

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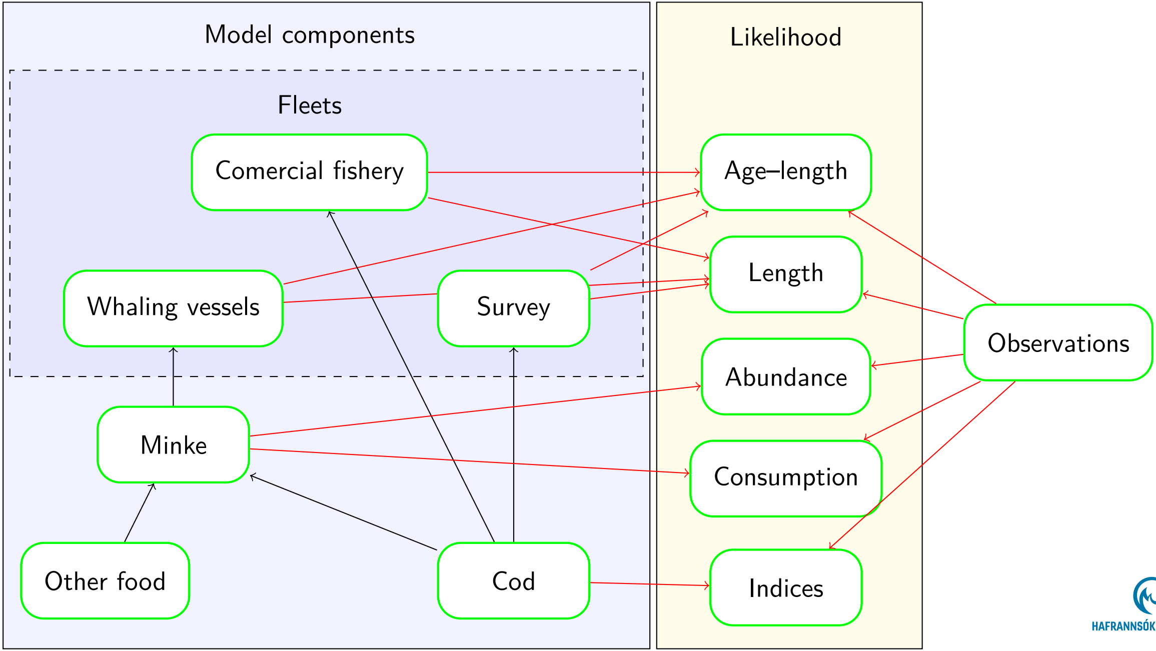
Illustration of a model



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General population dynamics

The population is governed by the following equations:

$$
\begin{aligned}
N_{alsy,t+1} &= \sum_{l'} G^{l}_{l'} \left[(N_{al'syt} - \sum_{f} C_{fal'st}) e^{-M_a \Delta t} + I_{al'lsyt} \right] && \text{if } t < T \\
N_{a,ls,y+1,1} &= \sum_{l'} G^{l}_{l'} \left[(N_{a-1,l'sy,T} - \sum_{f} C_{fa-1,l's,T}) e^{-M_{a-1} \Delta t} + I_{a-1,l'lsy,T} \right] && \text{if } t = T \text{ and } a < a_{max} \\
N_{a,ls,y+1,1} &= \sum_{l'} G^{l}_{l'} (N_{al'sy,T} - \sum_{f} C_{fal'sy,T} + \\
&\qquad N_{a-1,l'sy,T} - \sum_{f} C_{f,a-1,l'sy,T}) e^{-M_a \Delta t} && \text{if } t = T \text{ and } a = a_{max}
\end{aligned}
\tag{2}
$$

where:

- N_{alsyt} is the number if fish at age a, length l, stock s, year y and timestep t
- $G^{l}_{l'}$ is the proportion in length-group l that has grown $l - l'$ length-groups in Δt
- C_{falsyt} denotes the catches by fleet
- I_{alsyt} indicates movement between substocks (e.g. maturation)

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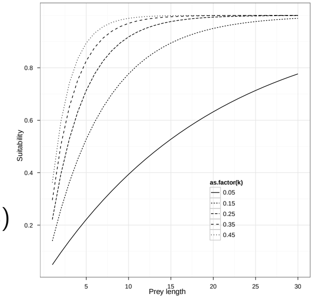
Growth

