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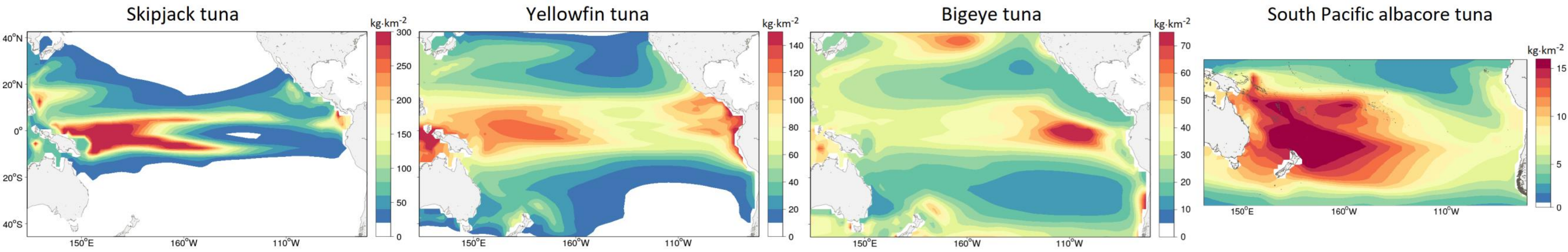
Inna Senina, **Pacific Community**

SPATIAL ECOSYSTEM AND POPULATION DYNAMICS MODEL



Modelling physical-biological interaction between fish populations and the ocean pelagic ecosystem

OUTLINE

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1. **The Model**
   - How we model tuna habitats and spatiotemporal dynamics of tuna biomass
2. **Learning from Data**
   - How we estimate biomass distributions and abundance
   - Model estimations for four target tuna species
   - Existing uncertainties
3. **Tuna & Climate**
   - Projected biomass redistributions under climate change, related implications for the Pacific Island Countries and Territories

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1. THE MODEL

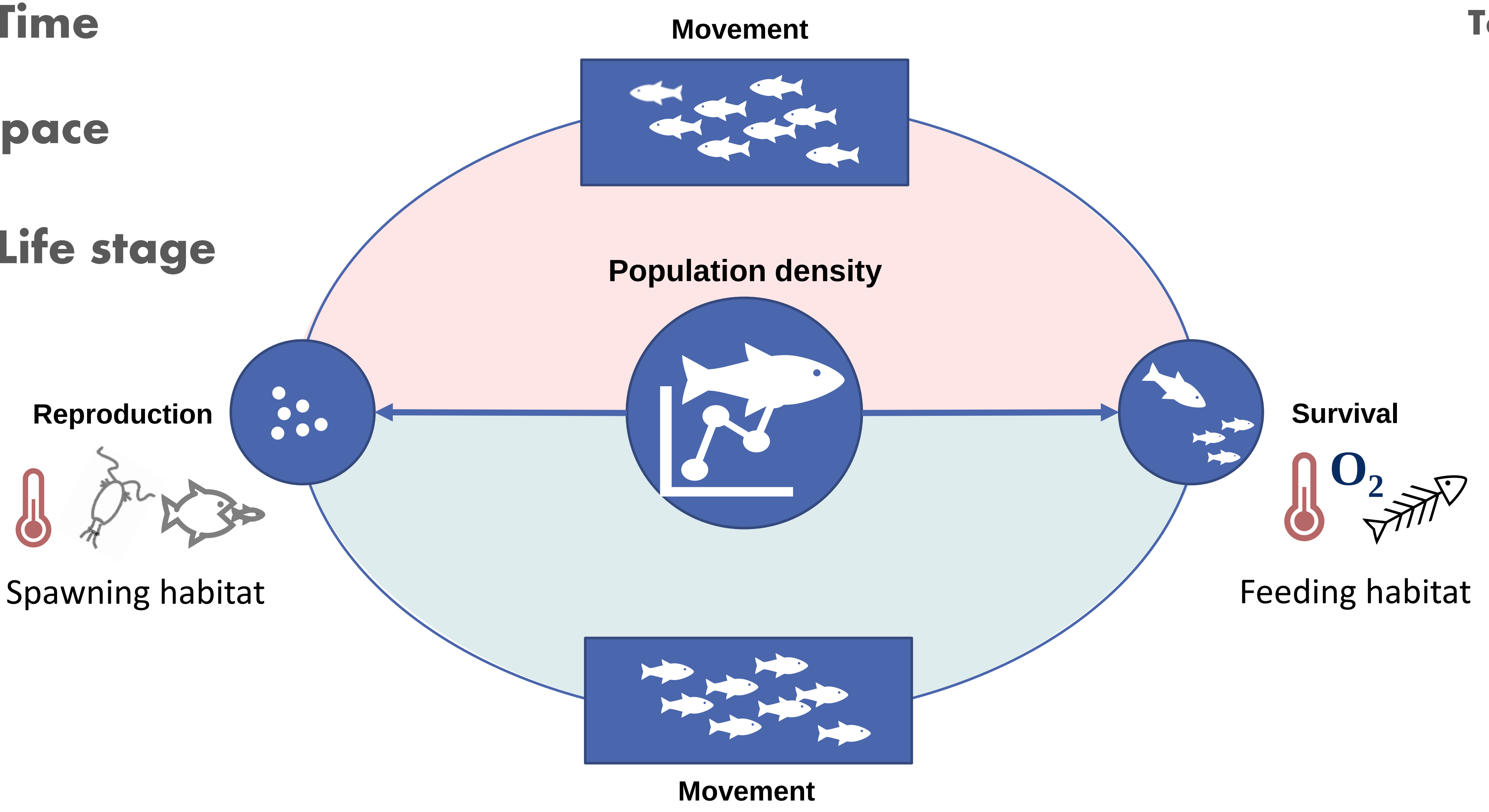
- Simplifying the reality: view of the ecosystem and tuna environment, tuna life cycle, behaviours and population dynamics;
- Modelling habitats and tuna movements;

