Investigating complex growth patterns and sexual dimorphism in yellowfin tuna (*Thunnus albacares*) from individual growth trajectories

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Otoliths as complementary tools to tagging data

Chronological properties

- Age-structured information is key in fisheries science
- Development of otolith microstructure examination in the early 1970s (Pannella 1971)
- About 1 million otoliths aged annually worldwide in the early 2000s (Campana & Thorrold 2001)
- Ageing tropical fishes is very difficult due to continuous spawning and the absence of growth cycles
- Otolith microstructural features useful for ageing tropical fishes (Pannella 1974) and larvae and juveniles (Brothers et al. 1976)

Ageing tropical tunas from otolith reading

Region	Species	Size-range	Source
E. Pacific	Yellowfin	40-110 cm	Wild & Foreman 1980
E. Pacific	Skipjack	42-64 cm	Wild & Foreman 1980
E. Pacific	Yellowfin	30-170 cm	Wild 1986
E. Pacific	Bigeye	30-149 cm	Schaefer & Fuller 2006
W. Pacific	Skipjack	3-80 cm	Uchiyama & Struhsaker 1981
W. Pacific	Yellowfin	7-93 cm	Uchiyama & Struhsaker 1981
W. Pacific	Yellowfin	15.2-79 cm	Yamanaka 1990
W. Pacific	Skipjack	1.3-4 cm	Tanabe et al. 2003
W. Pacific	Yellowfin	20-145 cm	Lehodey & Leroy 1999
W. Pacific	Bigeye	25-157 cm	Lehodey et al. 1999
Atlantic	Bigeye	37-124 cm	Hallier et al. 2005
Atlantic	Yellowfin	5.2-179 cm	Shuford et al. 2007
Indian	Yellowfin	28-154 cm	Stéquert et al. 1996
Indian	Bigeye	30-160 cm	Stéquert & Conand 2004

Table: Otolith reading used worldwide for ageing tropical tunas

Daily rate of increment deposition validated in the otolith

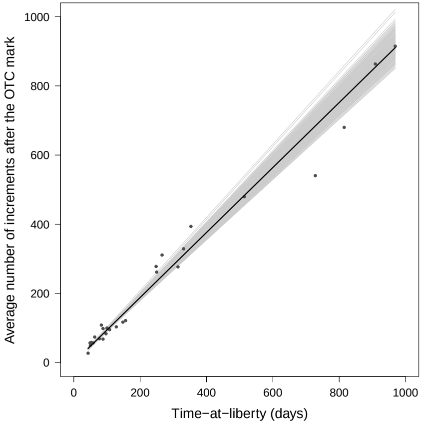


Figure: **The number of increments reflects fish age**. Consistency between the number of otolith increments and time-at-liberty

Otolith growth proportional to fish growth

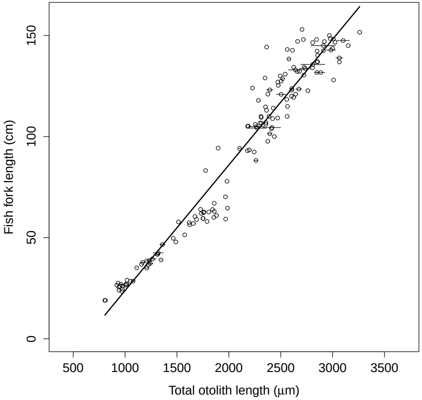
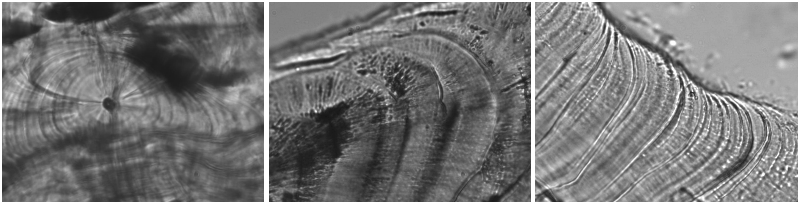


Figure: **Otolith growth reflects somatic growth**. Relationship between otolith length and fish fork length for yellowfin (Cf. Sardenne et al)

Increment widths have revealed useful to:



