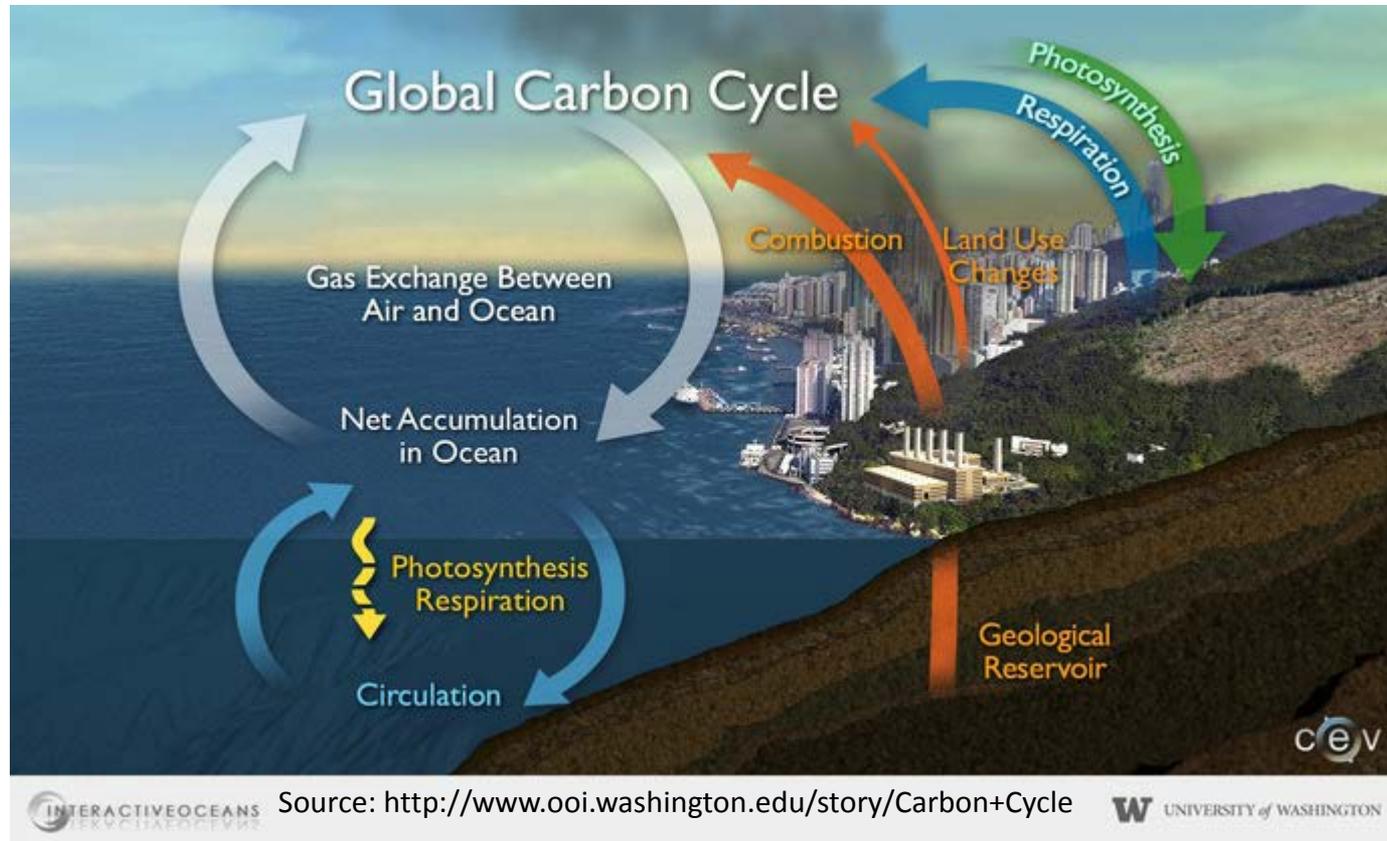


**THE POTENTIAL IMPACT OF
OCEAN ACIDIFICATION ON
EGGS AND LARVAE OF
YELLOWFIN TUNA**

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Ocean acidification and tuna

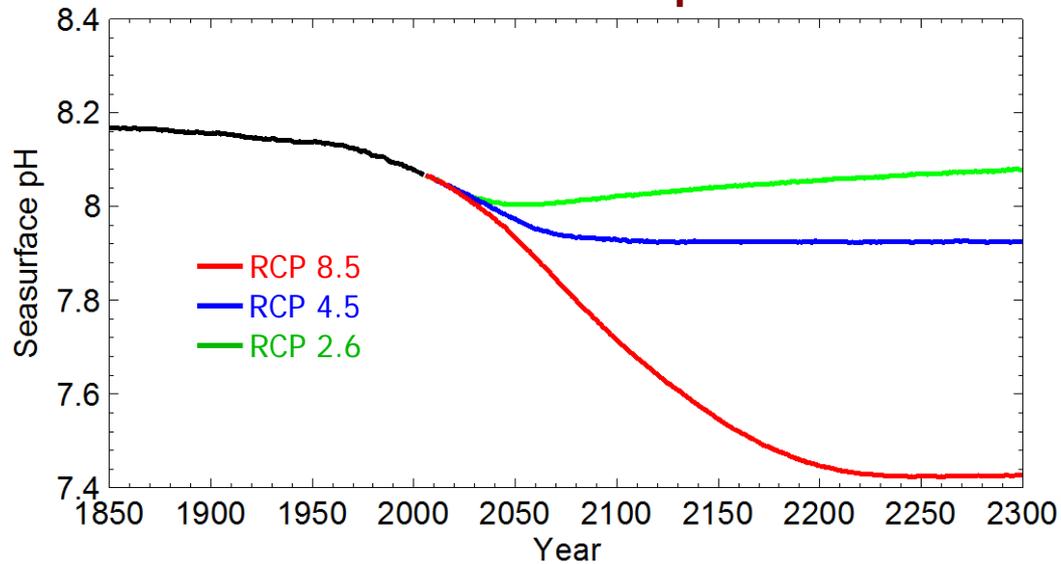


- Global industrial and agricultural development has substantially increased the amount of $\text{CO}_2(\text{g})$ in the atmosphere
- Some of this is absorbed by forests, but a larger percentage (30-50%) by the oceans.

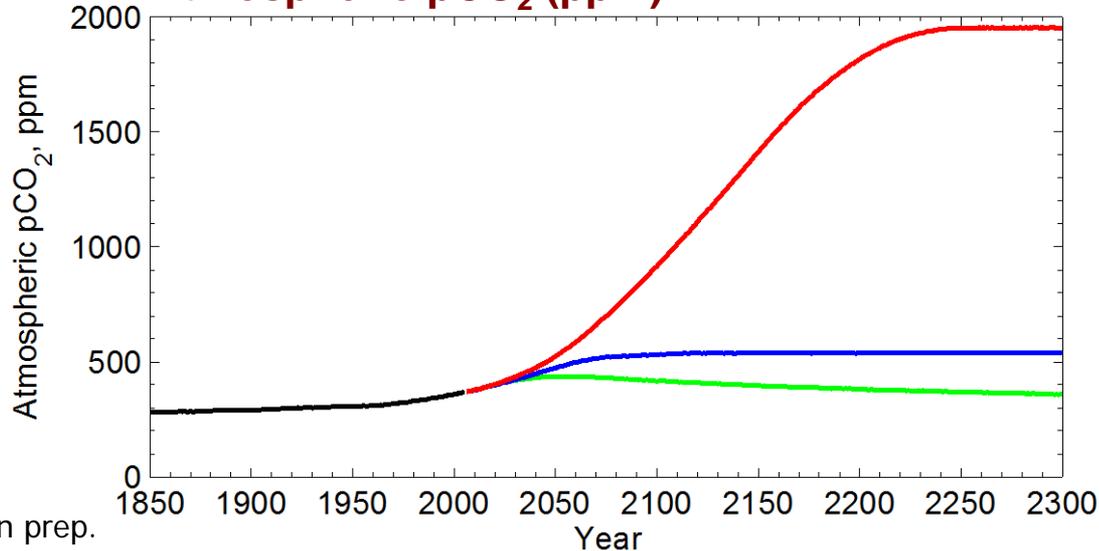
Projections of Ocean Acidification in CMIP5 simulations

calculated with the model MPI-ESM

Global mean surface ocean pH



Atmospheric pCO₂ (ppm)

