A hierarchical Bayesian integrated model for growth of Indian Ocean yellowfin tuna (*Thunnus albacares*)

Indian Ocean Tuna Tagging Symposium

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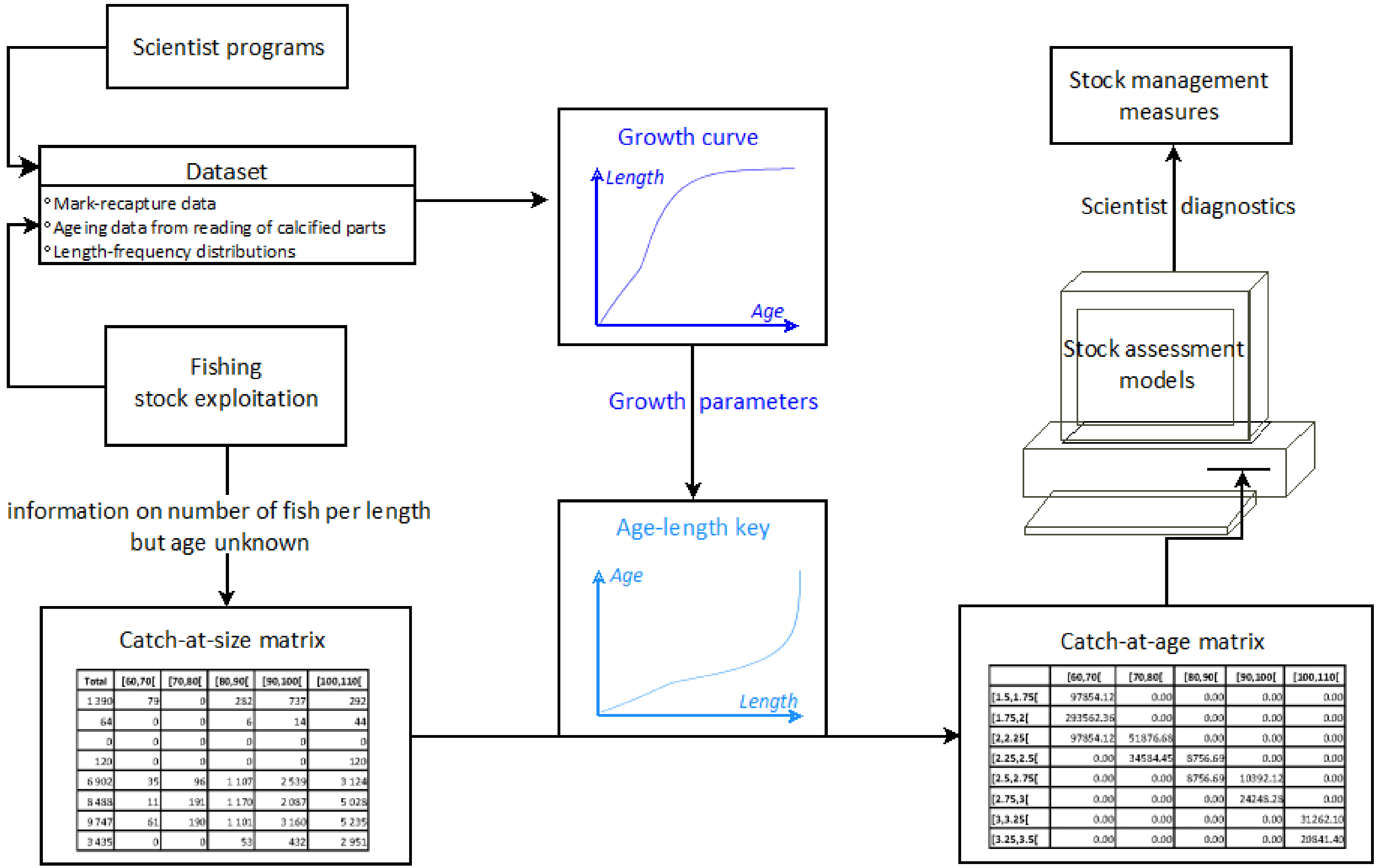
Importance of growth curve for stock assessment



Catch-at-size matrix

Total	[60,70[	[70,80[	[80,90[	[90,100[	[100,110[
1 390	79	0	282	737	292
64	0	0	6	14	44
0	0	0	0	0	0
120	0	0	0	0	120
6 902	35	96	1 107	2 539	3 124
8 488	11	191	1 170	2 087	5 028
9 747	61	190	1 101	3 160	5 235
3 435	0	0	53	432	2 951

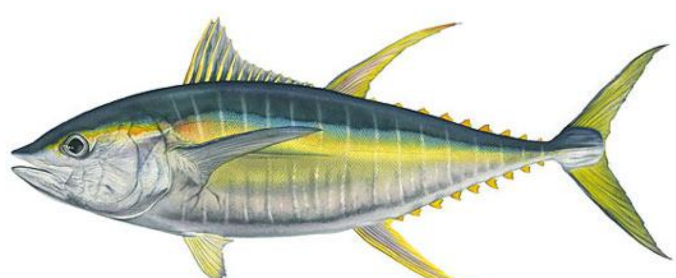
Catch-at-age matrix

	[60,70[	[70,80[	[80,90[	[90,100[	[100,110[
[1.5,1.75[	97854.12	0.00	0.00	0.00	0.00
[1.75,2[	293562.36	0.00	0.00	0.00	0.00
[2,2.25[	97854.12	51876.68	0.00	0.00	0.00
[2.25,2.5[	0.00	34584.45	8756.69	0.00	0.00
[2.5,2.75[	0.00	0.00	8756.69	10392.12	0.00
[2.75,3[	0.00	0.00	0.00	24248.28	0.00
[3,3.25[	0.00	0.00	0.00	0.00	31262.10
[3.25,3.5[	0.00	0.00	0.00	0.00	20841.40

