Climate Awareness Workshop (CLAW)
Wellington NZ, 19-22 Feb 2024

Pacific Community
Communauté du Pacifique

Day 2: Physical and Biological Impacts of Climate Change

Ocean Marine Ecosystems

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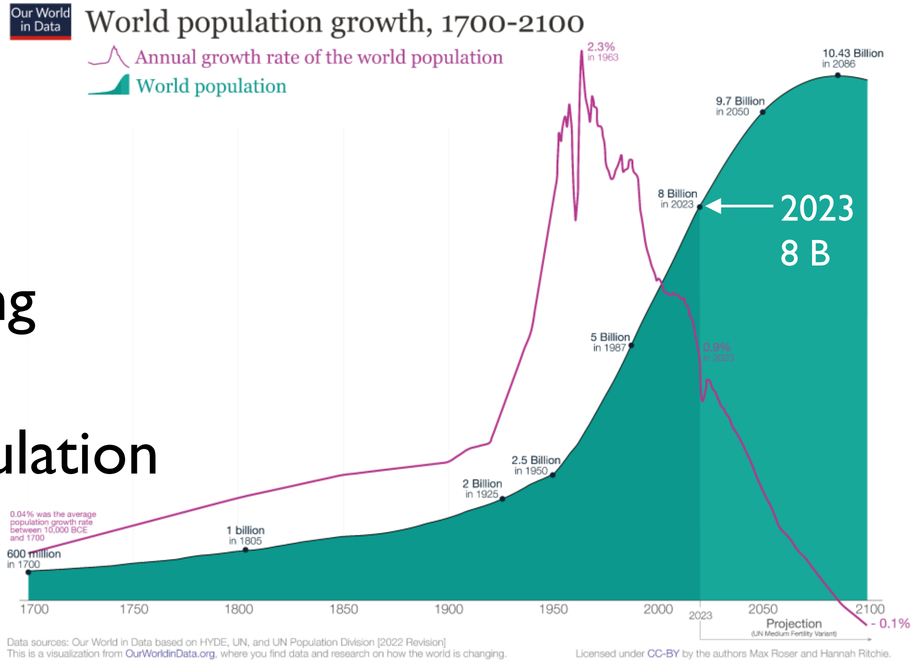
SPC - Fisheries, Aquaculture and Marine Ecosystems

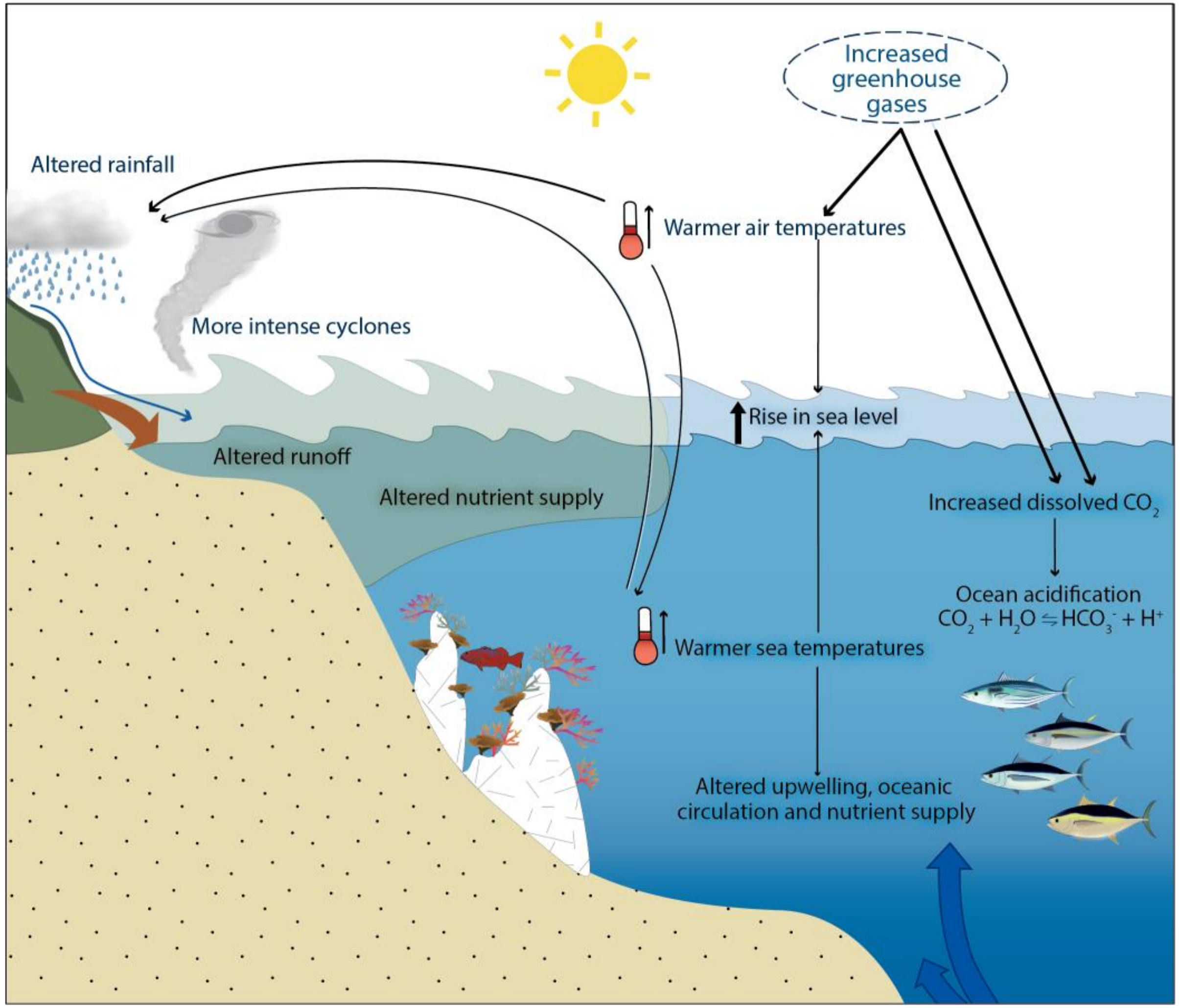
Climate (and Global) Change

- More intense weather extremes (cyclones)
- Temperature increase and heat waves
- Sea level Rise
- Change in ocean circulation
- Decrease in dissolved Oxygen concentration
- Ocean acidification

- Increasing Pollutions
- Habitat degradation
- Over (and illegal) fishing
- Loss of Biodiversity
- Increase in World Population



Ecosystem Essential Ocean Variables (eEOVs)



Increasing atmospheric CO2 and Heat

Warming, °C: All species have evolved to an optimal range of temperature (thermal niche), with either narrow or wide preferred ranges; this can change with age and life stage.

ocean stratification (°C, σ) and currents (U,V,W)

Deoxygenation, [O_2]: ocean–atmosphere exchanges; water temperature; ocean circulation, production by photosynthesis; consumption by bacteria (remineralisation).

Productivity, (…): impact the food web, starting by the Primary level (vegetal) that support (photosynthesis) higher trophic levels

Acidification, pH. All living species maintain an optimum range*. Higher risks for early life stages and marine invertebrates, eg. calcifying species. Compound effects with warmer and less oxygenated waters is of concern

**pH: 7.8<Ocean<8.2; (7.36< Human blood <7.44)*

eEOVs and tuna behavior

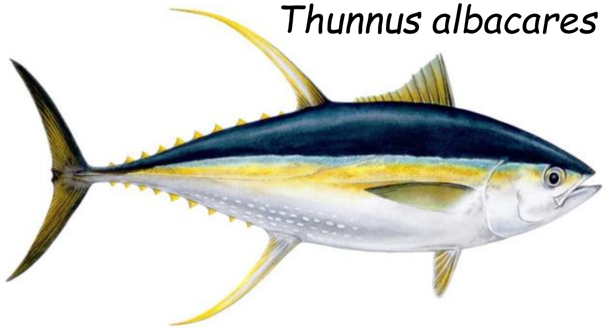
High natural mortality
Early age age at maturity
Short-living

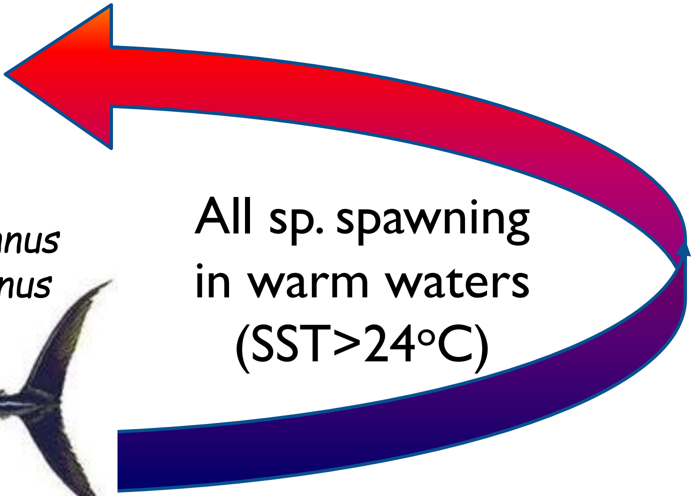
Tropical species

Skipjack *Katsuwonus pelamis*

(No swimmblader)