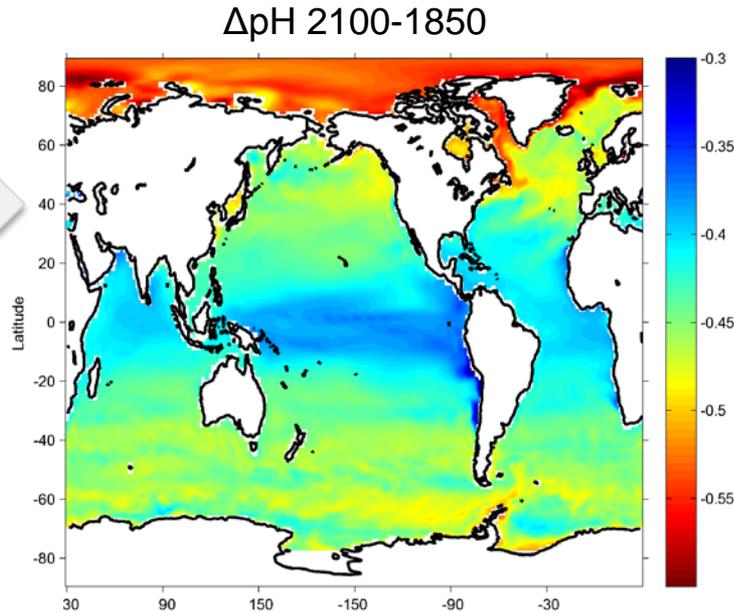


Projections of Ocean Acidification in CMIP5 simulations

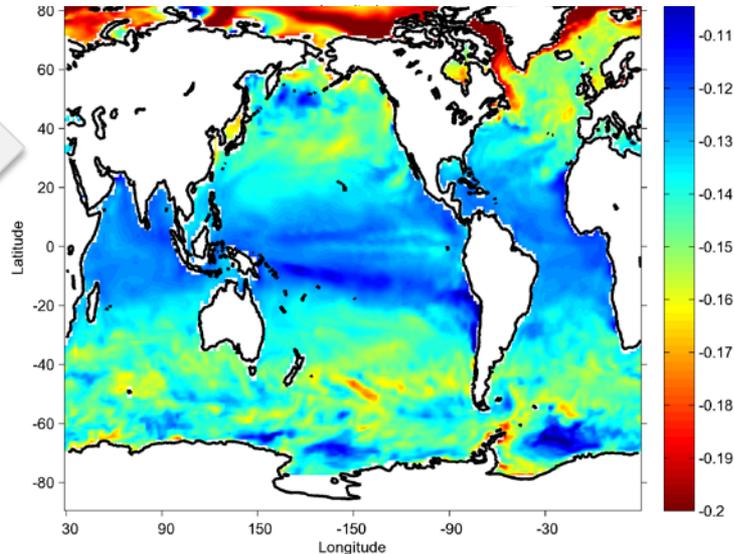
calculated with the model MPI-ESM

calculated with the model HAMOCC in CMIP5 simulations

scenario
RCP8.5



scenario
RCP2.6

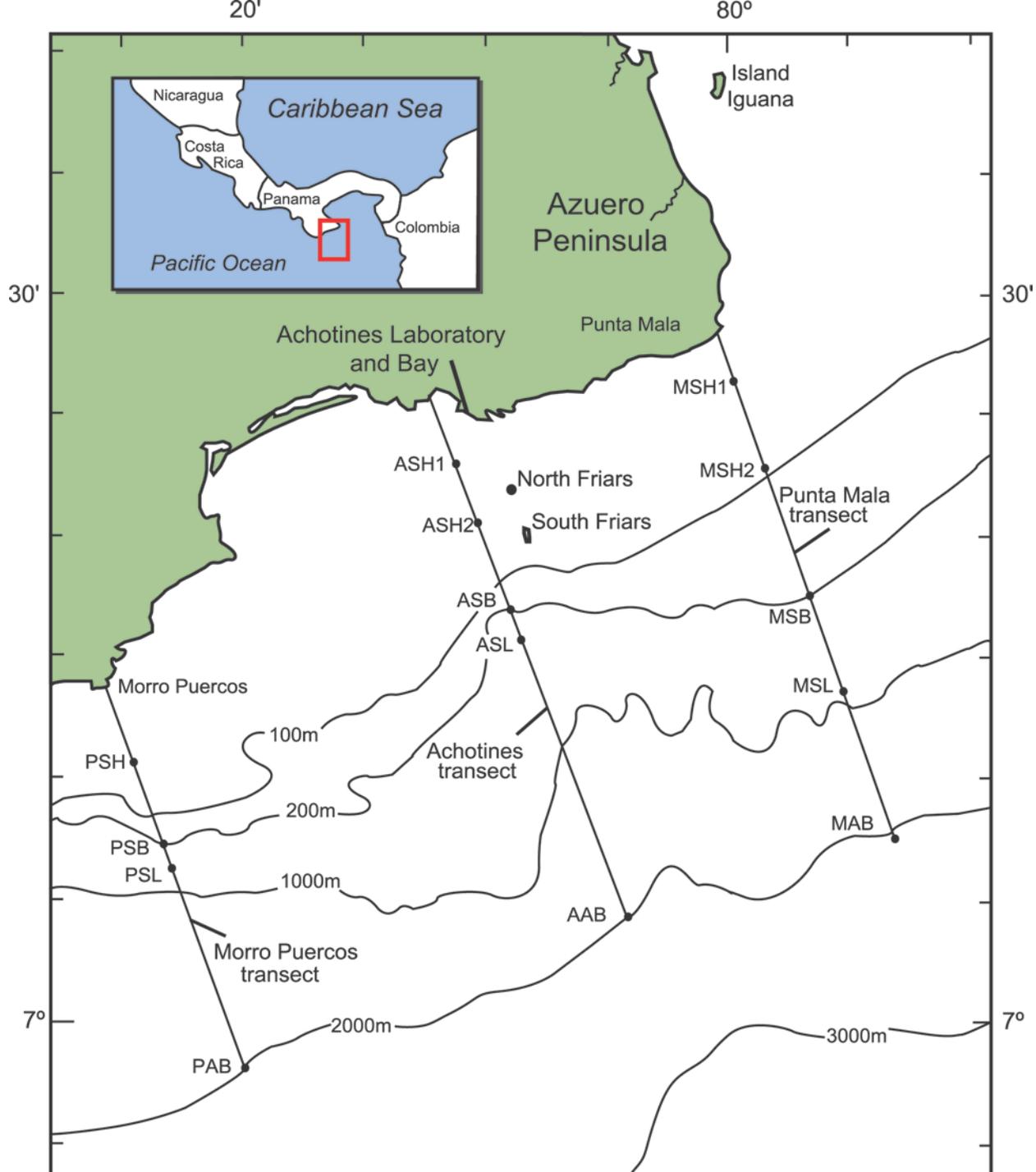


- Seawater pH decreases globally, but at different rate in different regions.
- Largest changes are projected in high latitudes.
- Surface pH drops by up to 0.6 units by the year 2100 compared to preindustrial in the high- CO_2 scenario.
- It decreases also in the low- CO_2 scenario which assumes mitigation efforts.

Ocean acidification and tuna

Fish

- **General mechanism of impact**
 - * Calcification is internal (bones, otoliths) so main effects are expected to depend upon capacity for metabolic compensation
 - * Adult fish known to have very effective acid-base and osmoregulatory mechanisms to overcome elevated metabolic CO₂ levels (during activity) and acidosis.
 - * Larval stages have not developed such mechanisms and are likely to be more vulnerable
 - * Ecosystem effects likely to be very important (prey spp impacts etc)
- **Evidence to date from other studies**
 - * growth and survival impacts in larvae of some species
 - * otolith growth impacts
 - * increased boldness and activity, loss of behavioural lateralization, altered auditory preferences and impaired olfactory function
 - * Interference with neurotransmitter (GABA-A) function (implications for other species, given its highly conserved nature)







1

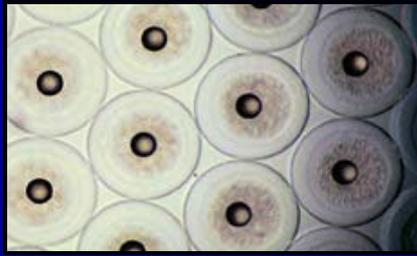


Ocean acidification and Tuna

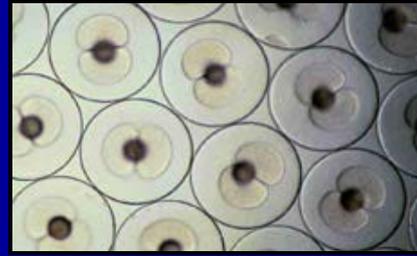
- **Treatment Continuous but consisted of three phases:**
- Egg
- Yolk-sac larvae
- First-feeding larvae

- **Sampling and measurements**
- Eggs
 - * Sperm motility
 - * Hatching rates, morphology, development
- Larvae
 - * Survival
 - * Growth (length and dry weight)
 - * Development (whole larvae and individual organs)
 - * Condition (histological samples)
 - * Morphometrics
 - * Otolith morphometrics
 - * Genetic selection and adaptability

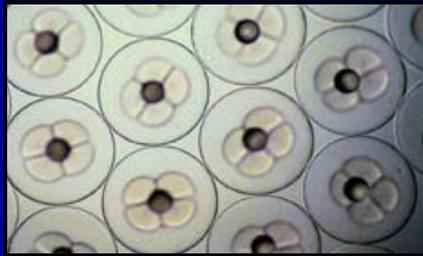
Embryonic Development of Yellowfin Tuna (*Thunnus albacares*) – Elapsed Time: 20 h



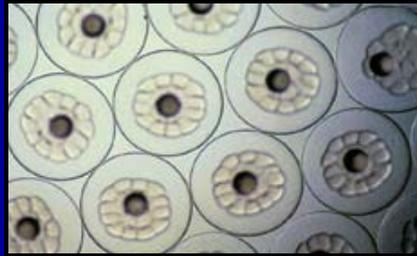
a. Fertilized eggs (blastomere)



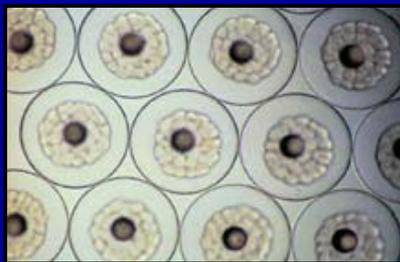
b. First cell division (1st cleavage)



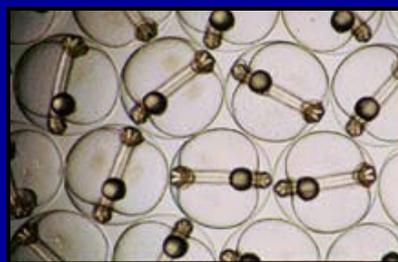
c. Second division (4-cell stage)



d. Fourth division (16-cell stage)



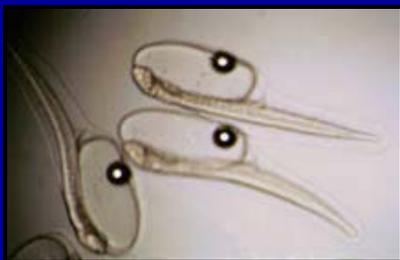
e. Fifth division (multicell stage...)



f. Early embryo (tail bud stage)



1-Day-Old Larvae (1 DPH)



g. Newly-hatched (yolk-sac) larvae



h. Yolk-sac larvae (20X)

