FIELD AND LABORATORY STUDIES OF PTEROPOD ECOLOGY AND PHYSIOLOGY IN RELATION TO NATURAL VARIABILITY IN CARBONATE CHEMISTRY

Gareth Lawson

Woods Hole Oceanographic Institution

Woods Hole Oceanographic Institution

OA PI Meeting – June 9, 2015

The Pteam

WHOI Collaborators


Aleck Wang


Peter Wiebe


Andone Lavery


Ann Tarrant


Houshuo Jiang


Veronique Le Roux

Former Postdocs

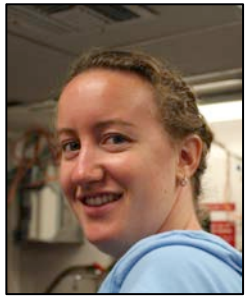

Amy Maas


Leo Blanco Bercial


Kakani Young

Technicians


Nancy Copley


Katherine Hoering

Graduate Students


Alex Bergan
WHOI-MIT


Sophie Chu
WHOI-MIT


Ali Thabet
Al-Azhar University

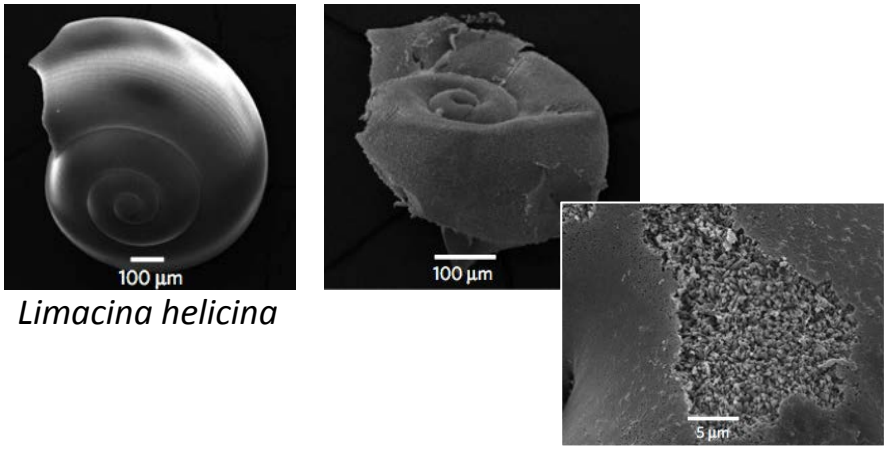
Undergrad Students


Shannon Crosby
DePauw University

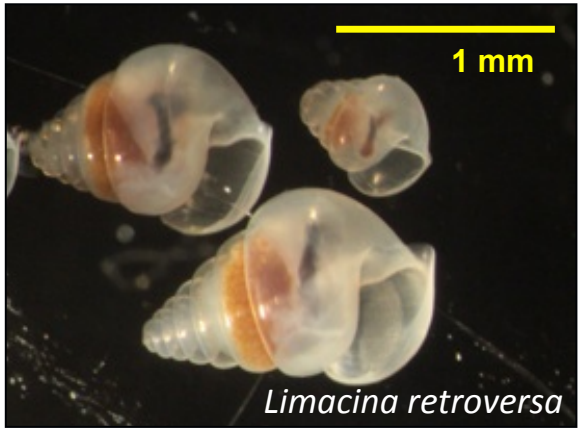

Camille Pagniello
Dalhousie University

Thecosomatous Pteropods

- Aragonitic shell-forming planktonic gastropods
- Important to biogeochemistry and as prey item for many commercial fish (e.g., salmon)
- Lab and field studies have shown shell dissolution in response to under-saturation (Ω_A<1)



Limacina helicina

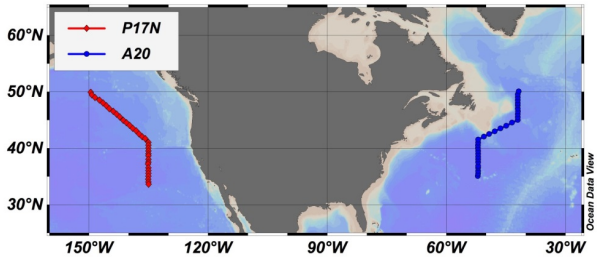


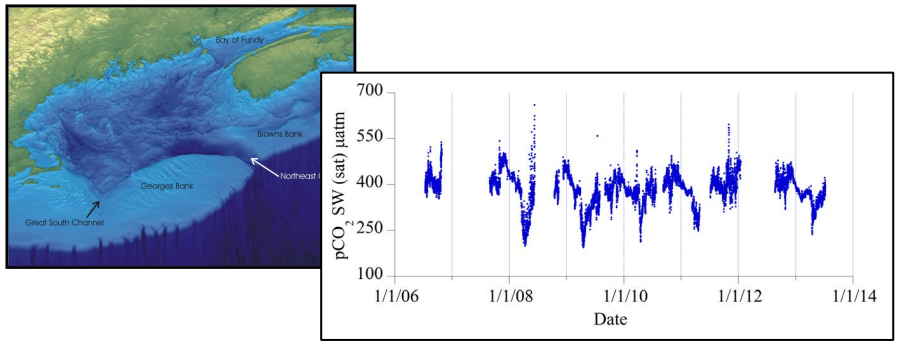
Overall Approach

- Combine field studies with shipboard and lab experiments
- Capitalize on natural variability in carbonate chemistry (spatial and seasonal) as natural experiments
- Goals are to gain improved understanding of thecosomatous pteropod biology in order to understand potential response to OA

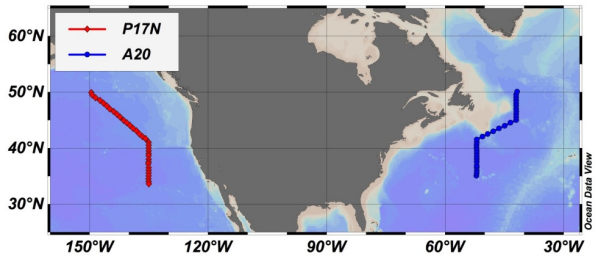
SHIPS!

LAB!

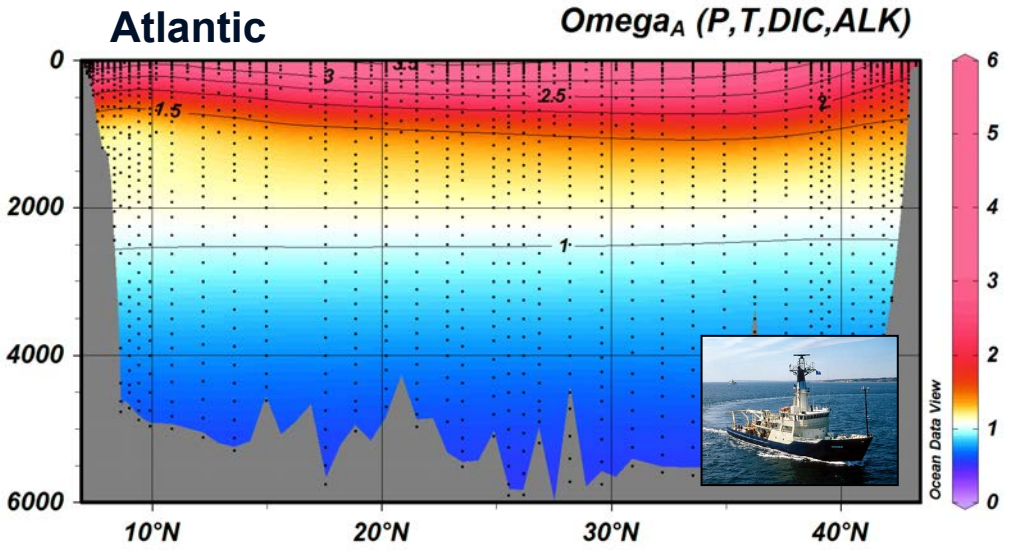


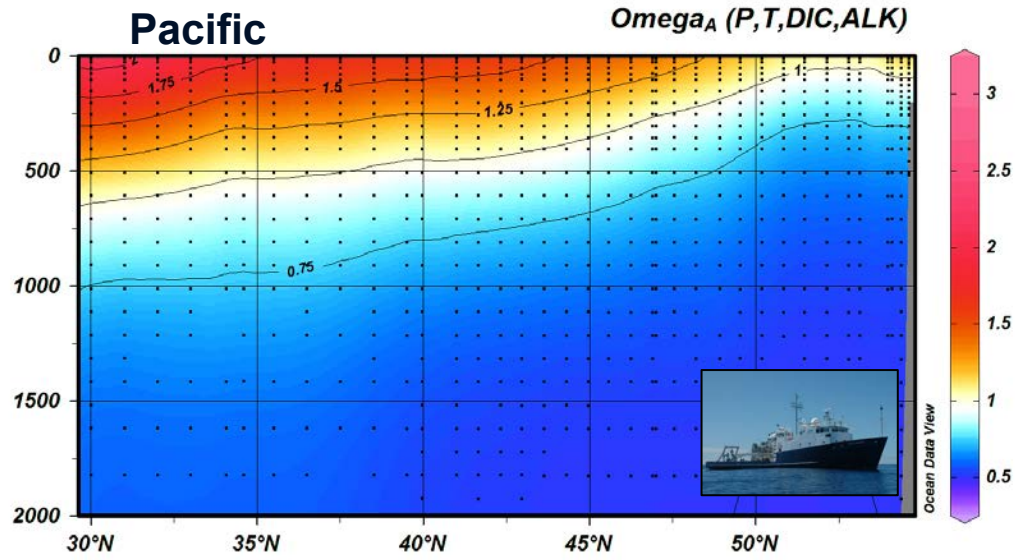


Ocean Acidification Pteropod Study (OAPS)



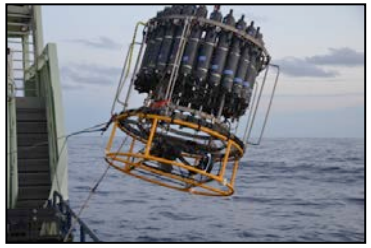
- Differences exist between and within the modern-day Atlantic and Pacific Oceans in the Aragonite Compensation Depth (ACD)
- Goal is to examine:
  - Carbonate chemistry
  - Natural distribution, behavior (including DVM), species diversity, shell condition
  - Physiology (metabolism and gene expression)
- Open-ocean cruises in August of 2011 (Atlantic) and 2012 (Pacific)

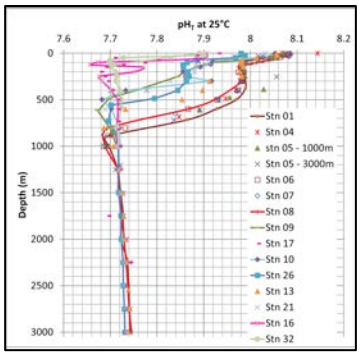




Sampling Methods

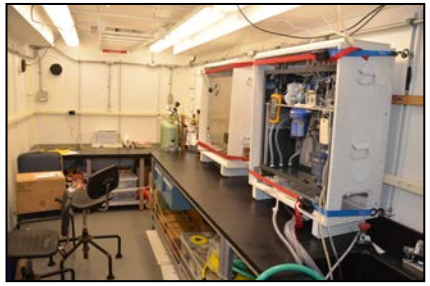
- CTD to characterize physical environment (to 1000-3000m)
- Niskin bottle sampling to measure pH, DIC, alkalinity, nutrients, salinity
- Depth-stratified net system and Video Plankton Recorder to sample directly the zooplankton (to 1000m)
- On-board CO_2 exposure experiments of animals sampled by Reeve net