Conceptual diagram of process-based modelling

Time

Space

Age/Life stage



Temperature

Currents

Plankton

Oxygen

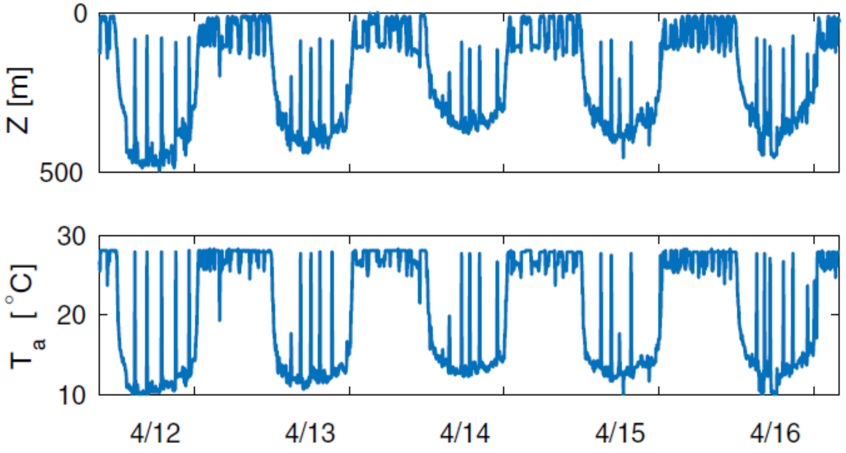
Light

Food

Tuna Environment

Bigeye tuna

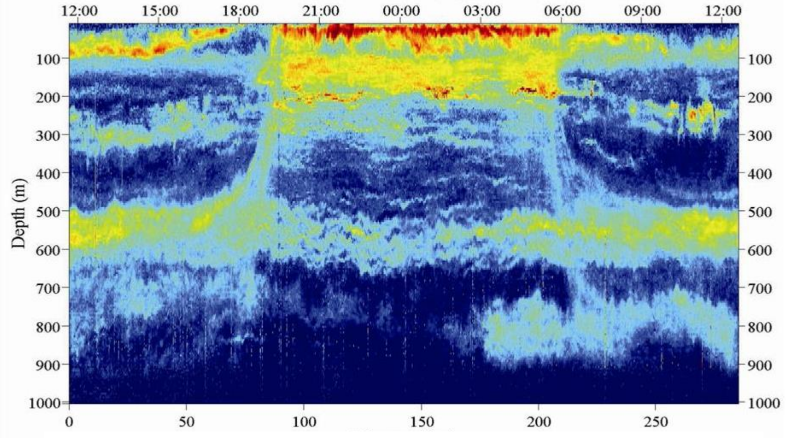
(Western Coral Sea, April 2002)



From: Thygesen et al., 2016; Evans et al., 2008

Prey of tuna

(micronekton)



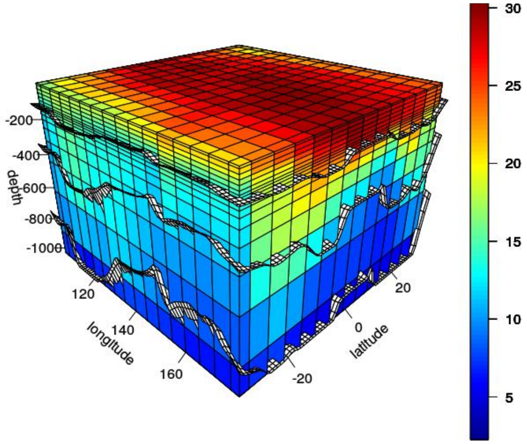
epipelagic

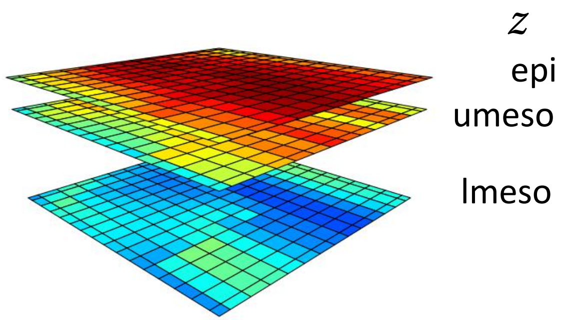
upper mesopelagic

lower mesopelagic

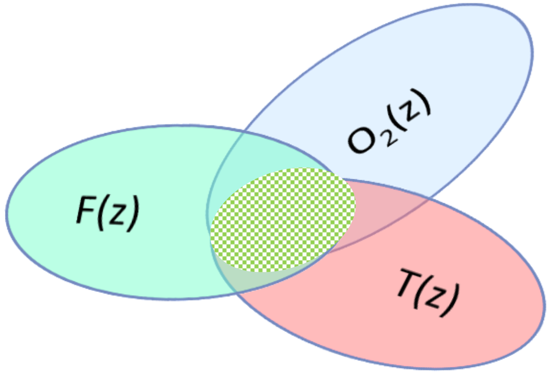
Credit: Réka DOMOKOS (NOAA)