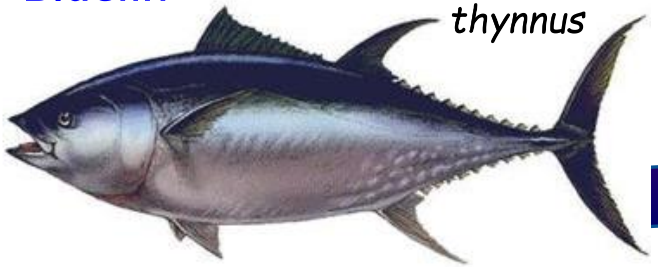
Yellowfin *Thunnus albacares*



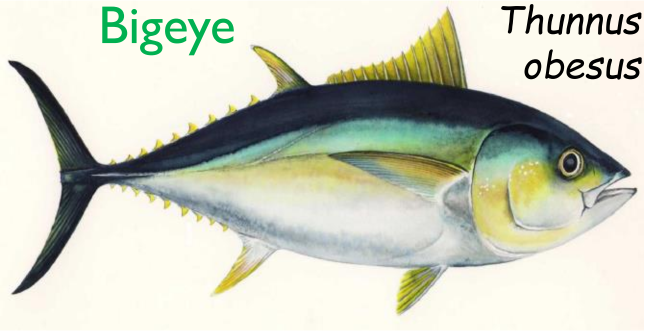


All sp. spawning in warm waters (SST>24°C)

Bluefin *Thunnus thynnus*

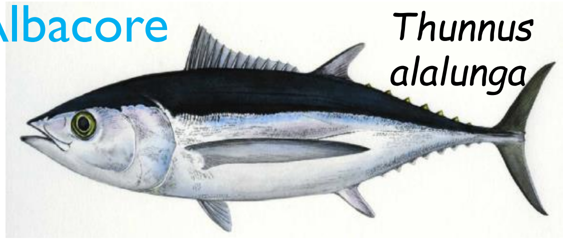


Bigeye *Thunnus obesus*



high blood–oxygen-binding affinity

Albacore *Thunnus alalunga*



Low natural mortality
late age age at maturity
long-living

Temperates species

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eEOVs and tuna behavior

Behavior and distribution are linked to the distribution of prey (productivity) and their accessibility, which depends mainly on temperature and dissolved oxygen (and the good skill of the hunter...).

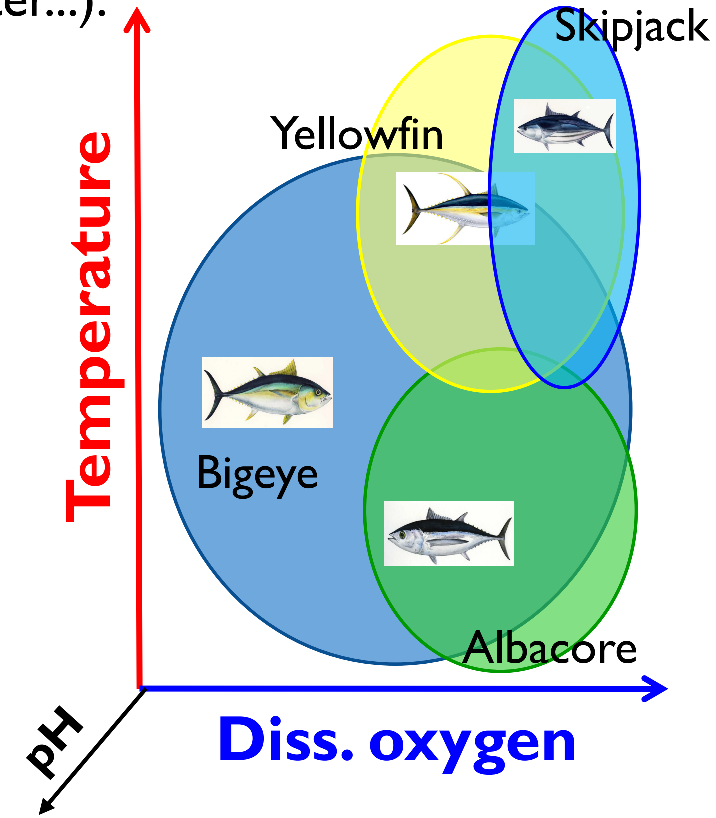
Range of sea surface temperature with substantial catches

Species	Temperature (°C)
Skipjack	20-29
Yellowfin	20-30
Bigeye	13-27
Albacore	15-21
Sth. bluefin	17-20

Estimated lower lethal oxygen

Species	Fork length (cm)	Lower lethal O_2 levels (ml l^{-1})
Skipjack	50	1.87
Albacore	50	1.23
Yellowfin	50	1.14
Bigeye	50	0.40

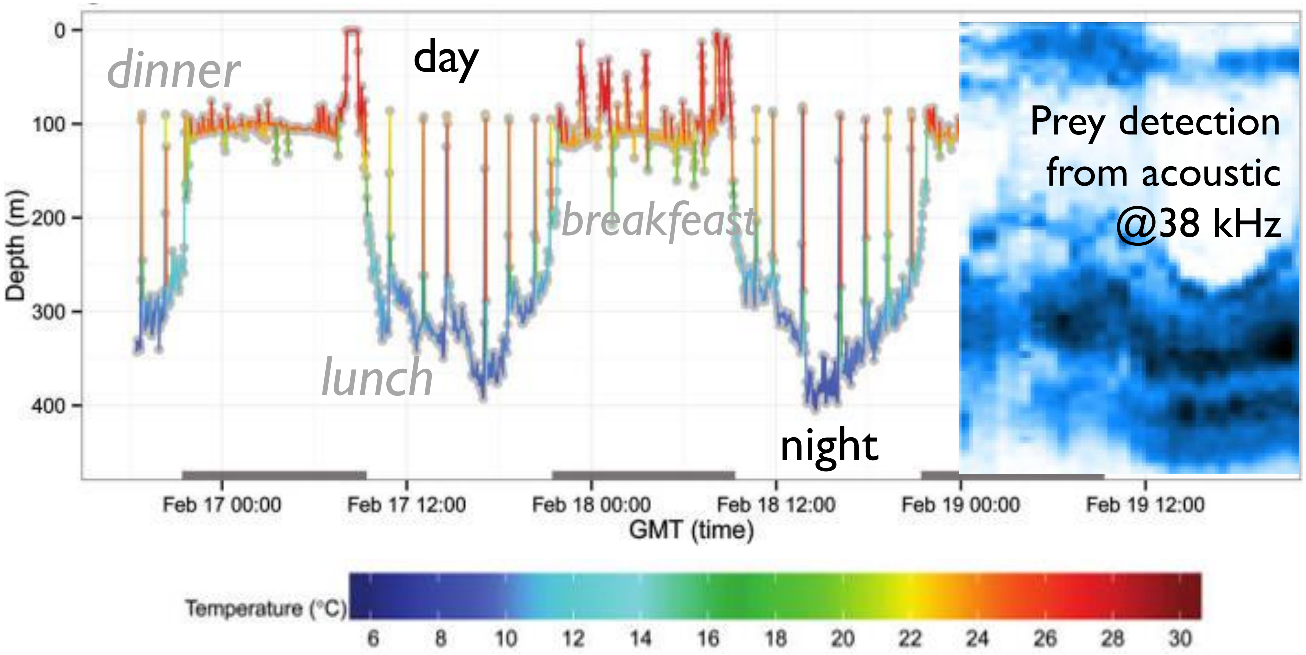
Graham 1973; Sharp & Dizon 1977; Sund et al. 1981; Brill et al 1987



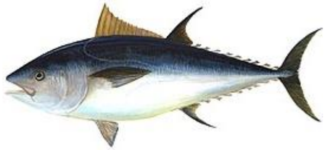
pH could be of concern for larval stages (Frommel et al 2016; Nicol et al.2023), though maximum change projcted in surface in high latitudes and upwelling regions (Kwiatkowski et al 2020). Impact of compound effects just starting to be investigated

eEOVs and tuna behavior

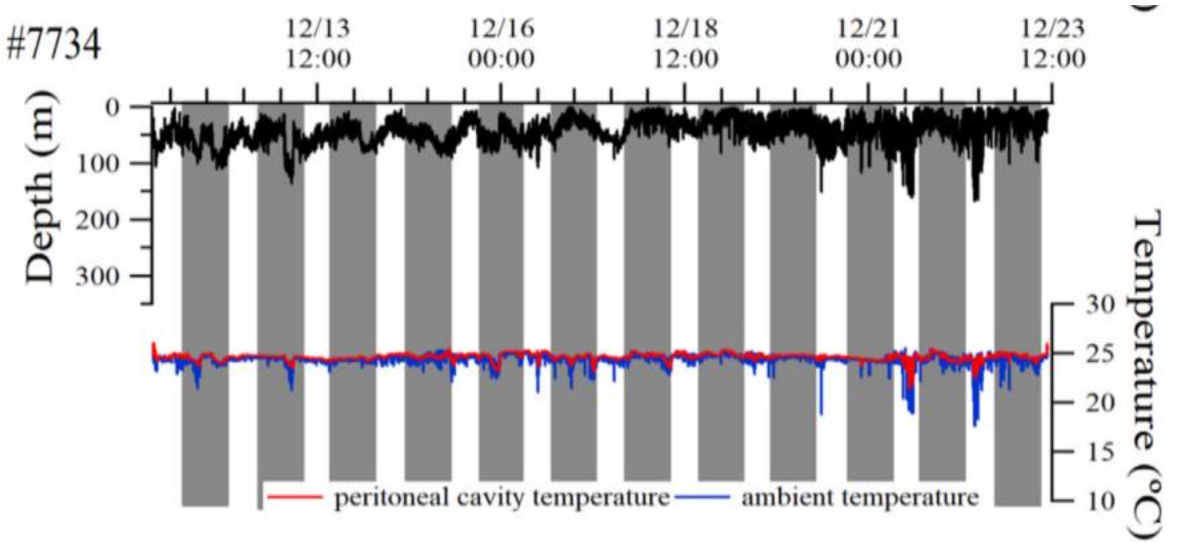
Behavior and distribution are linked to the distribution of prey (productivity) and their accessibility, which depends mainly on temperature and dissolved oxygen (and the good skill of the hunter...).