Yellowfin tuna larvae 6 days after hatching. Photo University of Miami

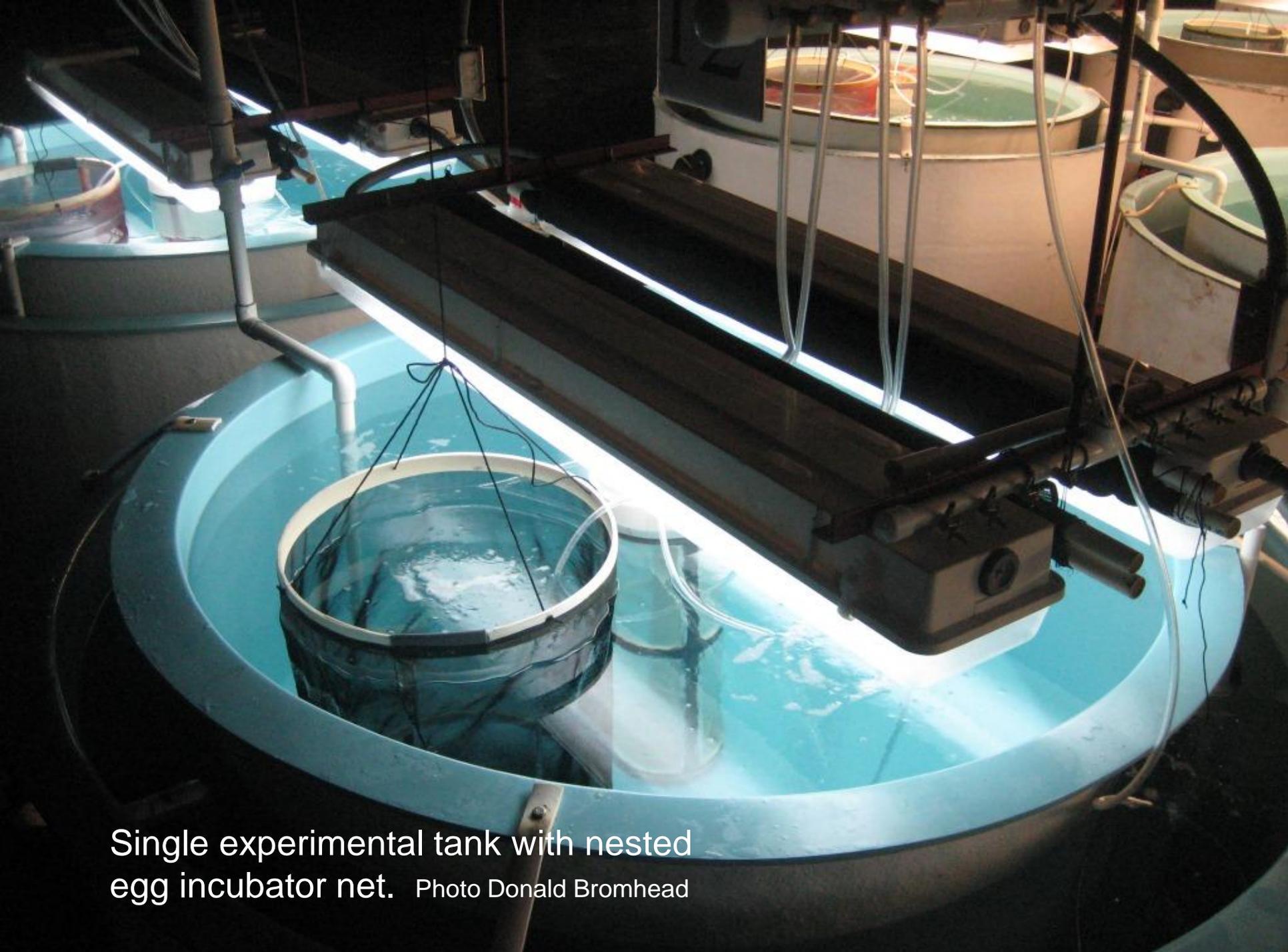




Compressed air reservoir and CO2 cylinder bank. Photo Donald Bromhead

Gas Flow controllers and manifolds used for mixing and distribution of air and CO₂. Photo Donald Bromhead





Single experimental tank with nested egg incubator net. Photo Donald Bromhead



Multiple experimental tanks with nested egg incubators. Photo Donald Bromhead

Ocean acidification and tuna

- **Target pH levels**
- 8.2
- 7.7
- 7.3
- 6.9
- 6.5

- **Water quality parameters measured**
- Temperature
- Dissolved oxygen
- Salinity
- pH
- Dissolved CO₂
- Alkalinity

- **Estimated parameter (using Excel CO2SYS macro)**
- pCO₂

Ocean acidification and Tuna

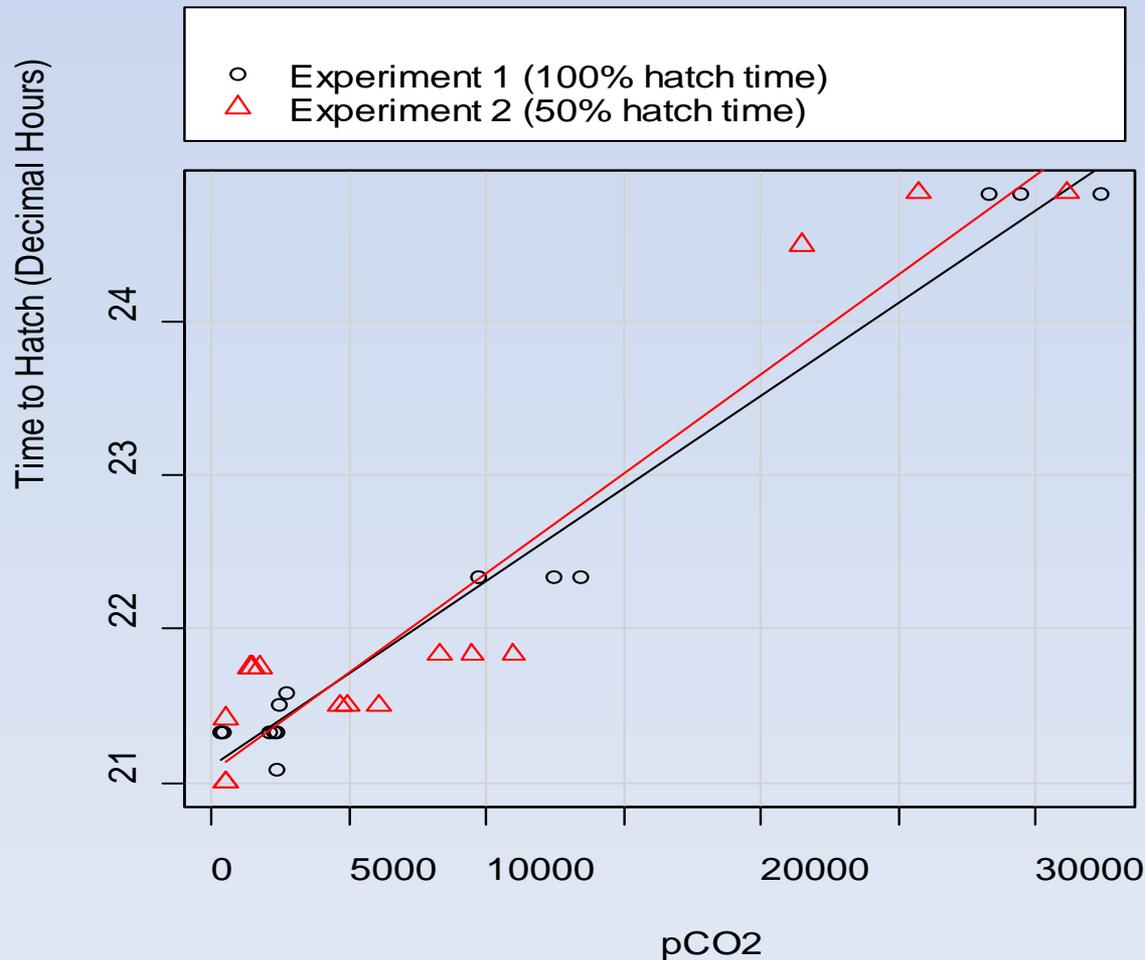
Statistical Analyses

- Generalised Linear Models
 - * Egg hatching rates
Time at hatch ~ pCO₂ + salinity + temperature + dO₂
 - * Larval survival
Survival no.s ~ pCO₂ + Trial
 - * Larval growth (in progress)

Ocean acidification and tuna

Egg hatch times

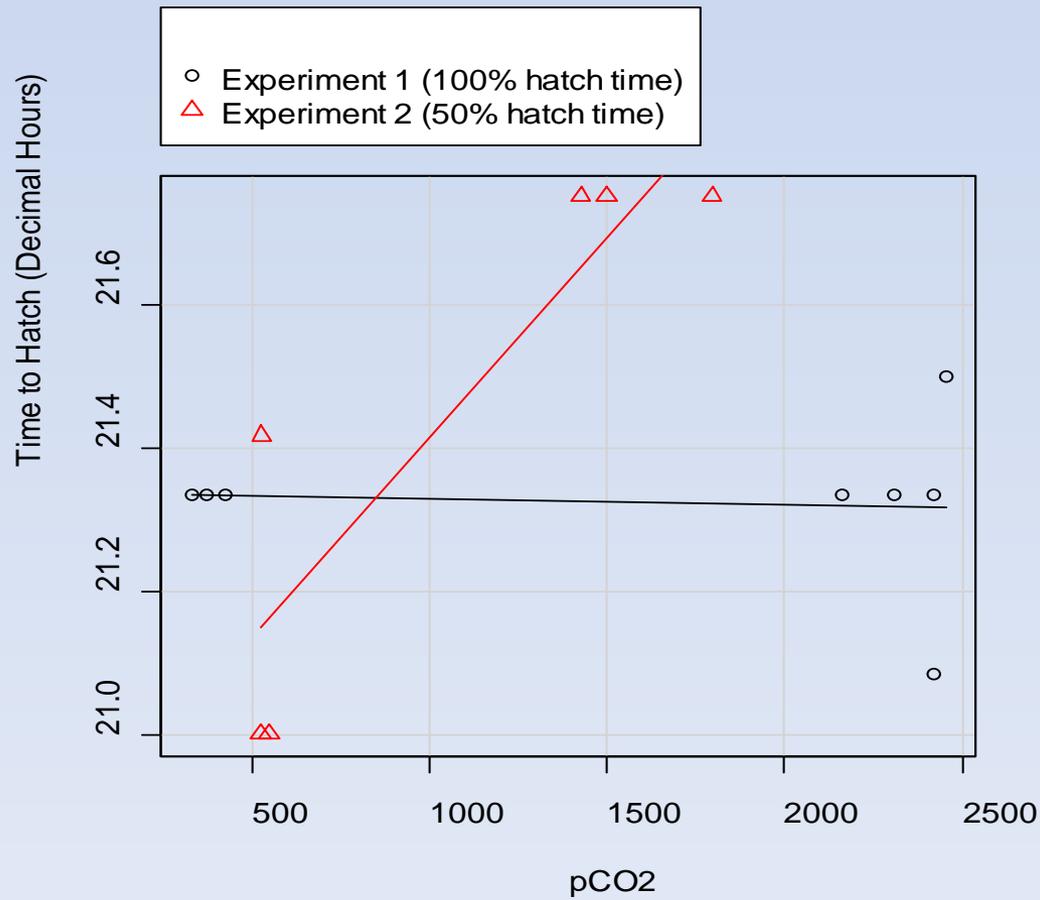
- Key outcome – pCO₂ very significantly related to hatch time over the full range of pCO₂ examined