3D variable -> Average over pelagic layer -> Simplified vertical structure





*Feeding habitat index is **accessible micronekton density***



Modelling movement: directional and non-directional

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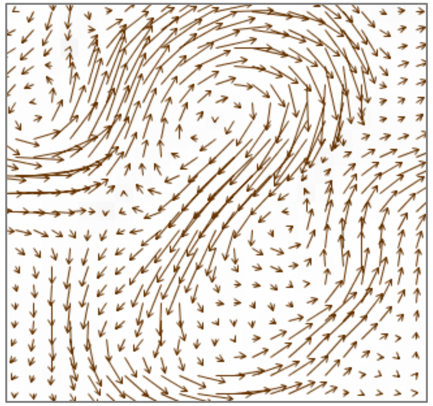
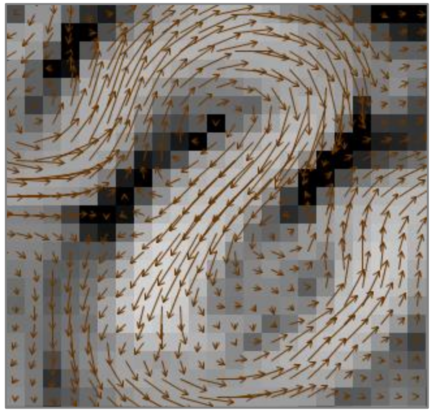
passive | active

directional | non-directional

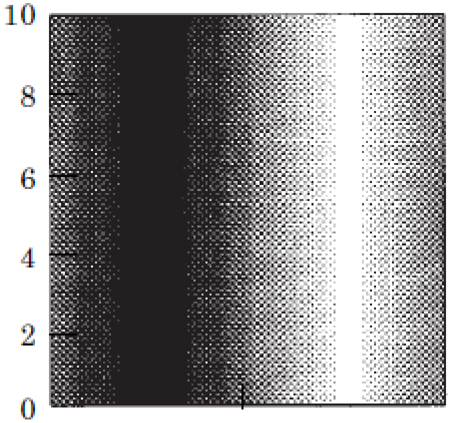
Ocean currents



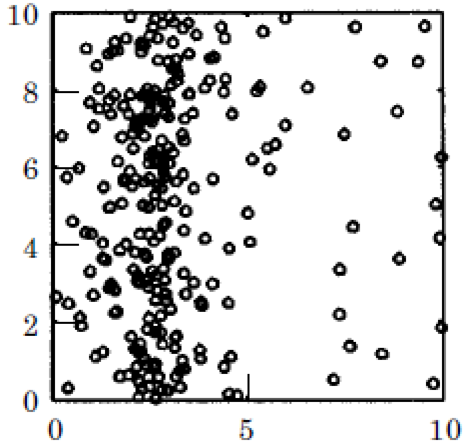
Biomass distribution



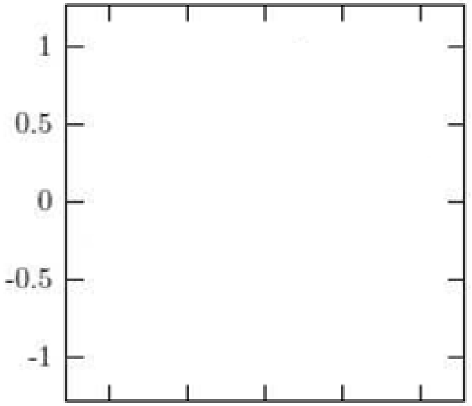
Habitat



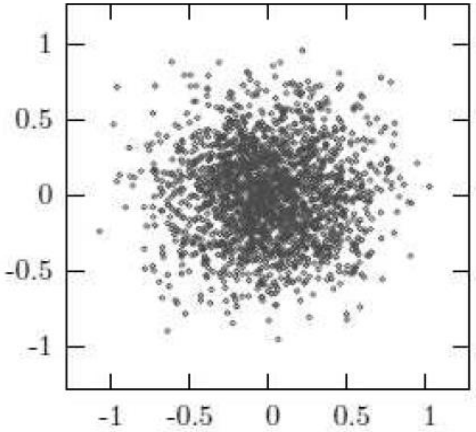
Resulting distribution of fish



Habitat



Resulting distribution of fish



From: Grunbaum, 1999; Flierl et al., 1999; Fougeras et Maury, 2007

2. LEARNING FROM DATA

- Parameter estimation, validation and abundance estimation;
- Impact of environmental variability;
- Differences among the four target tuna species;
- Existing uncertainties

Data inform modelled dynamic processes

Underlying equation of SEAPODYM:

$N(a, t, \mathbf{x})$ - density of fish population at age a, time t and position $\mathbf{x} = (x, y) \in \Omega \in \mathbf{R}^2$

$$\partial_t N + \partial_a N = -\mathrm{div}(\mathbf{v} N) + \nabla(D \nabla N) - M N$$