Yellowfin growth: current knowledges and uncertainties

- Indian Ocean yellowfin have a two-stanza growth with distinct juvenile and adult phases

- But uncertainties in growth remain:
    - physiology and ecology of yellowfin poorly understood
    - differential gear selectivity and various fishing areas
    - different features of methods and data used



Yellowfin tuna *Thunnus albacares*

Growth information sources

Different sources of information for studying fish growth:

- mark-recapture data

  information on the individual growth rate coefficients

- direct ageing data from calcified structures (scales, vertebrae, otoliths, spines)

  information on the length of the fish at a given age

- modal progression data

  information on the mean growth rate coefficients between successive length-age pairs

Objective

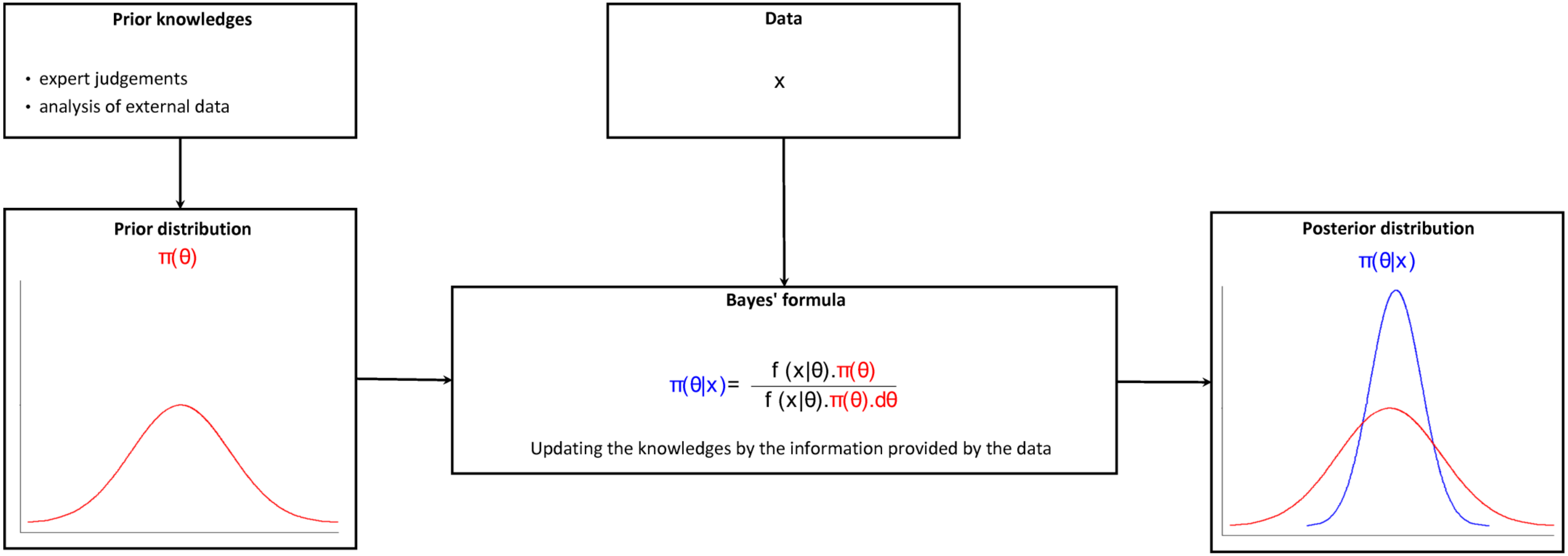
Estimate the yellowfin growth using an integrated model which combines:

REGIONAL TUNA TAGGING PROJECT INDIAN OCEAN

- mark-recapture data
- direct ageing data from otolith readings
- modal progression data

➯ **Developed in a hierarchical Bayesian framework**

Why a Bayesian framework ?