Lengthgroup growth is implemented using a two step approach:

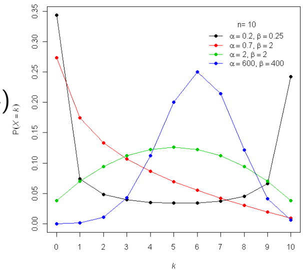
- Average lengthgroup growth can be calculated according to a number of growth functions, the simplest being a modified form of the Von Bertalanffy equation:

$$\Delta l = (l_\infty - l)(1 - e^{-k\Delta t}) \tag{3}$$



- The number in the lengthgroup prior to the length update is dispersed around the average growth according the growth implementation function

$$G_l^{l'} = \frac{\Gamma(n+1)}{\Gamma((l'-l)+1)} \frac{\Gamma((l'-l)+\alpha)\Gamma(n-(l'-l)+\beta)}{\Gamma(n-(l'-l)+1)\Gamma(n+\alpha+\beta)} \times \frac{\Gamma(\alpha+\beta)}{\Gamma(\alpha)\Gamma(\beta)} \tag{4}$$



where α is subject to $\alpha = \frac{\beta\Delta l}{n - \Delta l}$

Other stock specific processes

- **Maturation:** based on length, age and weight according to:

$$P(l, a) = \frac{1}{1 + e^{-4\alpha(l-l_{50})-4\beta(a-a_{50})-4\gamma(k-k_{50})}}$$

- **Recruitment and inital population:** $N_{a_{min}l0yt'} = R_y p_l$ and $N_{als11} = \nu_{as} q_{al}$
- **Spawning:** renewals can also be formulated using one of four spawning functions:
  - Fecundity
  - SimpleSSB
  - Ricker
  - Beverton-Holt
- **Movement and straying:** Parts of one stock can be moved/transferred to another stock. Potential uses include maturity stages or stock migrations.
- **Tagging:** allows the use of tagging data to estimate stock movement.

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Interaction between model components

A number of predator-prey relationships can be defined in a Gadget model:

- They include the obvious case where one substock predates the other
- Cannibalistic relationships can be defined if two stocks are modelled as an immature and a mature part of the same species
- Fleets (survey and/or commercial) can be integrated into the model by being considered as one of the predators

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Consumption

In general, Gadget will conceptually assign the following to its predators:

- **Preference**: i.e. if available what will the predator choose first
- **Need**: What does the predator need to sustain itself
- **Search area**: when will the predator stop searching for a prey
- **Availability** of a certain prey in comparison with other food sources

Combining these the number of predators, food availability and need the amount that the predator wants to consume is calculated. If the total biomass that all predators in the model want to consume is greater than the total biomass available the consumption is adjusted accordingly.

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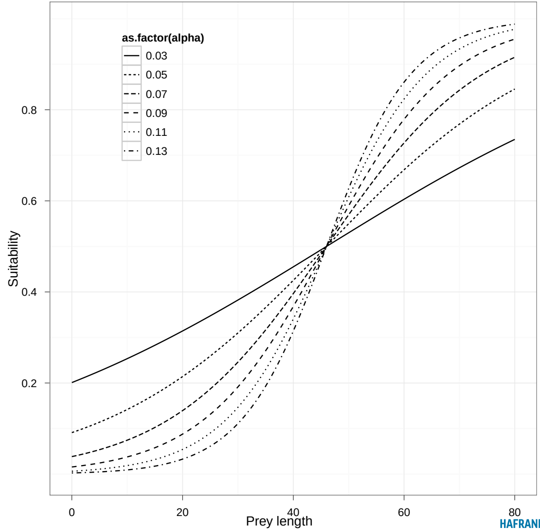
Suitability functions

Food availability is directly determined from the total biomass and the suitability functions that the predator uses. Suitability functions can be interpreted as the proportion of prey of length l predators of length L are willing to consume. A number of suitability functions can be defined

