Tuna spawning in the Phoenix Islands Protected Area: combining field data and computational methods

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Acknowledgements

- **Co-authors: Joel Llopiz, Jan Witting, Ciara Willis, Simon Thorrold, Randi Rotjan**
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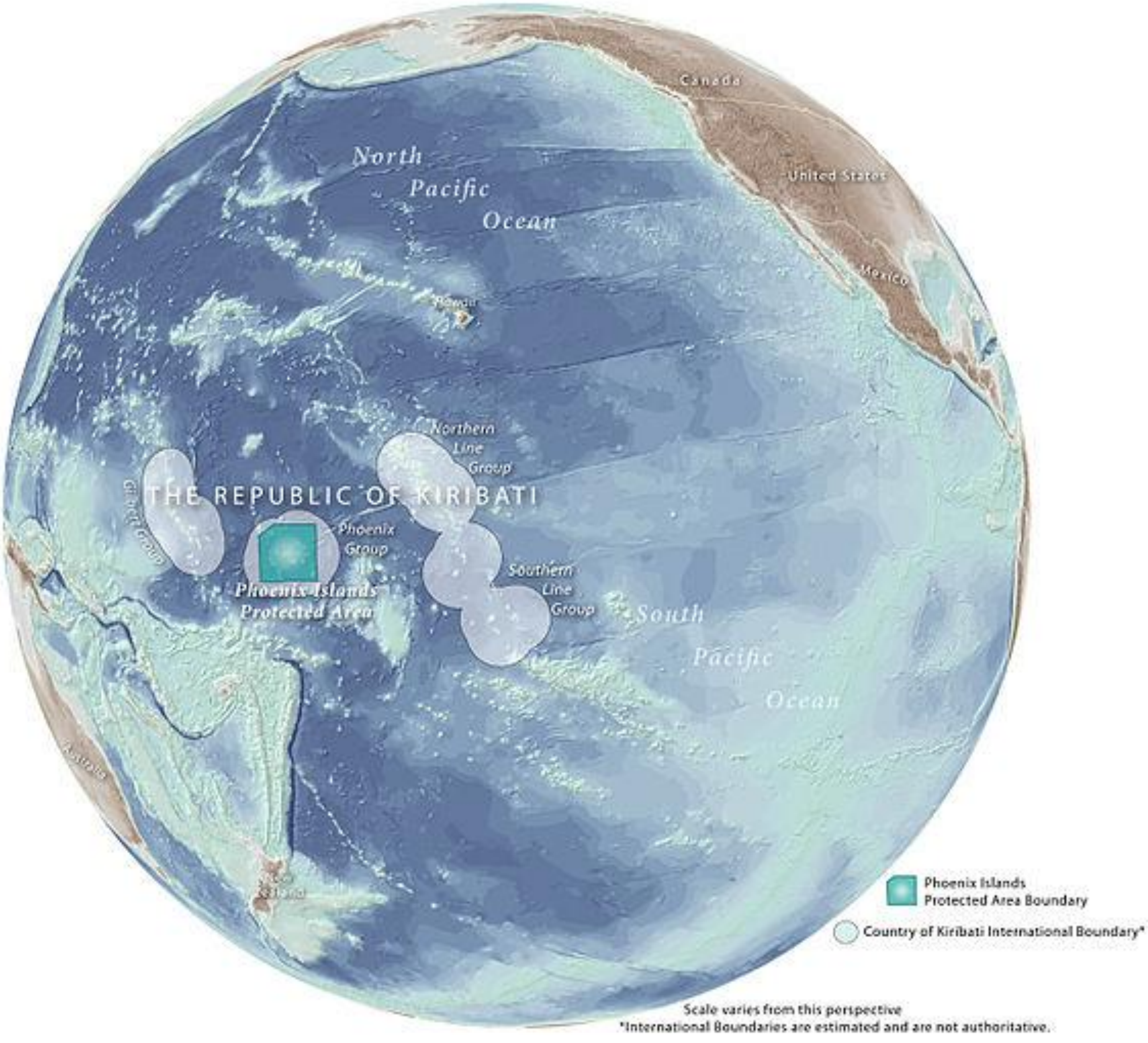
- **Llopiz Lab: Sarah Glancy, Julie Pringle**

Bathymetry in plots is from the GEBCO_2014 Grid, version 20150318, www.gebco.net



Canada
United States
Mexico
North
Pacific
Ocean
Hawaii
Northern
Line
Group
THE REPUBLIC OF KIRIBATI
Gilbert Group
Phoenix
Group
Phoenix Islands
Protected Area
Southern
Line
Group
South
Pacific
Ocean
Australia
Phoenix Islands
Protected Area Boundary
Country of Kiribati International Boundary*
Scale varies from this perspective
*International Boundaries are estimated and are not authoritative.

Making money on tuna

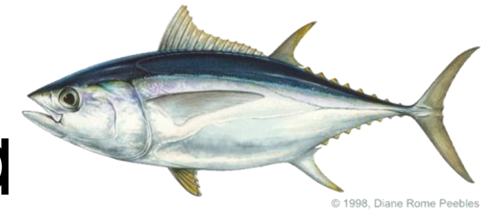
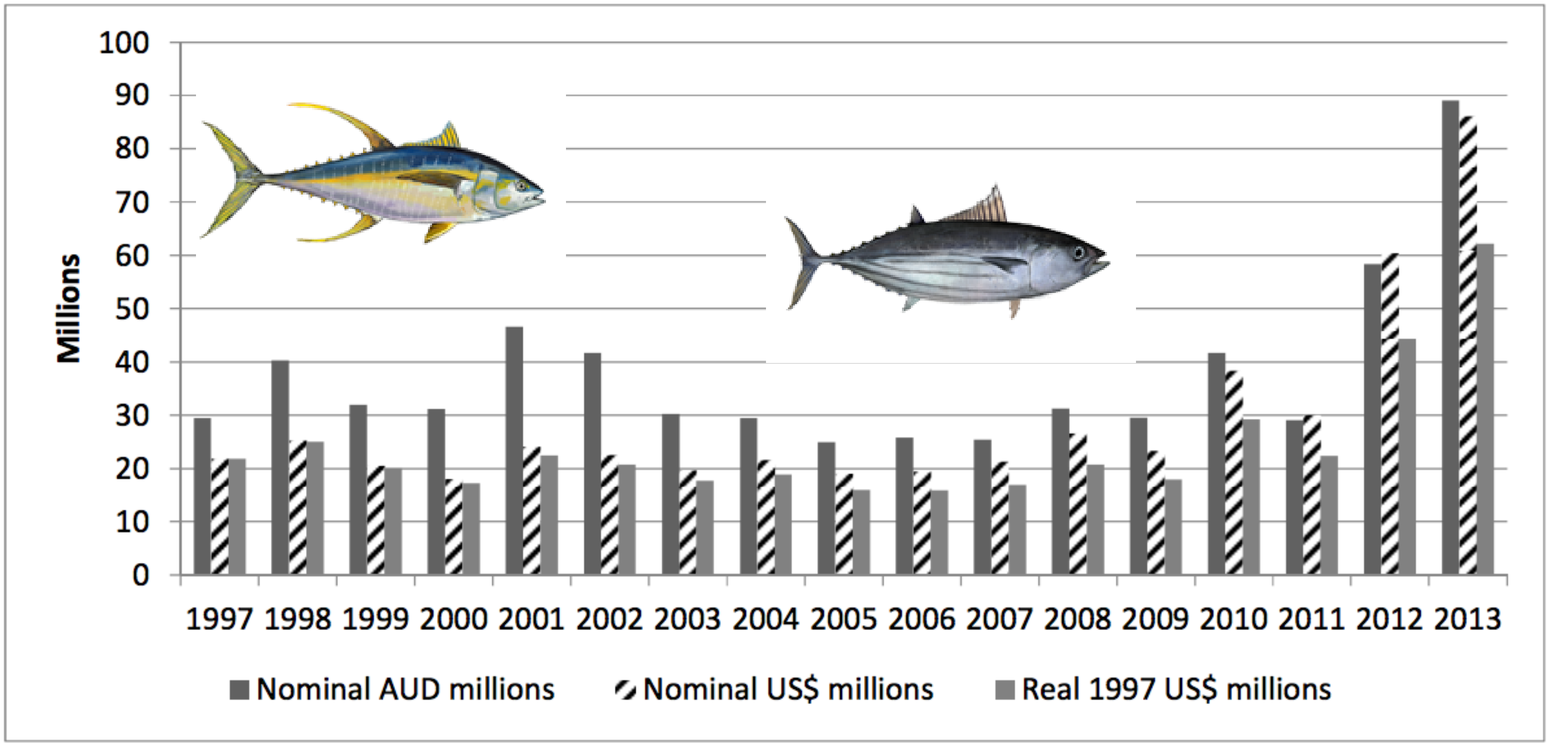