Ocean acidification and tuna

Egg hatch times

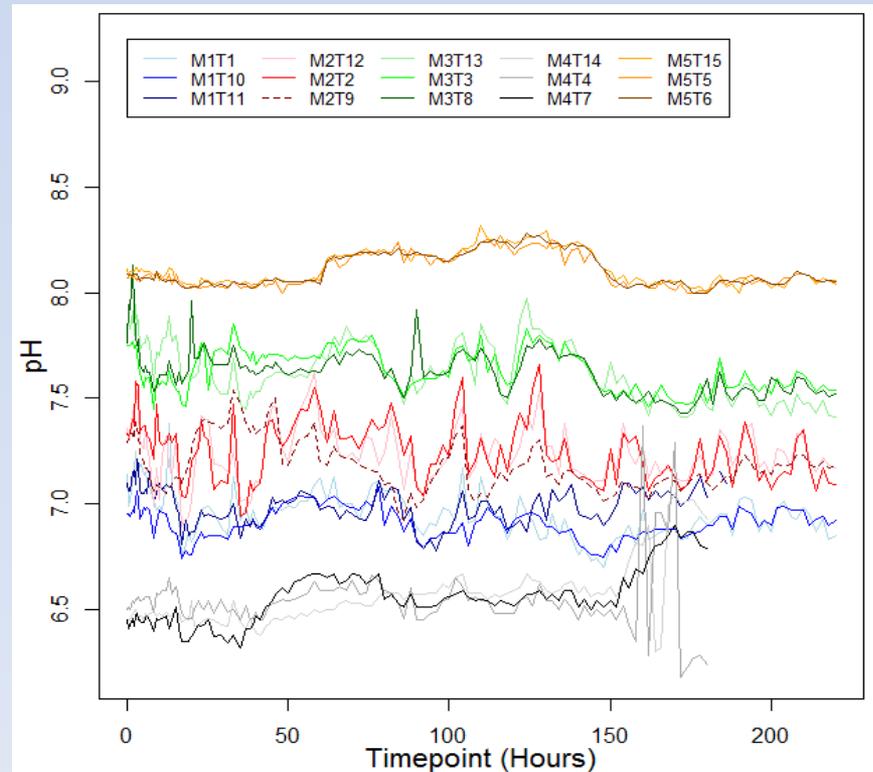
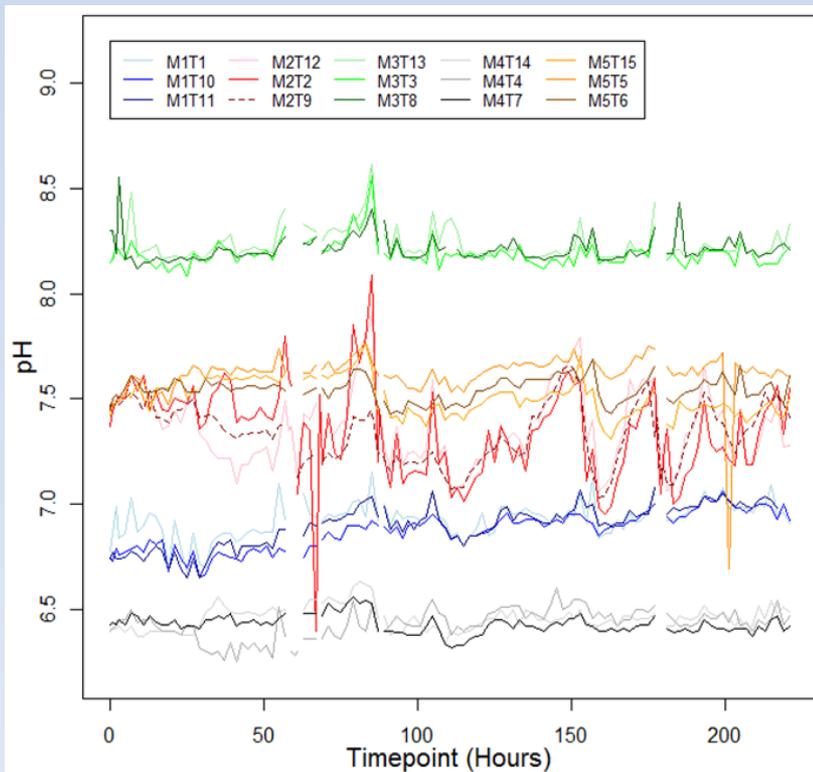
- pCO₂ is not significant if we restrict the data to pCO₂ levels relevant to the next 200 years (i.e. <2500uatm)...however sample sizes are very small and Experiment 2 results suggest some potential for an effect



Ocean acidification and tuna

Larval survival

- pH and environmental parameters were closely monitored throughout both trials
- In both trials, pH showed significant uncontrolled variation in tanks targeted to pH=7.3. This was likely due to a technical system problem.



Ocean acidification and tuna

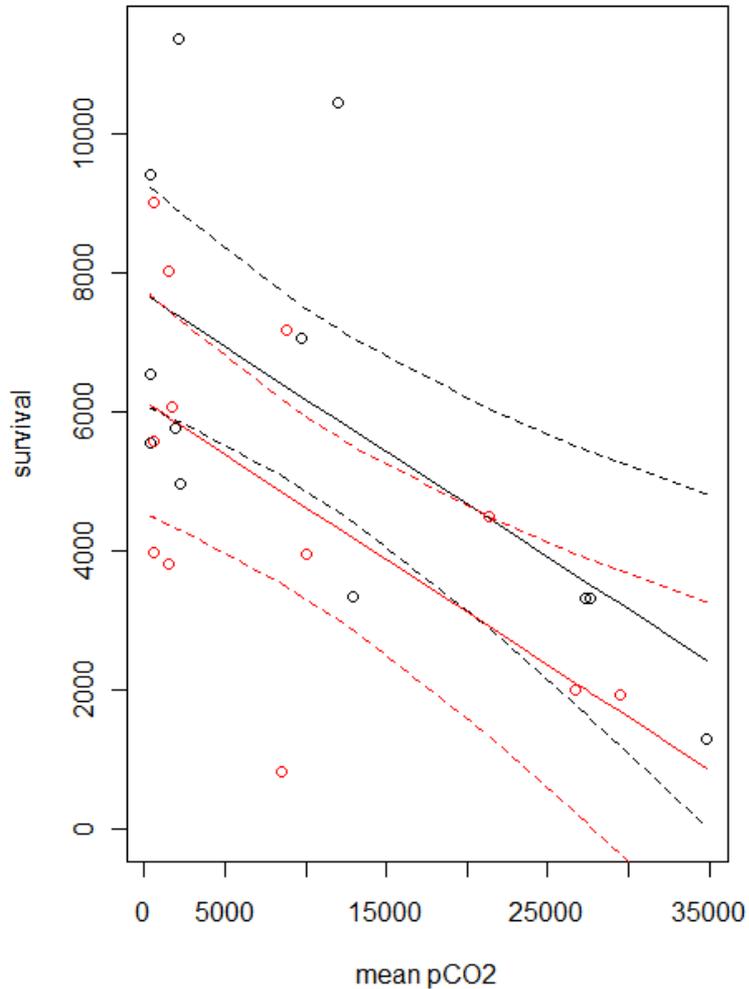
Larval survival

- At the end of trial 2, a red tide in the Ashotines Bay may have caused fluctuations in environmental parameters including pH in some tanks and also coincided with a mass mortality in two control tanks the night before final survival counts. Visual estimates of numbers in the control tanks were higher than any other treatment tanks but final counts the next morning were very low due to an overnight mortality event possibly due to an ammonia spike or the red tide.
- **Due to both occurrences, survival data from treatments targeted at pH=7.3 (both trials) and day 6 of larval feeding (trial 2) were excluded from analyses**