Time series of depth and temperature for one bigeye tuna tagged in the N-W Atlantic (C. H. Lam et al. 2014)



Bigeye



Time series of depth and temperature for one skipjack tuna tagged near Taiwan (Chang et al., 2021)

Skipjack

eEOVs and tuna behavior

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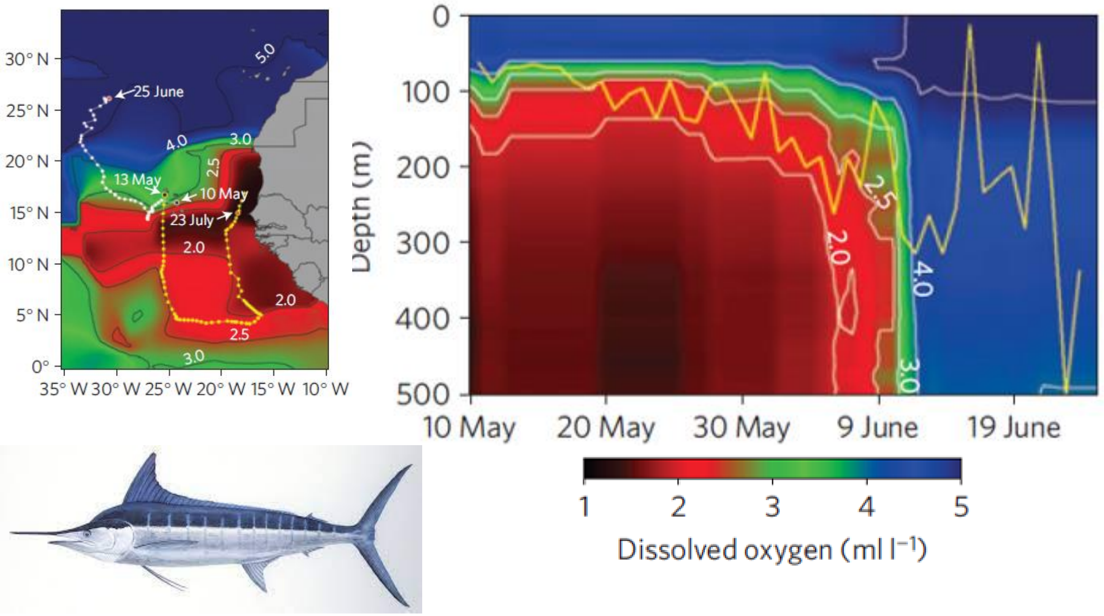
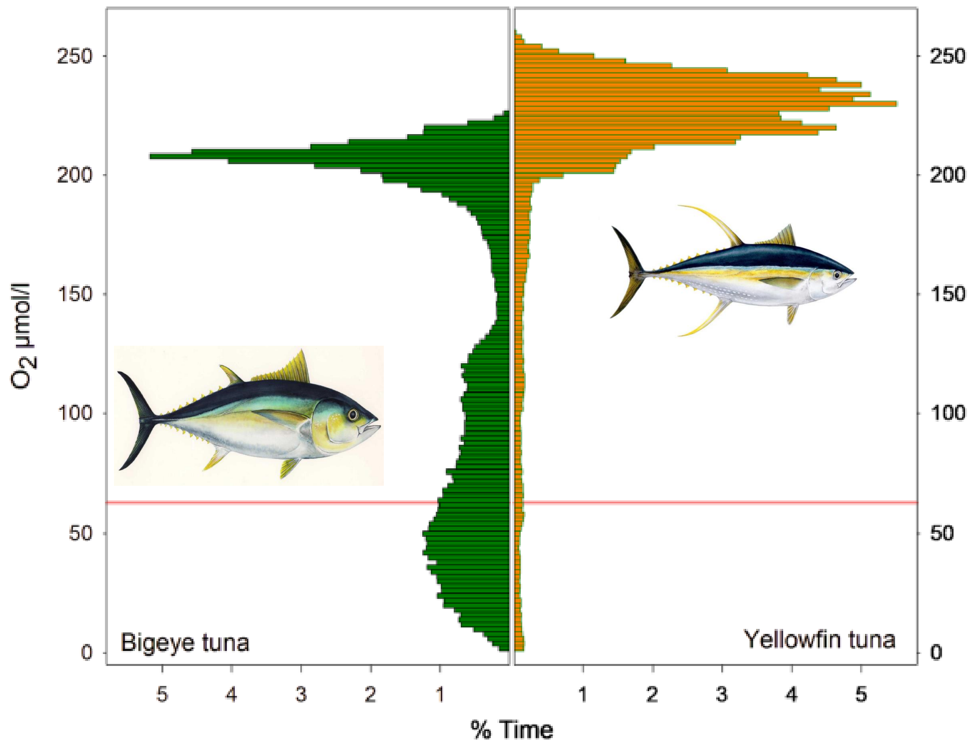
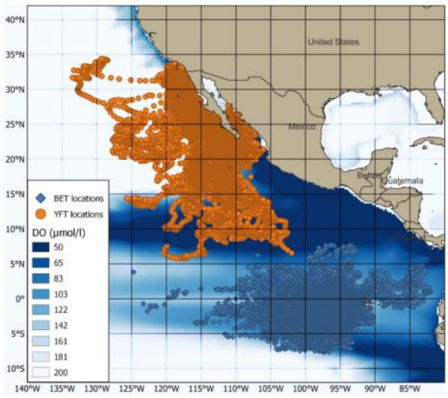
Behavior and distribution are linked to the distribution of prey (productivity) and their accessibility, which depends mainly on temperature and **dissolved oxygen** (and the good skill of the hunter...).



Vertical tracking of blue marlin vs dissolved oxygen in the Atlantic Ocean (Stramma et al (2011)





267 tagged tunas (59,910 days)

Humphries et al (2024)

“bigeye tuna increased the frequency of brief upward vertical excursions they performed by four times when DO at depth was lower … to re-oxygenate following time spent in hypoxic waters”

eEOVs and tuna behavior

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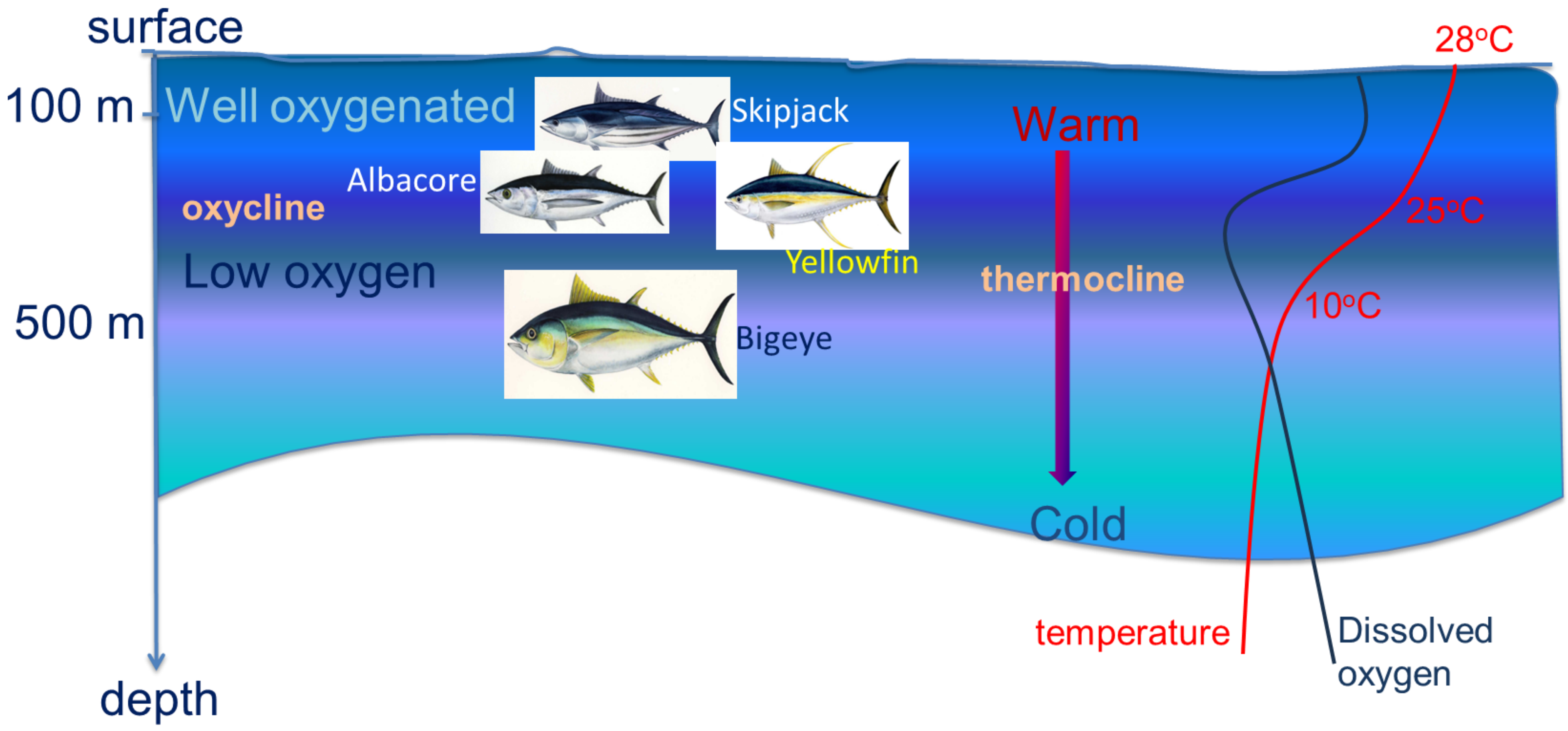
VERTICAL TUNA HABITAT