$$N(a, \mathbf{x}, t_0) = N_0(a, \mathbf{x})$$

$$N(0, \mathbf{x}, t) = S(t, \mathbf{x})$$

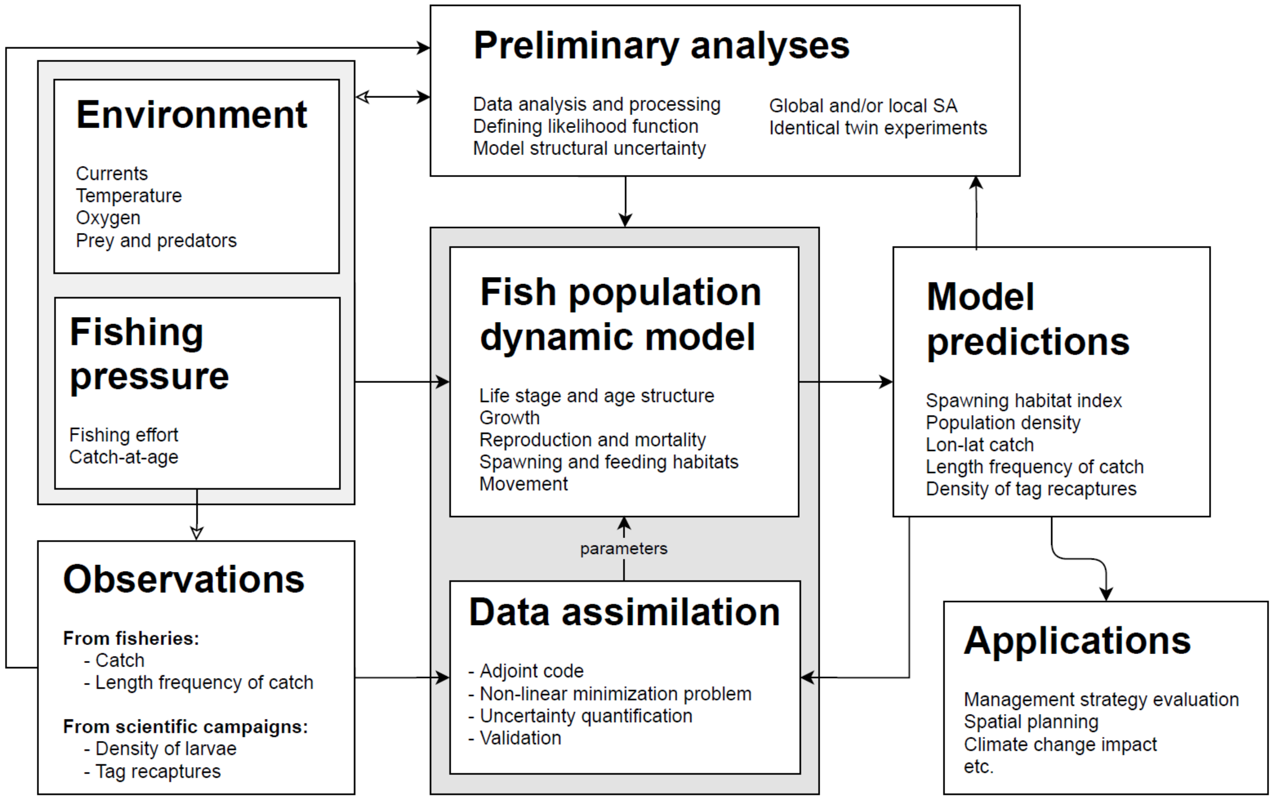
$$\mathbf{n} \cdot \mathbf{v}\Big|_{\mathbf{x} \in \partial\Omega} = \mathbf{n} \cdot \nabla N\Big|_{\mathbf{x} \in \partial\Omega} = 0$$

What we estimate (*):

1. Reproduction rate, spawning habitat;
2. Natural mortality rates, fishing mortality
3. Feeding habitat, active movement rates
4. #2-3 along the species life span

(*) Depend on environment (ocean forcings)

Parameter estimation workflow



Data inform modelled processes

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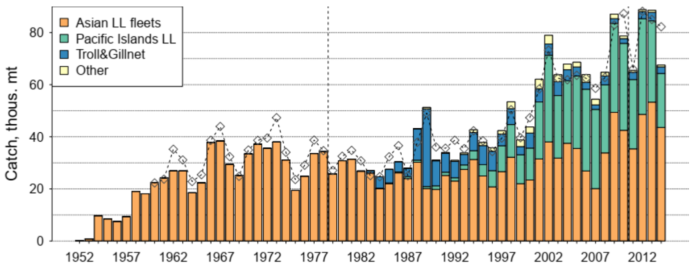
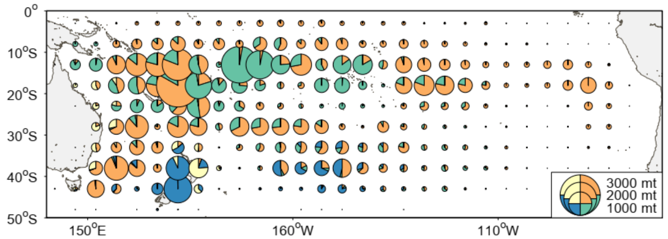
Industrial fishing

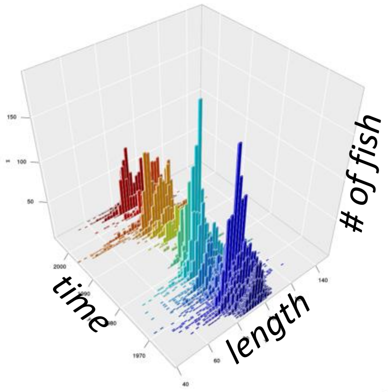
1 - Catch (and effort) data:





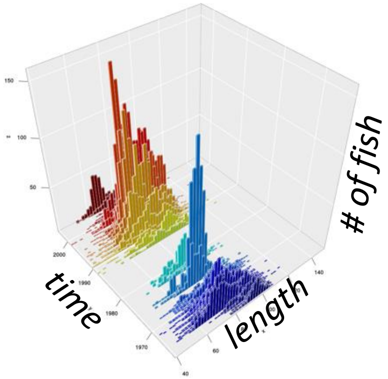
Poor: *abundance, natural and fishing mortality*
Bad: spatial distributions, habitats and movements, spawning sites

2 - Length data:



LL north of 25S

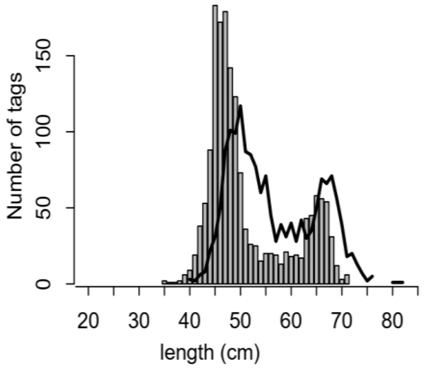
LL south of 25S

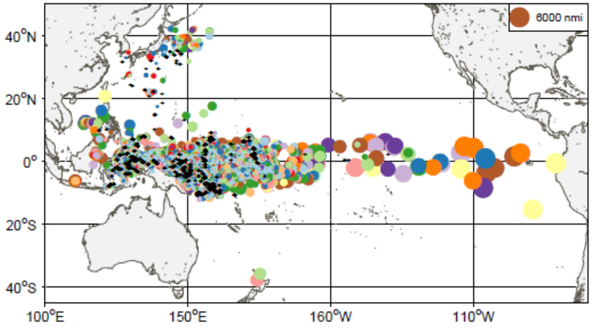


<u>Catch + Length</u>
Good: *reproduction and mortality rates, spatial extent*
Poor: *spatial distributions and movements*