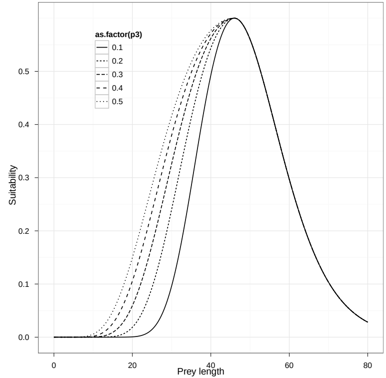
- $S(L,l) = \alpha$
- $S(L,l) = \alpha + \beta l$
- $S(L,l) = \frac{\delta}{1+e^{-\alpha-\beta l-\gamma L}}$
- $S(L,l) = \frac{\delta}{1+e^{-\alpha(l-l_{50})}}$
- $S(L,l) = \left(\frac{\delta}{1+e^{-\alpha-\beta l-\gamma L}}\right)^{\eta}$



Suitability functions (continued)

Andersen $S(L,l) = \begin{cases} p_0 + p_2 e^{-\frac{(\log \frac{L}{l} - p_1)^2}{p_4}} & \log \frac{L}{l} \leq p_1 \\ p_0 + p_2 e^{-\frac{(\log \frac{L}{l} - p_1)^2}{p_3}} & \log \frac{L}{l} > p_1 \end{cases}$

Gamma $S(L,l) = \left(\frac{l}{(\alpha-1)\beta\gamma}\right)^{(\alpha-1)} e^{\alpha-1-\frac{l}{\beta\gamma}}$



Fleet operations

As noted earlier, fleets operations are considered to similar to predator consumption. There are, however, some differences in implementation as fleets do not have a maximum consumption or half feeding value.
When defining the fleet consumption the user can choose between 5 different types of fleet operations:

- The first two are **TotalFleet** and **NumberFleet** that harvest according to landed biomass and landed numbers using the formula:

$$C_s(l) = \frac{ES_s(l)N_{sl}W_{sl}}{\sum_{stocks}\sum_{lengths} S_s(l)N_{sl}W_{sl}}$$

  where E is the biomass/numbers.

Fleet operations (continued)

- The next two are **LinearFleet** and its multi stock extension **EffortFleet** that harvest according to fleet effort:
$$C_s(L) = E\Delta t q_s S_s(l) N_{sl} W_{sl}$$
where E is the effort and q_s is the stock catch ability (i.e. preference). These fleet types are often used in future predictions.
- **QuotaFleet** is simple extension to LinearFleet that allows for the use of simple harvest control rules based on total biomass in future predictions.

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Comparison with data

- Age-length based models can be compared directly against a wide variety of different data sources. Thus it is not necessary to convert length into age data before comparisons.
- Gadget can use various types (e.g. length, maturity, CPUE, tagging) of data that can be included in the objective function.
- This means that the model can be used for stocks where age data is sparse and/or are unrelible.
- Data are assimilated using a weighted log–likelihood function:

$$l^{\mathrm{T}} = \sum_{g} w_{gf}^{\mathrm{SI}} l_{g,S}^{\mathrm{SI}} + \sum_{f \in \{S,T,G,L\}} \left(w_f^{\mathrm{LD}} l_f^{\mathrm{LD}} + w_f^{\mathrm{AL}} l_f^{\mathrm{AL}} \right) + w^{\mathrm{M}} l^{\mathrm{M}} \tag{5}$$

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Survey indices

For each length range g the survey index is compared to the modeled abundance at year y and time-step t using:

$$l_g^{\mathrm{SI}} = \sum_y \sum_t (\log I_{gy} - (\log q_g + b_g \log \widehat{N_{gyt}}))^2 \tag{6}$$

where

$$\widehat{N_{gyt}} = \sum_{l \in g} \sum_a \sum_s N_{alsyt}$$

Length distributions are compared to predictions using

$$l_f^{\mathrm{LD}} = \sum_y \sum_t \sum_l (\pi_{flyt} - \hat{\pi}_{flyt})^2 \tag{7}$$

where f denotes the fleet where data was sampled from and

$$\pi_{flyt} = \frac{\sum_a \sum_s O_{falsyt}}{\sum_{a'} \sum_{l'} \sum_s O_{fa'l'syt}}$$

and

$$\hat{\pi}_{lyt} = \frac{\sum_a \sum_s C_{falsyt}}{\sum_{a'} \sum_{l'} \sum_s C_{fa'l'syt}}$$

i.e the observed and modeled proportions in length-group l respectively at year y and time-step t.