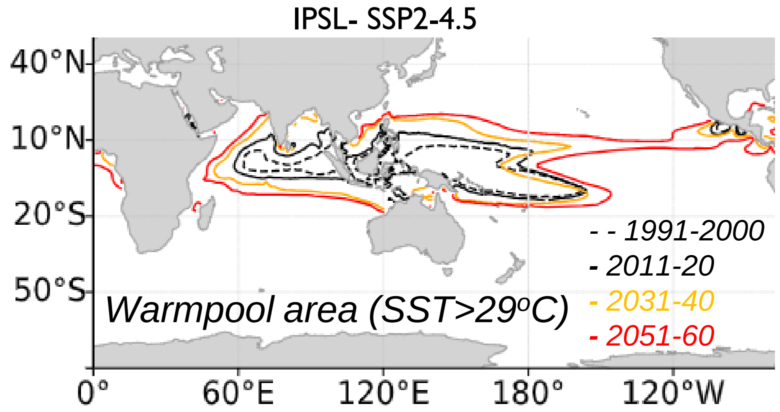


Changes and consequences on tuna behavior

Temperature

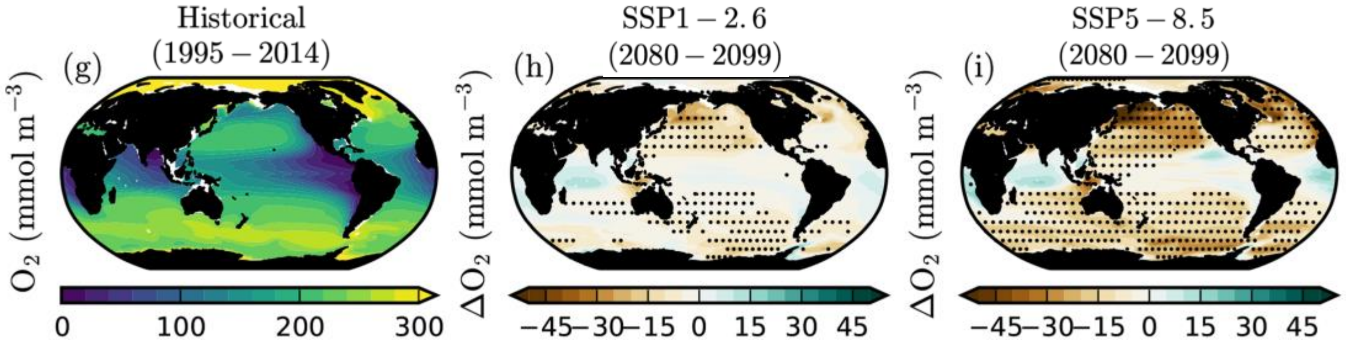
The rate of warming is higher in surface than in subsurface. In the Pacific O. there is asymmetry with colder waters warming more than warm waters

- Larger surface area of warmer waters (eg, the warmpool).
- More contrasted temperature conditions between surface and lower vertical layers



Dissolved Oxygen

- The range of oxygen declines between 1970 and 2010 is 0.5–3.5% in the 0-600 m layer
- Largest decline in North Pac. and Southern Ocean (observed and projected).
- OMZ regions (***<80 mmol/m³***) expanded by a range of 3.0–8.3%. But possibly also linked to decadal changes in tropical trade winds.
- Uncertainty associated to primary production



subsurface (averaged 100-600 m; mmol /m³) dissolved O2 conc. (Kwiatkosvski et al 2020)

Move!

- Vertical habitat: Colder water in subsurface.
- Horizontal habitat: West to East or poleward

⁉

- Sufficient level of D. Oxygen at depth?
- Still need to find sufficient amount of accessible food
- Larvae are drifting with currents

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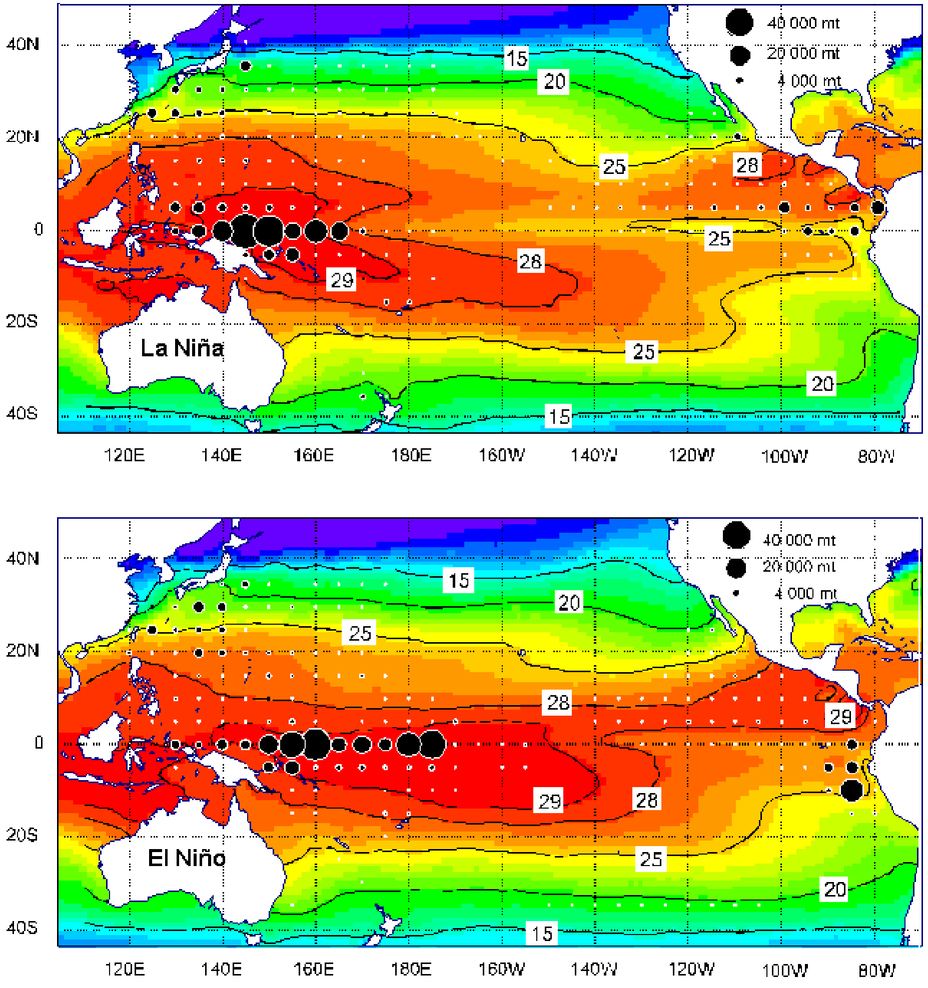
Consequences at population scale

Skipjack provide a good illustration of change in distribution associated to expansion and contraction of the warm pool under ENSO influence