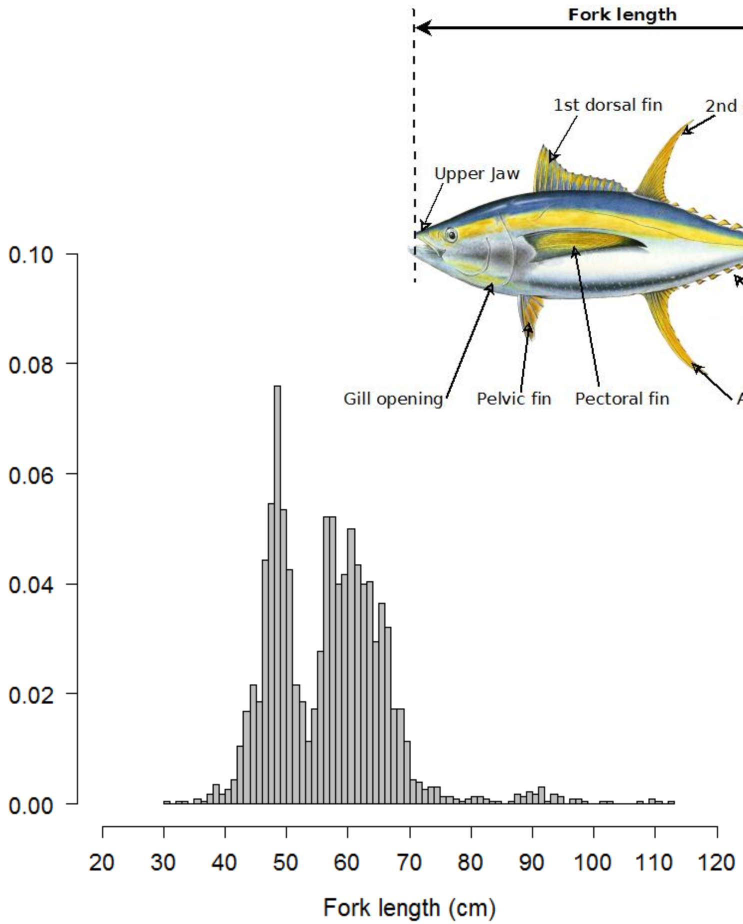


↳ accounting for various sources of uncertainties

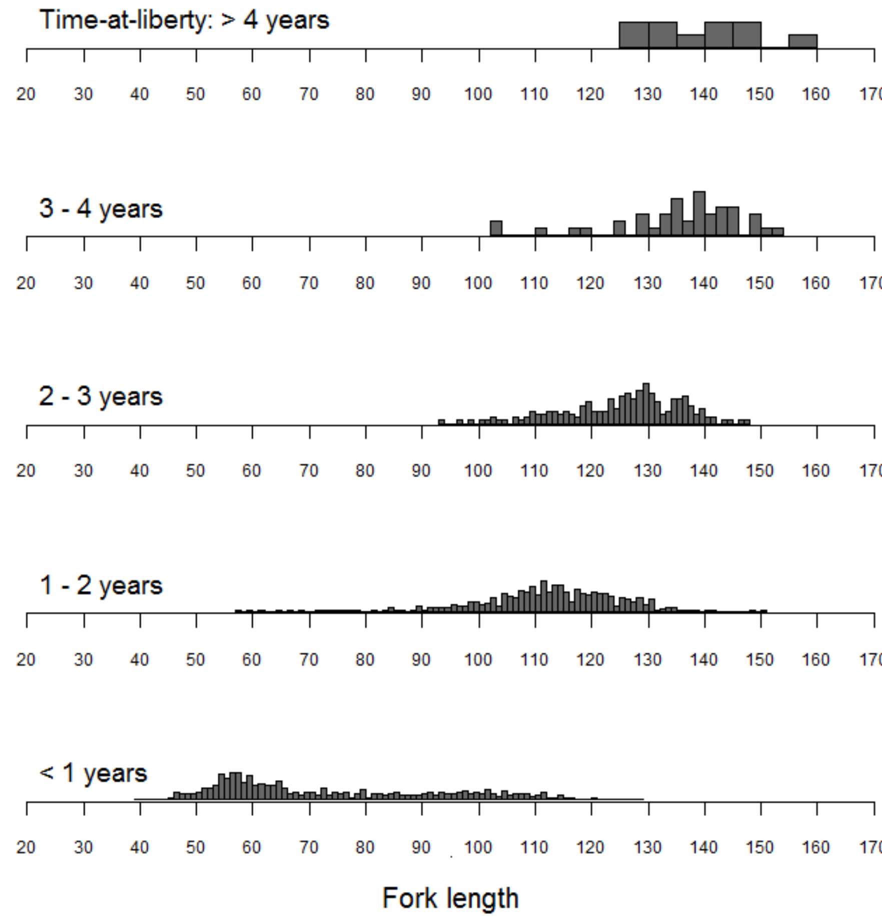
↳ integrating expert knowledge or information from external data

Mark-recapture data

- Some selection criteria have been applied to mark-recapture data leading to a reliable dataset composed of 2,068 fish