Getting Gadget

- Gadget: github.com/hafro/gadget
- Rgadget: github.com/hafro/rgadget
- MFDB: github.com/mareframe/mfdb
- Example scripts: github.com/fishvice/gadget-models/

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What next...

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Red Seabream

- Taxonomy: Pagellus bogaraveo
- Superclass GNATHOSTOMATA
- Class ACTINOPTERYGII
- Subclass NEOPTTERYGII
- Division TELEOSTEI
- Subdivision EUTELOSTEI
- Superorder ACANTHOPTERYGII
- Order PERCIFORMES
- Family SPARIDAE
- Genus Pagellus (Valenciennes, 1830)

Key characteristics:

- Slow growth
- Hermaphrodite: males L50 $\pm$30 cm TL, $\pm$35 cm TL in females
- Spawning season in the 1st quarter
- Main preys: small crustaceans and deepwater fish
- Predators: blue fin tuna?

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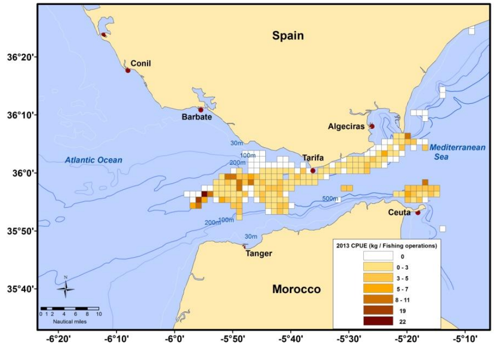
STRAIT of GIBRALTAR (TARGET) FISHERY INFO

SPAIN

- Main ports : Tarifa and Algeciras
- Landings by market category: from 1997 to 2016
- Effort info (days at sea): from 1983 to 2016 (number of sales as a proxy of fishing trips) and since 2009 (fishing trips from VMS)
- Length distributions by market category: from 1997 to 2016
- Biological data (sexratio, maturity and limited ageing) by market category but only from certain years
- Tag-recapture data
- Bottom trawl surveys both sides of the Strait of Gibraltar (recently started)

MOROCCO

- Main port : Tangier
- Total landings: from 2001 to 2016
- Effort info (days at sea): from 2001 to 2016
- Length distributions: from 2005 to 2016



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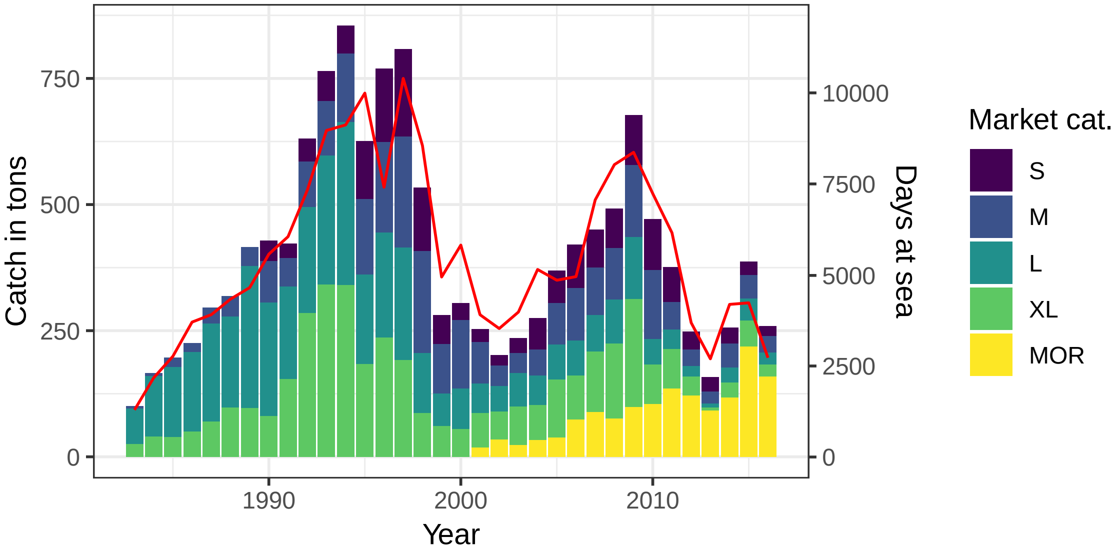
STRAIT of GIBRALTAR (TARGET) FISHERY INFO