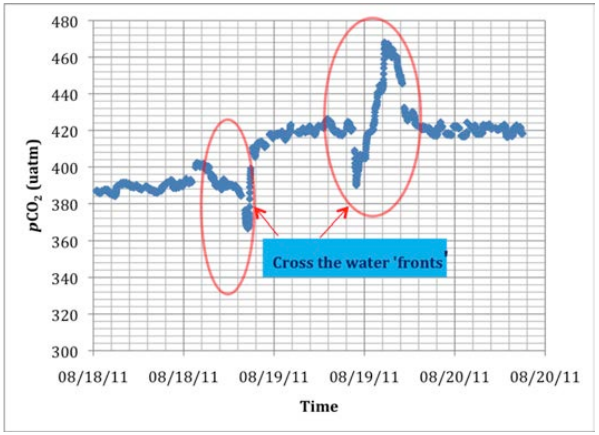


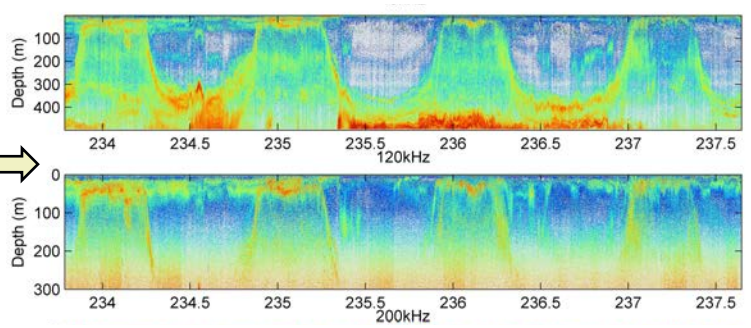


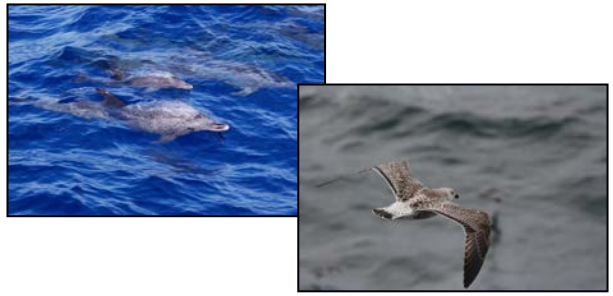
Underway Sampling

- Measurements of surface sea water fCO_2, DIC, pH, and air pCO_2
- Multi-frequency and broadband echosounders to map the zooplankton and fish scattering
- Visual surveys for surface-associated predators (seabirds, marine mammals, large fish)



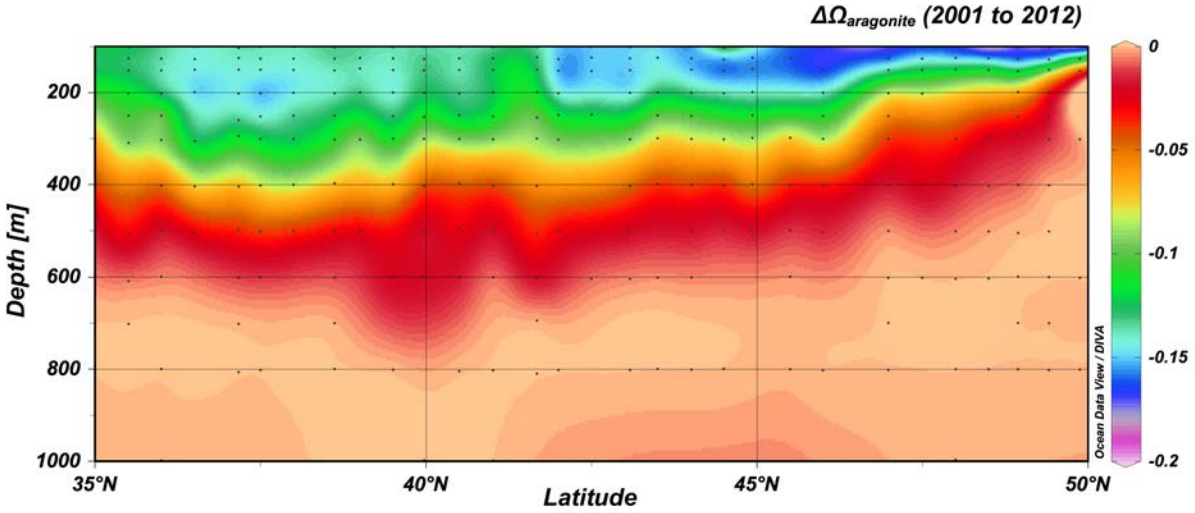


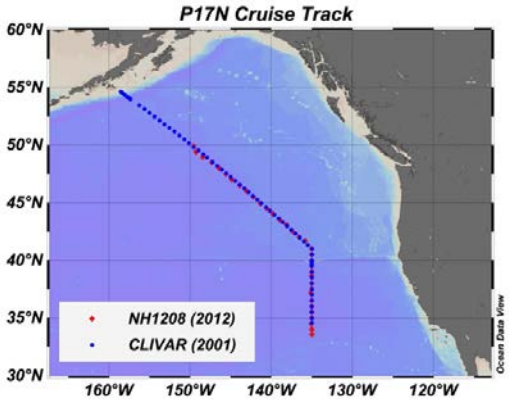


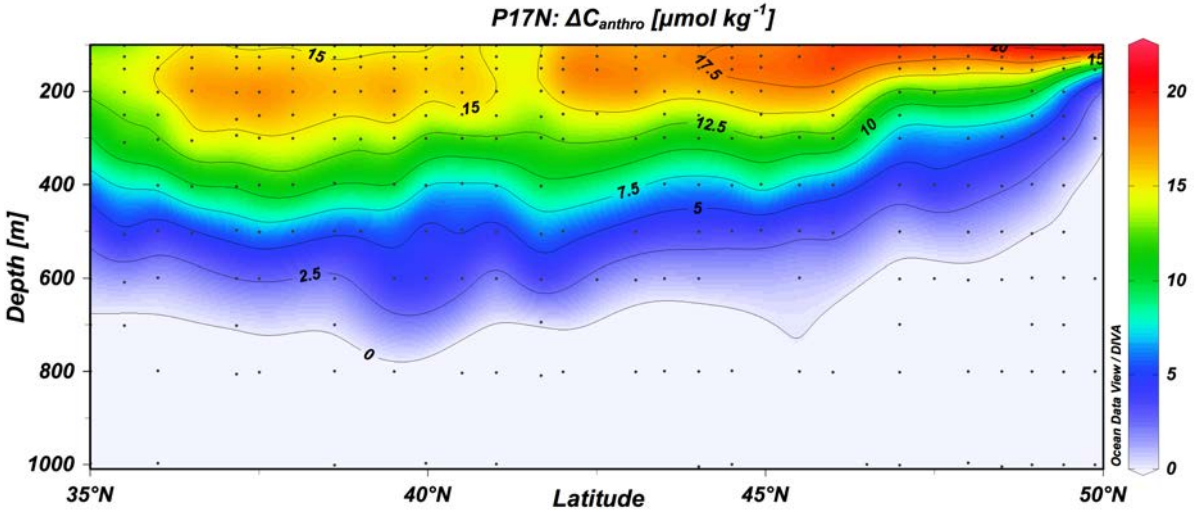


Pacific Carbonate Chemistry

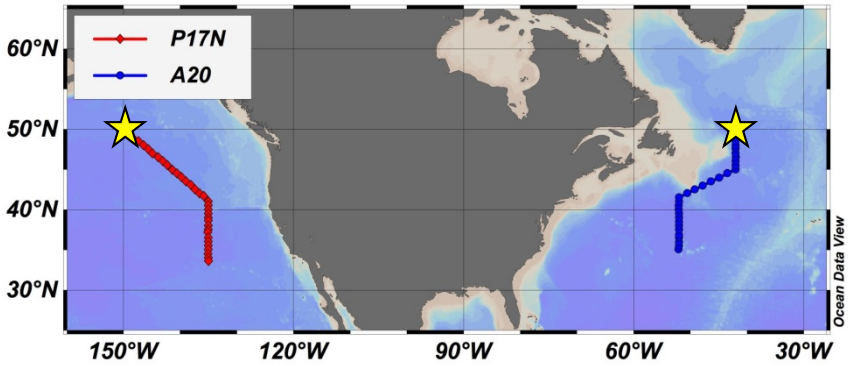
- Decrease in pH since 2001, the last time CLIVAR/WOCE line P17N was occupied
- Shoaling of aragonite saturation state contours