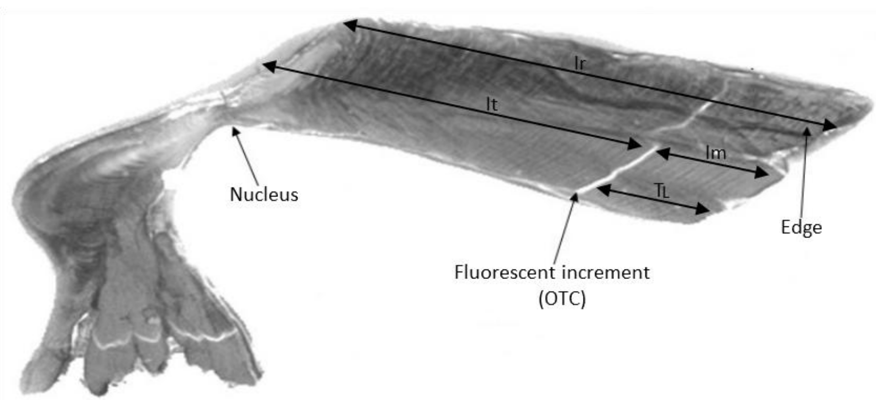
Distribution of length at tagging

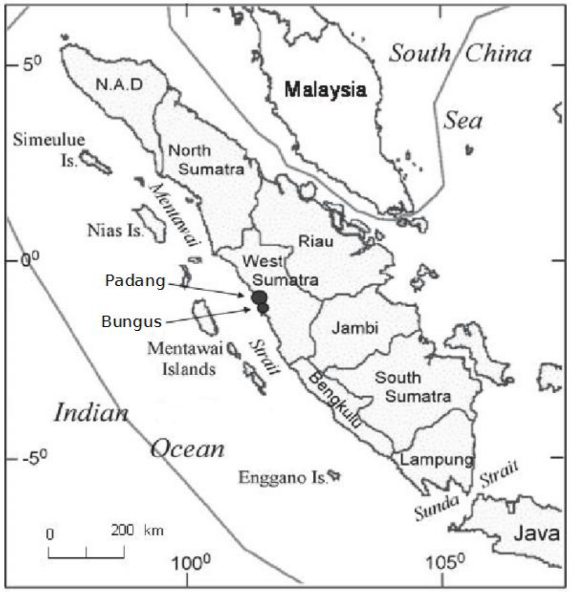


Distribution of length at recapture

Otolith readings data

	Regional Tuna Tagging Project Indian Ocean	WSTTP	IOT cannery
Number of otoliths	128	18	28
Length-at-tagging (cm FL)	46-85	×	×
Length-at-recapture (cm FL)	47.9-135.4	19-29	31-128.7
Time-at-liberty (days)	32-969	×	×