Figure 1: Total Fishing License Revenue (Excl. Development Funds)

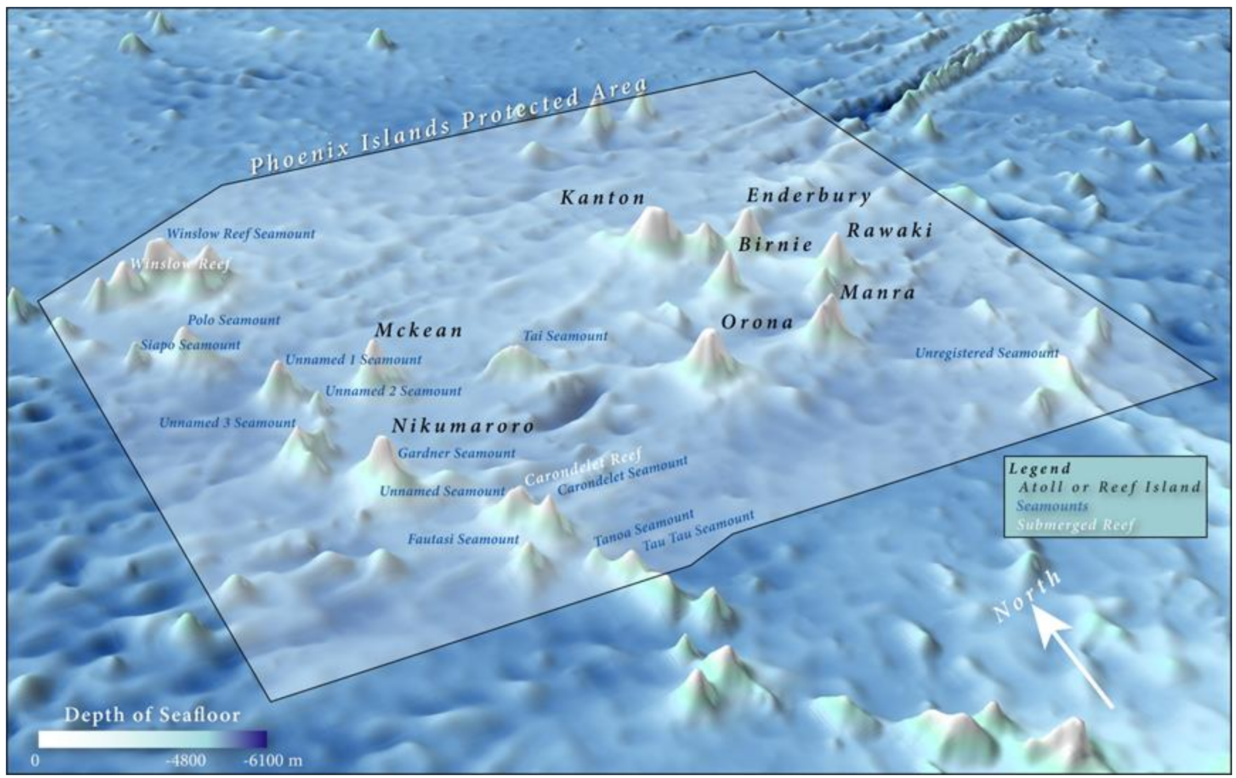


Source: MFED and MFMRD data

From MFED report, Sept 2014: http://www.mfed.gov.ki/sites/default/files/Fishing-License-Revenues-in-Kiribati-Report-2014_1.pdf

- PIPA represents ~11% of the Exclusive Economic Zone of Kiribati

- Completely closed to fishing as of January 1, 2015

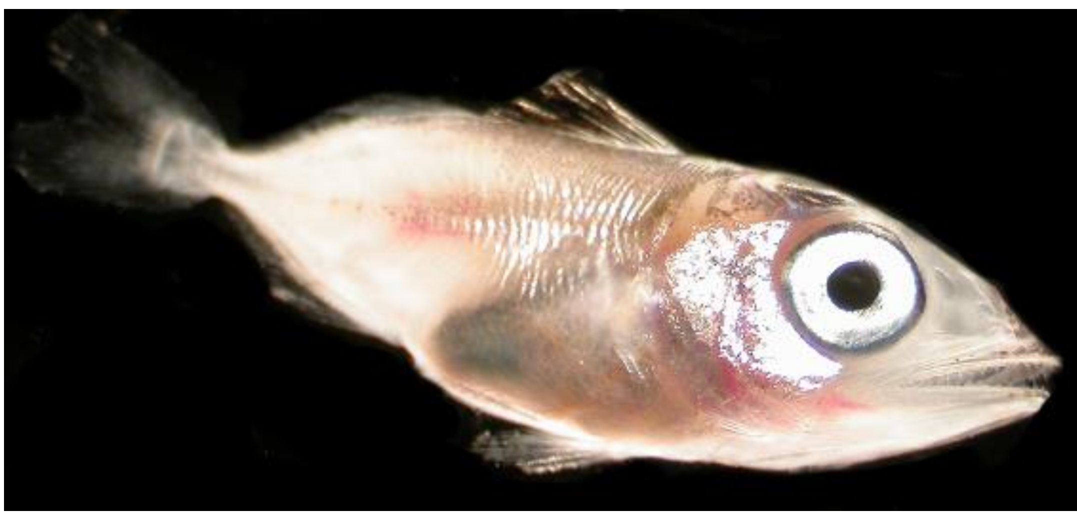


Research questions

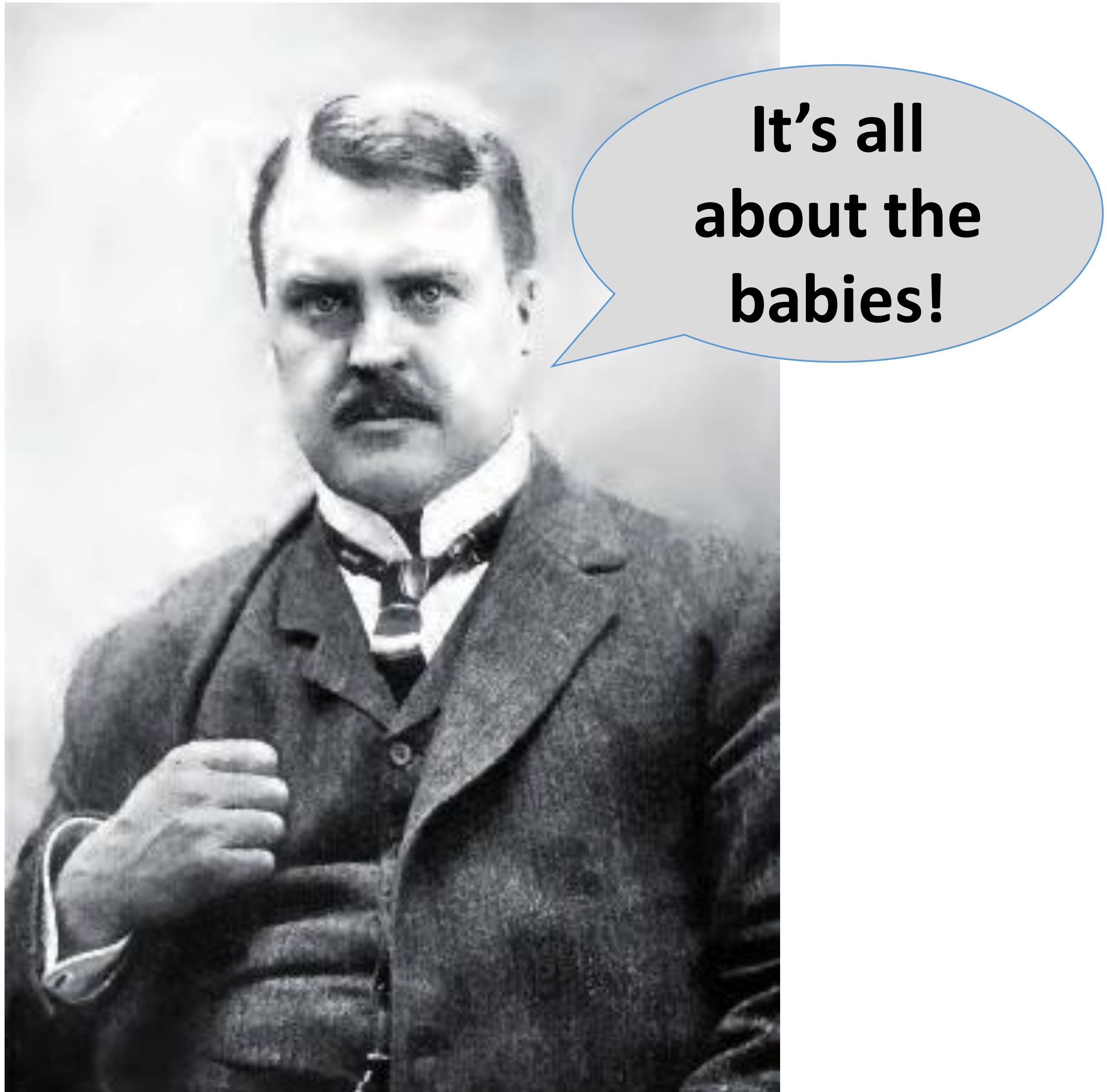
- *What is the abundance and distribution of larval tunas in PIPA?*
  - Establish timeseries for monitoring protected area