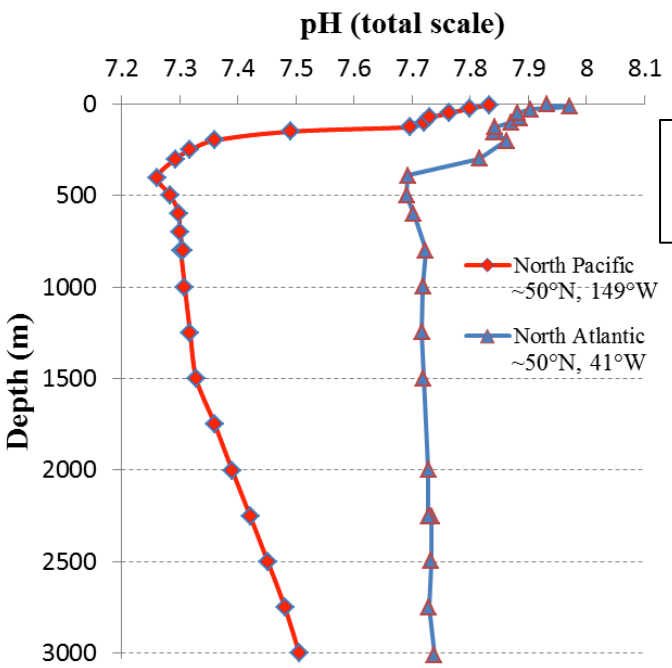


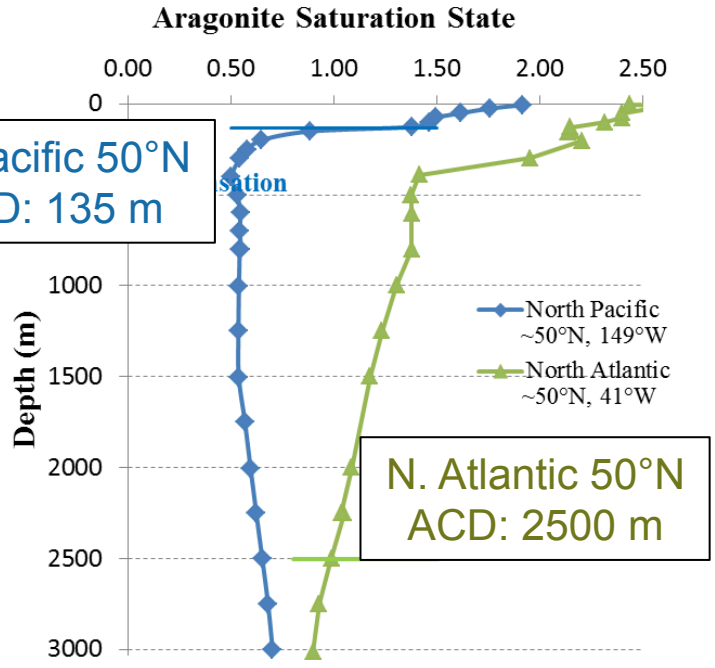




Natural Experiment



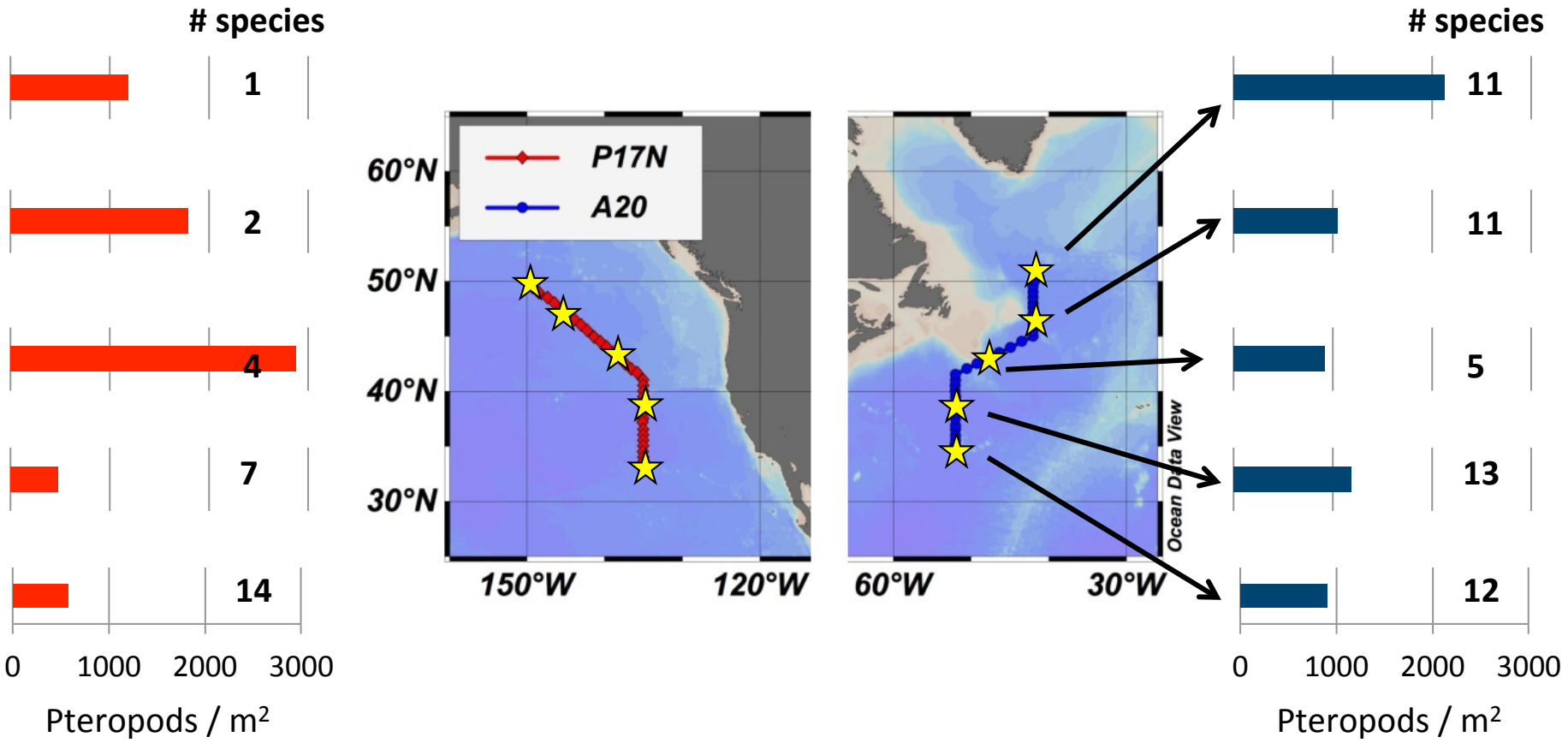




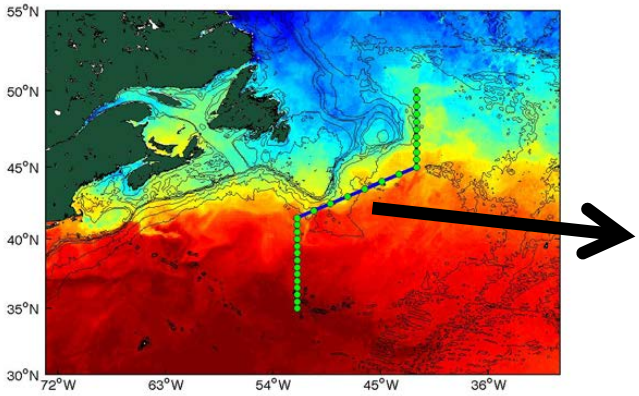
N. Pacific 50°N
ACD: 135 m

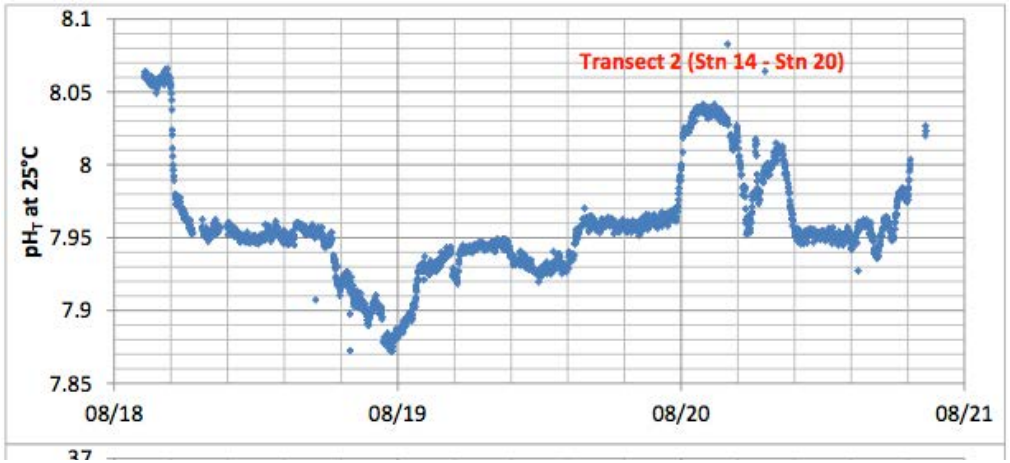
N. Atlantic 50°N
ACD: 2500 m

Diversity and Abundance

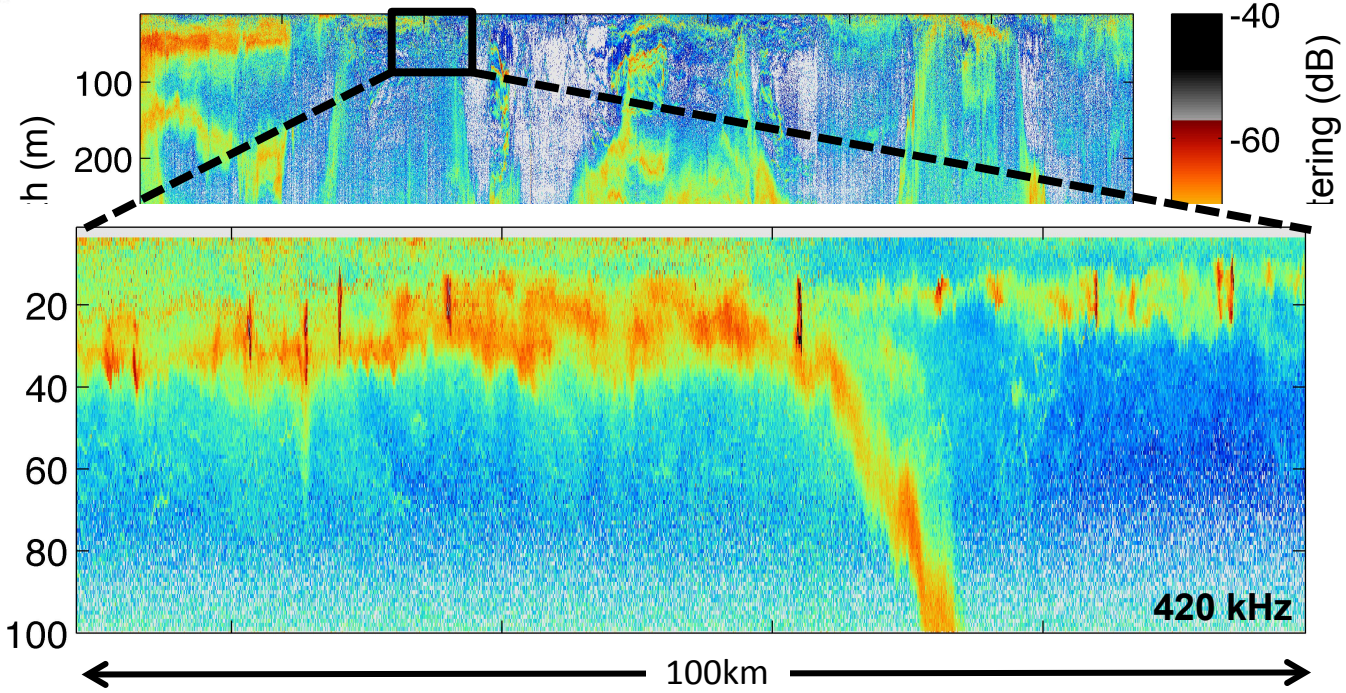


Acoustic Observations of Pteropod Swarms

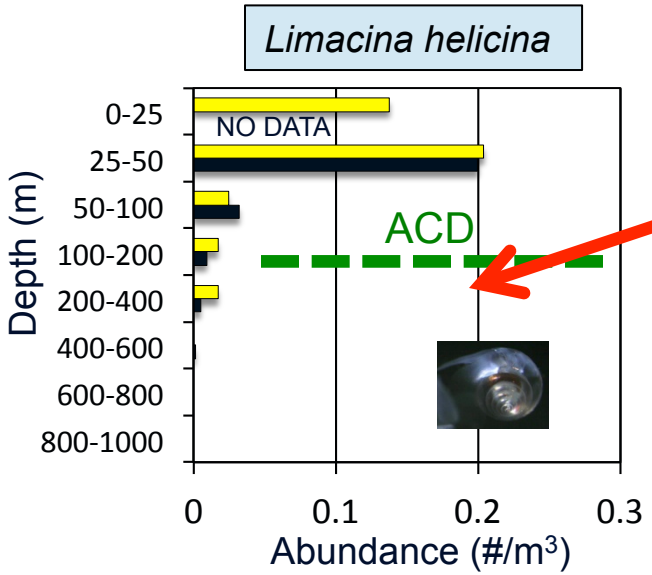


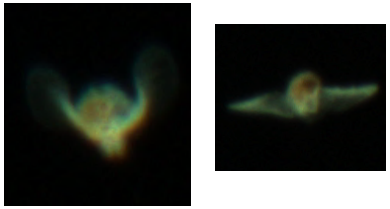


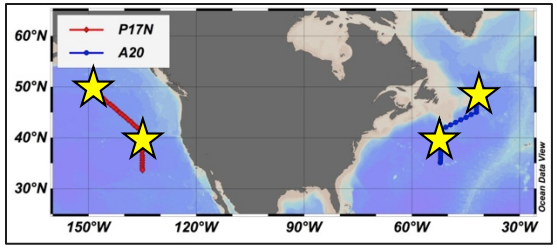
- Tongue of low salinity waters off the Grand Banks
- Dense swarms of *Limacina retroversa* on average 630 m in extent, 7.9km apart, mean densities of ca. 3000 inds.m^{-3}