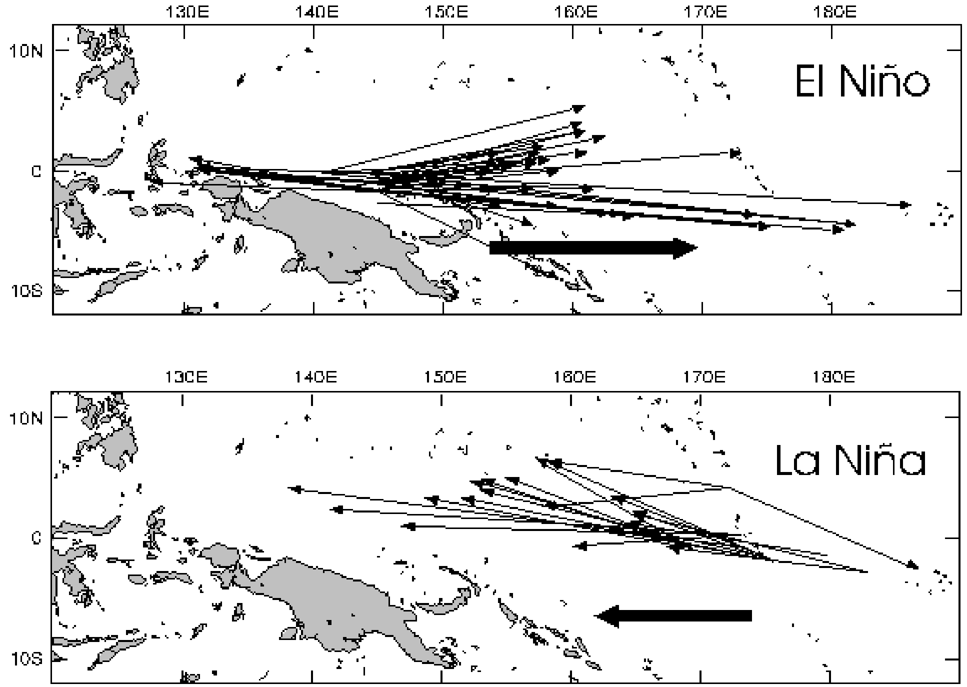
Purse seine skipjack catch and SST



Lehodey et al (1997)

Eastward (El Nino) or westward (La Nina) shift of equatorial PS fishery correlated to expansion (contraction) of the Western Pacific Warmpool

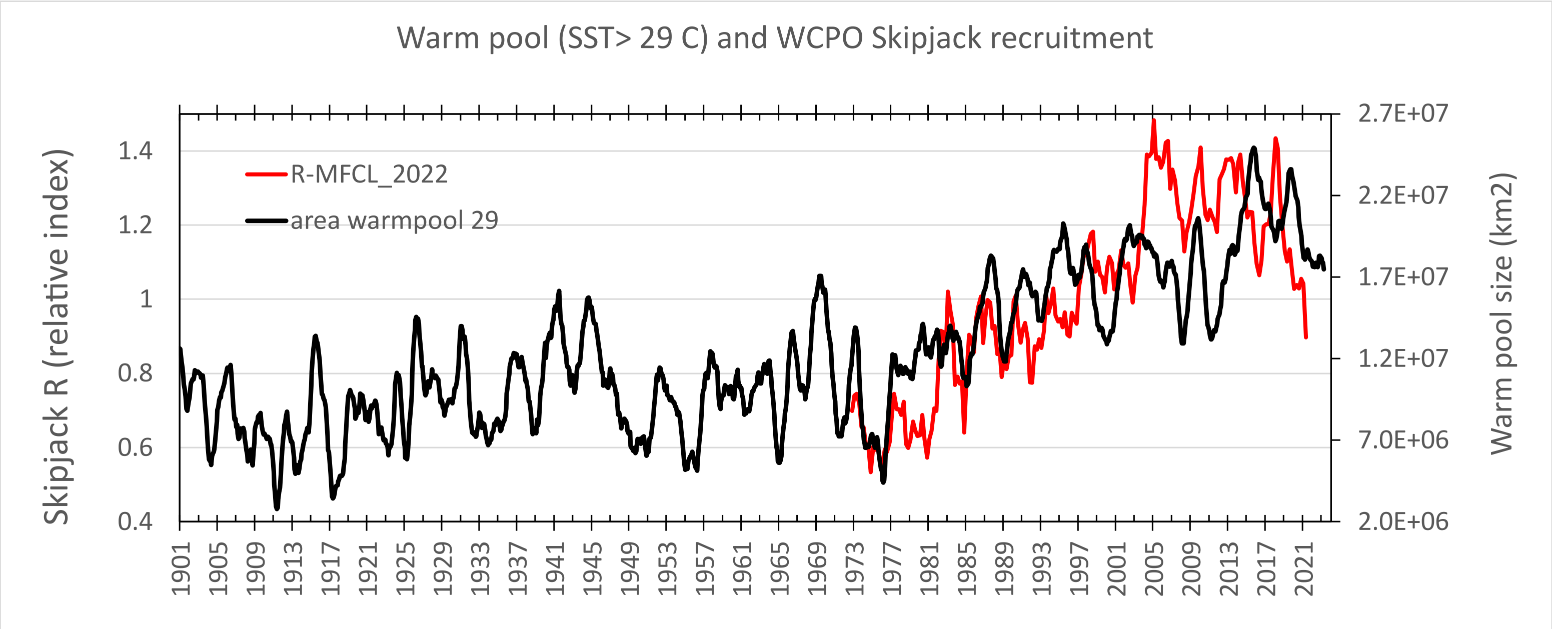
Tagging data indicate that part of this change is due to fish movement, likely also under the change in equatorial circulation



Consequences at population scale

While ENSO is a natural climate variability with a frequency of 3-7 years, we have seen also that the warmpool area is increasing due to climate change.

Regular stock assessment studies (independent of environmental data) suggest that the recruitment of the species is following the same increasing trend.



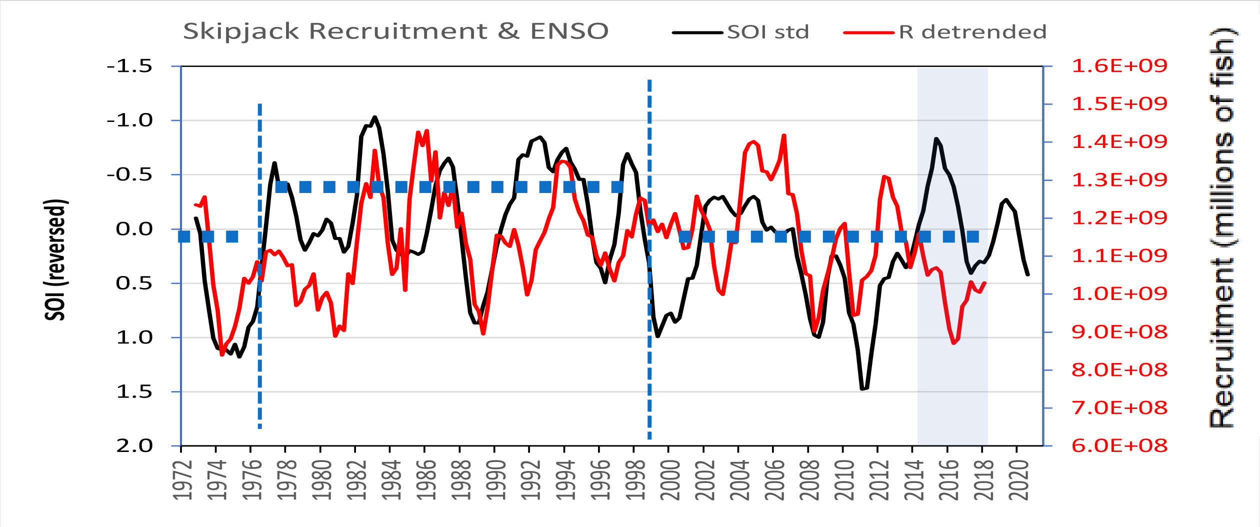
Skipjack recruitment time series for the Western Central Pacific Ocean from last stock assessment study* (Castillo-Jordan et al. 2022) and evolution of the size of the western tropical warmpool defined by SST >29ºC.

** No environmental data are used in stock assessment studies, only catch, size frequencies of catch and tagging data*

Consequences at population scale

Skipjack

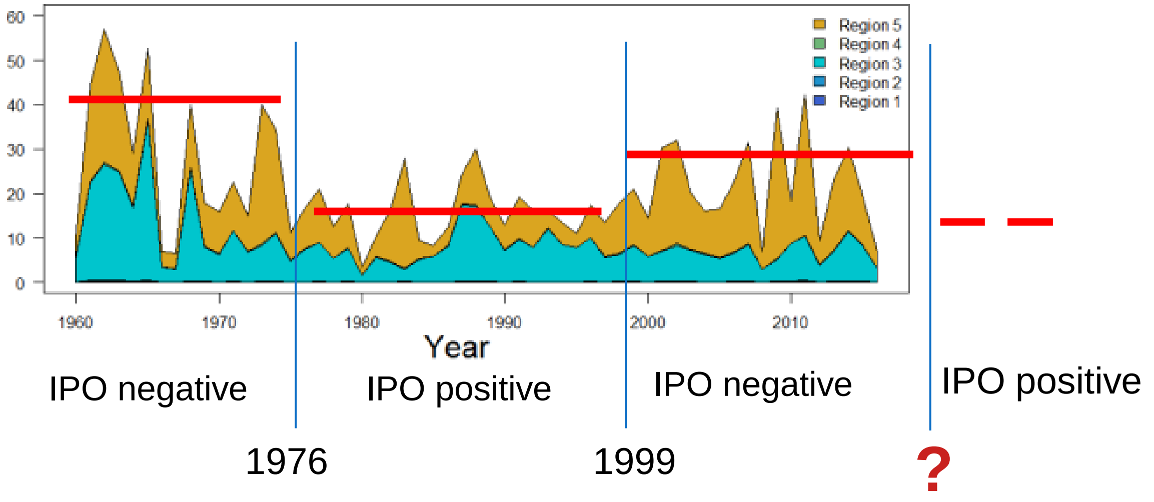
El Nino => Skipjack ☺
La Nina => Skipjack ☹



Skipjack recruitment from Stock Assessment MFCL after removing increasing trend and ENSO index SOI (note that SOI y axis is reversed)

South Pacific Albacore

El Nino => Albacore ☹ ?
La Nina => Albacore ☺ ?