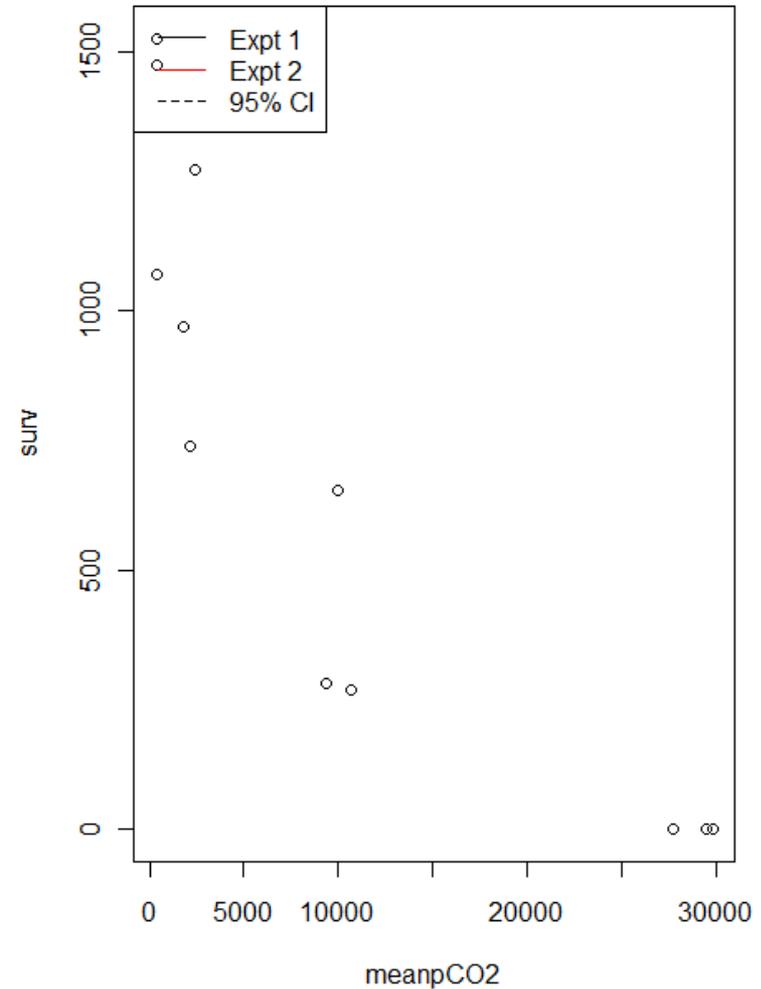
Ocean acidification and tuna

Larval survival

Yolk-sac stage

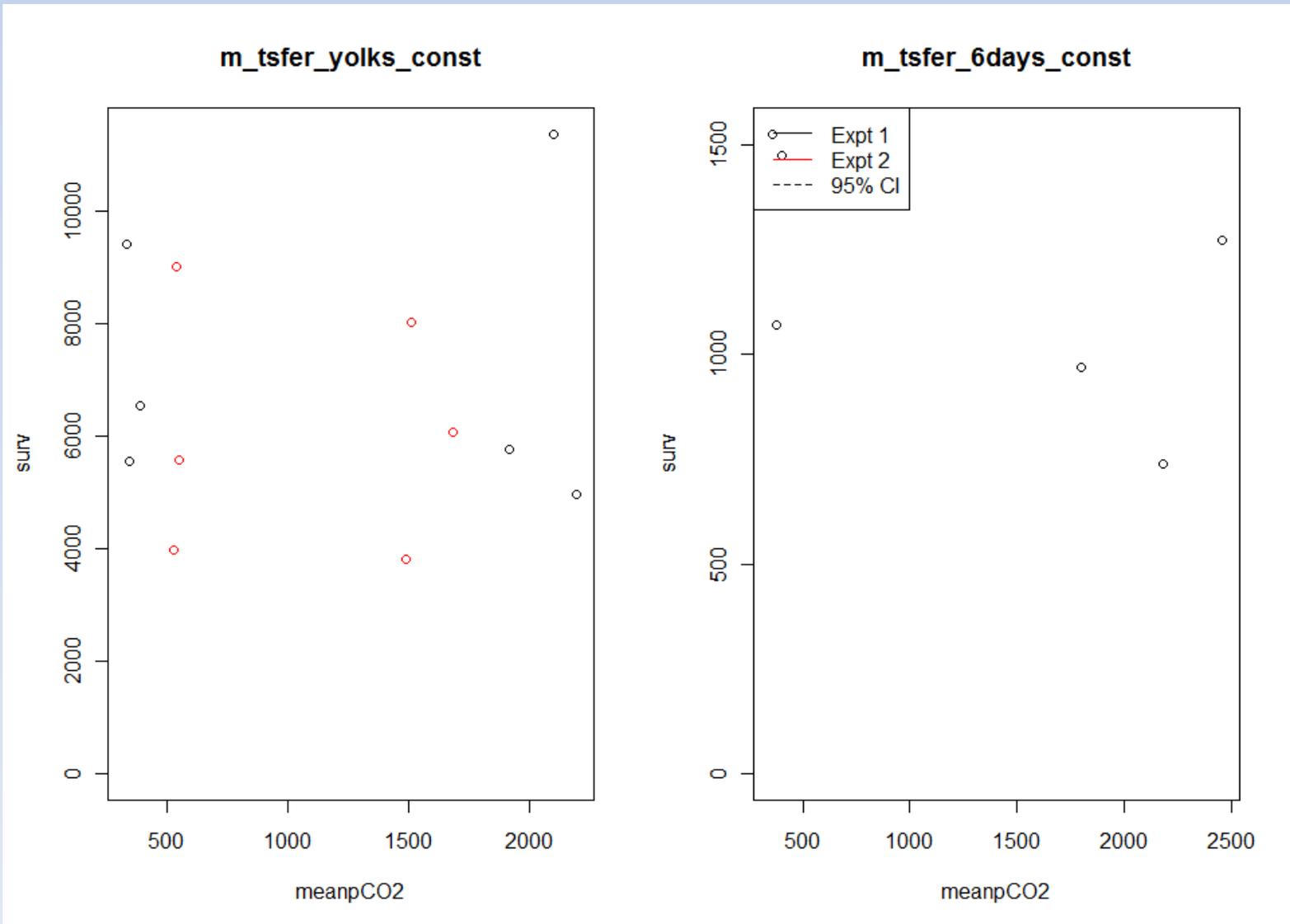


6 days after first feed stage

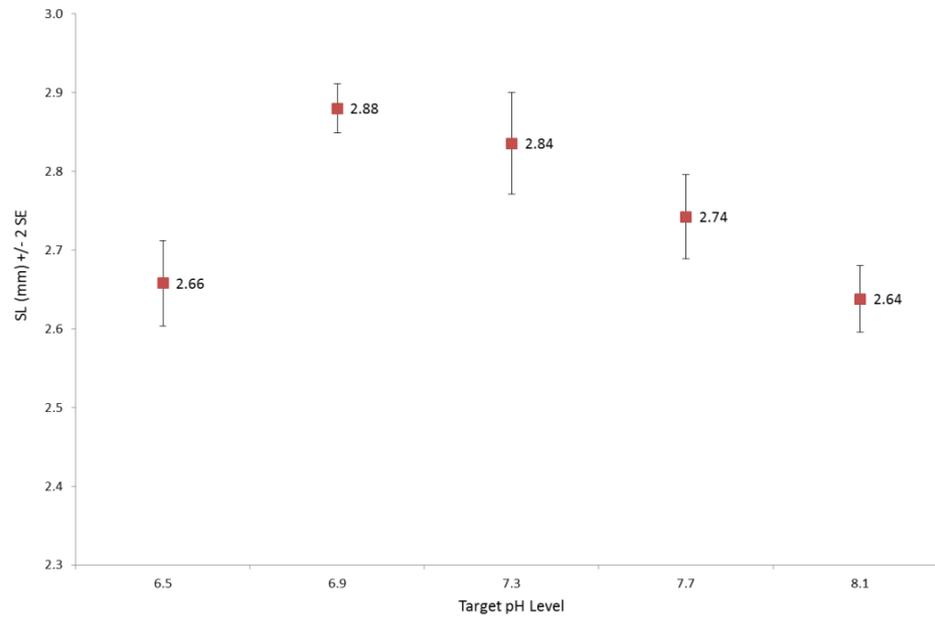


Ocean acidification and tuna

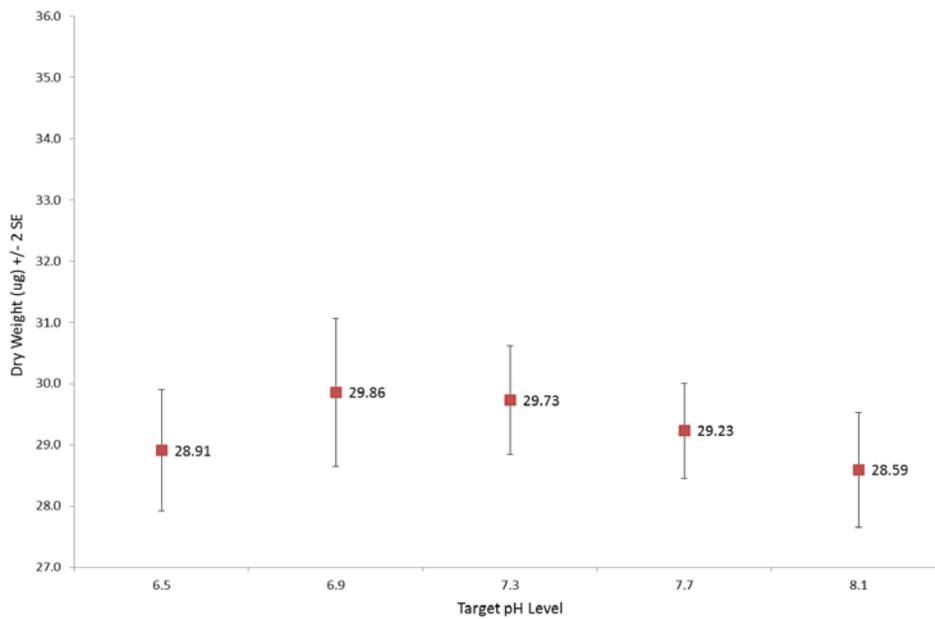
Larval survival

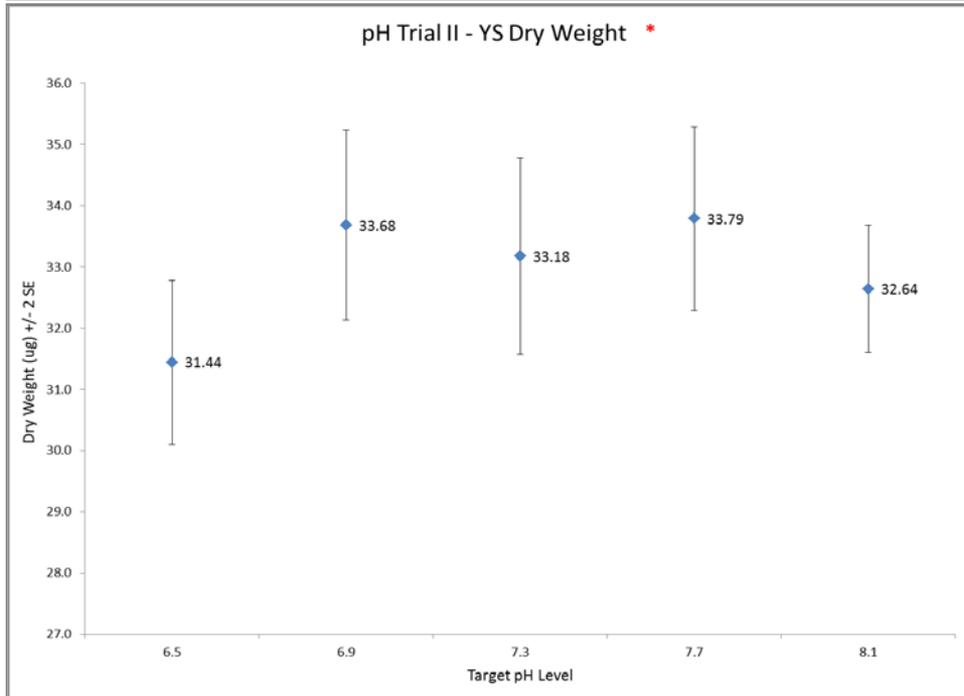
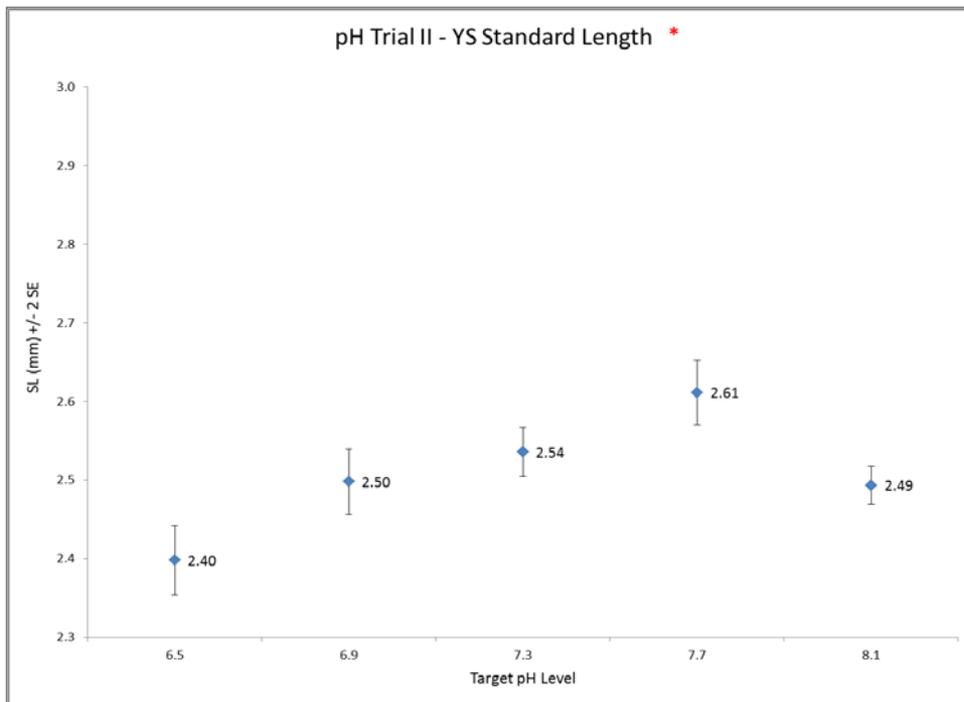