- Provide information on the day-to-day growth of fishes (Brothers 1981)
- Detect life-history transitions (Campana 1984)
- Track changes in environmental factors such as temperature and food conditions (Eckmann & Rey 1987)
- Study size-based selective mortality (Baumann et al. 2003)

Objectives

- Gaining insights into growth of early life history stages of tunas: Never observed in fisheries data
- Testing the hypothesis of 2-stanza growth during exploited phase: No potential size-based selectivity effect of gear
- Testing the hypothesis of sexual dimorphism through the comparison of sex-specific individual growth trajectories

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43 yellowfin collected through the RTTP

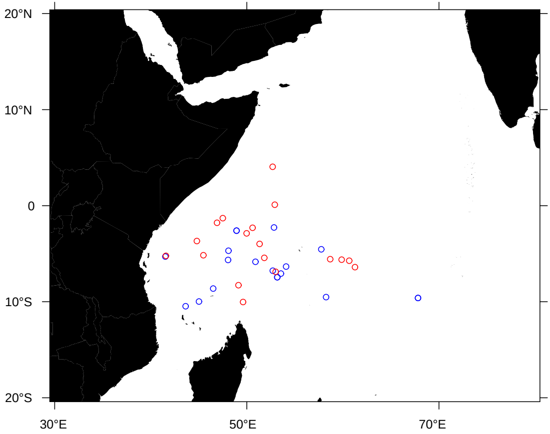

Figure: 22 males and 20 females yellowfin (+1 unknown) tagged at sizes 46-89 cm and recovered at sizes 121-153 cm during 2009-2012

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Figure: Otoliths of yellowfin tunas at 30, 50, 90, and 150 cm fork length

480 otolith length measurements with binoculars

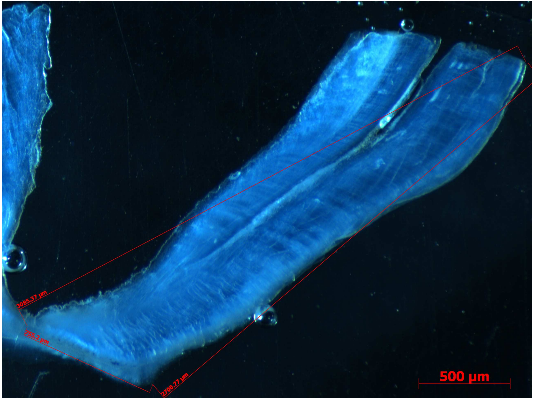

Figure: Otolith slide for a yellowfin male of 152 cm. $L_{tot} = L_1 + L_2$

More than 60,000 measures of ring width

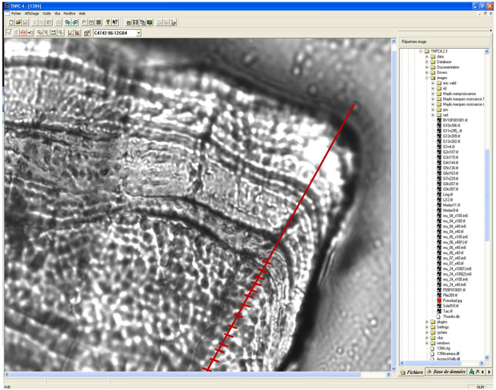

Figure: 2-5 analyses of each otolith through image analysis of otolith slides (TNPC software - 'Traitement Numérique des Pièces Calcifiées')

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High-frequency daily variability and patterns in growth

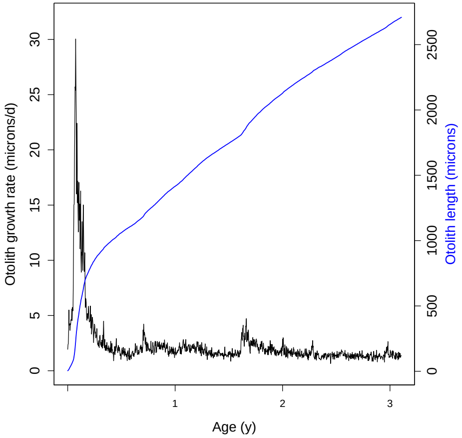

Figure: Otolith growth trajectory back-calculated for a yellowfin (KK04666). 1 increment = 1 day