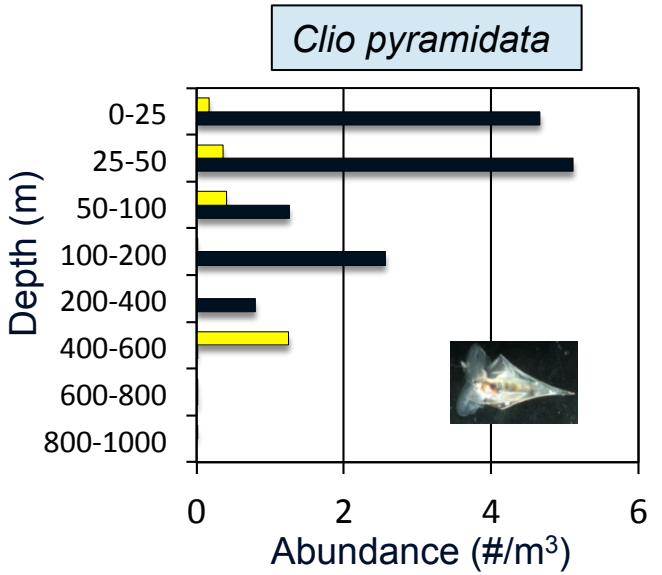


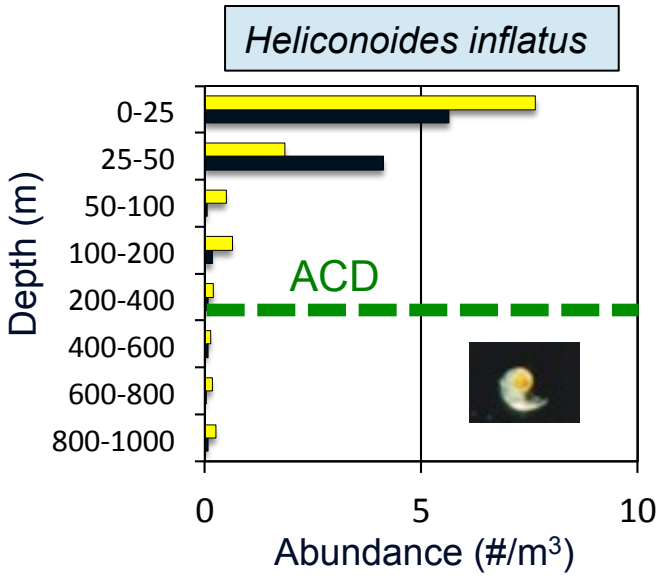
Vertical Distribution

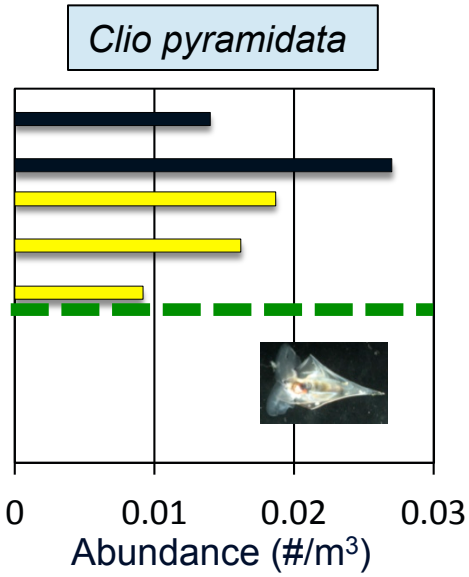


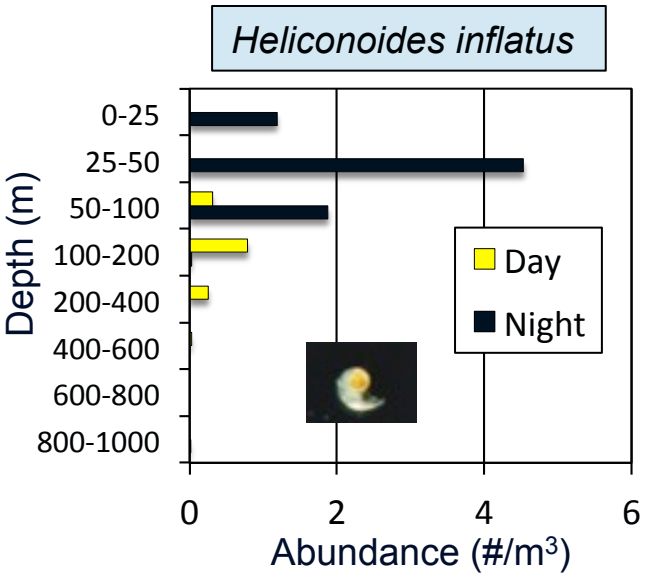




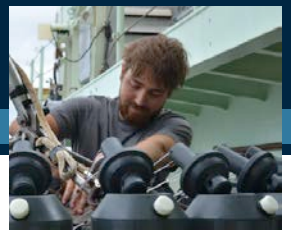








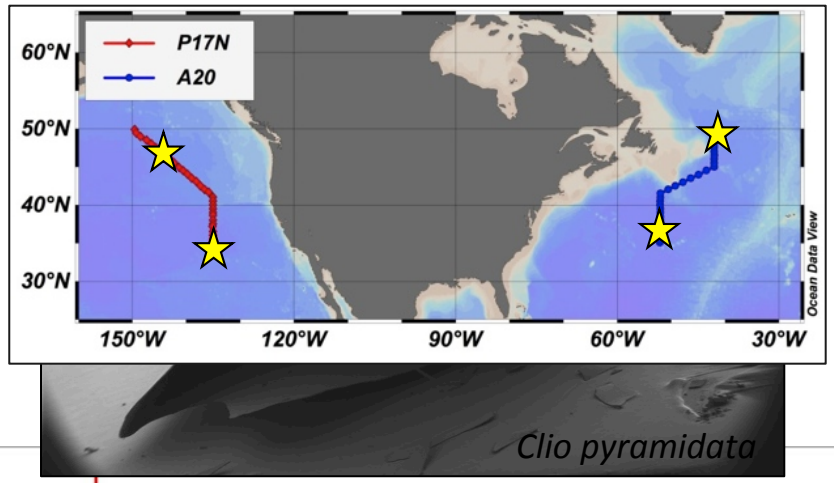
Shell Condition

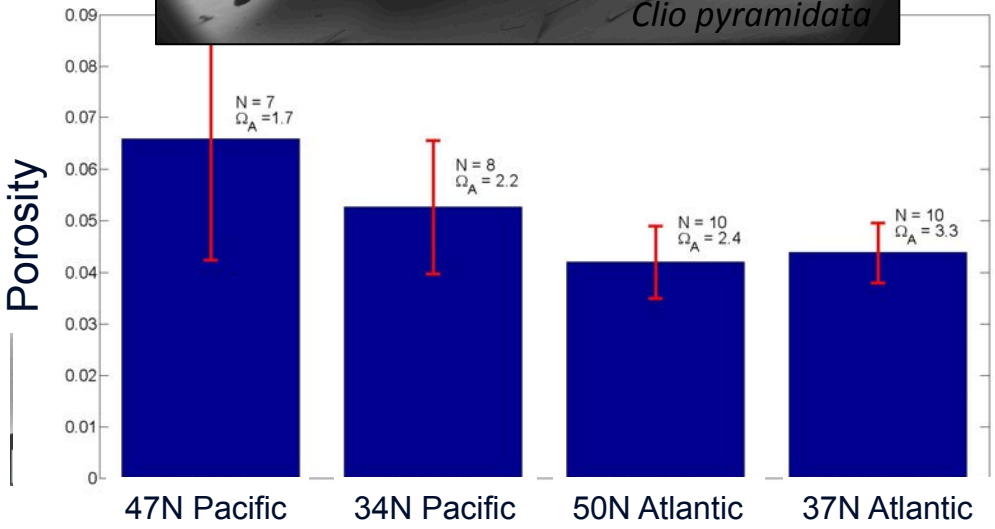


Alexander Bergan
PhD Student

Scanning Electron Microscopy

- Used to measure "porosity" and thickness of leading edge
- Differences in the porosity of the adult shell of *Clio pyramdiata* between regions but not significant

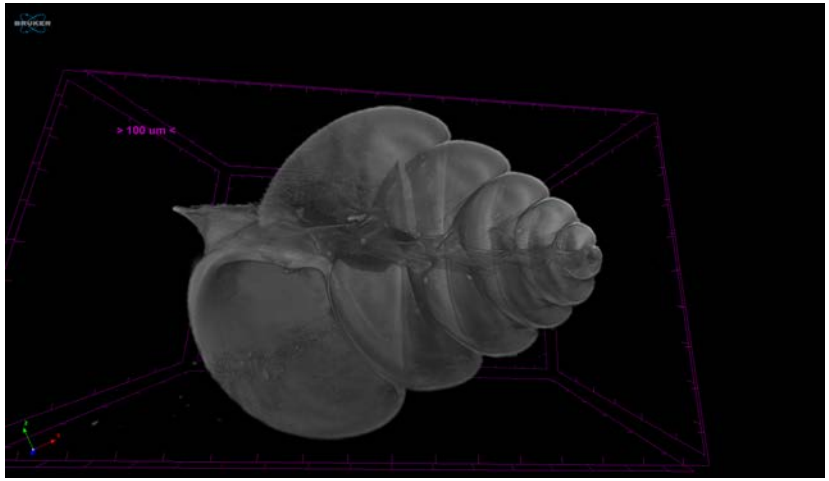


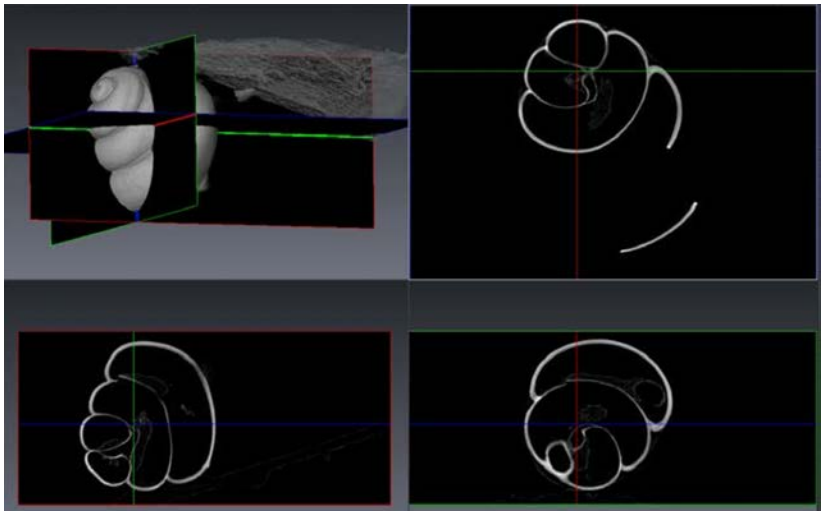


Shell Condition

Micro CT

- X-ray micro computed tomography shows inner structure at fine resolution (<1µm)
- Developing methods for quantifying shell thickness and density





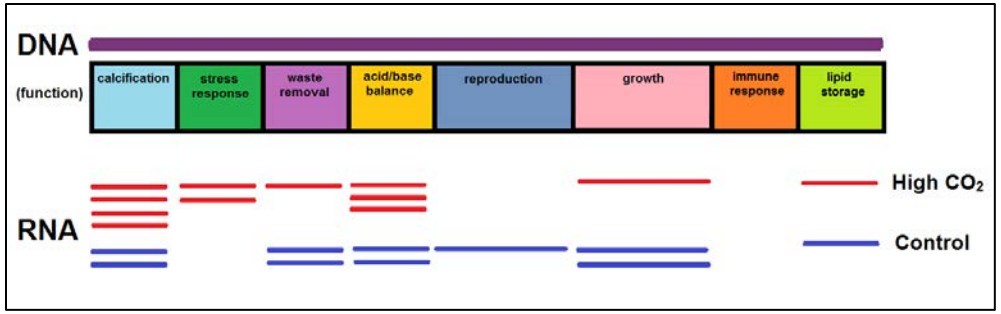
Physiology

Dr. Amy Maas

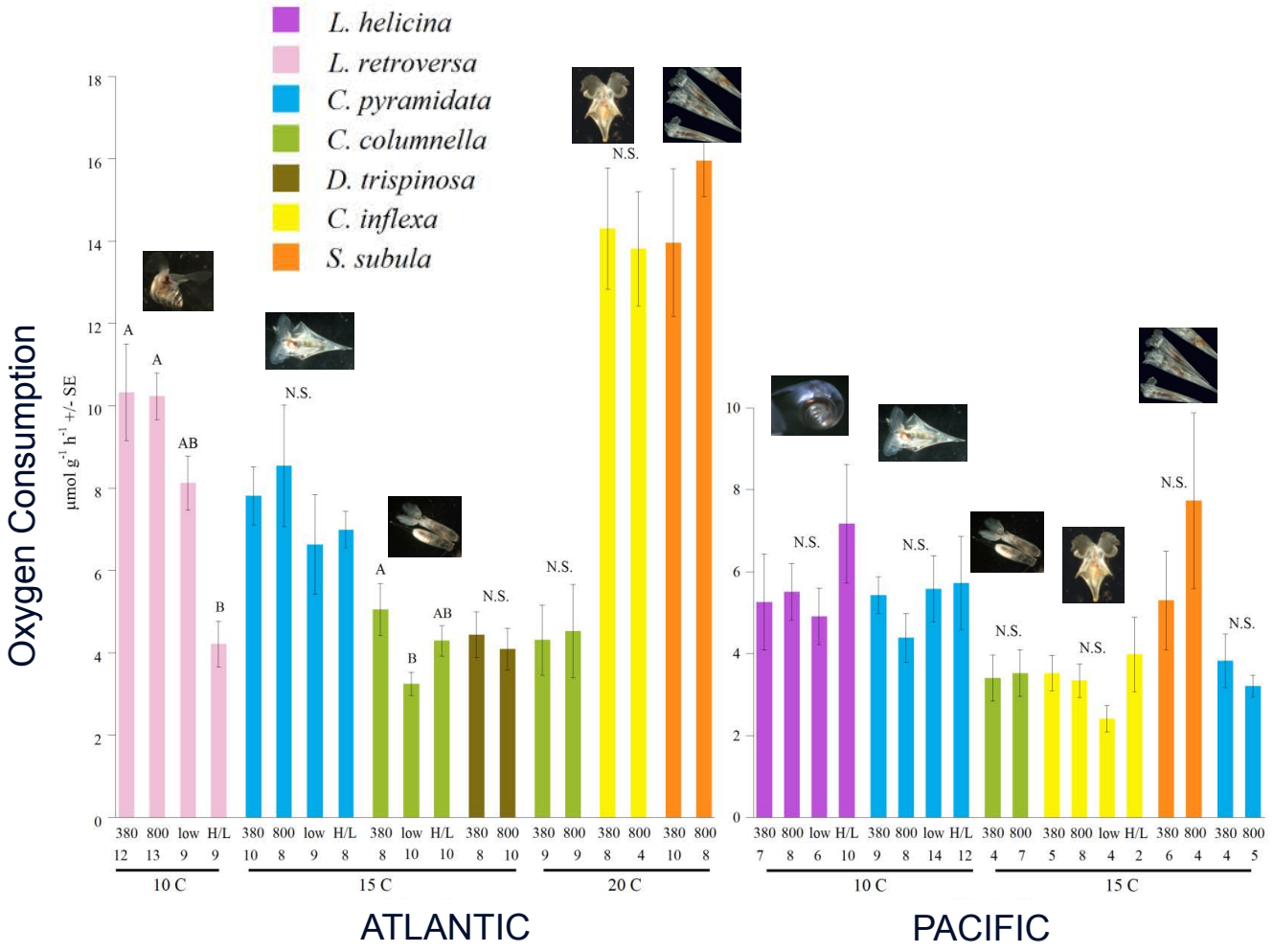
Short-term (3-18 hr) experimental exposure:
High CO_2 (400 vs. 800 PPM)
Low O_2 (21 vs. 10%)