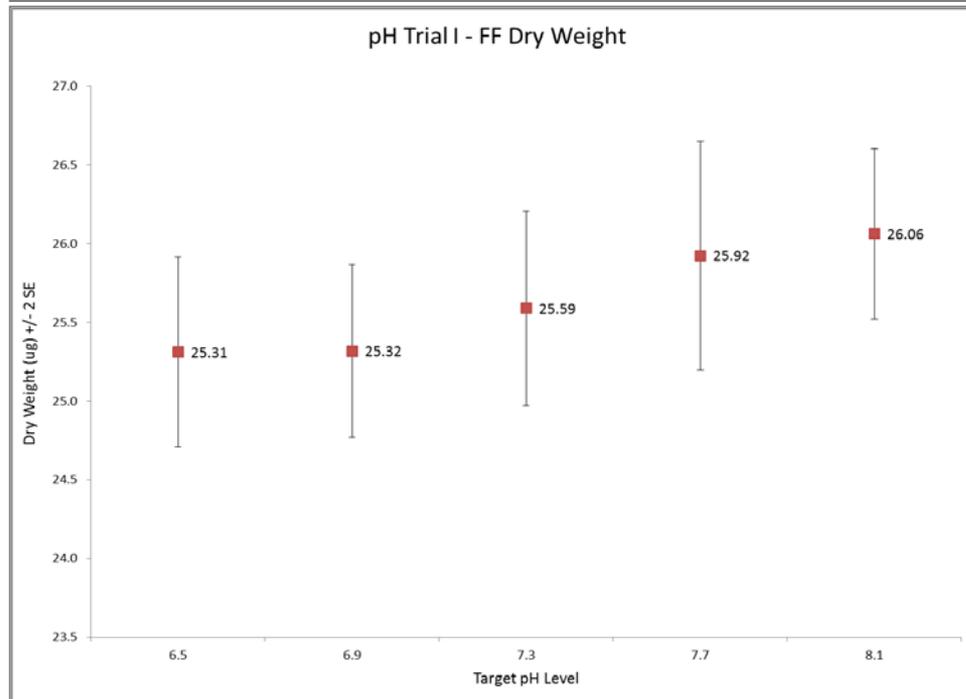
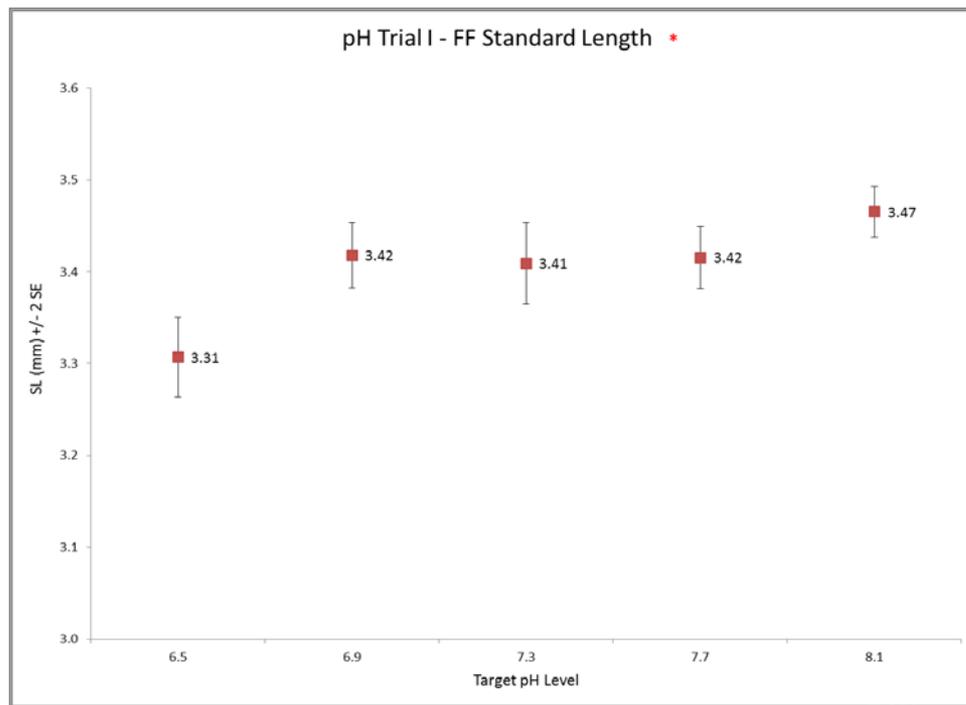
pH Trial I - YS Standard Length *