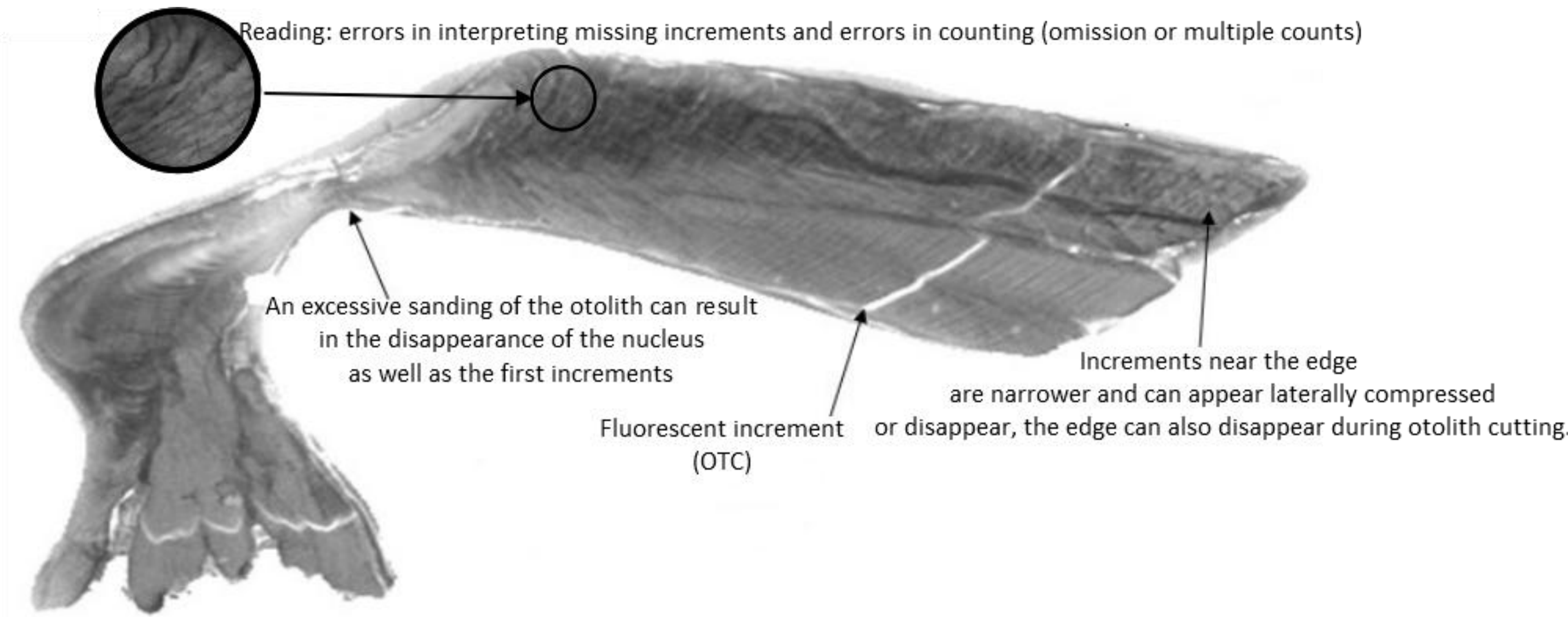




WSTTP = West Sumatra Tuna Tagging Project

Otolith readings data

Various uncertainties around readings otoliths



↳ developing an ageing error model

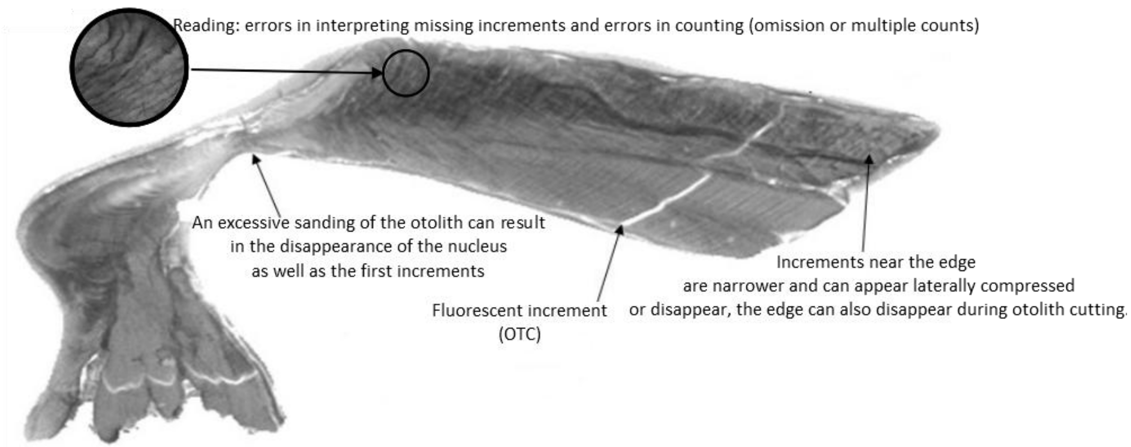
Ageing error model

- Exploits the information provided by the multiple readings of the same otolith as well as expert knowledge to explicitly consider the sources of uncertainty associated with otolith reading

- Two-steps model:

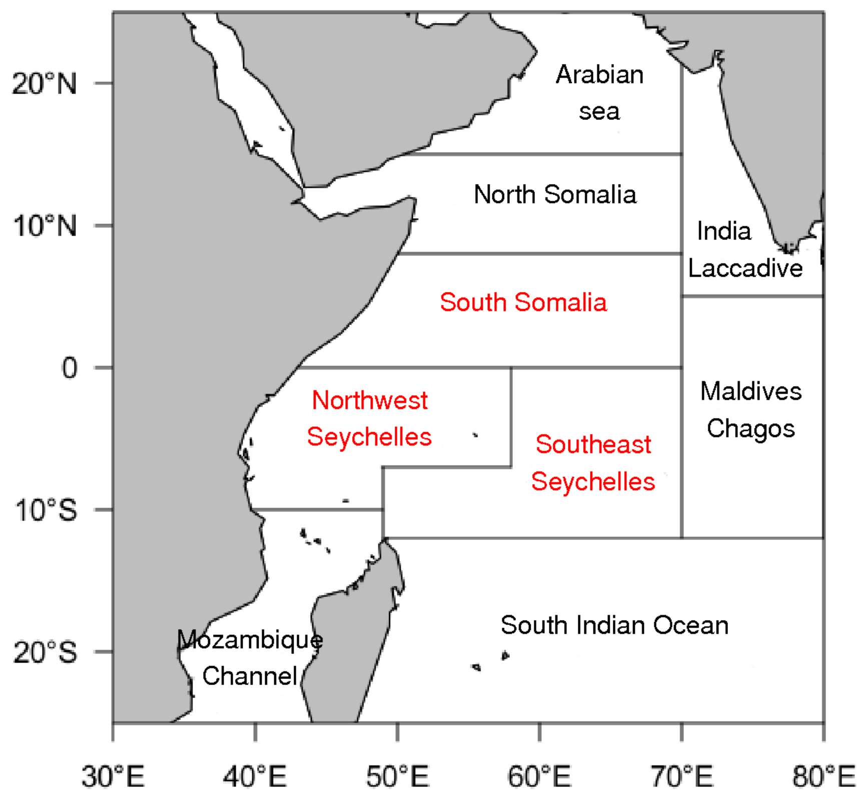
1) testing the daily increment deposition from a subset of OTC-tagged fish

2) estimating the age of each fish



Modal progression data

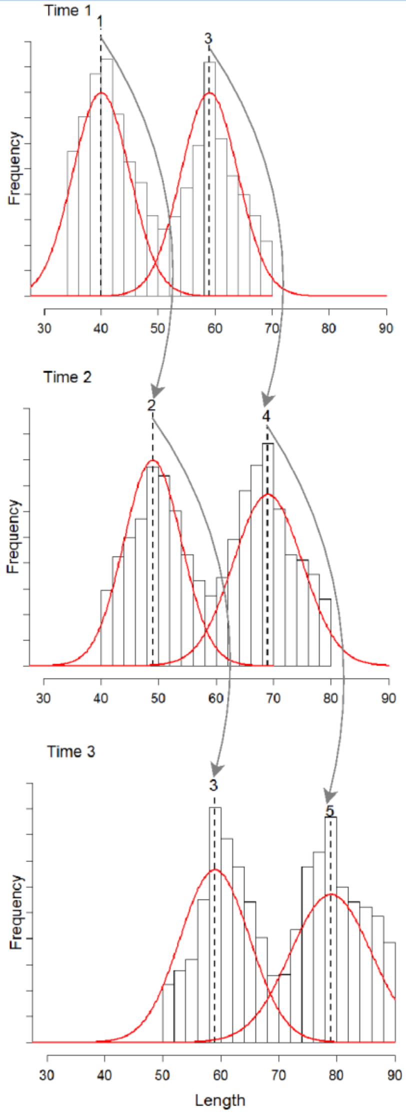
- Commercial catches of European purse-seine vessels from December 2000 to March 2010