Oxygen Consumption

Gene Expression

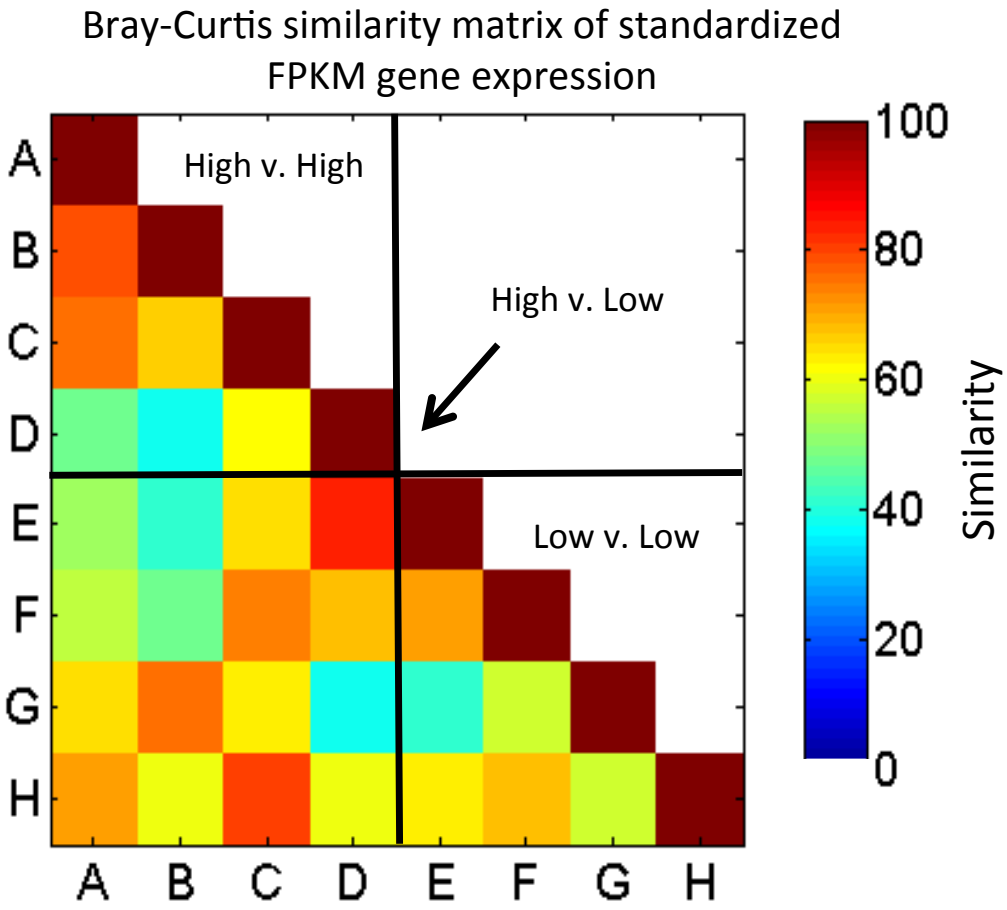


Physiology – Metabolism



- No effect of CO_2 alone on metabolism for any species in either basin
- O_2 (alone or in concert with high CO_2) only affected two Atlantic species

Physiology – Gene Expression

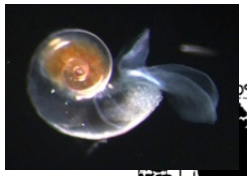


- *Clio pyramidata* transcriptome included homologs of genes with known biomineralization role in other molluscs
- High variability but some significant patterns of differential expression
- Down-regulated some genes associated with aerobic respiration in response to high CO_2
- Up-regulated some genes associated with biomineralization

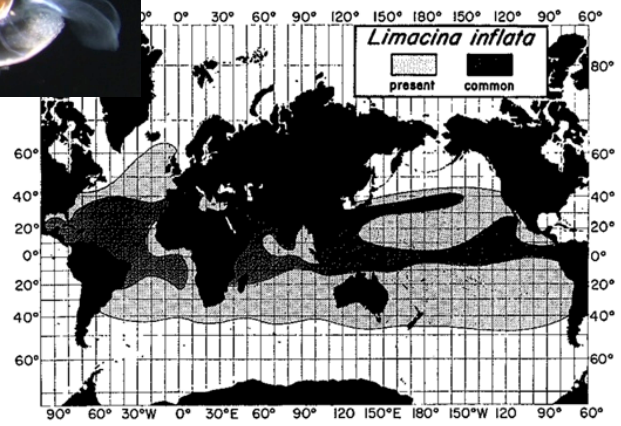
Biogeography and Taxonomy

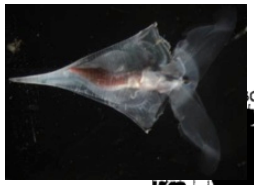
Dr. Amy Maas

Dr. Leo Blanco Bercial

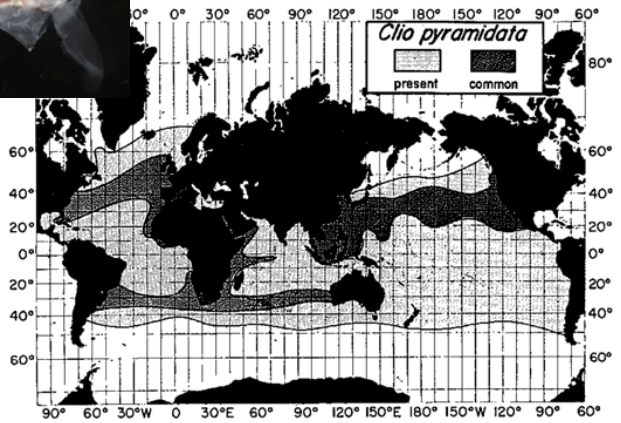


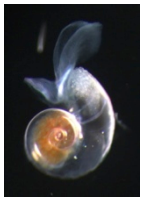
Heliconoides inflatus

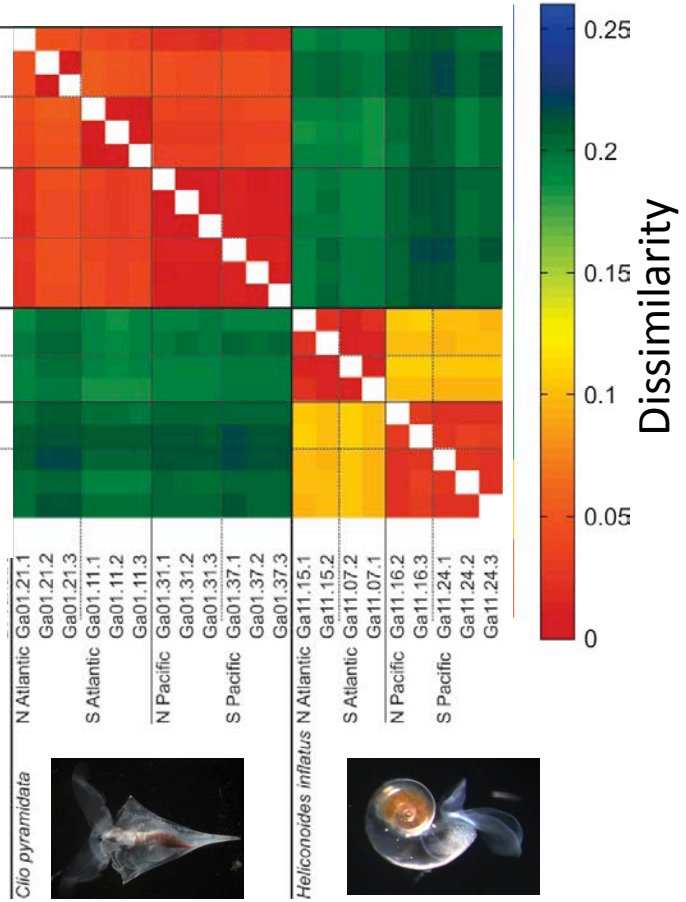




Clio pyramidata







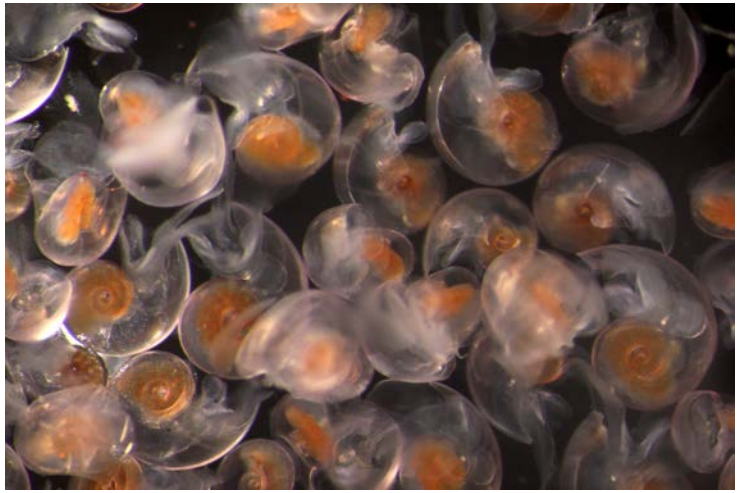
Summary

CONCLUSIONS

- Inter-disciplinary sampling and approach
- Value in natural experiments
- Variability in diel vertical migratory behavior and physiological response to high CO_2/low O_2
- Check out our posters on Gulf of Maine pteropods (acclimation, effects on early life stages and fitness)

OUTSTANDING QUESTIONS

- Trans-generational effects, adaptive capacity
- Ecosystem/foodweb effects
- Biogeochemical implications



Acknowledgements

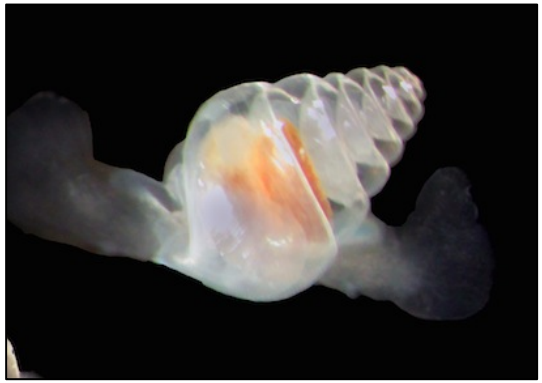
Clio polita

glawson@whoi.edu
www.whoi.edu/people/glawson
funwithkrill.blogspot.com

- **External Funding**: NSF Ocean Acidification Program
- **Internal WHOI Funding**:
  - The Grayce B. Kerr and Penzance Endowed Funds in Support of Assistant Scientists
  - Pickman Foundation
  - Coastal Ocean Institute