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Population model

- 2 stocks: males and females (instead of immature and matures)
- Length-Weight relationship (from biological samplings)
- M = 0.2 assumption for all ages every year
- Num. Recruits at age 0 from 1983 to 2016, estimated by the model
- Abundance at age (1 to 17) at first year (1983), estimated by the model
- Growth: VBGF parameters, could be estimated by the model or fixed by the user (L_∞)
- Effort data (Spain and Morocco) as (4+1) linear fleets (q) Landings, length distributions and biological info are also dissaggregated according to these (4+1) fleets

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Model settings

The blackspot seabream model includes 4 different types of data to enter the likelihood:

- length distribution from commercial fleets (Morocco and Spain),
- age-length distribution and 3 sex ratio at length (from biological samplings) and
- fleets effort (in fishing days). Thus, the likelihood included a total of 20 different components

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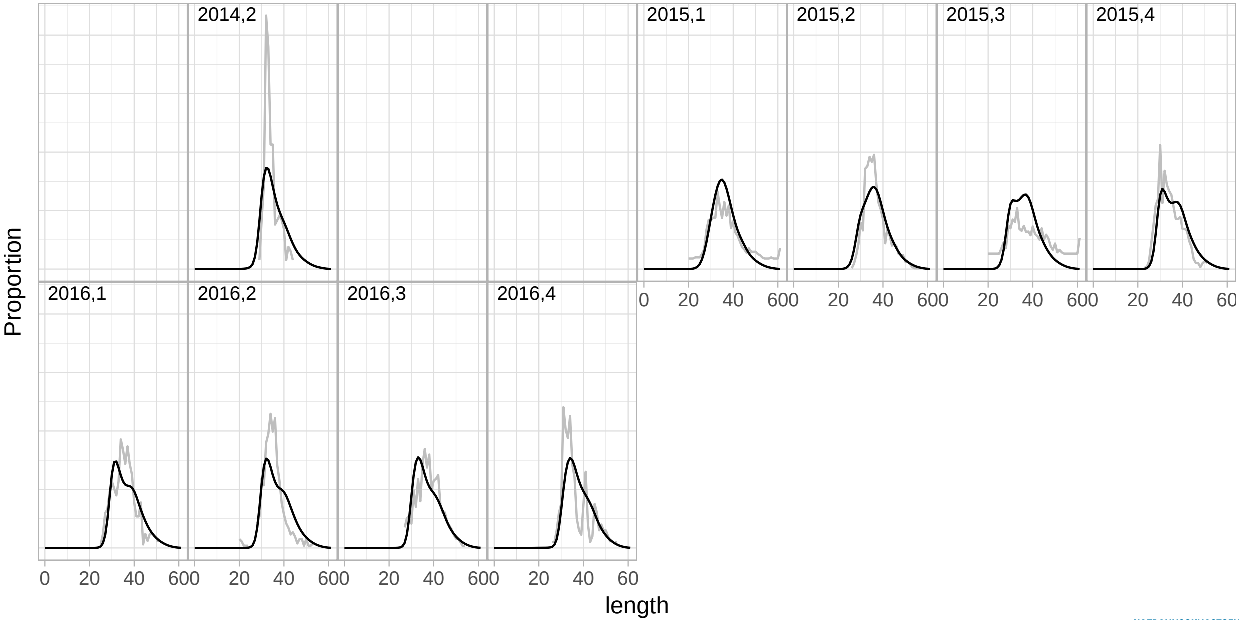
Fit to length distribution data