Indian Ocean fishing areas

Modal progression data

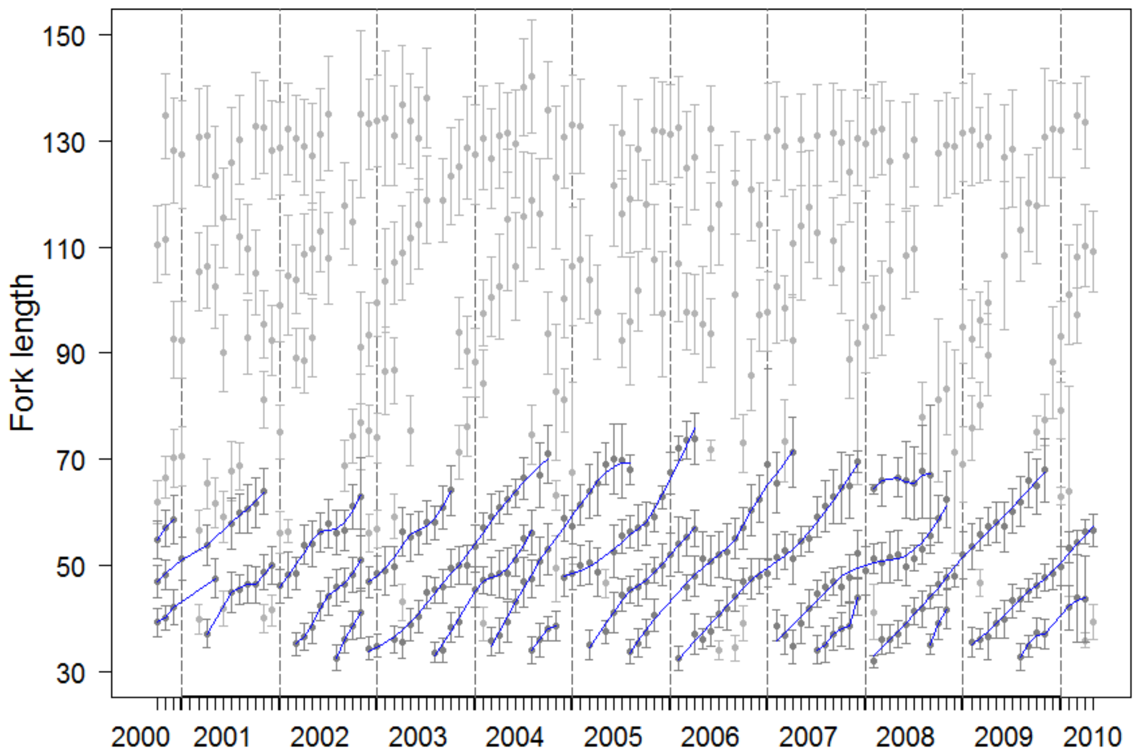
- Commercial catches of European purse-seine vessels from December 2000 to March 2010
- Determination of length mode using a mixture of normal distributions
- Progression in length of modes tracked monthly



Modal progression data

- Knowing the spawning period, an average age can be assigned to each mode

- 23 cohorts



Integrated growth model

- The 3 data sources complement each other in an integrated two-stanza growth model: VBlogK model (Laslett & al. 2002)

- **direct ageing data**:

    - Growth model coupled with ageing error model
    - Length expressed as a function of age

$$L^*_{i,j} = L_\infty(1 - exp(-k_2(A_{i,j} - t_0)) \times \left(\frac{1 + exp(-\beta(A_{i,j} - t_0 - \alpha))}{1 + exp(\beta\alpha)}\right)^{\frac{(k_1 - k_2)}{\beta}} + \varepsilon_{i,j}$$

i = fish, *j* = capture opportunity (1 at tagging, 2 at recapture), * corresponds to observed data

Integrated growth model

- The 3 data sources complement each other in an integrated two-stanza growth model: VBlogK model (Laslett & al. 2002)

- **mark-recapture data**: information on increasing $L_2 - L_1$ over the time interval *[t_2, t_1]* but age of fish unknown

  - Length L_2 express as a function of L_1 and $T_L = t_2 - t_1$

$$L^*_{i,2} = L^*_{i,1} + (L_\infty - L^*_{i,1})(1 - exp(-k_2 \times T^*_{Li})) \times \left(\frac{1 + exp(-\beta(t_1 + T^*_L - t_0 - \alpha))}{1 + exp(-\beta(t_1 - t_0 - \alpha)} \right)^{\dfrac{(k_1 - k_2)}{\beta}} + \varepsilon_{i,2}$$

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Integrated growth model

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➢ **mark-recapture data**: information on increasing $L_2 - L_1$ over the time interval $[t_1, t_2]$ but age of fish unknown

- Length L_2 express as a function of L_1 and $T_L = t_2 - t_1$
- For each fish i: $\lambda_i = t_0 + \alpha - t_{1i}$

$$L^*_{i,2} = L^*_{i,1} + (L_\infty - L^*_{i,1})(1 - exp(-k_2 \times T^*_{Li})) \times \left(\frac{1 + exp(-\beta(T^*_{Li} - \lambda_i))}{1 + exp(\beta \times \lambda_i)}\right)^{\frac{(k_1 - k_2)}{\beta}} + \varepsilon_{i,2}$$

i = fish, *j* = capture opportunity (1 at tagging, 2 at recapture), * corresponds to observed data

Integrated growth model

- The 3 data sources complement each other in an integrated two-stanza growth model: VBlogK model (Laslett & al. 2002)

- **modal progression data**: similar to multiple mark-recapture events with knowledge of the initial age