- *Where are those larvae spawned, and what can we infer about adult use of the protected area?*
  - Understand role of protected area for large pelagics

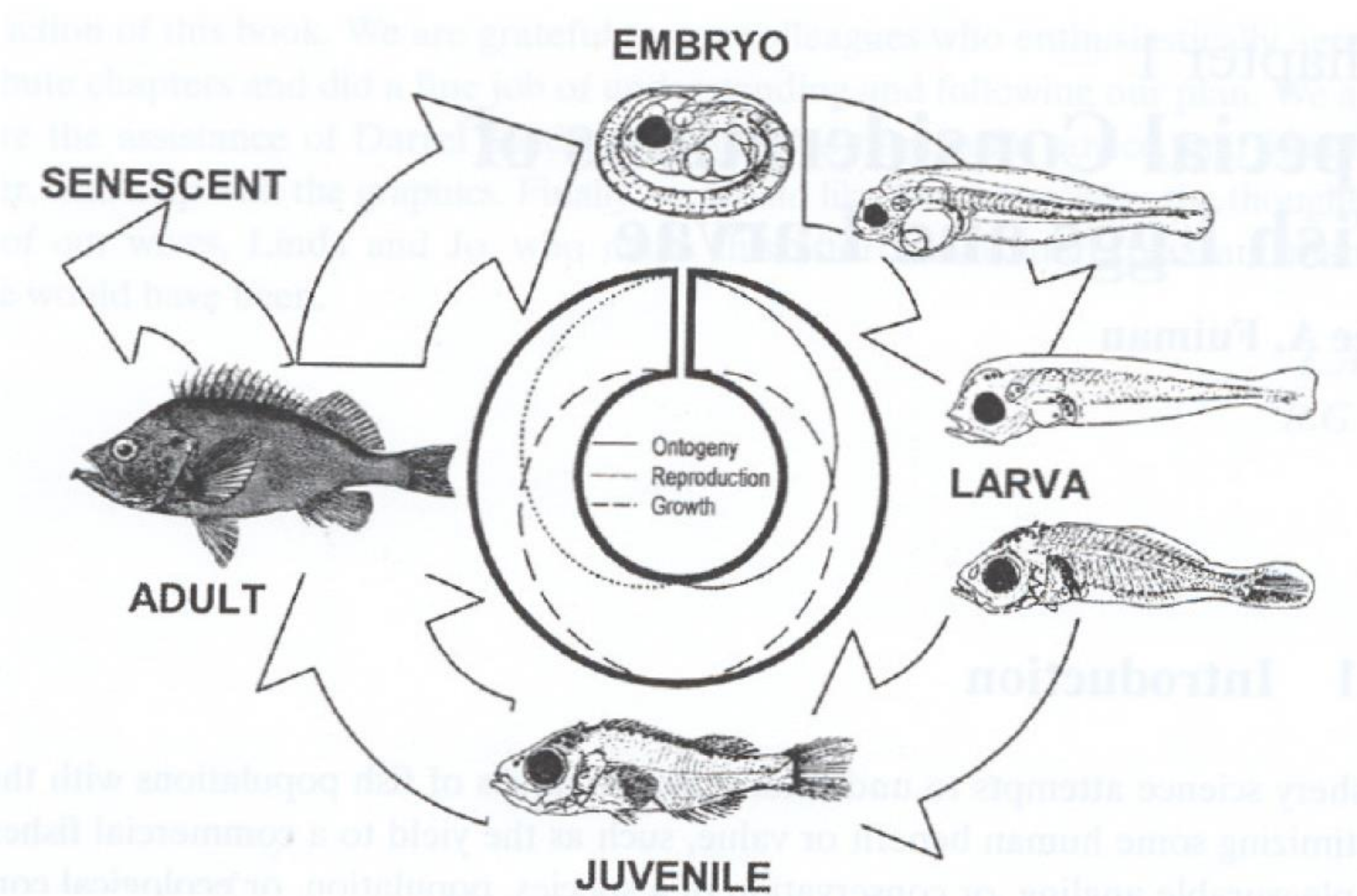
Llopiz Lab



Johan Hjort



Complex (bipartite) life history

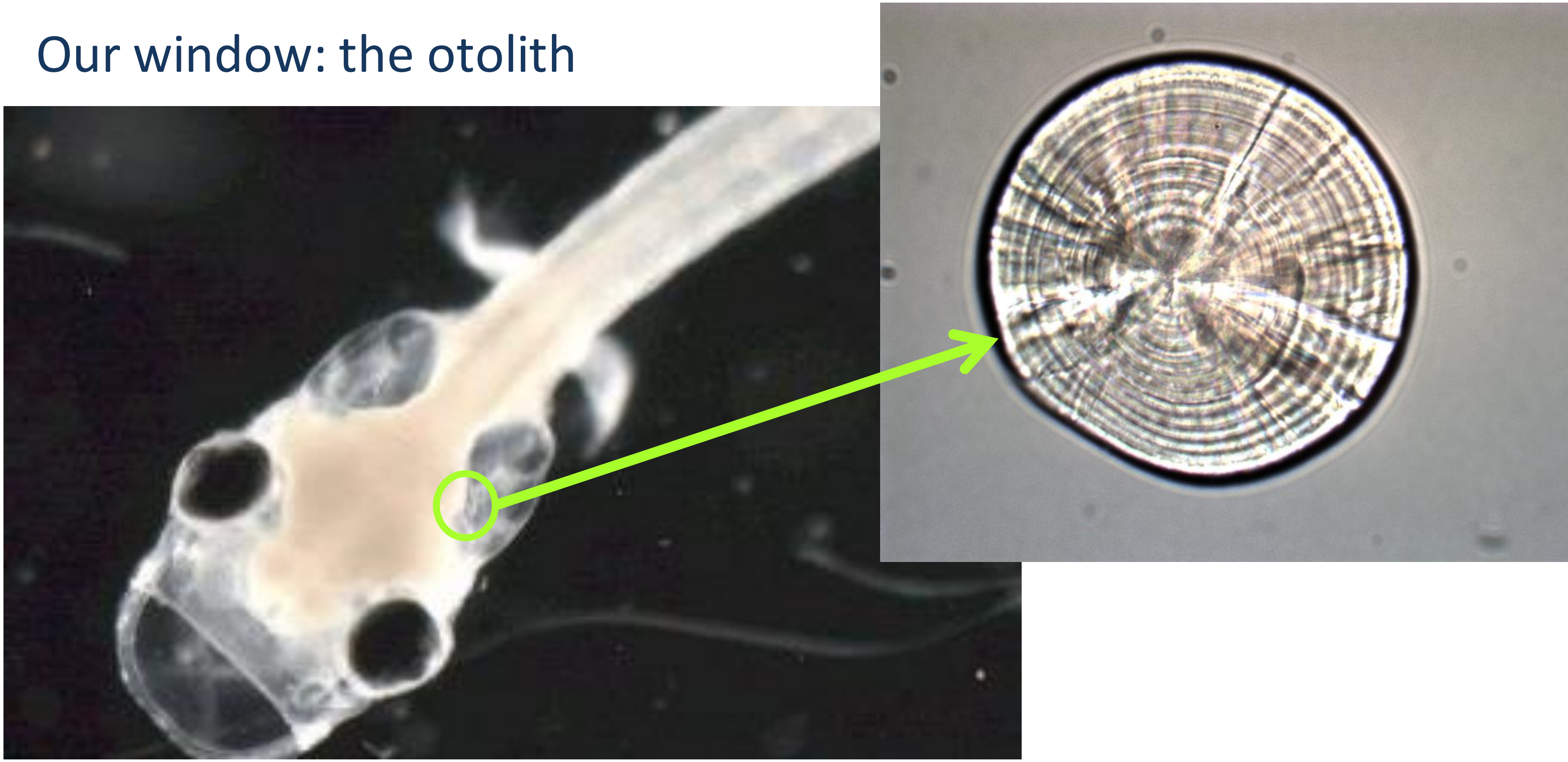


Why study larvae?