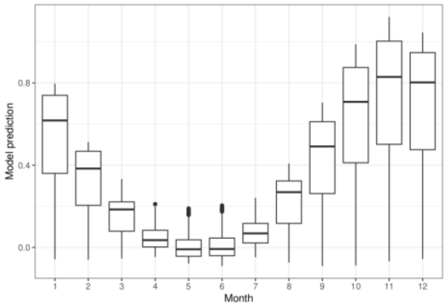
Scientific campaigns

3 – Conventional tagging data:

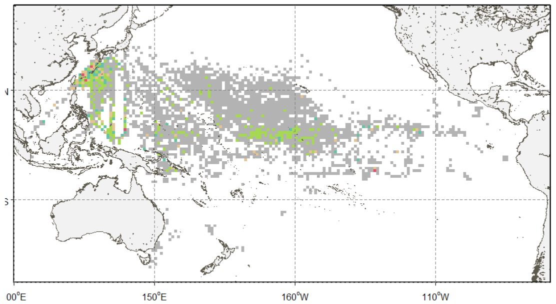




4 – Female gonad data:

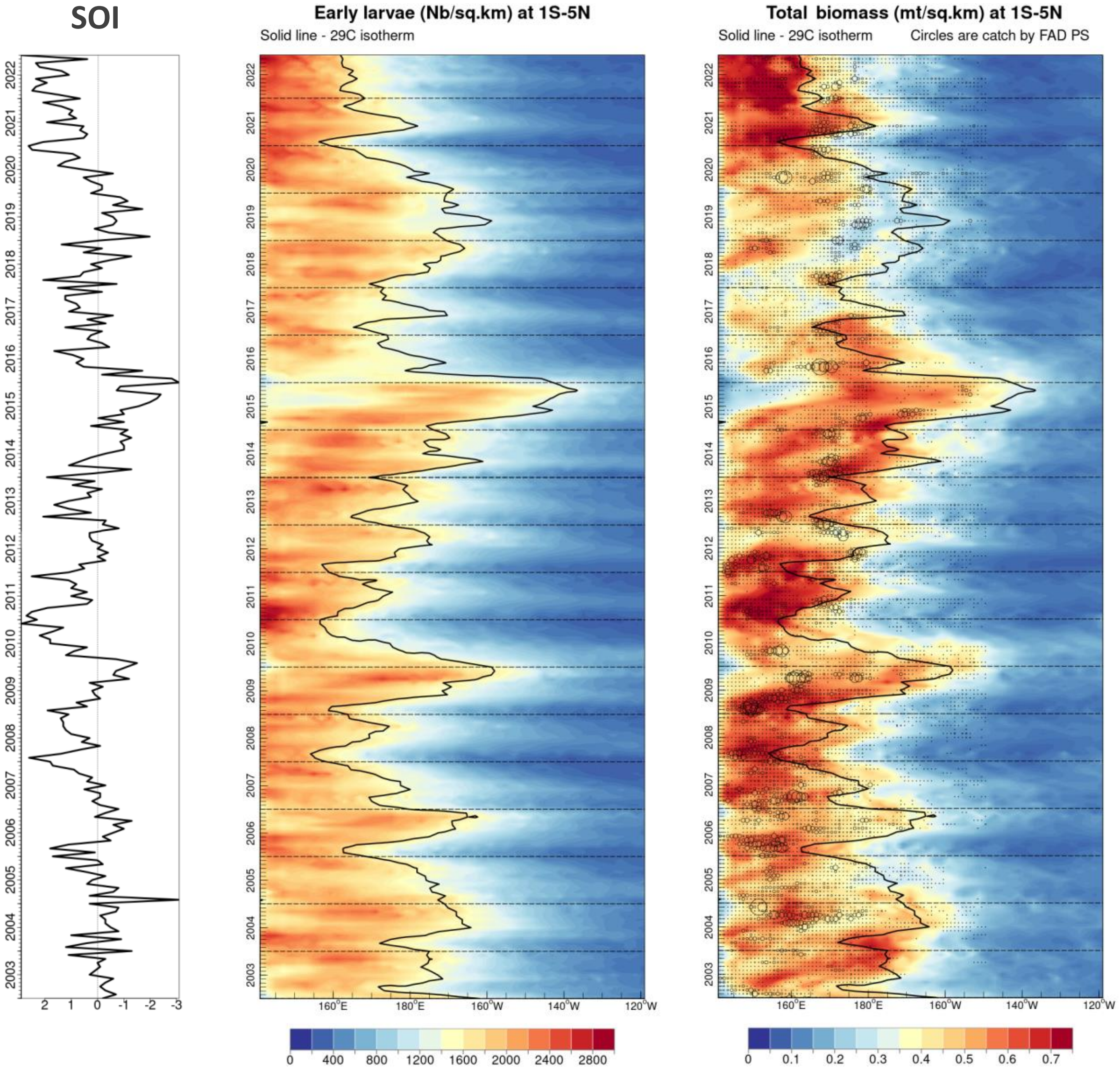


5 – Larval sampling data:



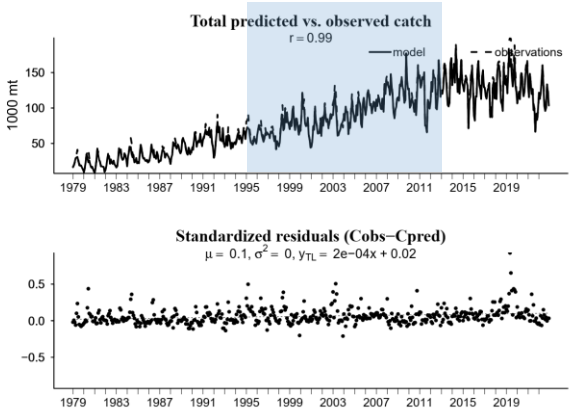
Good: *reproduction, spawning and feeding habitats, movement rates, spatial distribution of spawning stock*