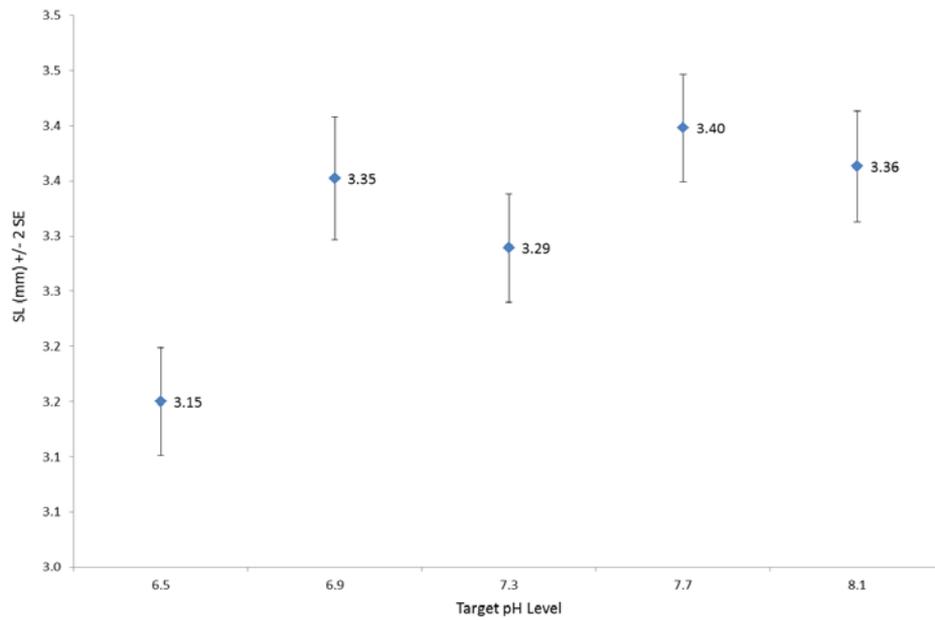
pH Trial I - YS Dry Weight



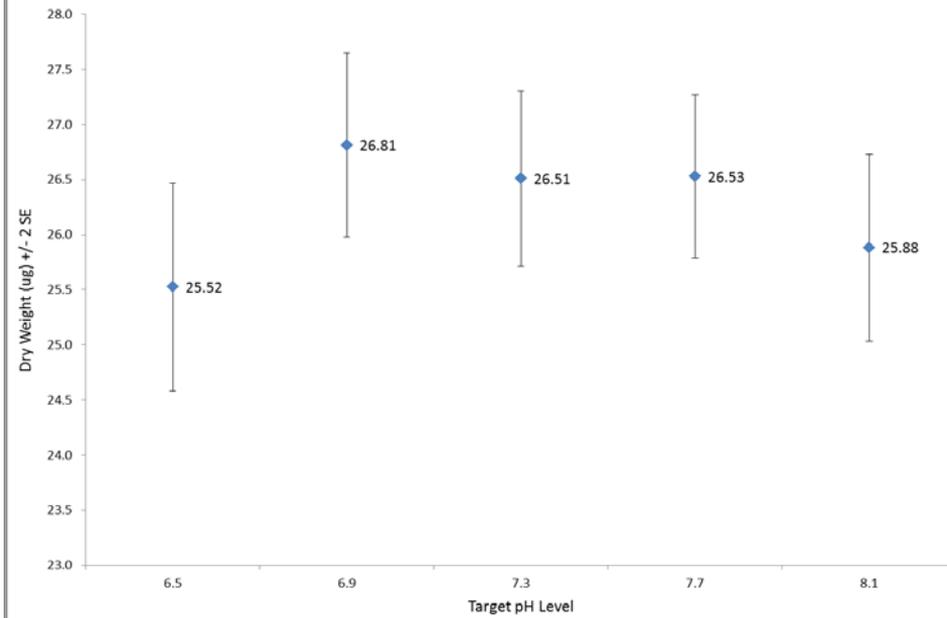




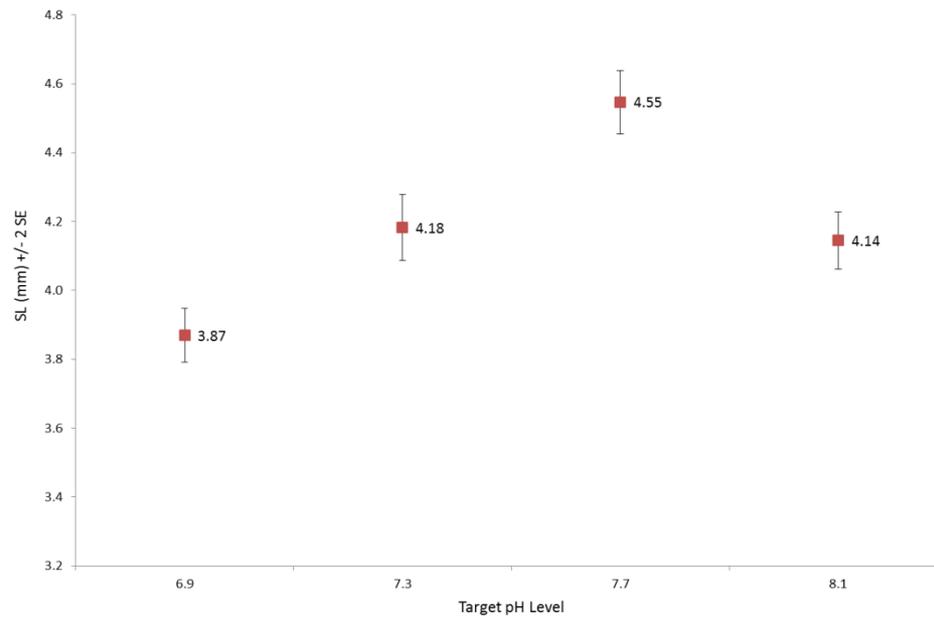
pH Trial II - FF Standard Length



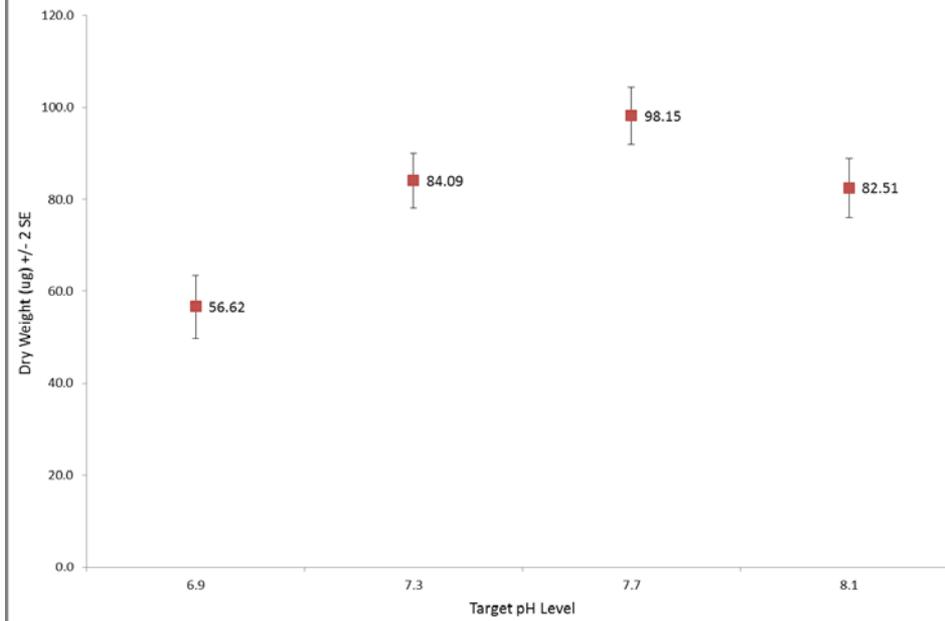
pH Trial II - FF Dry Weight

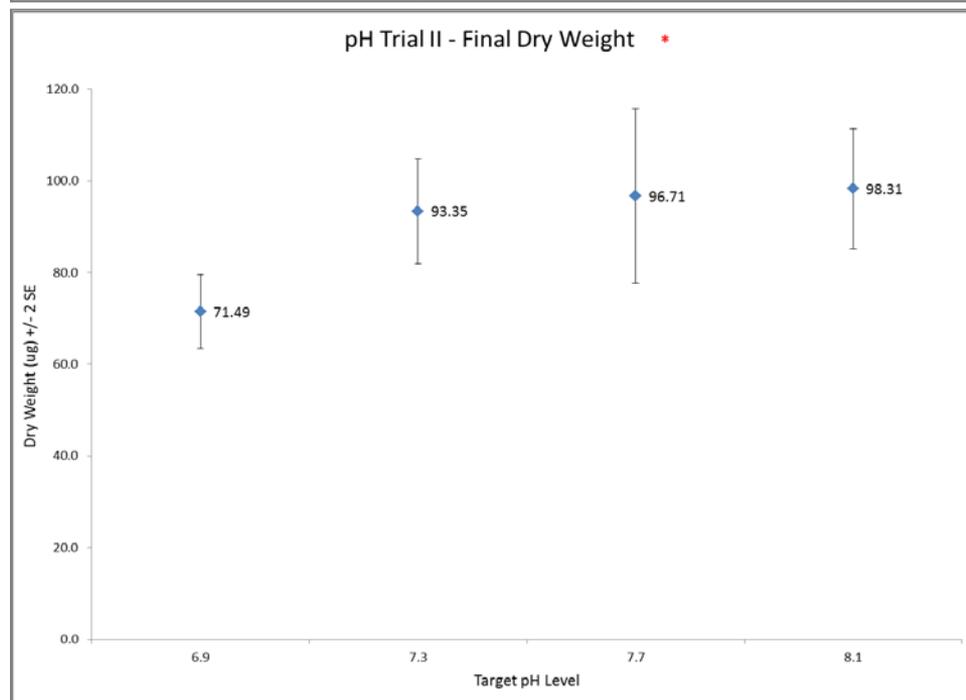
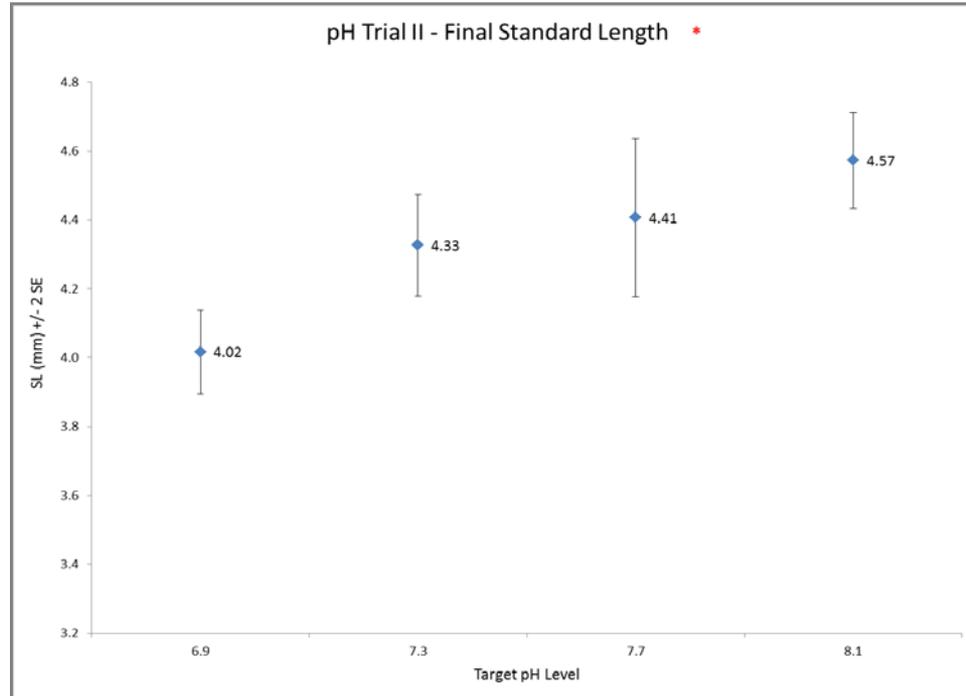