Variability between readings: averageing growth trajectories

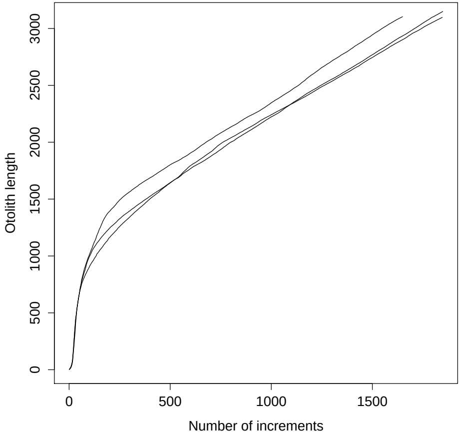

Figure: **Measurement errors**: 3 growth trajectories for YFT CC47569

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An exponential growth for otolith larvae

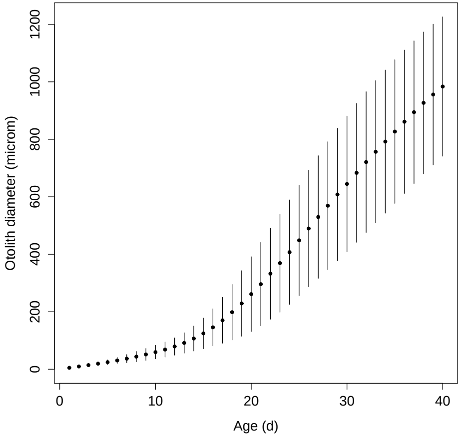

Figure: Daily otolith growth during the 40 first days of yellowfin life

Otolith size and fish size correlated during larvae phase

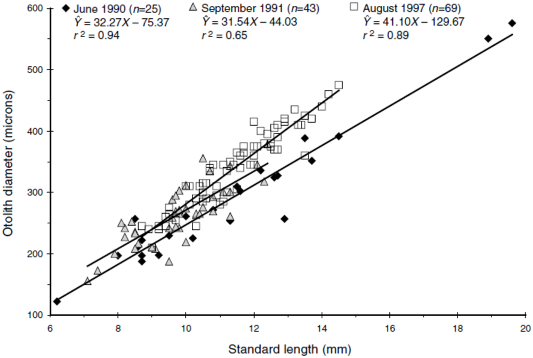

Figure: Relationship between otolith diameter and fish length from yellowfin larvae caught in the eastern Pacific (Wexler et al. 2007)

Simple “conversion“ of otolith diameter into fish length

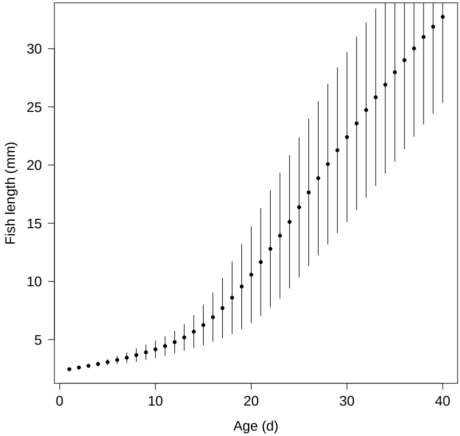

Figure: Estimated growth of yellowfin tuna larvae

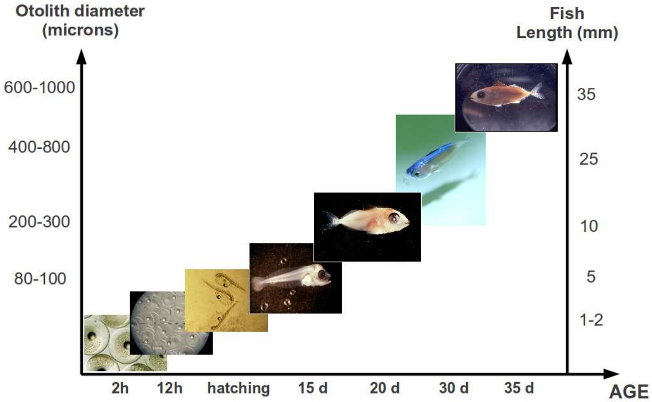

Figure: **Early life history of yellowfin**. Pictures: Courtesy of Daniel Benetti and IATTC (Dan Margulies, Achotines Laboratory, Panama)

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Apparition of a second stanza at 70-85 cm (2-2.5 years)