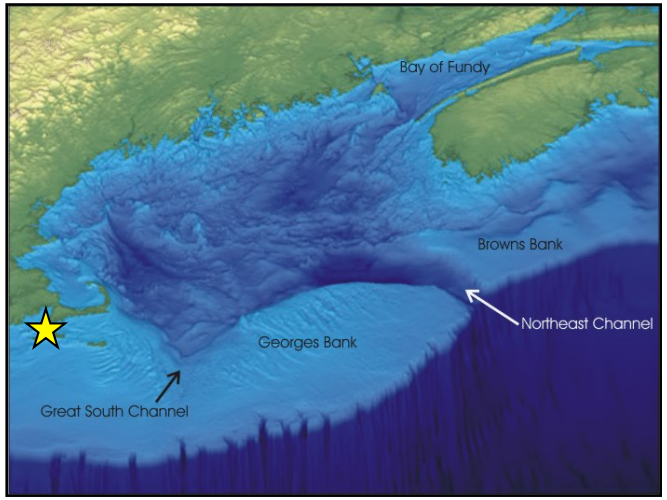
Gulf of Maine

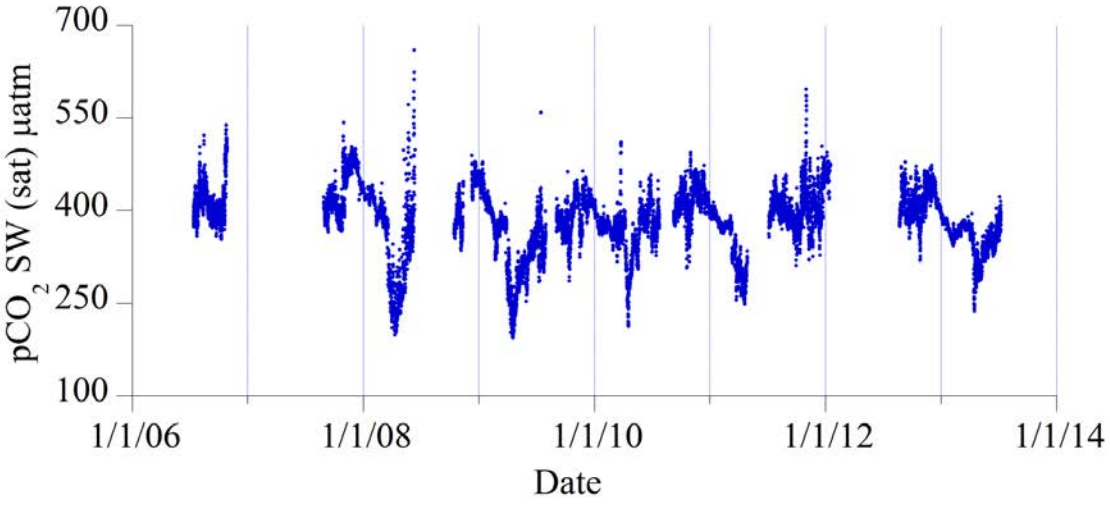
- Seasonal variability in surface conditions
- Examining carbonate chemistry through the water column
- Implications to thecosomatous pteropods and possibility for acclimation
- Using *Limacina retroversa* as a lab rat for OA studies.



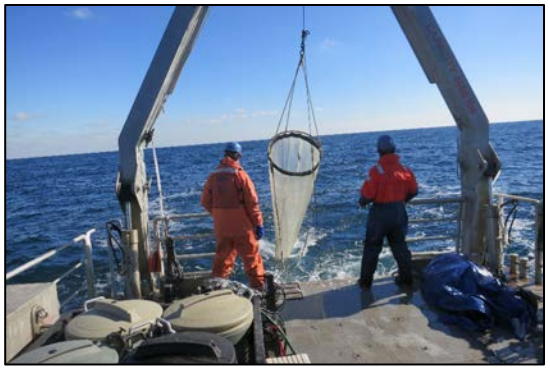
Limacina retroversa

The Gulf of Maine





Laboratory Exposure Experiments



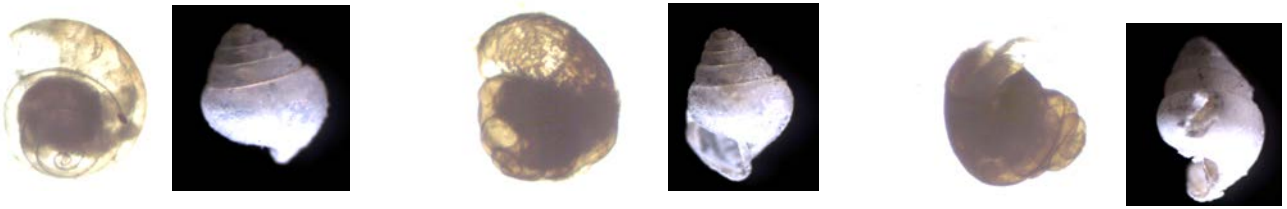
Seasonal field sampling

Ambient
400 ppm

Medium
800 ppm

High
1200 ppm

14+ day exposure to ambient (400), medium (800) and high CO_2 (1200 ppm)

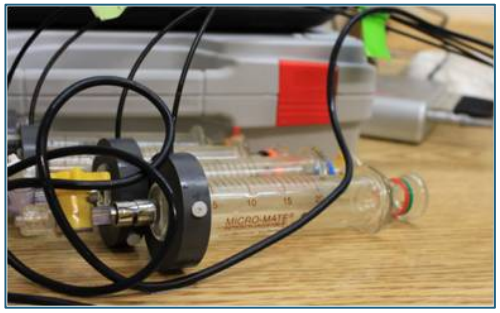


Laboratory Studies

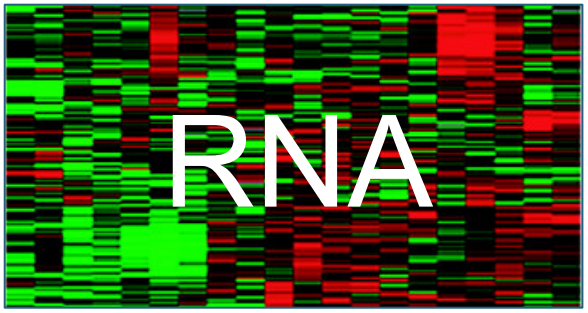
Early life stages & development

Culture Protocols

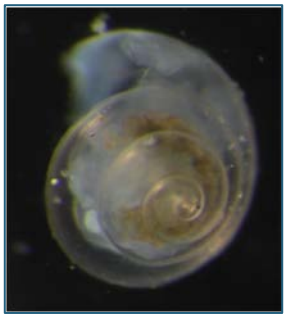
Sinking / Swimming



Respiration rates

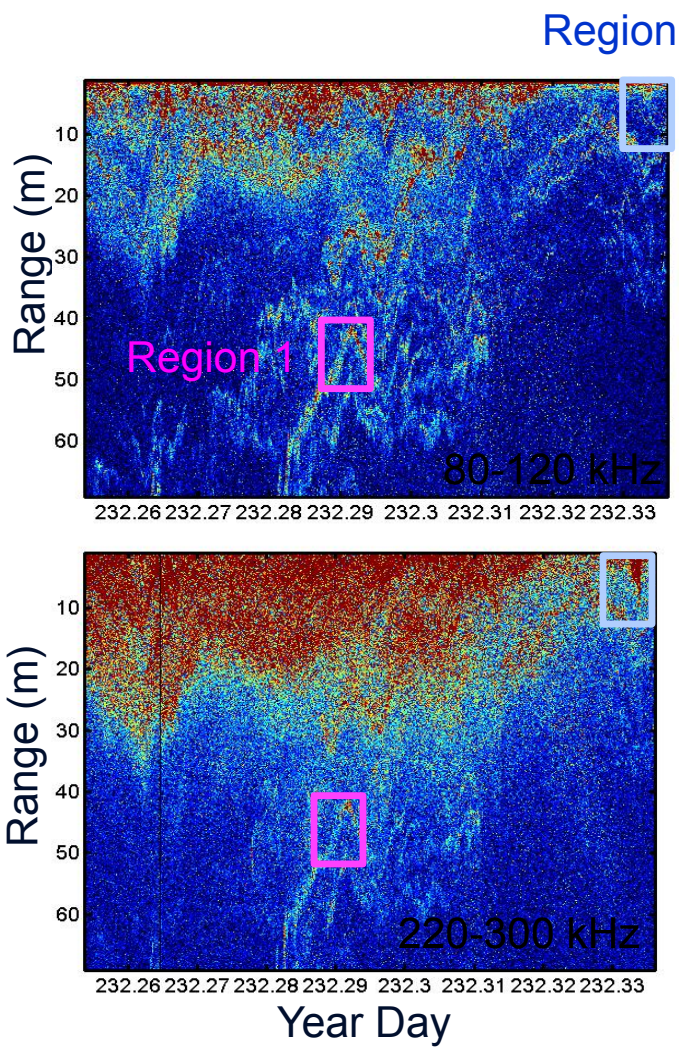


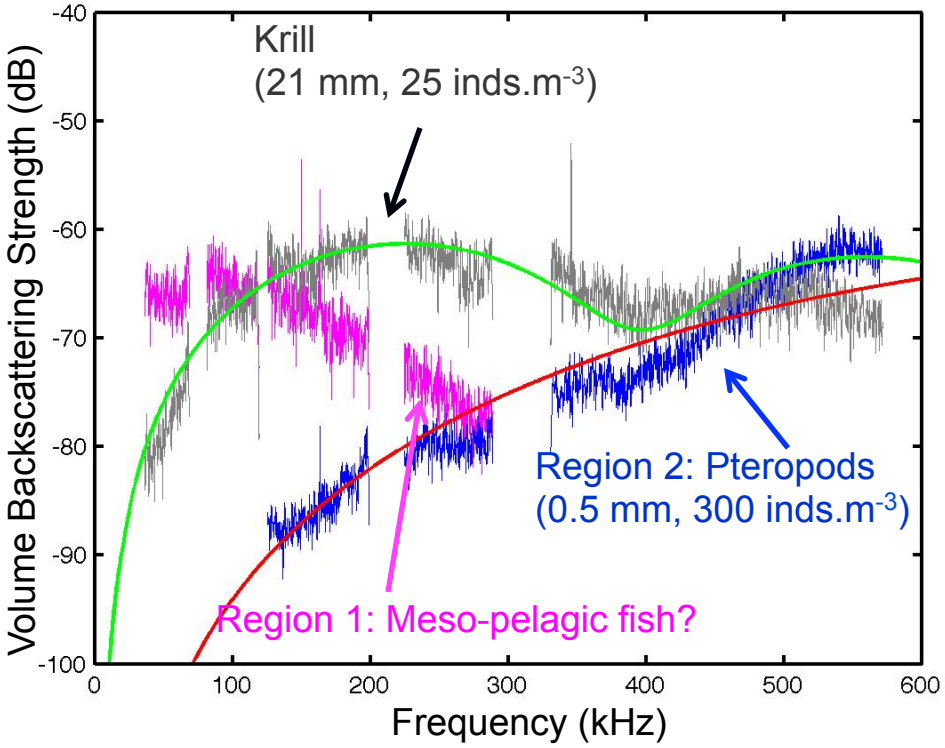
Gene Expression



Shell condition

Broadband Acoustic Sampling



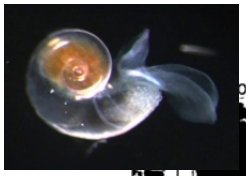


- Broadband acoustic system measured scattering spectra consistent with thecosomatous pteropods, euphausiids, and mesopelagic fishes