- Map spawning locations
- Understand larval growth and survival
- Understand population dynamics
- Ecosystem health
- Population connectivity

pc: Cedric Guigand

Our window: the otolith



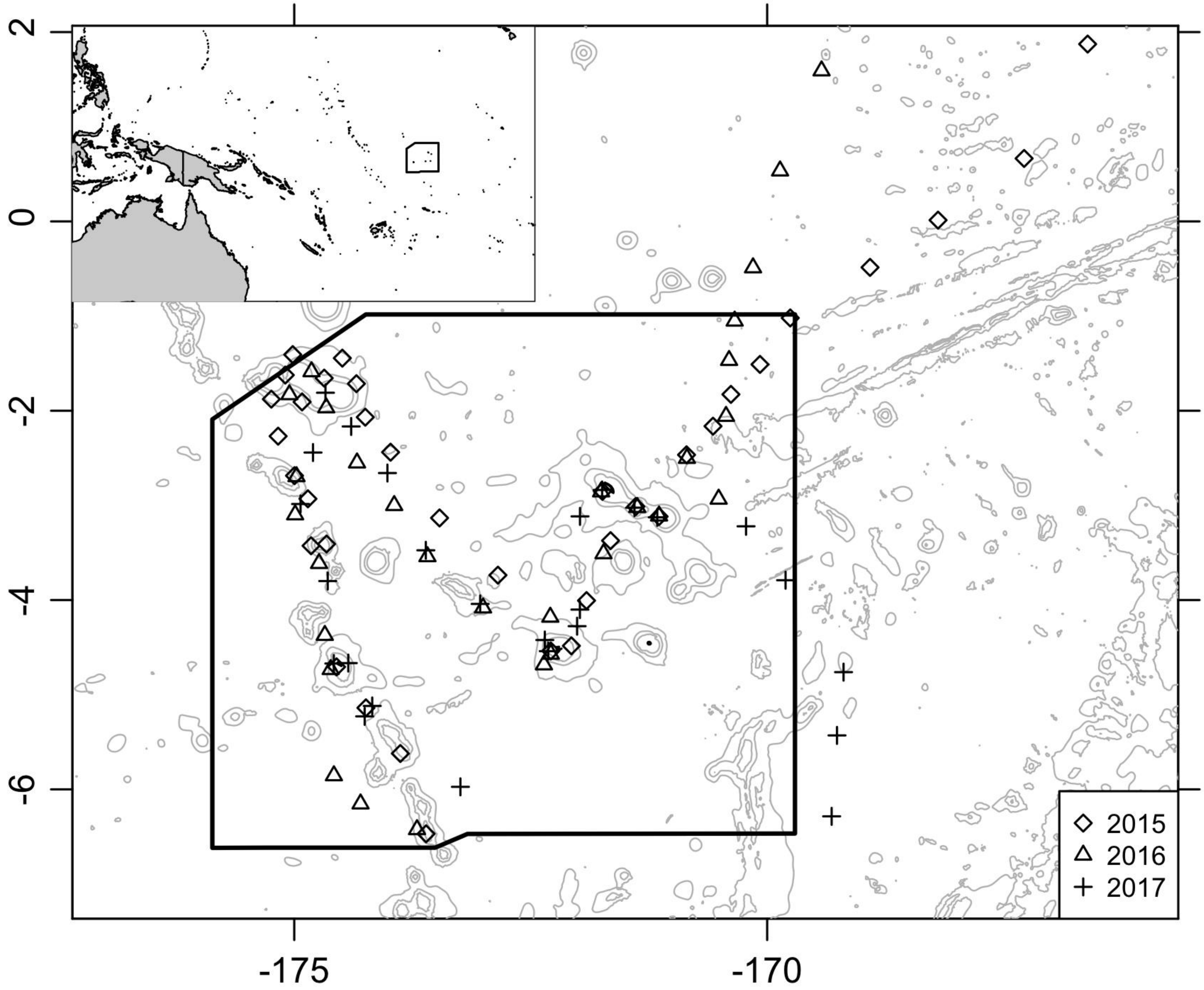
- Larval age
- Hatch date
- Daily growth rates

  (from increment widths)

Methods

- *What is the abundance and distribution of larval tunas in PIPA?*
  - Establish timeseries for monitoring protected area

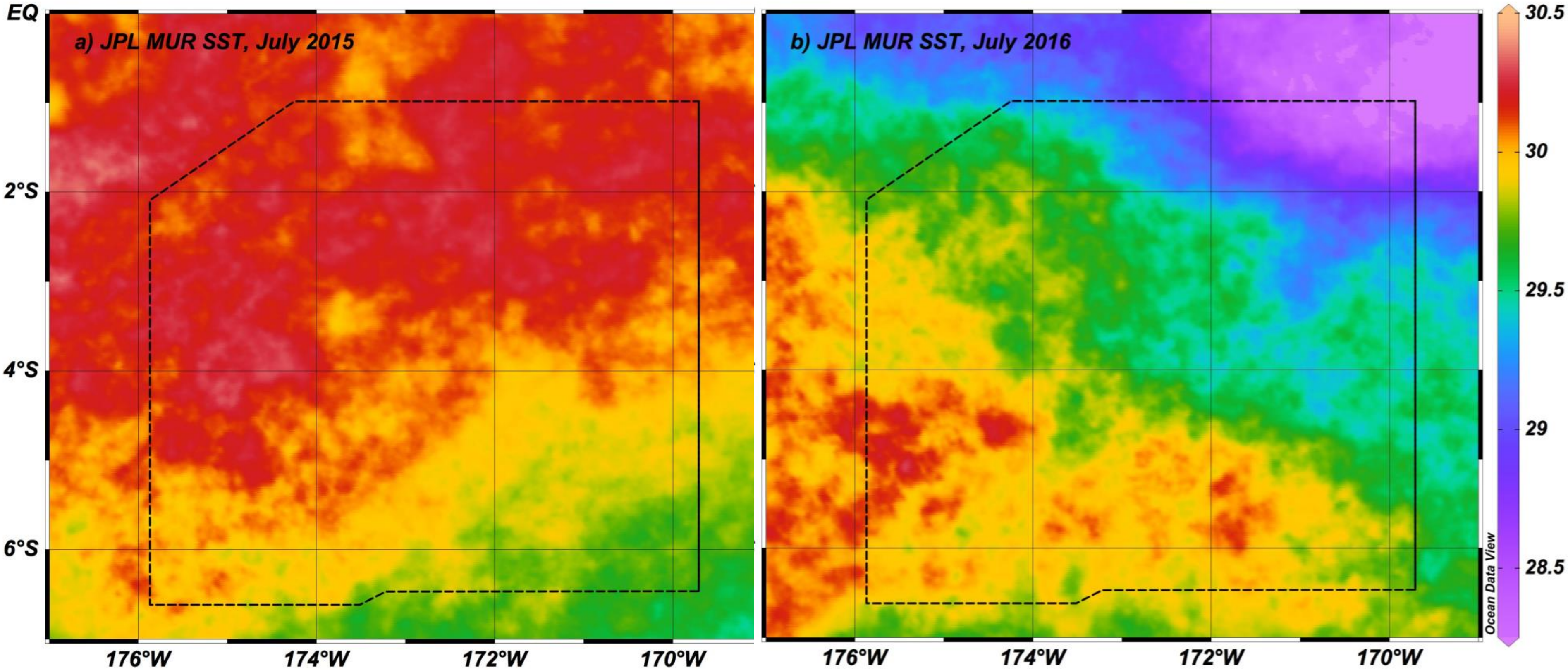
- Larval sampling with plankton nets
  - Morphological ID of tuna larvae