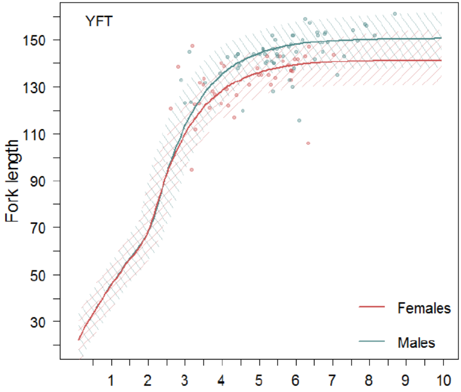


Figure: Integrated models indicate a 2-stanza growth with sexual dimorphism (Dortel et al. 2012, Eveson et al. 2012)

Strong decrease in growth rates until 6-8 months

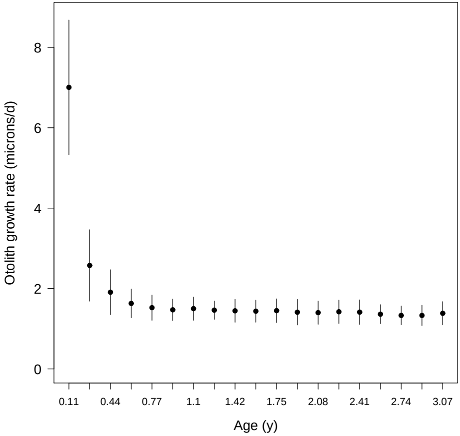


Figure: **Juveniles of yellowfin**. Daily growth rates for yellowfin from 40 days to 3 years

No apparent stanza in the growth of otolith

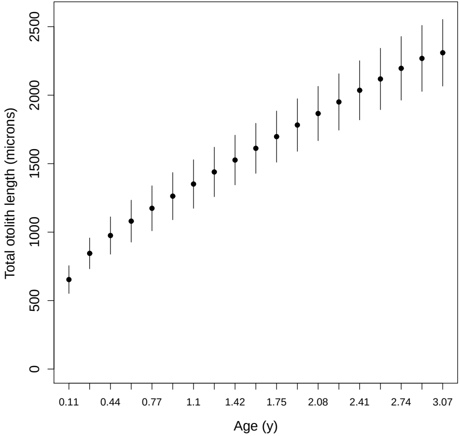


Figure: **Juveniles of yellowfin**. Otolith growth almost linear

BUT, detection of a shift in the length-length relationship

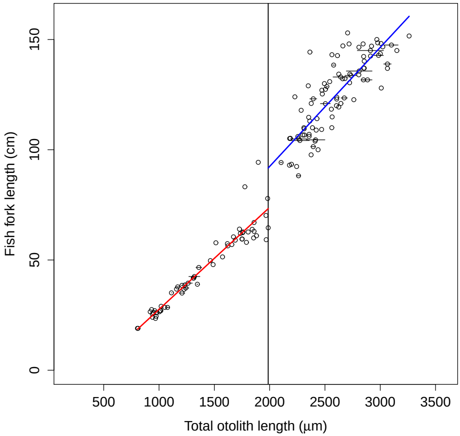


Figure: **Otolith length - fish length relationship** estimated from change point analysis at $\sim$ 2000 μm, i.e. about 2.4 y

The shift would predict a change in growth at 73-91 cm

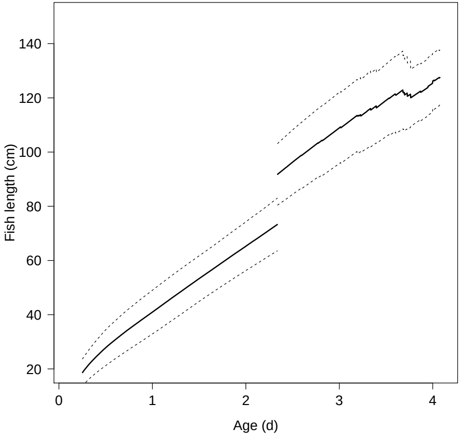


Figure: Fish growth curve derived from otolith growth and linear length-length relationships