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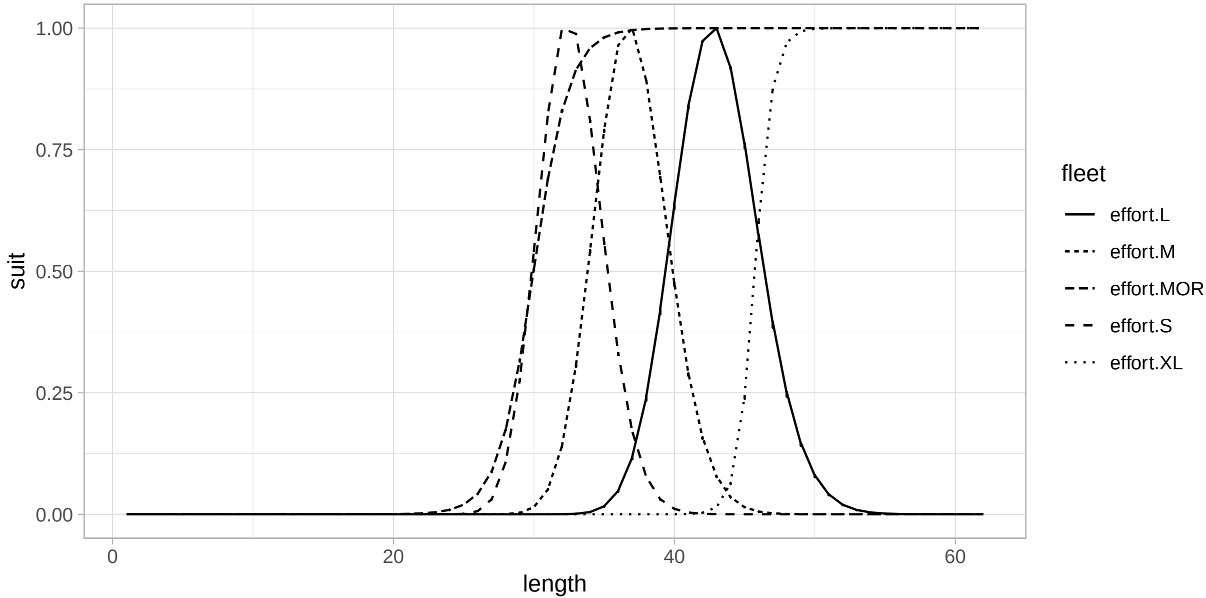
Estimated fleet selection



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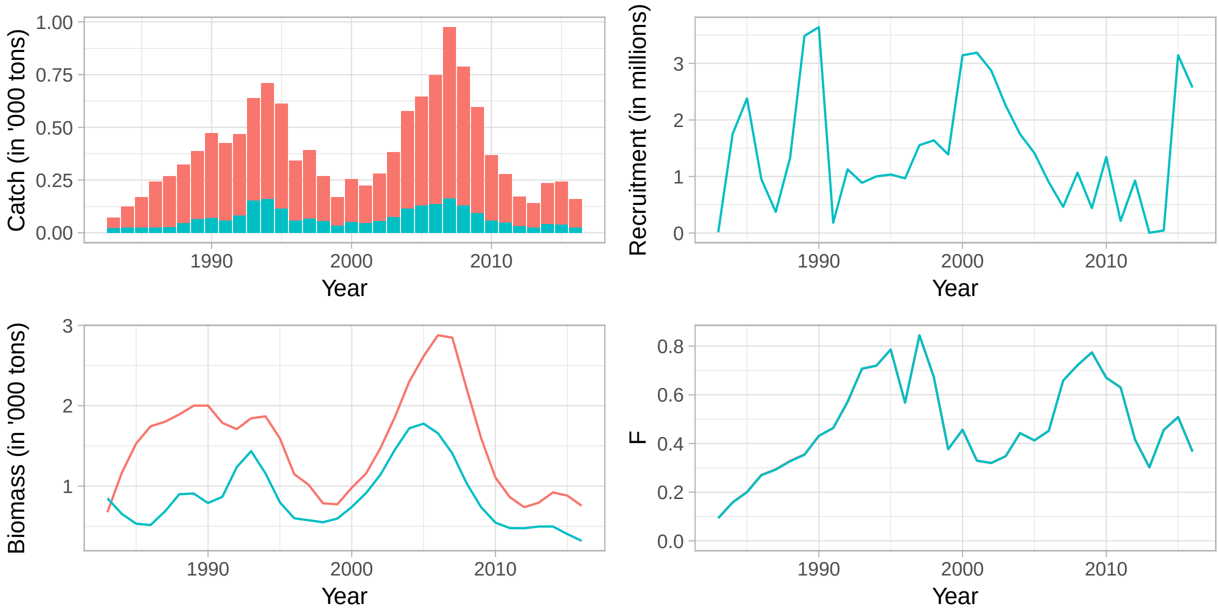
Stock overview



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