2
0
-2
-4
-6
-175
-170
2015
2016
2017

MUR Sea Surface Temperature

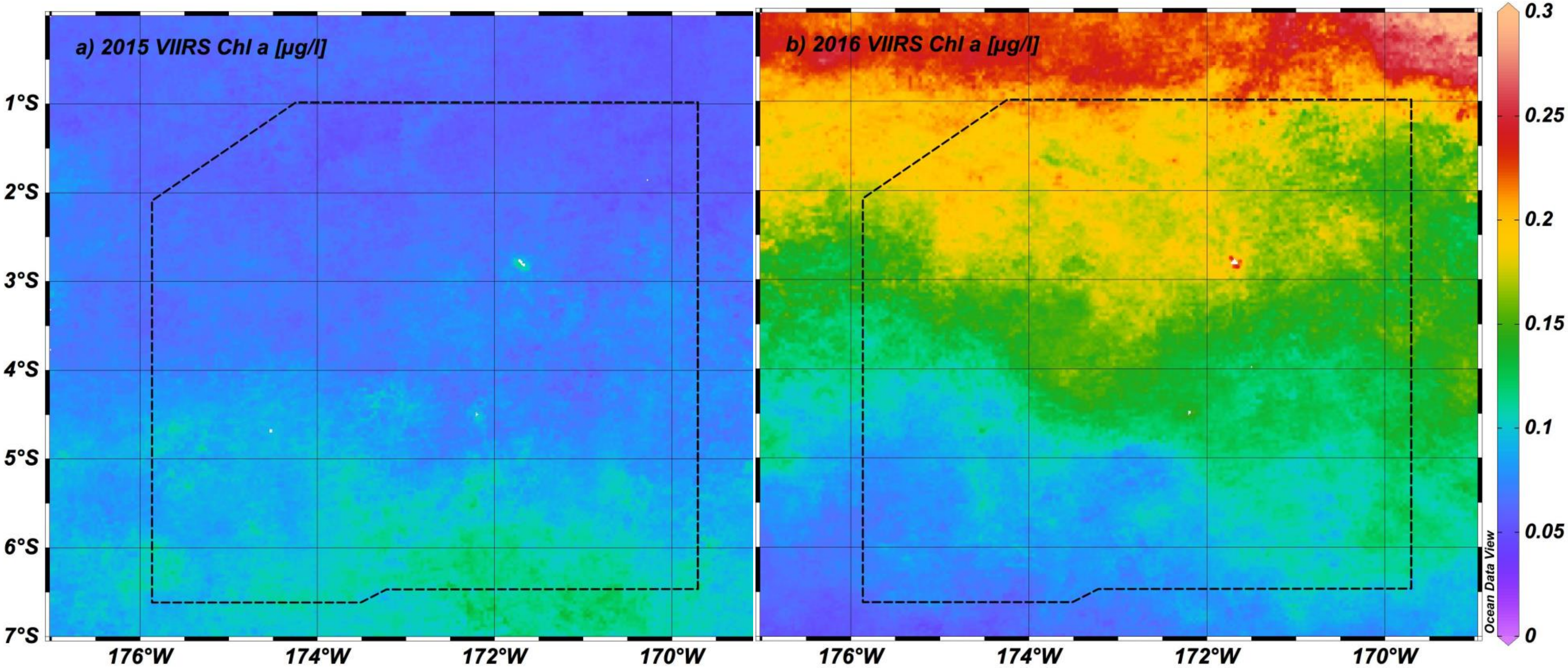
July 2015 July 2016



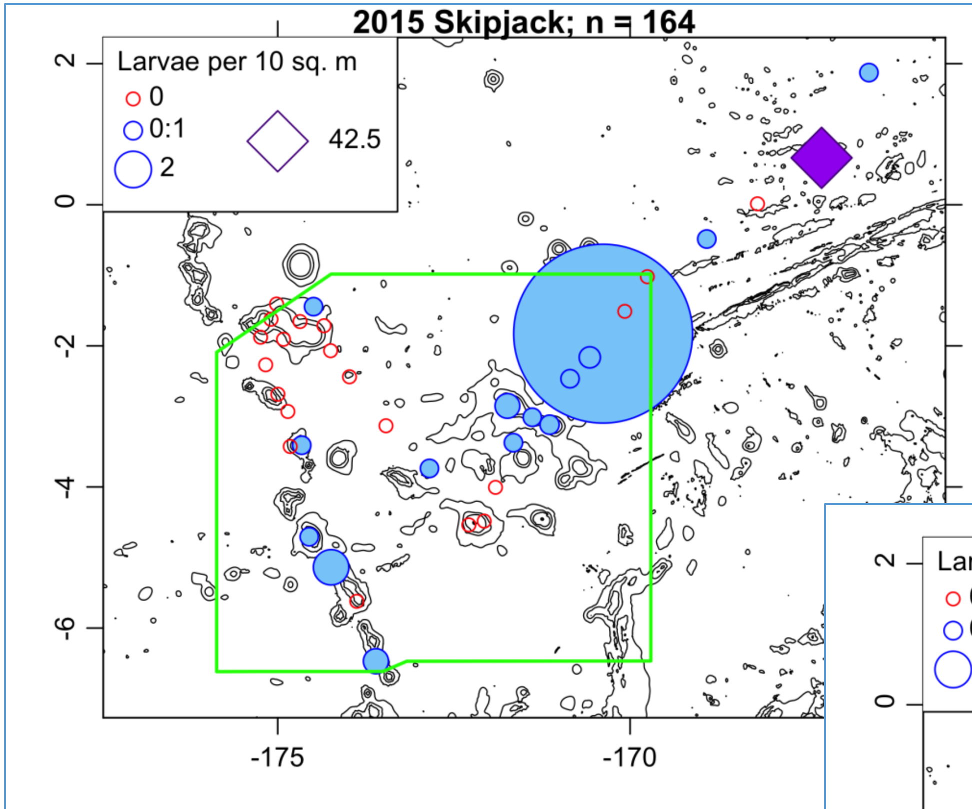
VIIRS Satellite Chlorophyll

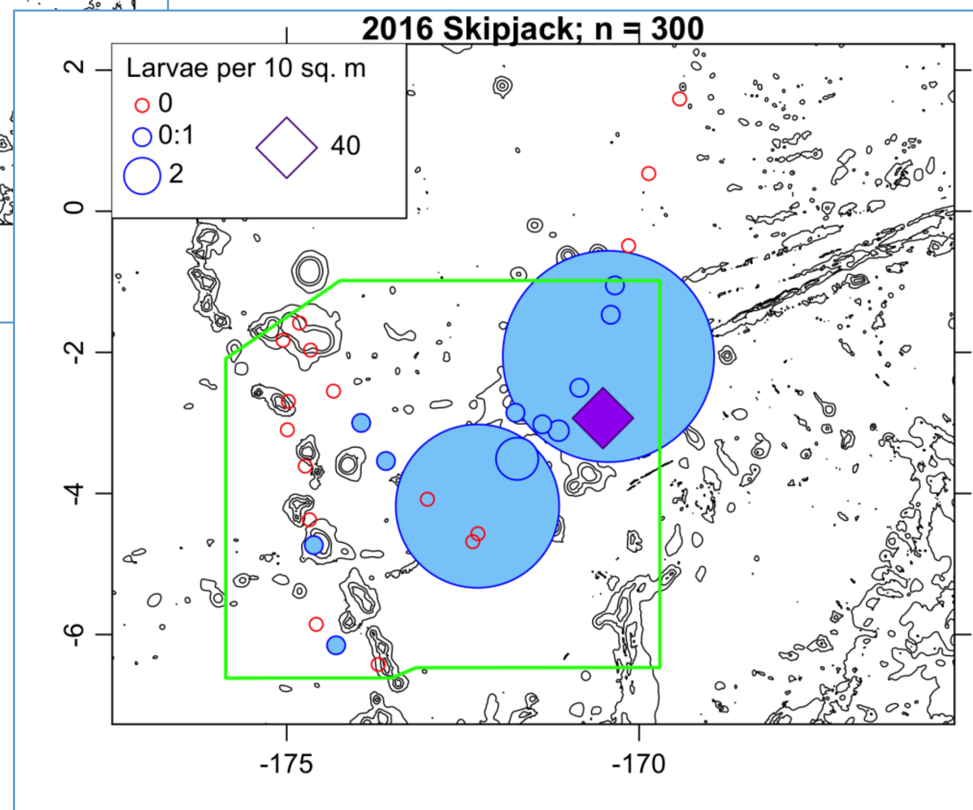
July 2015

July 2016



Skipjack tuna larval distribution and abundance



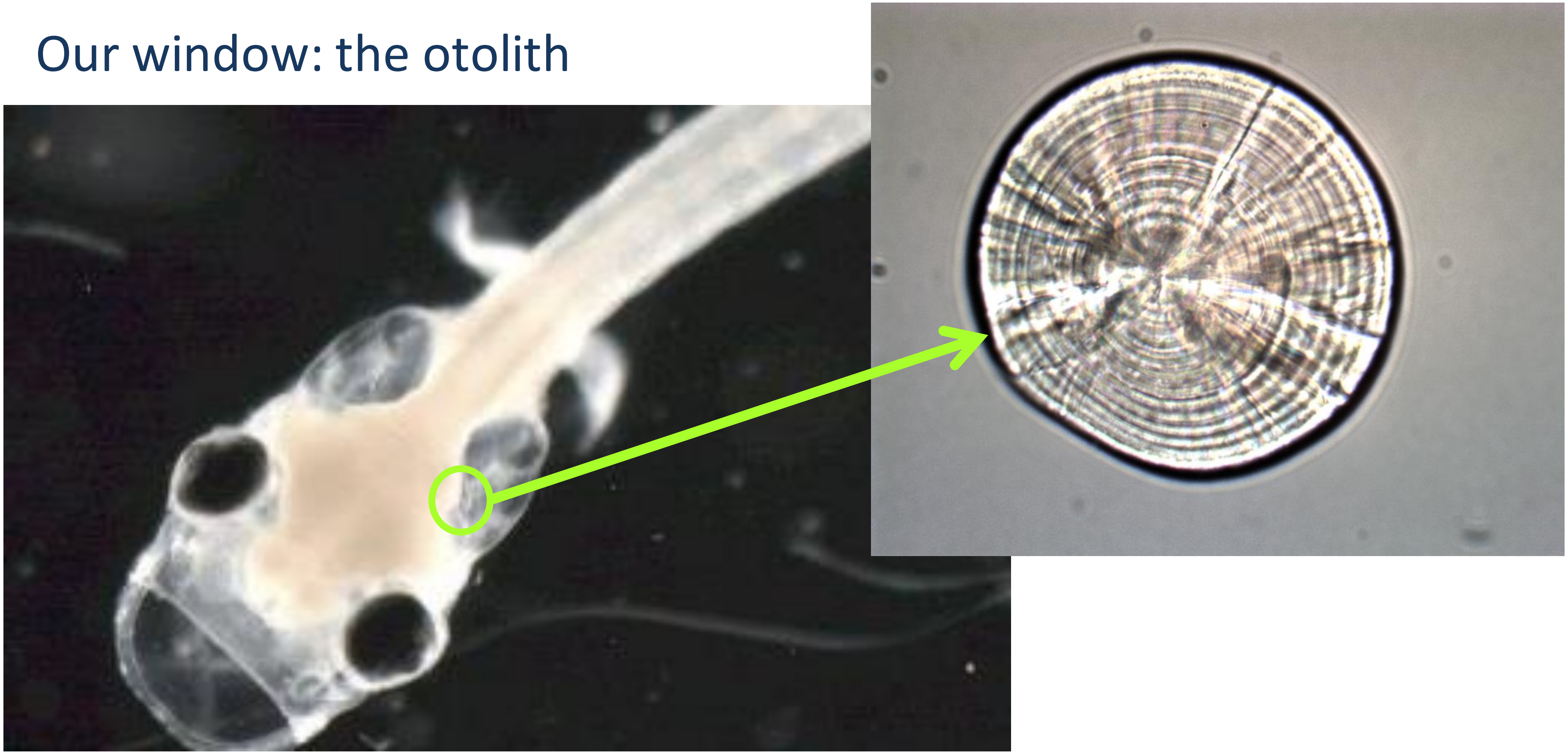


Methods

- *Where are those larvae spawned, and what can we infer about adult use of the protected area?*
  - Understand role of protected area for large pelagics

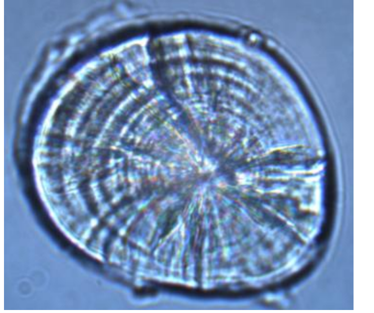
- Estimate spawning sites
  - Use larval otoliths to estimate age at a given size
  - Particle backtracking simulations to estimate spawning sites