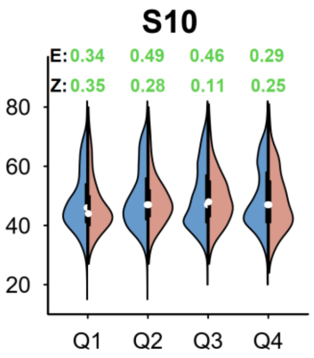
Quantitative model of skipjack tuna: environmental variability

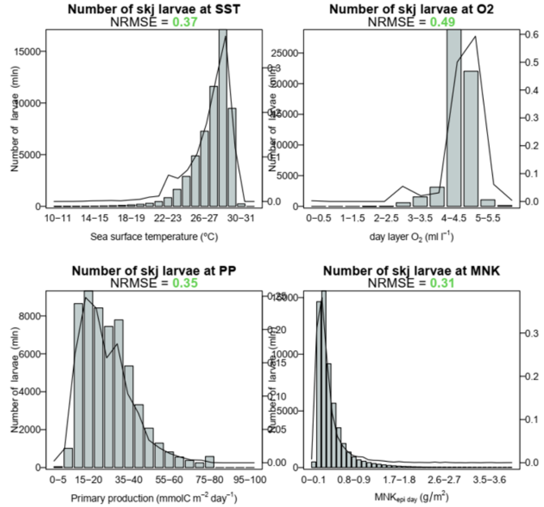


Model validation

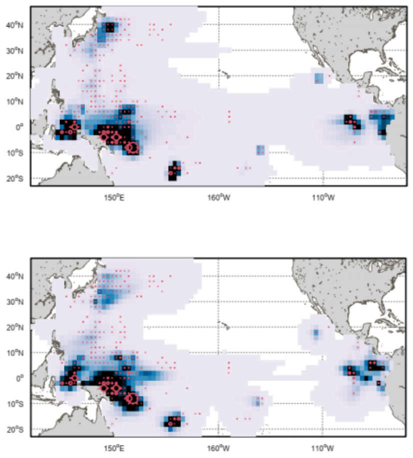
Optimization: 1995-2012







Tag recaptures



Reference models of four target tuna species

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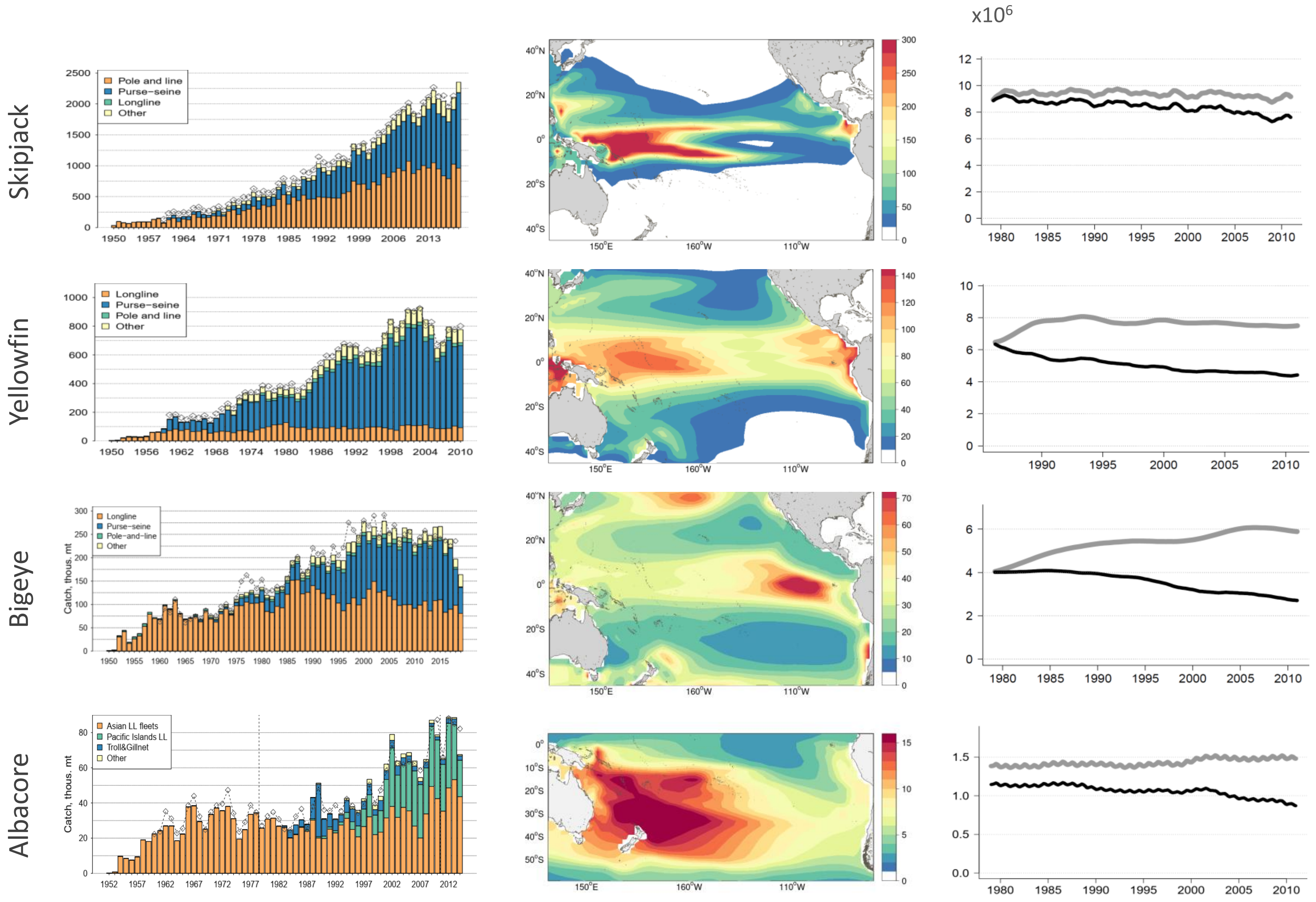