SP Albacore recruitment from last MFCL stock assessment and IPO phases

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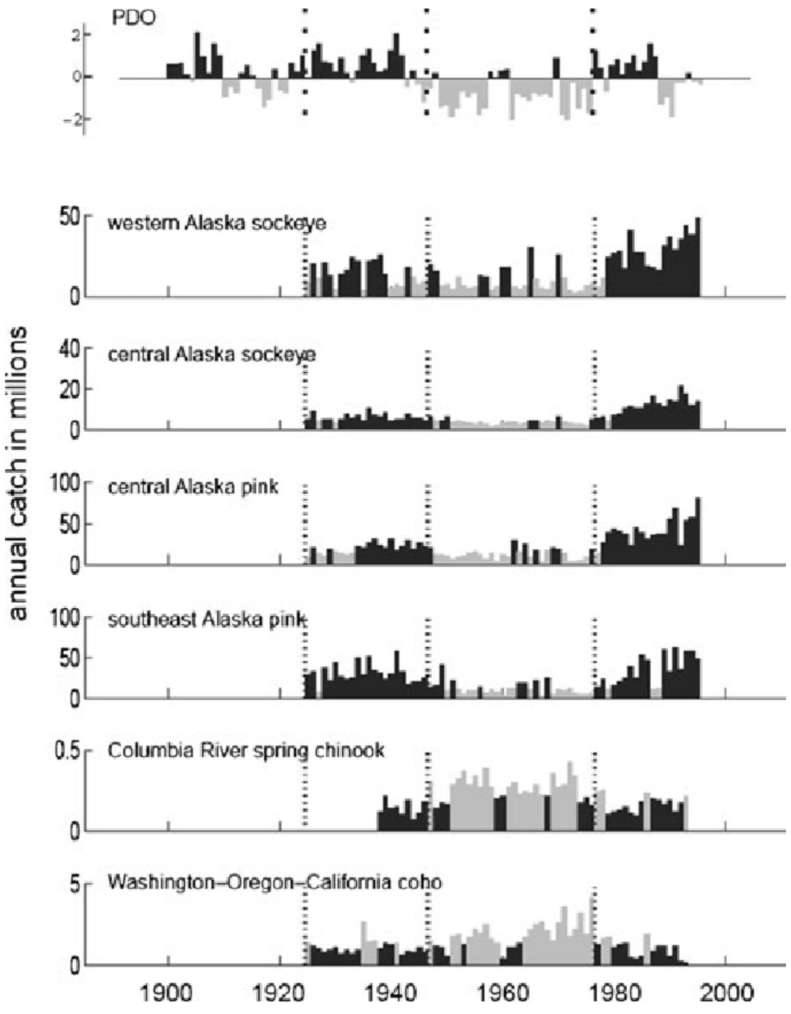
Consequences at population scale

Mantua, N. J., S. R. Hare, Y. Zhang, J. M. Wallace and R. C. Francis (1997): A Pacific interdecadal climate oscillation with impacts on salmon production. Bull. Amer. Meteor. Soc., 78, 1069–1079.



South Pacific Albacore

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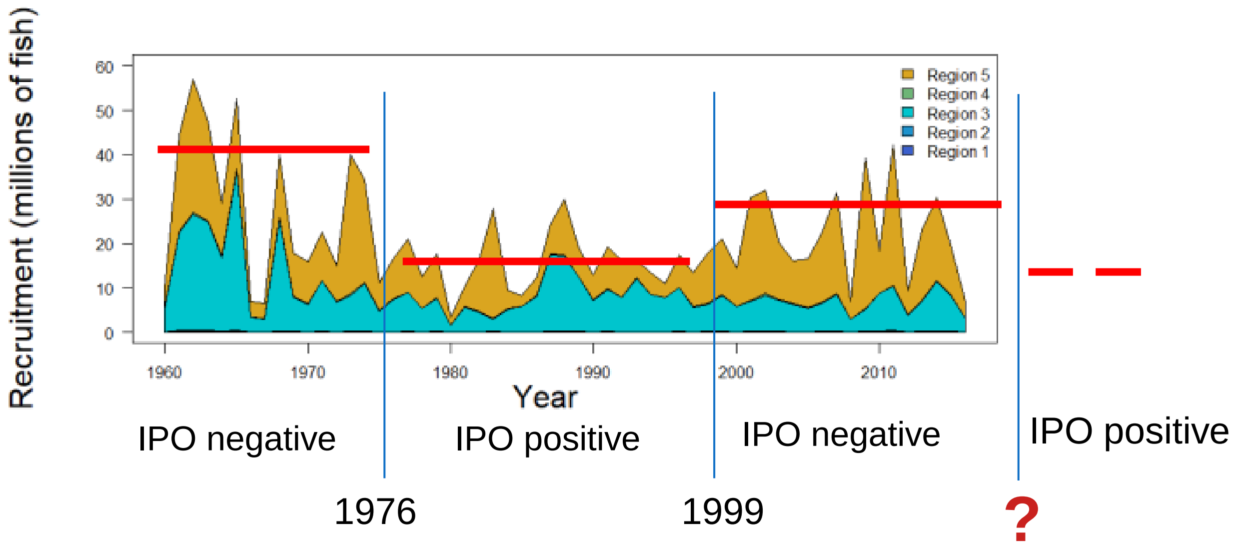


SP Albacore recruitment from last MFCL stock assessment and IPO phases

Consequences for management

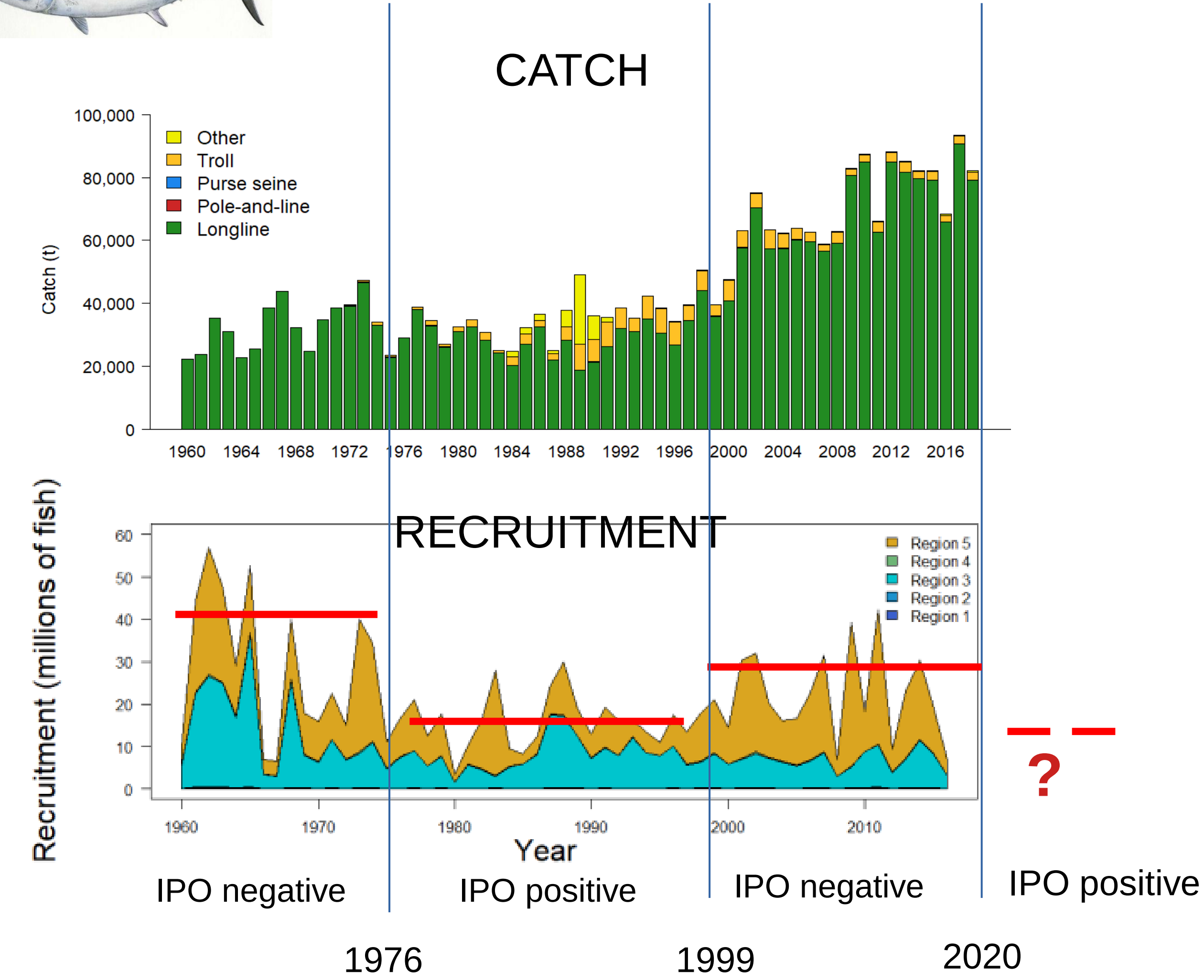
Understanding the mechanisms of variability in recruitment due to environmental changes is the key (holy grail!) to predict the future of fish population

If we could confirm and understand the relationship between albacore recruitment and ENSO, the frequency of which is influenced by decadal variability (IPO), we would be in better position to manage fisheries and fishing mortality when the positive productivity regime will reverse to a low productivity regime.