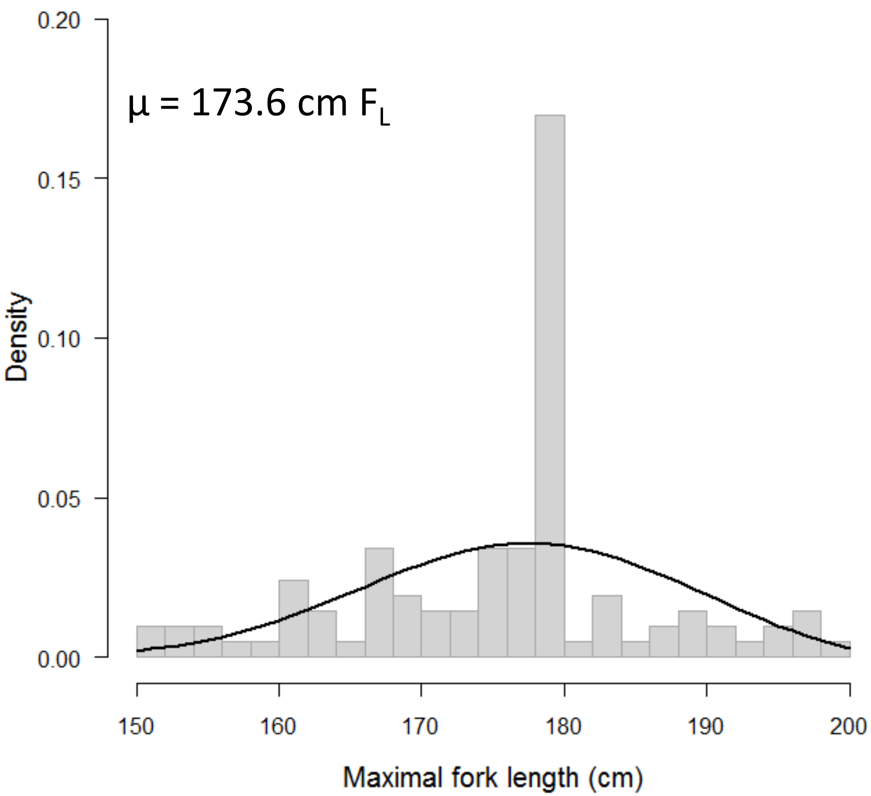
  - Mean length of cohort *c* at month *k*: $\mu_{c,k}$
  - Mean age of cohort *c* at month *k*: $a_{c,k} = a_{c,1} + (k-1).d$

$$\mu^*_{c,k} = L_\infty(1-exp(-k_2(a^*_{c,1}+(k-1)d-t_0))\times\left(\frac{1+exp(-\beta(a^*_{c,1}+(k-1)d-t_0-\alpha))}{1+exp(\beta\alpha)}\right)^{\frac{(k_1-k_2)}{\beta}}\times\varepsilon_{\mu c,k}$$

d = time interval between two length modes, * corresponds to observed data

Bayesian inference

- Asymptotic length = maximal size that a fish can reach
  - ↳ Generalize Extreme value distribution

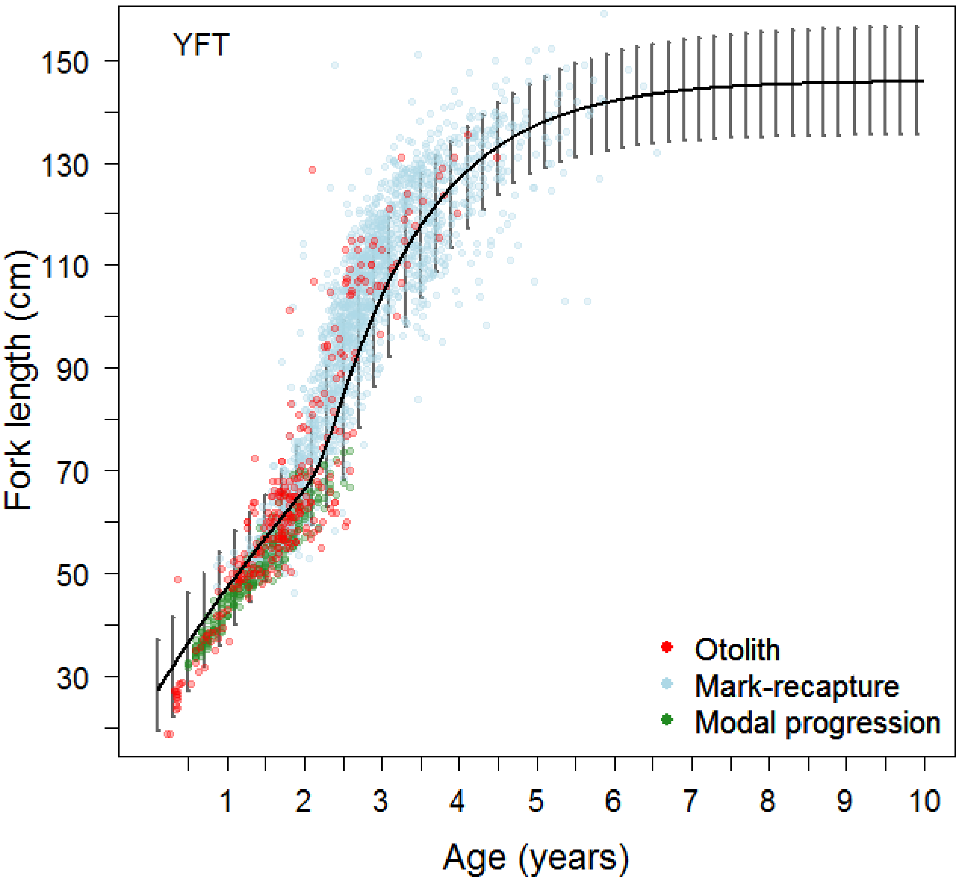


Estimation of the occurrence probability of largest asymptotic lengths from larger fish unusual in the catches