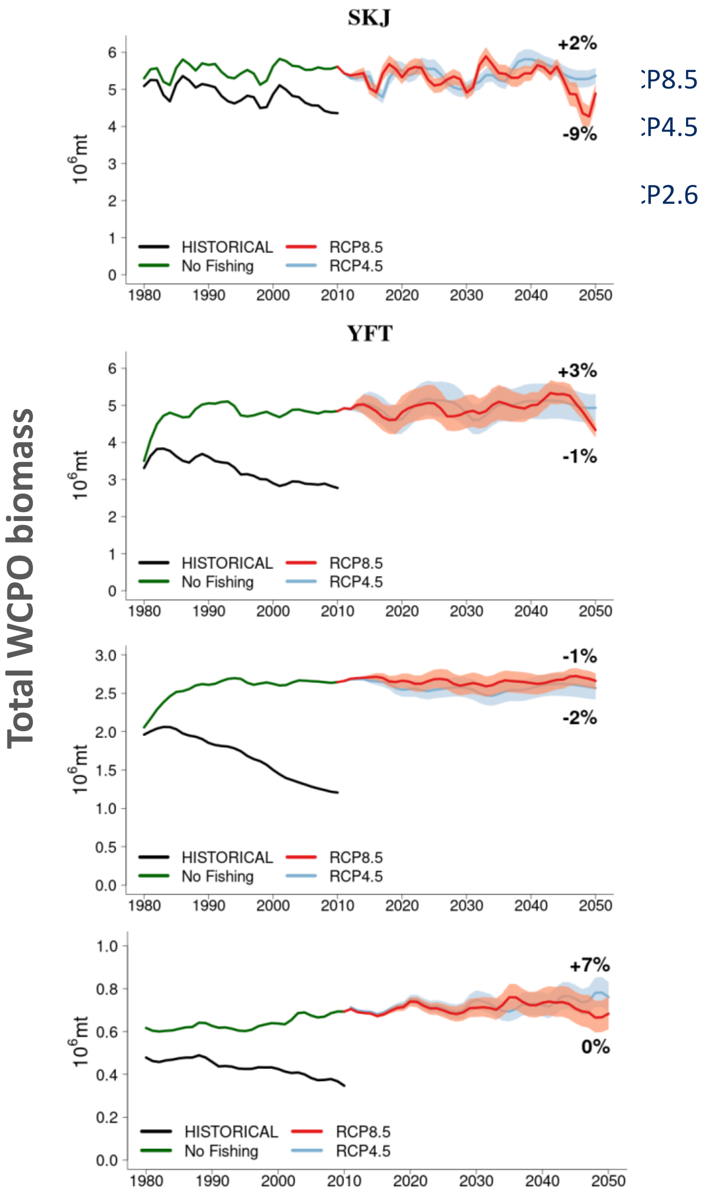
Uncertainties

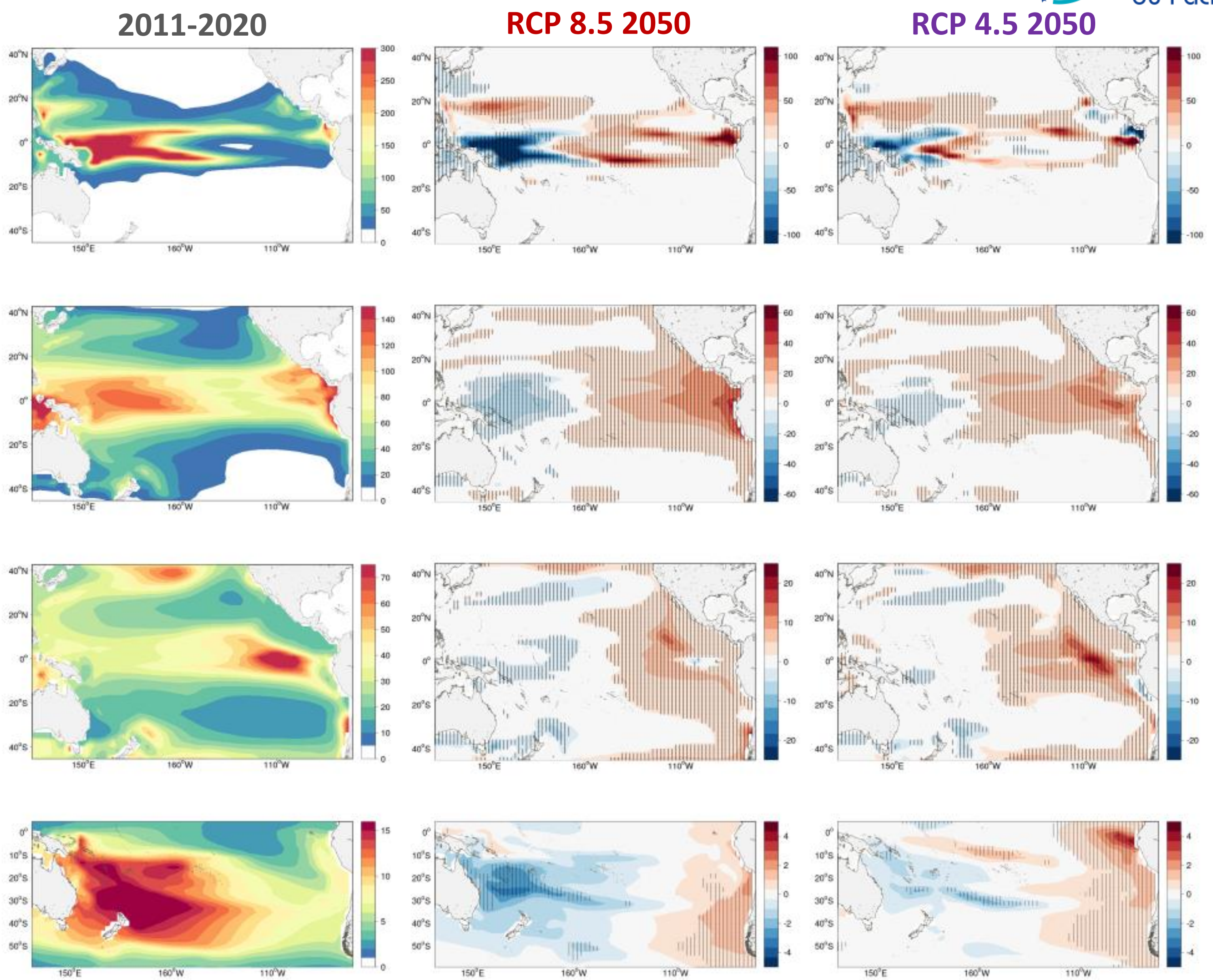
1. **Tuna environment**
   1. Definition
   2. Model precision
2. **Model structure**
   1. Simplifications
   2. Regional growth
   3. Functional relationships
   4. Numerics
3. **Data**
   1. Availability
   2. Observability