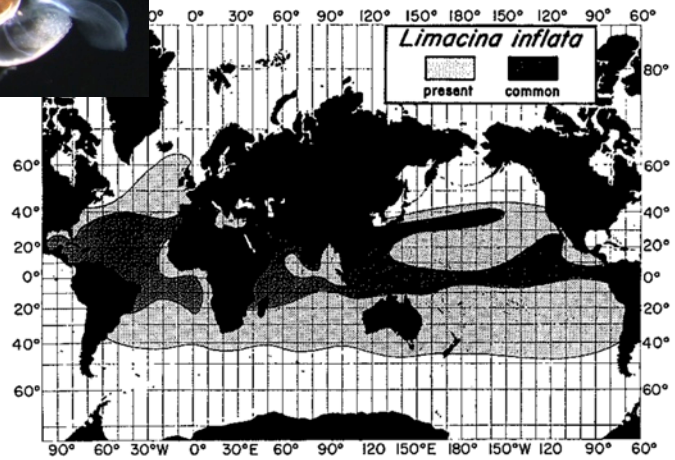
Biogeography and Taxonomy

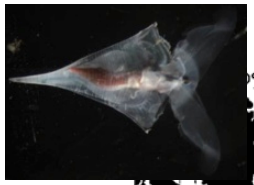
Dr. Amy Maas

Dr. Leo Blanco Bercial

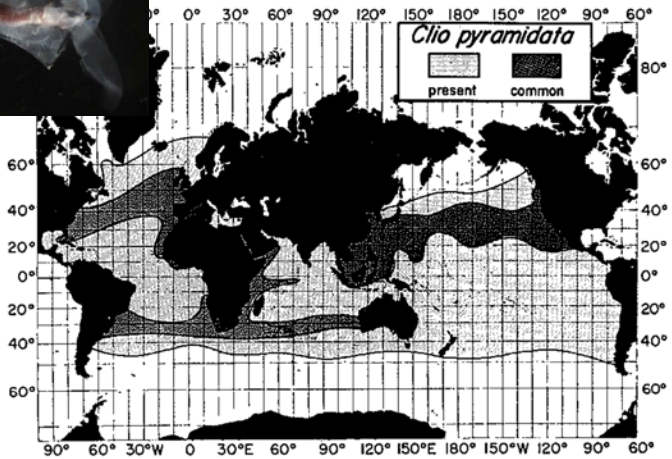


Heliconoides inflatus

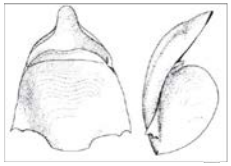




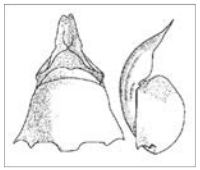
Clio pyramidata



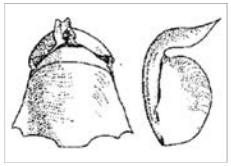
D. elegans



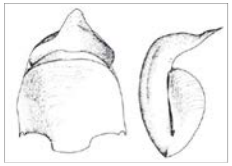
D. atlantica



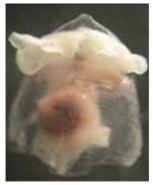
D. strangulata



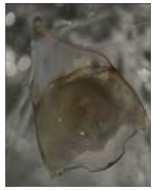
D. robusta

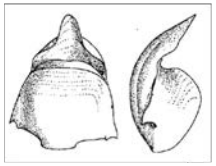


D. juvenile



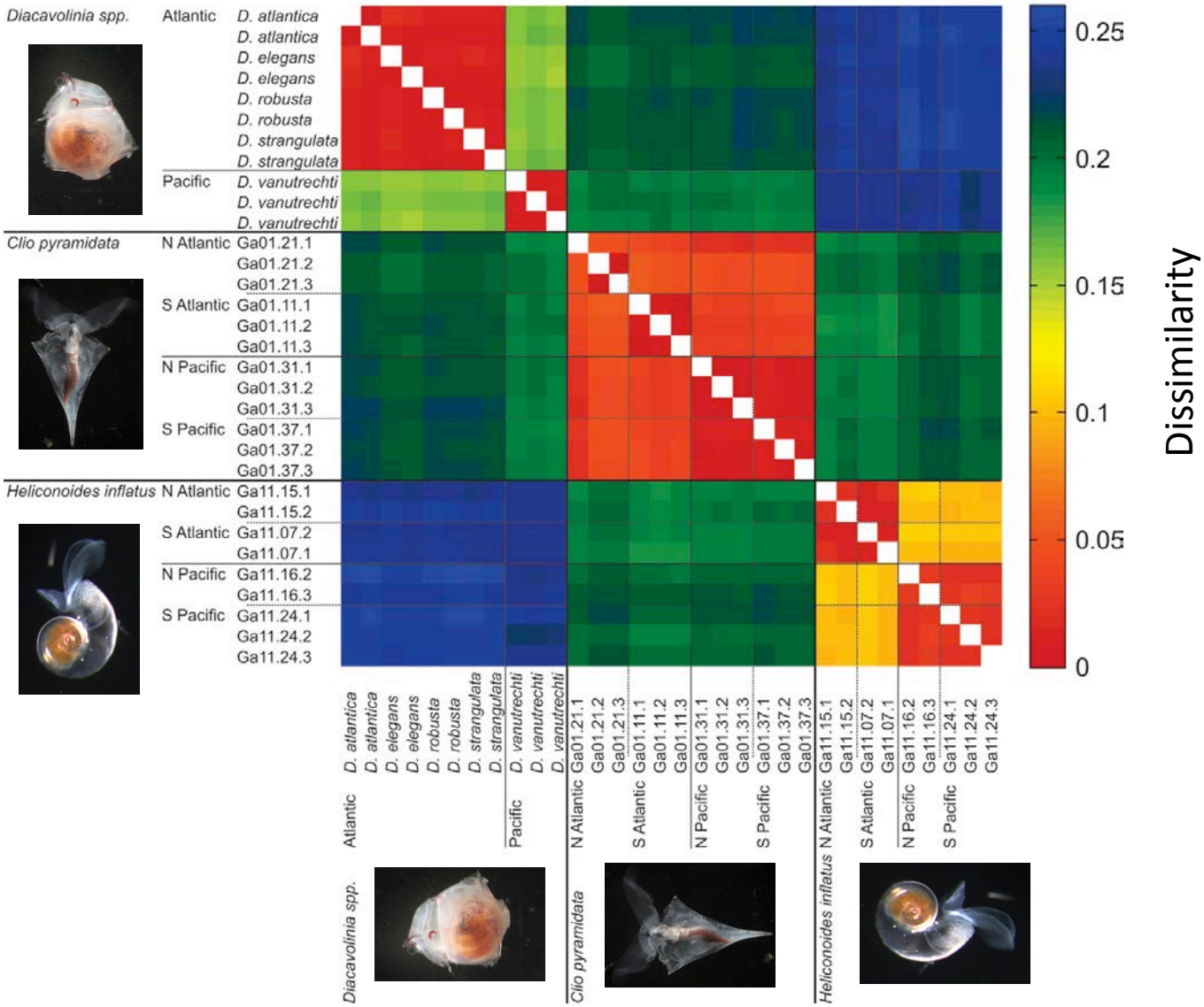
D. vanutrechti





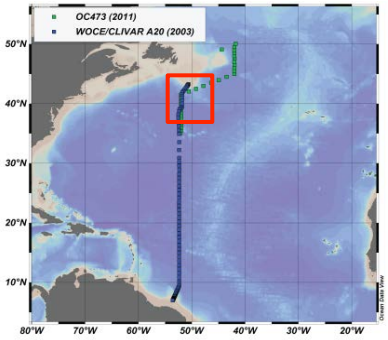
Diacavolinia spp.

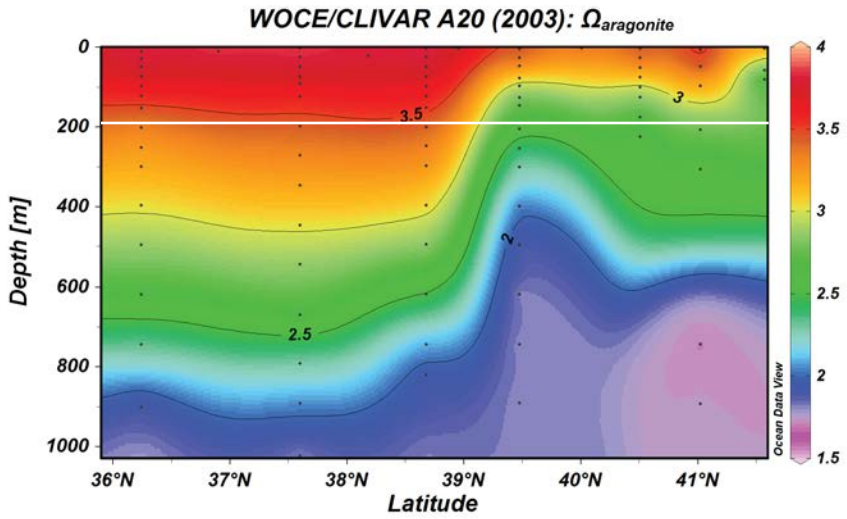
Biogeography and Taxonomy

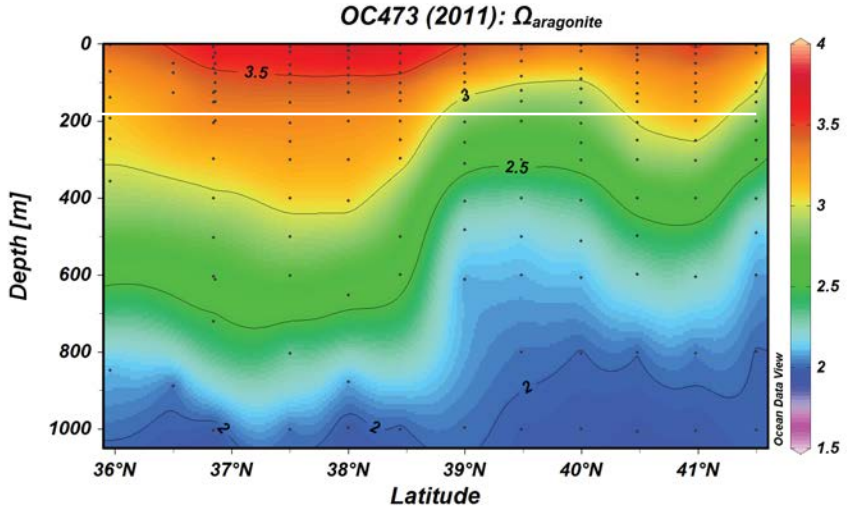


Atlantic Chemistry

- Decrease in pH since 2003, the last time CLIVAR/WOCE line A20 was occupied
- Aragonite saturation state contour of Ωa = 3.5 has shoaled by ca. 100m
- At northern end of survey lines, compensation depth ca. 2500m in Atlantic and 135m in Pacific