Size measurement data on fresh fish collected during 1952-2011 from the European and Seychelles purse seine fisheries, Maldivian pole and line vessels, and Taiwanese and Japanese longliners

Yellowfin growth

- 2 distinct phases over the fish lifespan initially slow growth which accelerates as from 62 cm F_L until a maximum around 81 cm F_L and decreases when the size gets closer to asymptotic length



Growth rate coefficients:

1st stanza: k_1=*0.182-0.22*

2nd stanza: k_2=*0.729-0.866*

Mean population asymptotic length between 142.6 and 150 cm F_L

Growth sexual dimorphism

- Posterior distributions from the integrated model use as prior information in sex-specific growth models

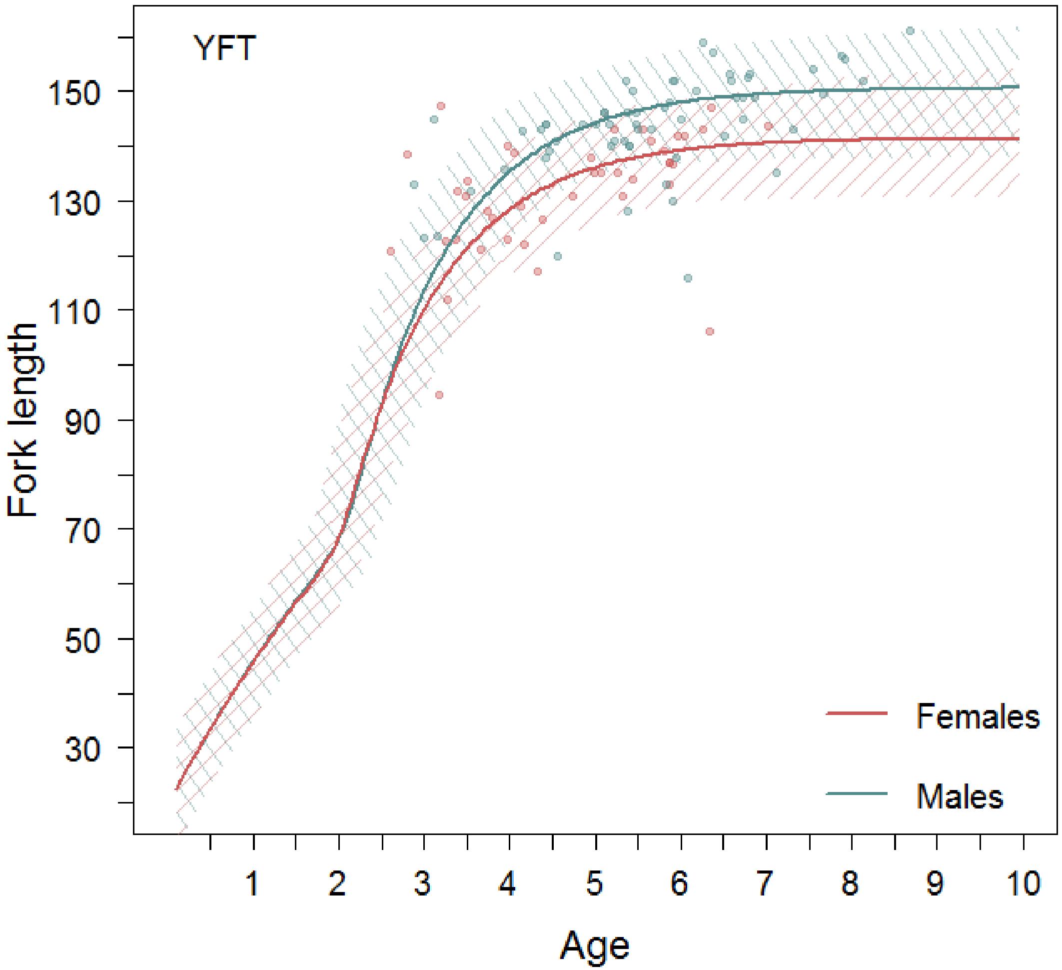
- Mark-recapture dataset of 34 females and 54 males (RTTP-IO)

- 7 individuals of each sex for which the age was estimated from otolith readings (IOT cannery)

	Female		Male	
	RTTP-IO	IOT	RTTP-IO	IOT
Length-at-tagging (cm FL)	47 - 71	×	42 – 100	×
Length-at-recapture (cm FL)	106 – 147.1	94.7 – 147.5	116 – 161	123.5 - 145
Time-at-liberty (month)	24 - 73	×	28 - 72	×

Growth sexual dimorphism

Faster growth and an asymptotic length larger for males than females



Asymptotic length

females: 137.46-145.24 cm F_L

males: 146.26-155.04 cm F_L

Thank you for your attention

Yellowfin Assumptions for a two-stanza growth