3. **TUNA & CLIMATE**

- Projected biomass and spatial redistributions;
- Implications for the Pacific Island Countries and Territories;
- Uncertainties in biomass projections.

Tuna projections under global warming with RCP8.5 and RCP4.5

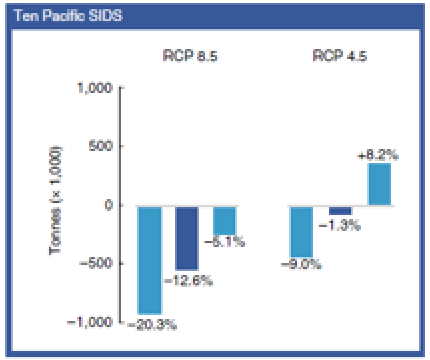


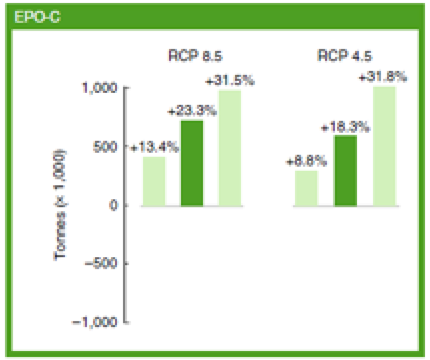


Predicted impacts on biomass and PS catches

From: Bell et al., 2021

Biomass





Overall Uncertainties

1-3. **Tuna model uncertainties**

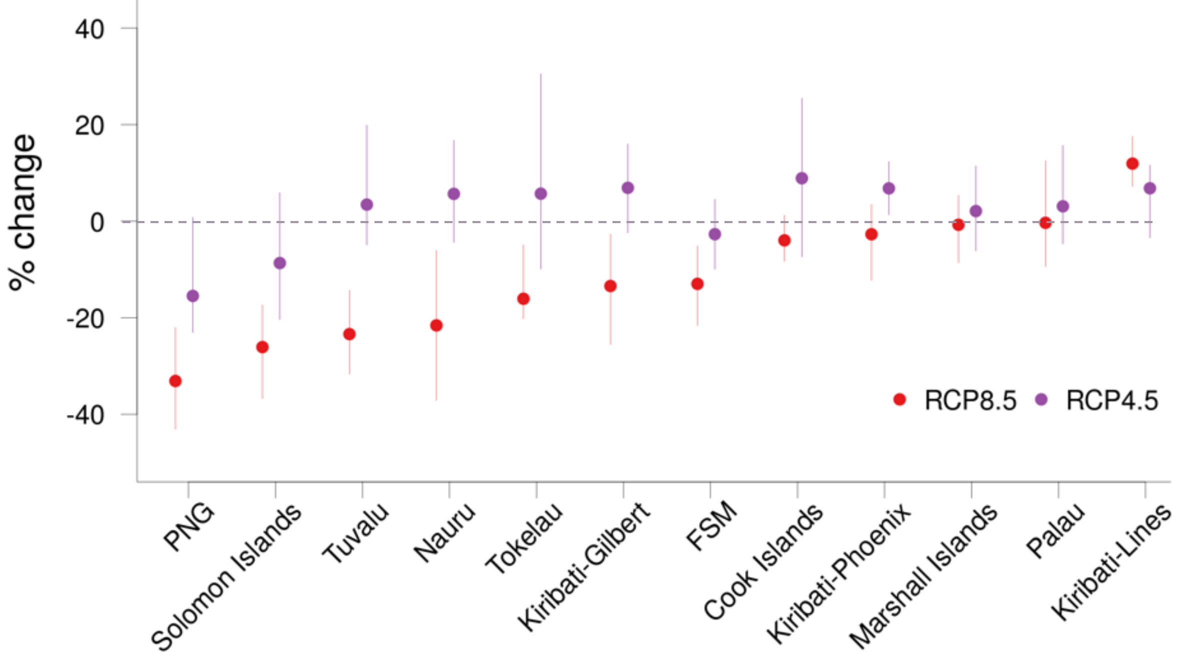
4. **RCP/SSP scenarios**

5. **Earth System Model biases**

Biomass change by 2050

	RCP 8.5	RCP 4.5
10 SIDS	-13%	-1%
EPO	+23%	+18%

PS catch change by 2050



Conclusions

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- Quantitative (predictive) modeling of fish populations dynamics requires data to observe **all modelled dynamic processes** and **realistic description of tuna environment** on historical, decadal and climate timescales.

- Despite of model uncertainties, agreement between different models on distributional shifts suggests that it's not a question of 'IF' the tuna biomass will shift due to climate change from the Pacific SIDS EEZs, but 'WHEN' and 'TO WHAT EXTENT'.

- Ongoing and future work is dedicated to reducing uncertainties linked to the model structure and parameter estimation, and to providing a better evaluation of uncertainties related to climate modelling.