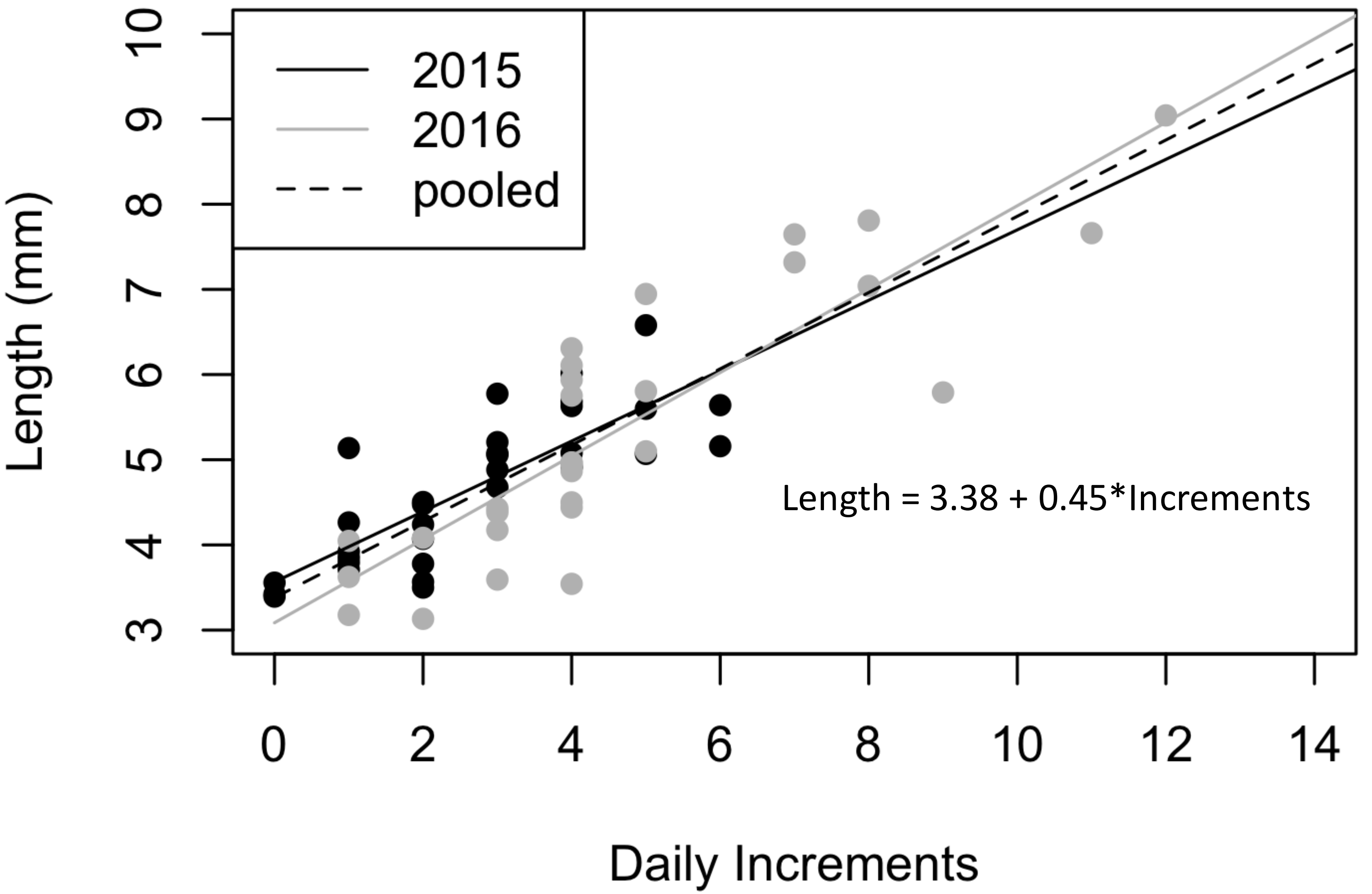
Our window: the otolith



- Larval age
- Hatch date
- Larval size at age

Skipjack

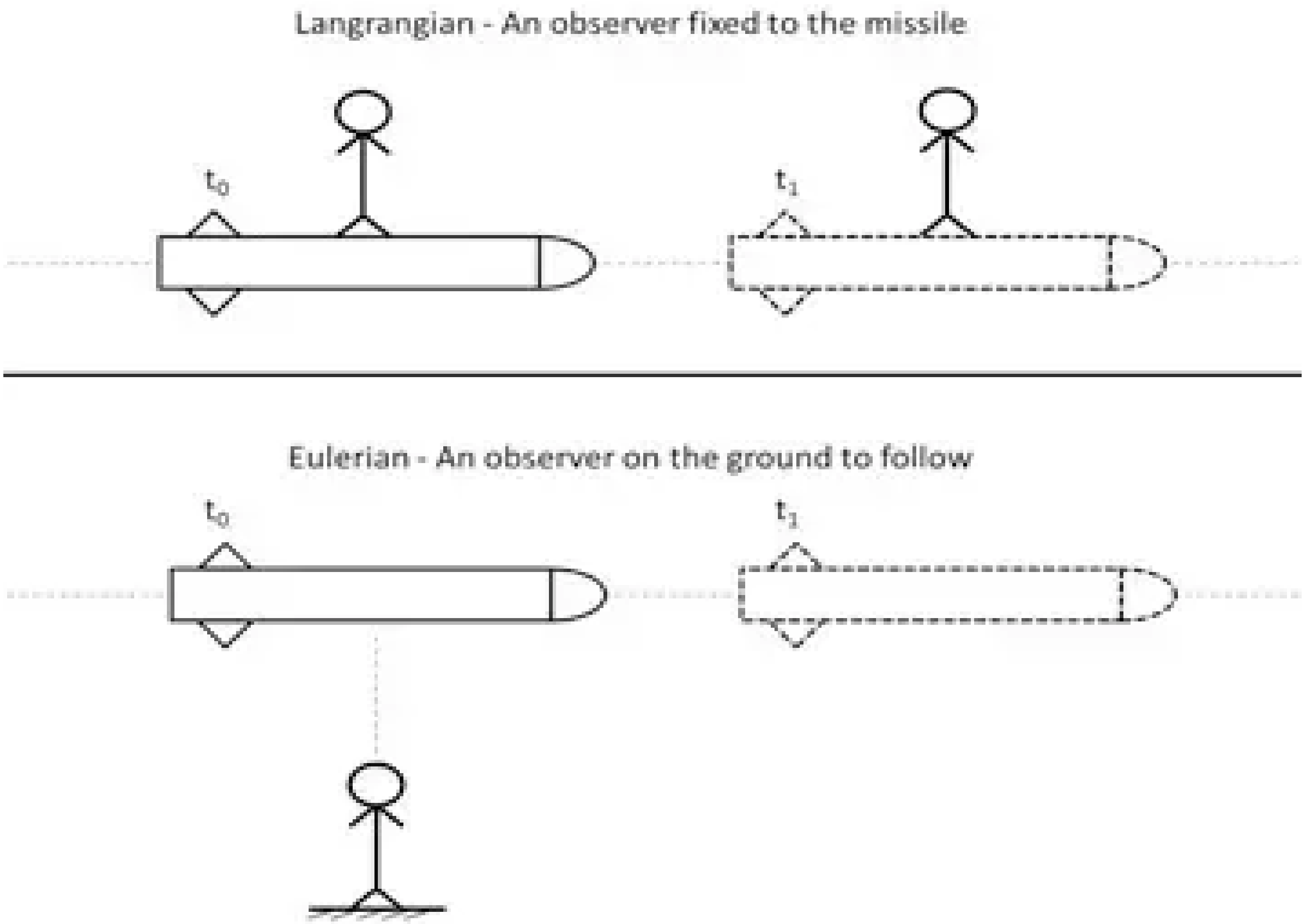




2015
2016
pooled
Length (mm)
Daily Increments
Length = 3.38 + 0.45*Increments
3
4
5
6
7
8
9
10
0
2
4
6
8
10
12
14

Particle backtracking

- Hydrodynamic model = ocean physics (including currents, temperature, salinity, etc)
- Lagrangian vs. Eulerian modeling perspective
  - Euler sits on a mooring and watches things go by
  - Lagrange rides on a drifter and experiences conditions along the trajectory



https://qph.fs.quoracdn.net/main-qimg-2c2acaa98631dd0db13779c97174523f.webp

Why ‘particles’?

- Simple to implement
- Can approximate:
  - Oceanographic drifters
  - Sediment
  - Oil globules
  - Eggs
  - Larvae
  - …Basically anything that doesn’t react chemically and that doesn’t swim too well!

Connectivity Modeling System

- Lagrangian particle tracking software
- Open source (free, but in Fortran 90)
- Built to simulate larval dispersal