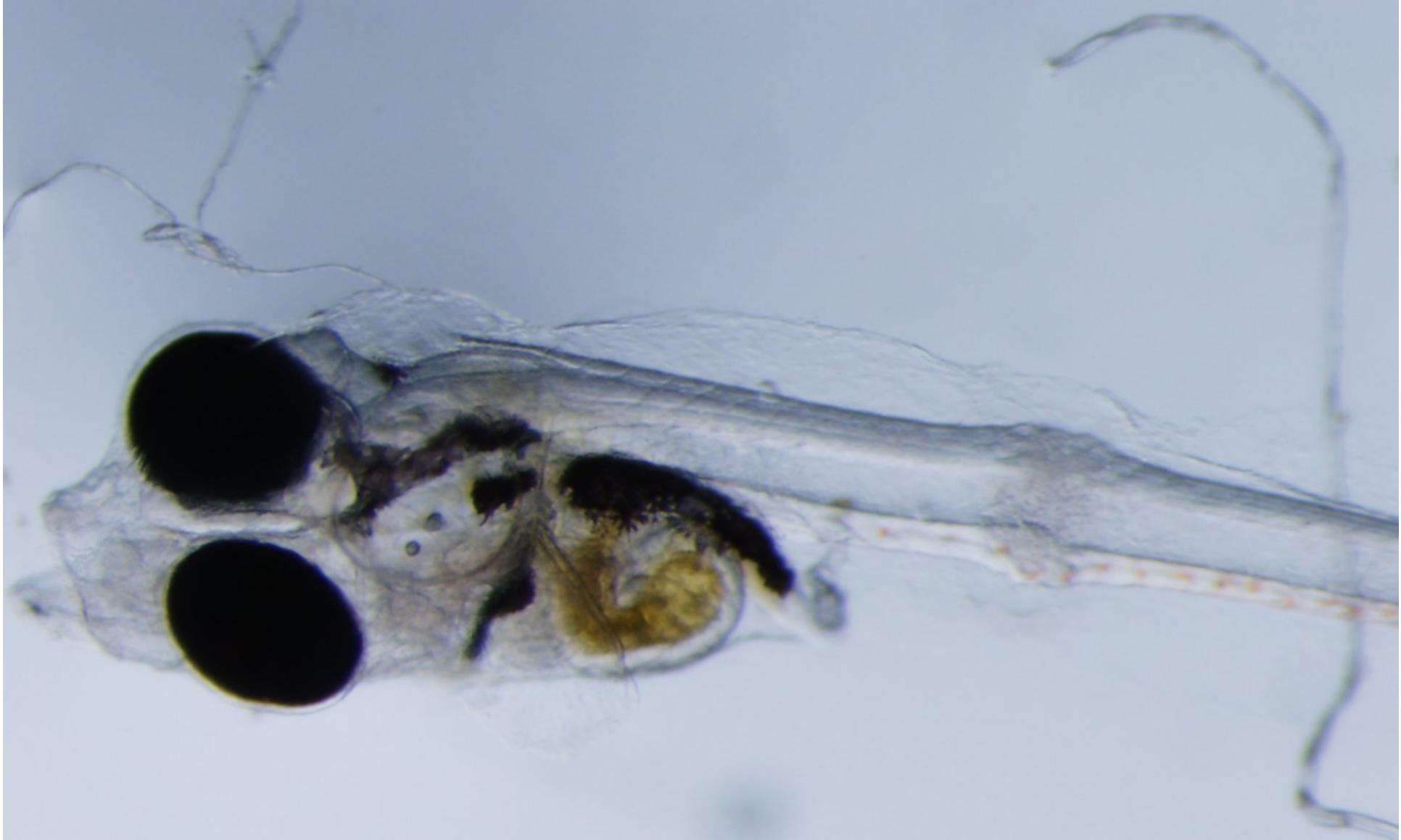
pH Trial I - Final Standard Length *



pH Trial I - Final Dry Weight *







Vertebral deformation observed at pH 7.3 and
7.7. Photo Jeanne Wexler

1 mm

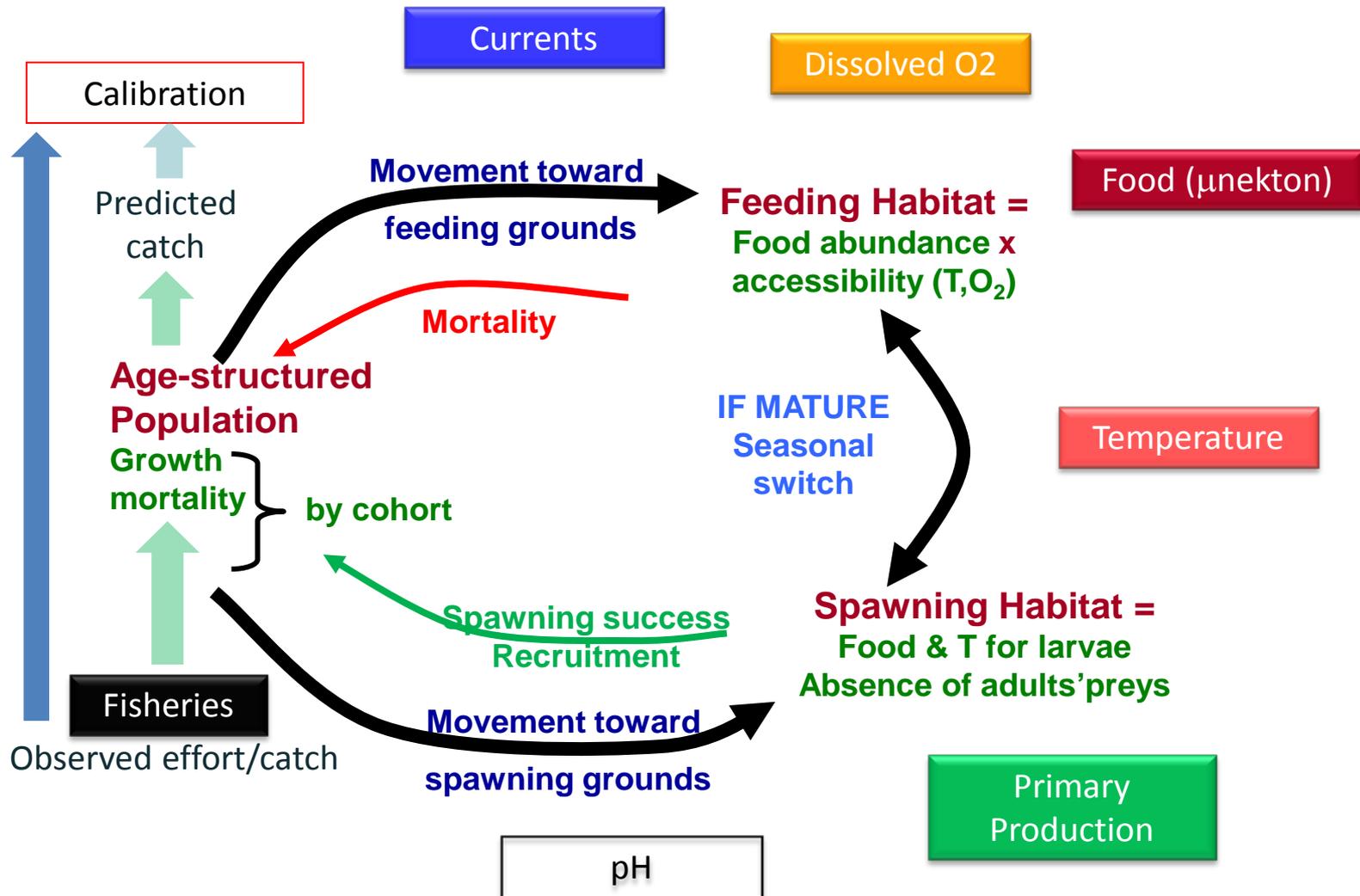
Ongoing Activities

- Histological Sample Processing and Analysis
- Final Data Analysis
- SEAPODYM modeling

Ecosystem Modeling

SEAPOODYM: Spatial Ecosystem And Populations Dynamics Model

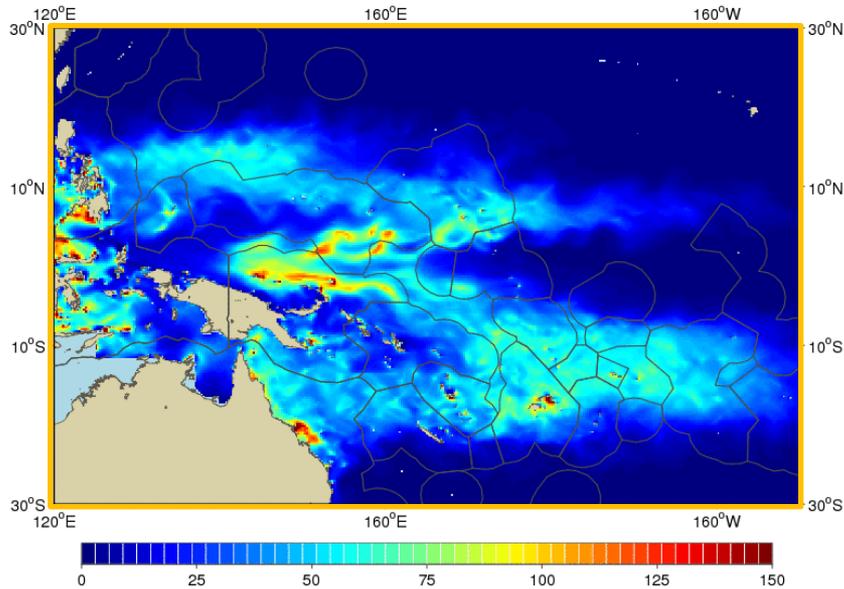
Modeling the interaction of oceanic variables and fishing impact with tuna biology and population dynamics (Lehodey et al 2008; Senina et al 2008; Lehodey et al 2010)



Projected change in Skipjack reproductive success

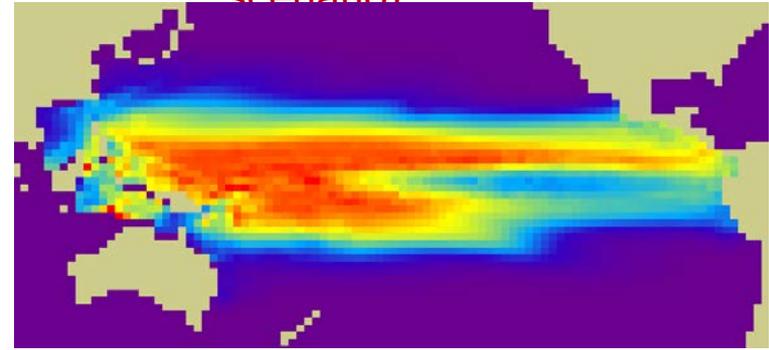
Operational model at $\frac{1}{4}^\circ \times$ week
with data assimilation

Skipjack tuna larvae, 2/2011

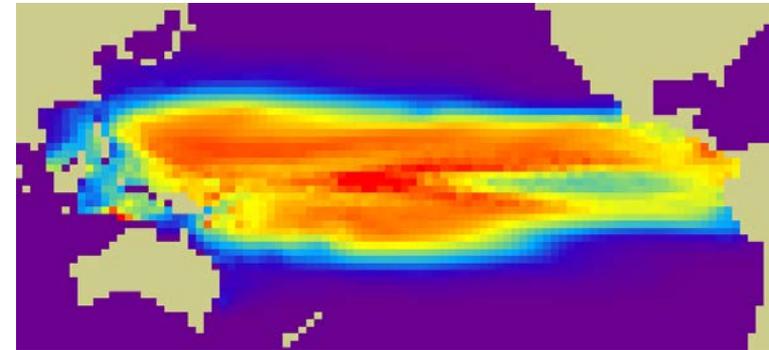


Projection of Skipjack Larvae density (A2 scenario)

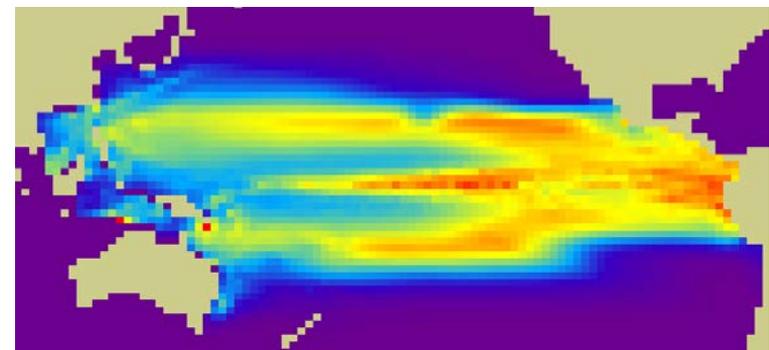
2000



2050



2099



The predictions of spawning habitat and larvae dynamics rely on optimal temperature for growth, density of both food and predators of larvae, circulation and density of adults. There is not yet pH effect.

Ocean acidification and tuna

The tuna OA trials represented the very first time the implications of OA have been experimentally tested on tuna species

From a technical and logistical perspective, the project was very challenging and some difficulties were encountered. Most of these were overcome through the development of novel techniques, while other problems led to ideas for improving experimental designs in the future.

The current trials represent the first step in investigating the impact of ocean acidification upon tuna resources of the Pacific Ocean.

It is our intention to pursue funding to further this work in the near future, to develop our understanding of the biological effects and to then apply these within predictive population models such as SEAPODYM.

Ocean acidification and tuna

Phase II Trials

- Concentrate on higher sample numbers and increased replicates from a restricted pCO₂ range
- Further investigations of impacts on sperm and egg fertilisation rates
- Look at interacting factors
 - * Temperature and pCO₂
 - * Food availability and pCO₂
- Larval behavior studies
- Dry Season (pH 7.8) and wet season (pH 8.2) trials to see if broodstock tuna/eggs/larvae adapt to shifts

ACKNOWLEDGEMENTS

- Pelagic Fisheries Research Program (PFRP)
- Staff of IATTC Ashotines Laboratory
- Integrated Aqua Systems, Inc.