Given the large increase in catch for this species after 2000, the next low regime that could be expected in the coming years with **the future phase of positive IPO would occur in a different context due to i) a larger reduction in spawning biomass and ii) additional climate change impacts**.

Need to be carefully monitored!

Albacore



Consequences for management

Other consequences of changes in eEOVs on behavior and therefore spawning and feeding habitats, and resulting distributions and movements

- Change in vertical habitat, shoaling or deepening would impact catchability and thus the stock assessment estimates that rely on CPUE (catch per unit of Effort).

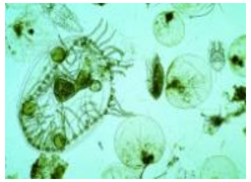
- Potential changes in growth, age at maturity and natural mortality to be considered due to warmer habitat, changes in food web, and compound effects (Heat Waves + deoxygenation + acidification)

- Change in horizontal tuna habitats and distributions could challenge present management organisations:
  - Increasing overlap between regional fisheries organisations (WCPFC, IATTC) requiring cooperation mechanisms to jointly define appropriate fishing limits for each stock and common conservation measures
  - Increasing catch in international waters vs Pacific Islands EEZs

Perspectives: I) Recruitment mechanisms

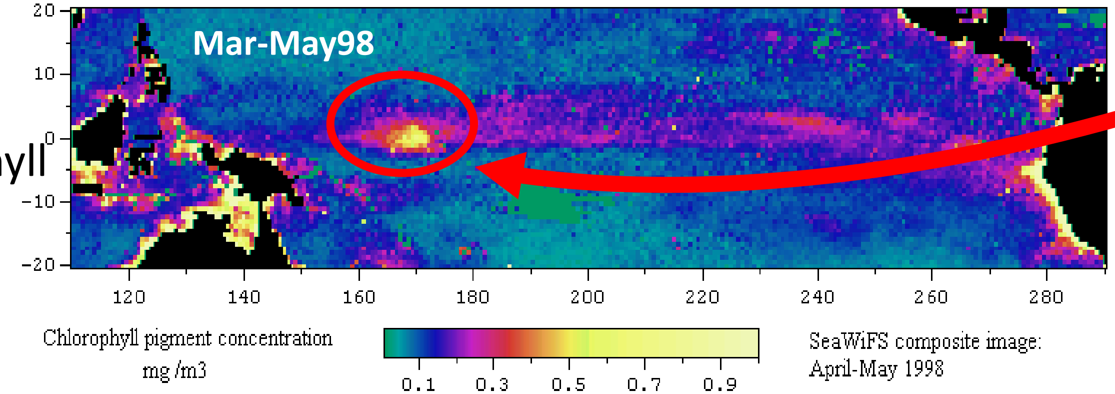
- Is temperature only sufficient to predict skipjack recruitment (and stock) trend? Until when?
- Confirm and explain possible opposite relationship for albacore

Tuna larvae feed on zooplankton that feed on phytoplankton



Satellite Chlorophyll

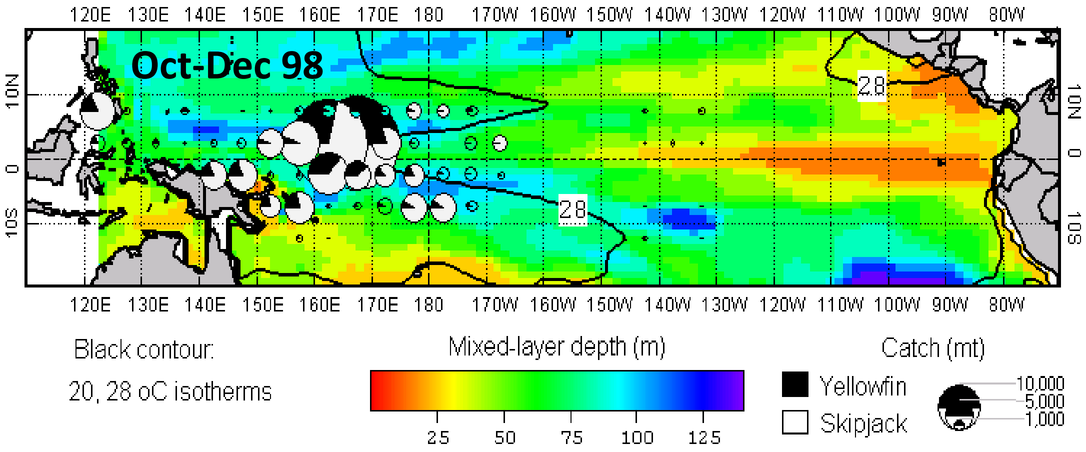
Bloom of phytoplankton at the end of 1997-98 El Niño

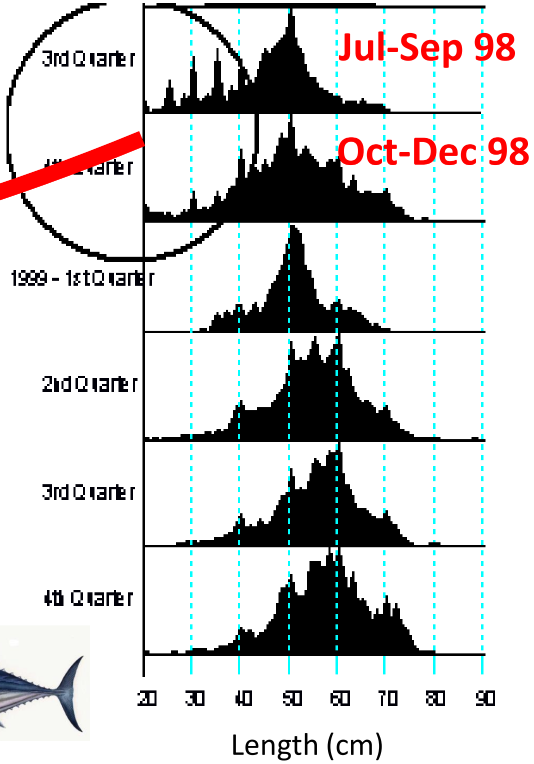


+ 7 months

Tuna catch by purse seiners

Lehodey et al. (2011)

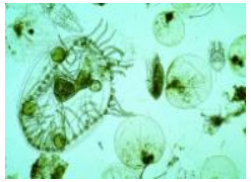




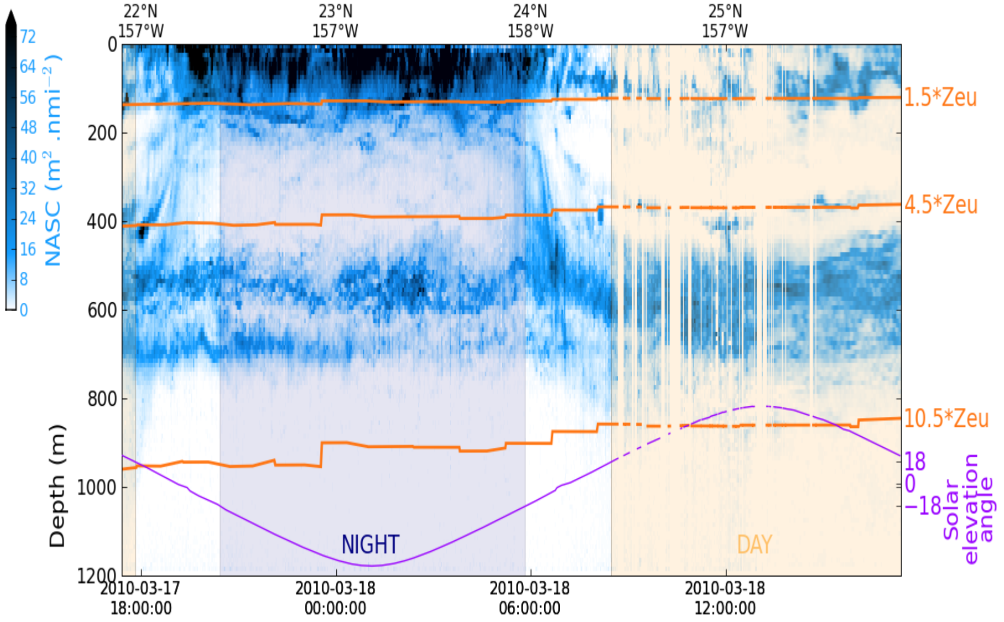
Size frequencies of skipjack caught by purse seiners showing unusual peaks of small juveniles in 1998