- Built for use with the HyCOM model, but can be adapted to other hydrodynamic output
- Requires pretty high computing power

- Developed by Claire Paris and colleagues (see Paris et al. 2013 *Environmental Modelling and Software*)

How do I use CMS?

- DISCLAIMER: I do not read or write Fortran.
- I use a Unix server, and I talk to it from the command line (Terminal on a Mac)
- Input files:
    - 3 that I edit on the server (starting from example files that came with the install)
    - 2 that I build in Excel or R and output as tab-delimited files, then upload to the server
- Run script: specific to the computing system

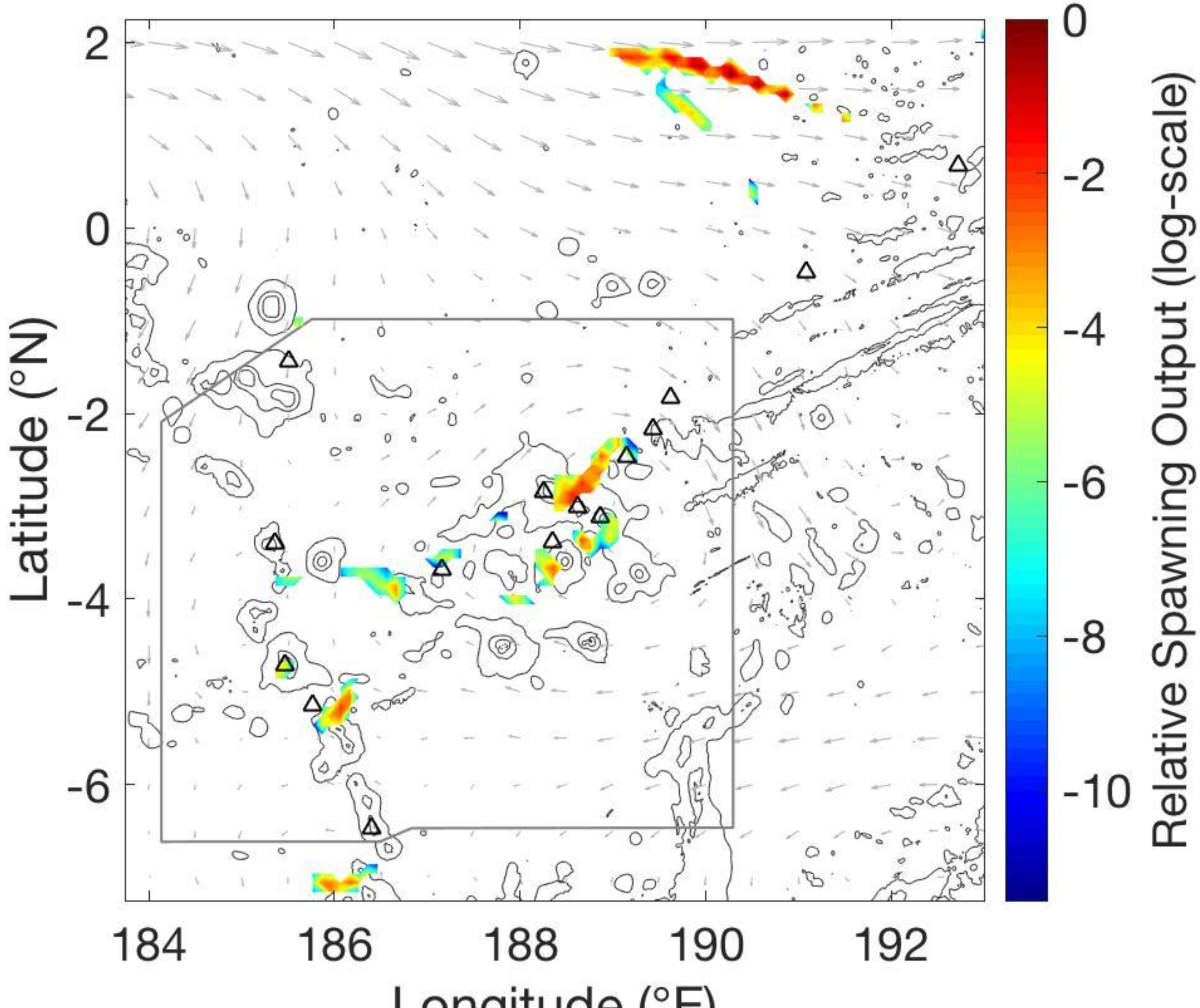
Output

- CMS provides trajectory output (location of particles at each time point) as a netcdf file:
  - Time
  - Particle ID
  - Latitude
  - Longitude
  - Depth
  - Particle status (dead, beached, still drifting, etc)
- I post-process in Matlab or R to pull out the particles that I'm interested in, and make plots