The shift matches well the transition between stanzas

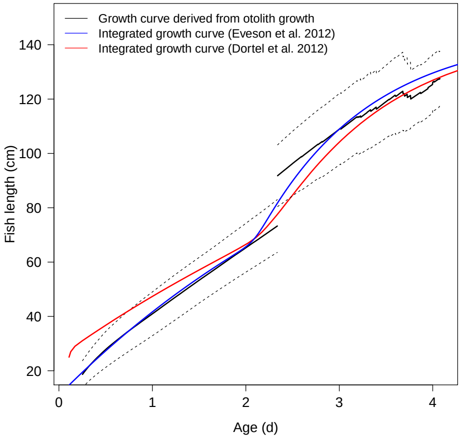
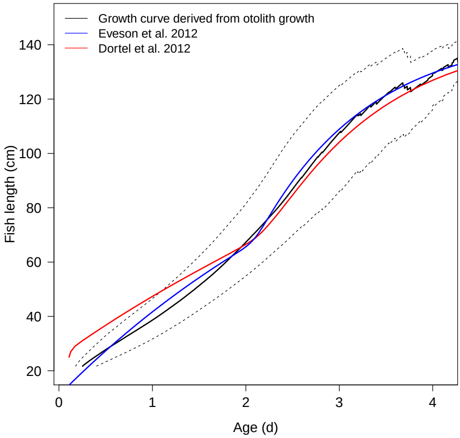


Figure: Fish growth curve derived from otolith growth and linear length-length relationships and integrated growth curves

The shift matches well the transition between stanzas



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No apparent sex-specific difference in otolith growth

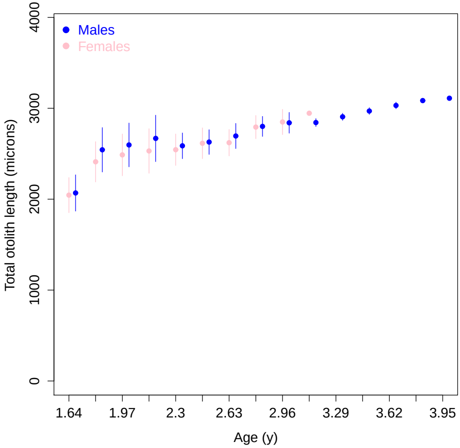

Figure: Otolith length as a function of the number of increments between 1.5 and 4 years

Some patterns that need further exploration

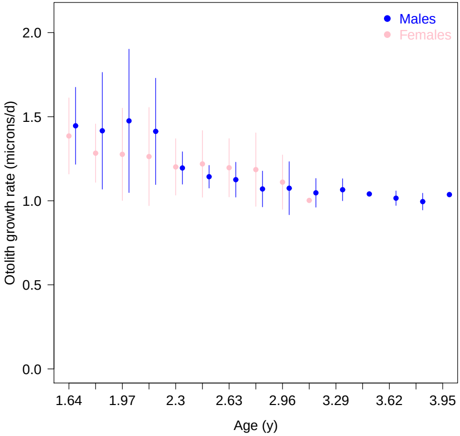

Figure: Otolith growth rates as a function of the number of increments between 1.5 and 4 years

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Otolith microstructural features of yellowfin

Key points

- Information on larval growth that seems fully consistent with experiments conducted at IATTC lab at Achotines
- The 2 stanzas observed from tagging data are not visible in individual otolith growth trajectories
- The stanzas however "appear" in the somatic growth if one accounts for changes in otolith length-fish length relationship
- No clear effect of sex in individual growth but needs further investigation

Multistanza growth

1. Exponential growth for larvae (1–30 d)
2. Transition phase with slower growth rates (1–7 mo)
3. Quasi linear growth for juveniles (0.6–2.4 y)
4. Transition phase linked to changes in metabolism (2.4–2.8 y)
5. Final growth similar to a classical von Bertalanffy model ($>$ 2.8 y)

Perspectives

- Inclusion of otolith data (counts, increments, length) in the MDST information system (Cf. J Barde)
- Non confidential biological data that should available (online) to promote inter-comparisons between stocks and oceans
- Ongoing work on the dynamics of lipids to to investigate the mechanisms of energy allocation between growth, reproduction, and maintenance (Cf. N. Bodin)
- Application of a bioenergetic model describing the biomineralization mechanisms involved in otolith construction (Fablet et al. 2011, Pecquerie et al. 2012)