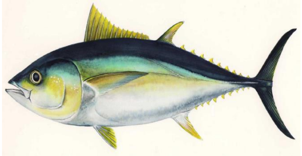
Perspectives: 2) Tuna feeding habitats

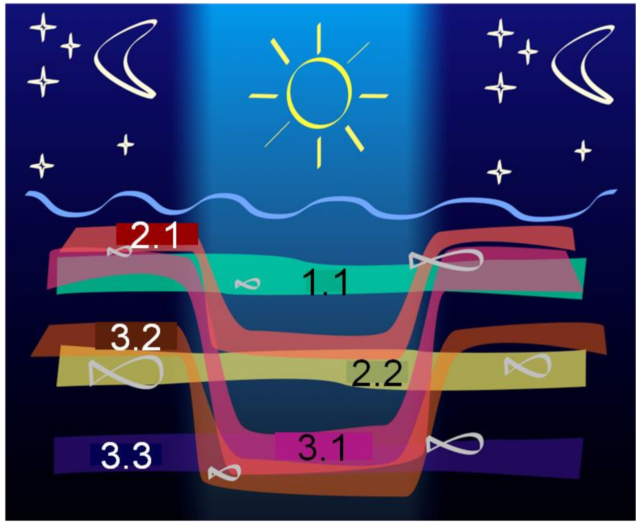
Tuna larvae feed on zooplankton that feed on phytoplankton



SPC 2019
Credit: Elodie Vourey







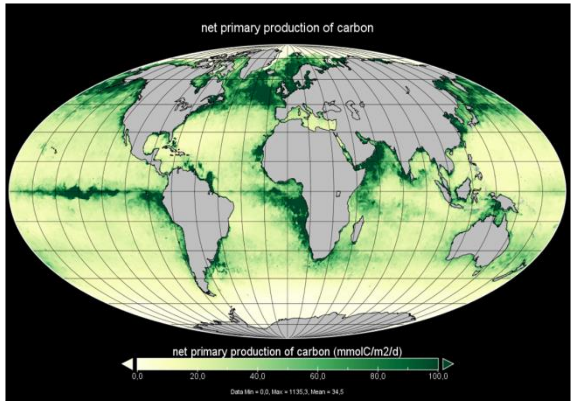
- For primary production we have satellite chlorophyll_a observation as a proxy (although not so good in the tropics)
- For zooplankton (prey of larvae) and micronekton (prey of juvenile and adult fish), no similar wide cover observation
- For zooplankton and micronekton we have to rely on models based on existing knowledge and sparse observation

Perspectives: 2) Tuna feeding habitats

SEAPODYM-LMTL

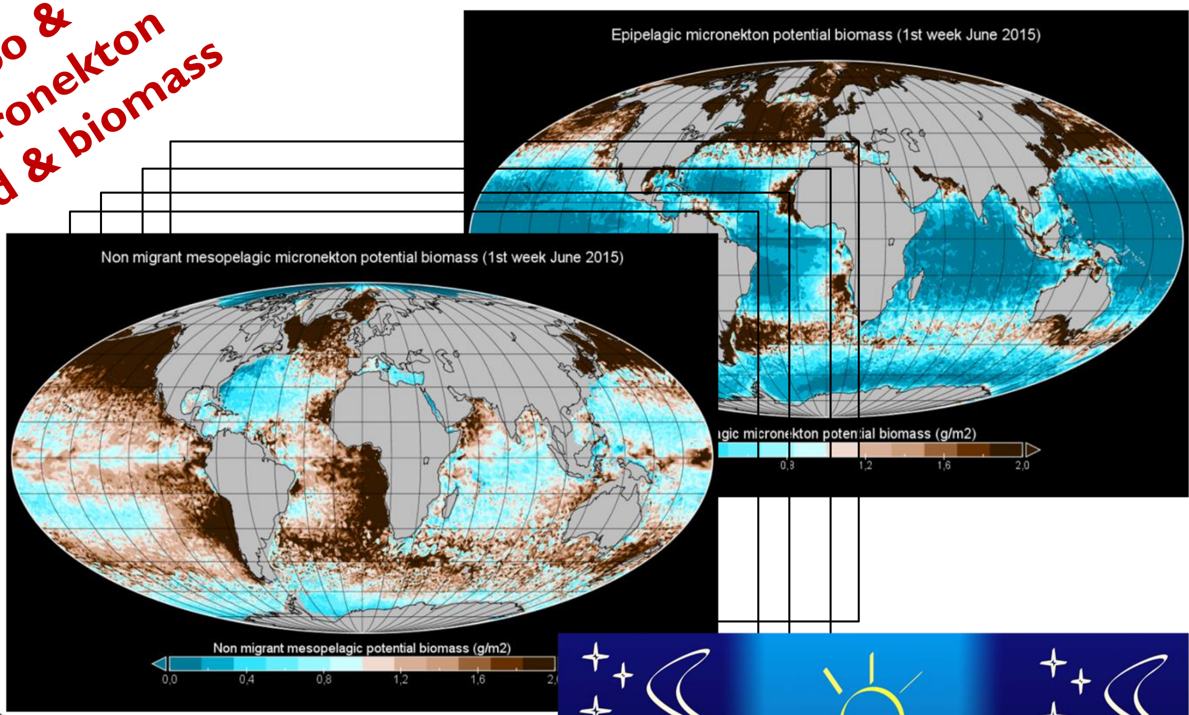
Using **temperature**, oceanic **currents and primary production**, the model simulates one zooplankton and 6 micronekton functional groups, according to their diel vertical migration behavior in 3 vertical layers (epi-, upper meso- and lower meso-pelagic).

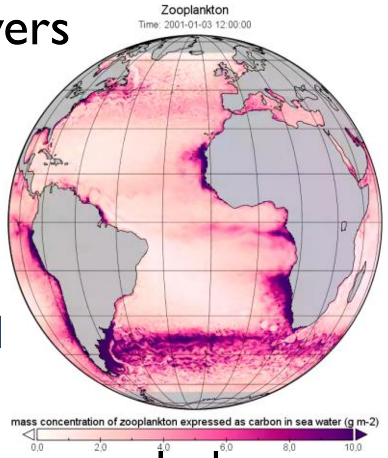
Primary Production



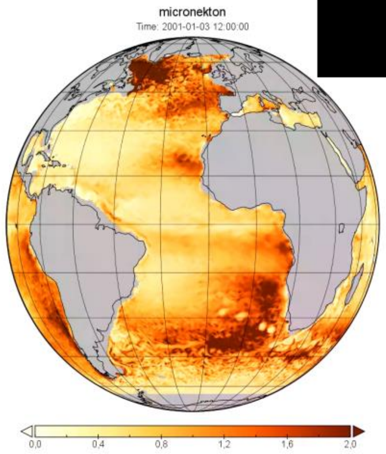
Zoo & micronekton Prod & biomass

E





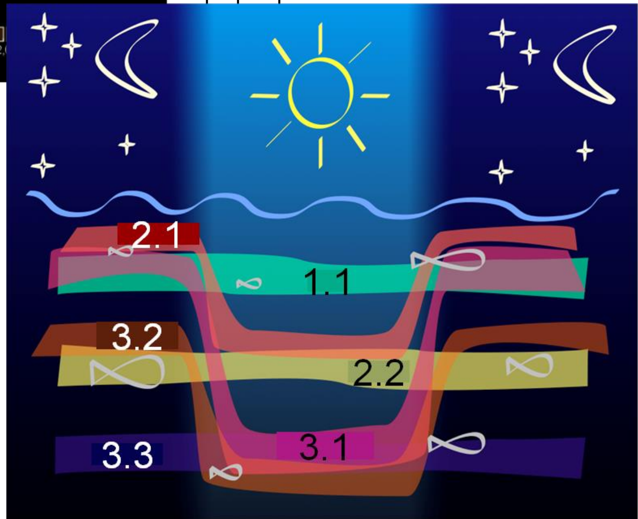
zooplankton



micronekton

Available at: https://data.marine.copernicus.eu/product/GLOBAL_MULTIYEAR_BGC_001_033/description

- new ongoing developments: several groups of zooplankton and use of acoustic data



Perspectives: 3) Modelling tuna dynamics

Next presentation by Inna

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Conclusions

- The impact of CC on one species can be perceived differently depending on whether we consider the species at the scale of the ocean or more regionally, eg EEZ
- Highly mobile young and adult tuna should very likely adapt to temperature and dissolved oxygen changes with the condition that overall productivity does not change too drastically. This is where largest uncertainty remains for the tropical ocean.
- For larvae, the vulnerability is likely higher since they cannot escape unfavorable areas. Multi-stressor effects on larvae mortality require particular attention. Understanding mechanisms of larval recruitment are key to get confidence in future projections of changes.
- We need better monitoring of eEOVs in the tropical Pacific, especially PP and phytoplanktonic communities, zooplankton and micronekton (biomass and species communities), and change in diets of tuna in relation to natural climate variability (ENSO and IPO). This requires standard and new technologies and more automatic acquisition.
- We need improved ocean and biogeochemical models with realistic initial conditions of the interdecadal variability and improved models of zoo and micronekton with validation from observations (cf above).
- Include more CC considerations in tuna assessment and management, and coordination between management organisations.

Thank you for your attention

Questions?