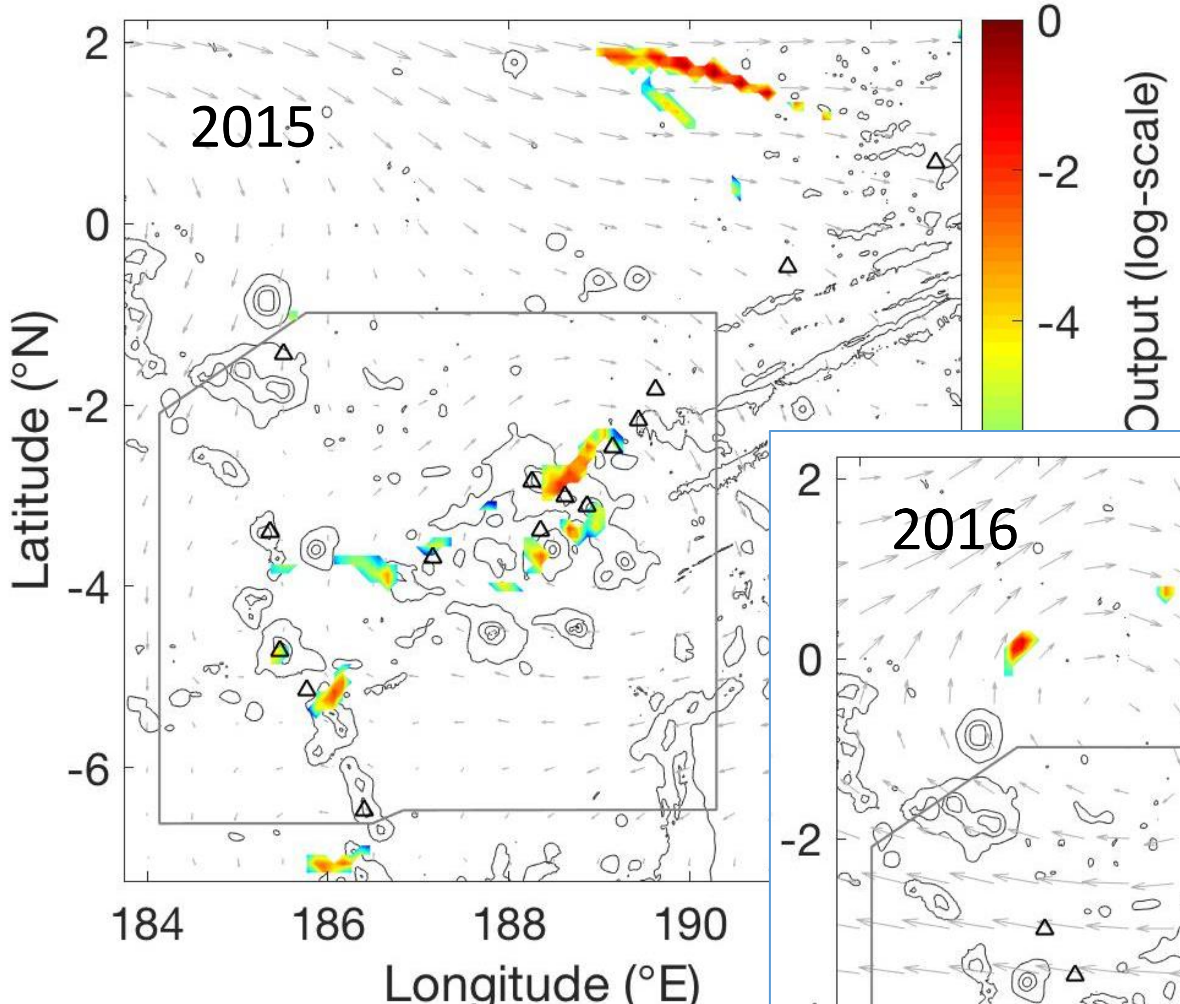
Calculating “relative spawning output”

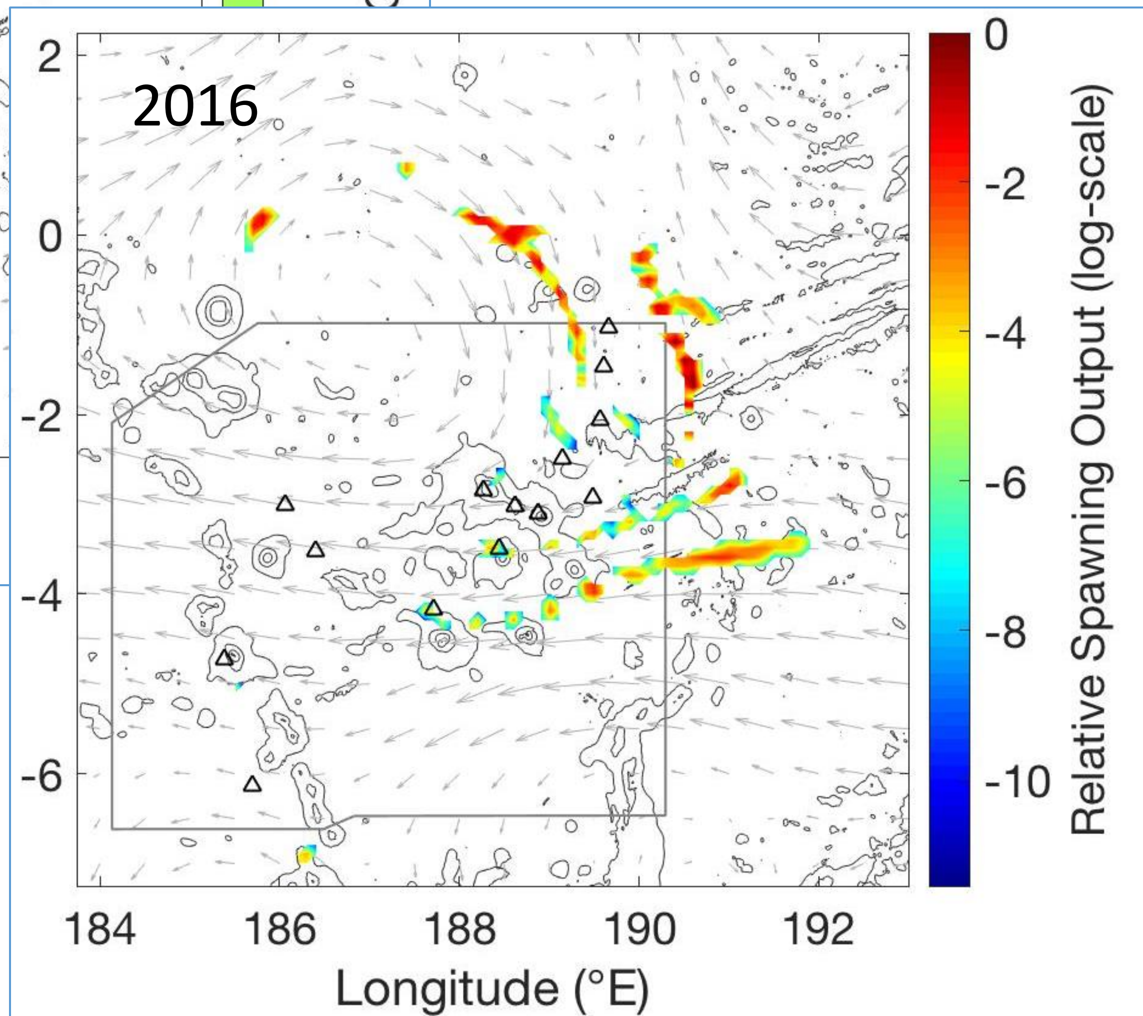
- Backtrack 1000 particles that correspond to each collected fish
- Estimate number of eggs spawned to yield 1 fish of that age
- Scale 1000 particles by number of eggs required
- Sum all the estimated spawning locations for a given year/taxon
- Scale so that the maximum value is 1

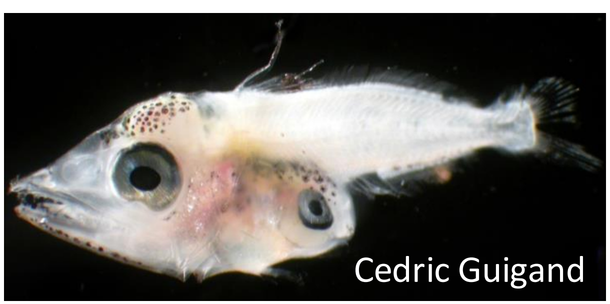
Backtracking 2015 skipjack



Skipjack tuna larvae







Takeaway Messages

- Tunas are spawning inside PIPA.
- The larval distribution and growth was similar in 2015 and 2016, despite big differences in the ecosystem (due to ENSO).
- Numerical simulations help us understand where the actual spawning activity (by adults) is occurring, relative to the protected area.
    - Stronger currents during the La Niña state in 2016 moved more larvae across the PIPA boundary.

Questions?