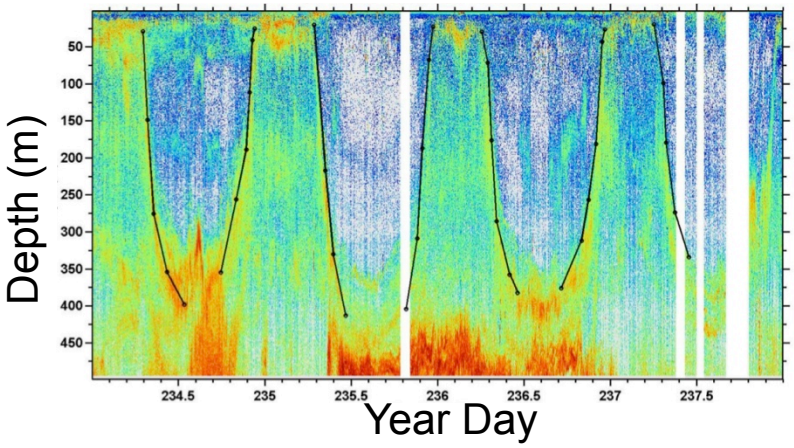


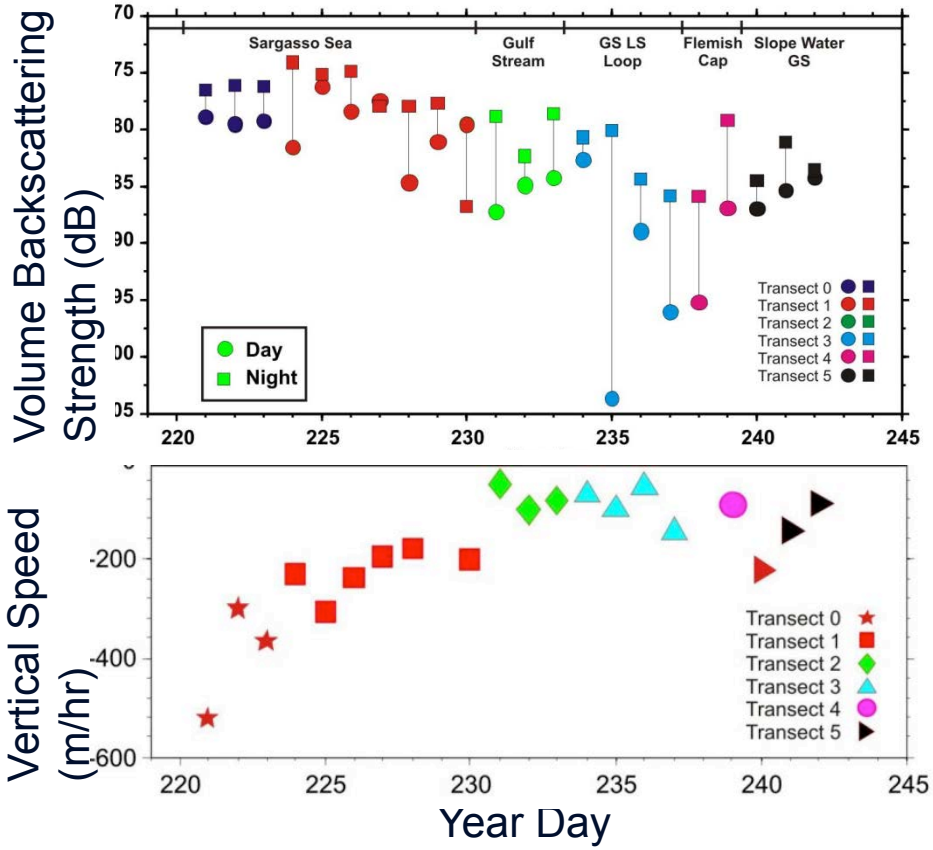




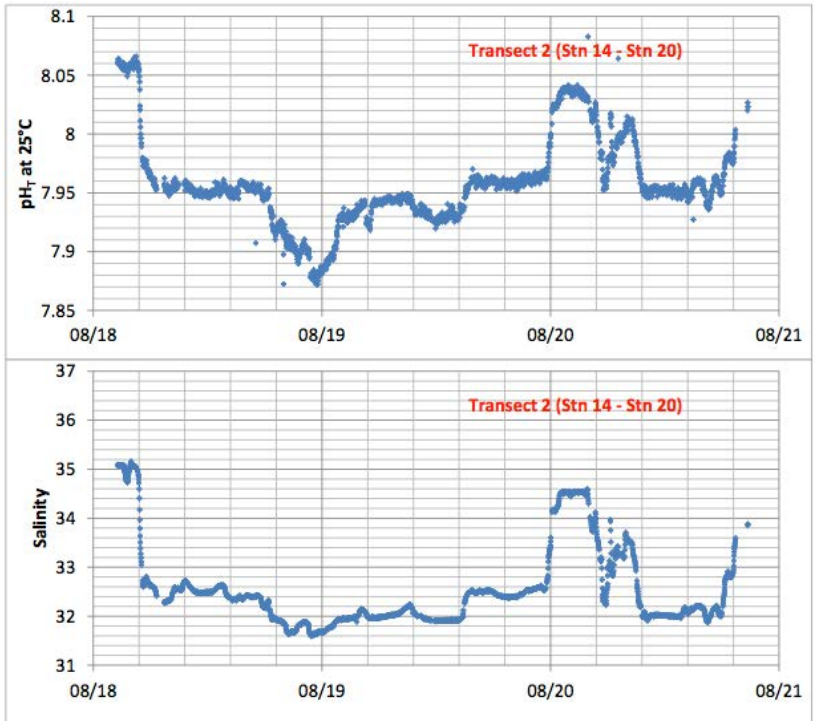
Underway Acoustic Observations

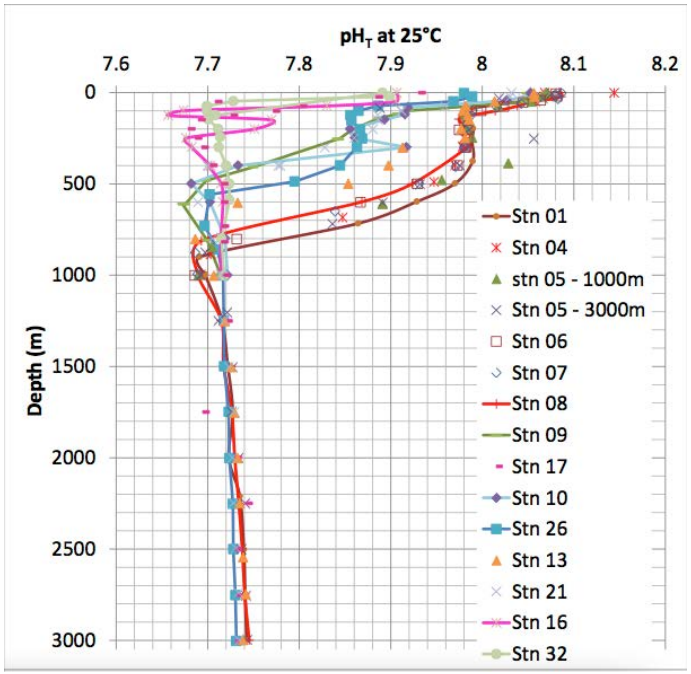
- Multi-frequency acoustics to characterize Deep Scattering Layer

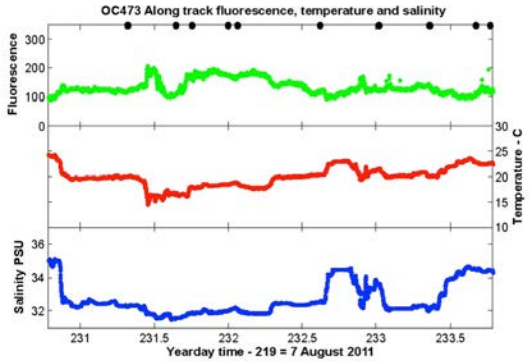




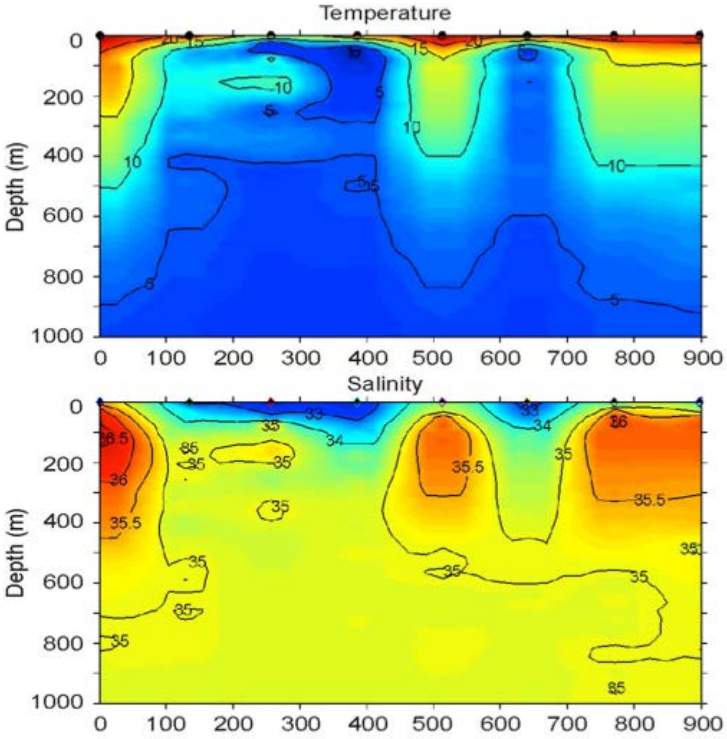
Underway Observations

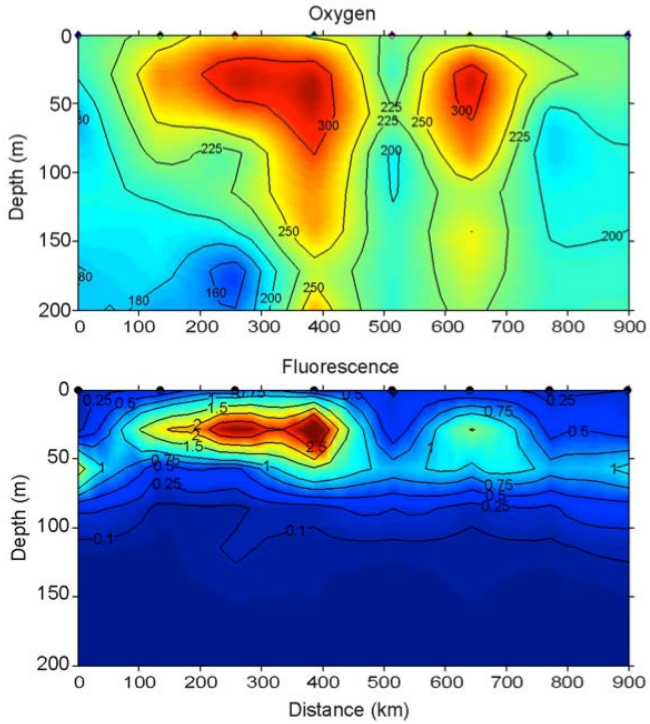






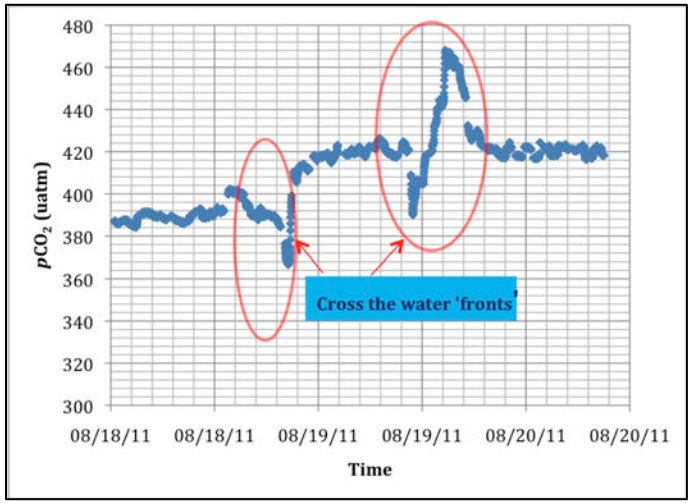
Underway Observations

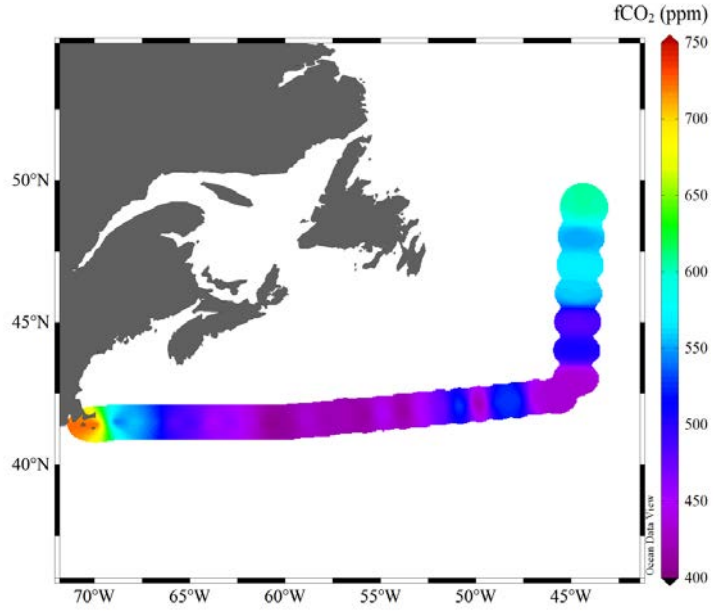


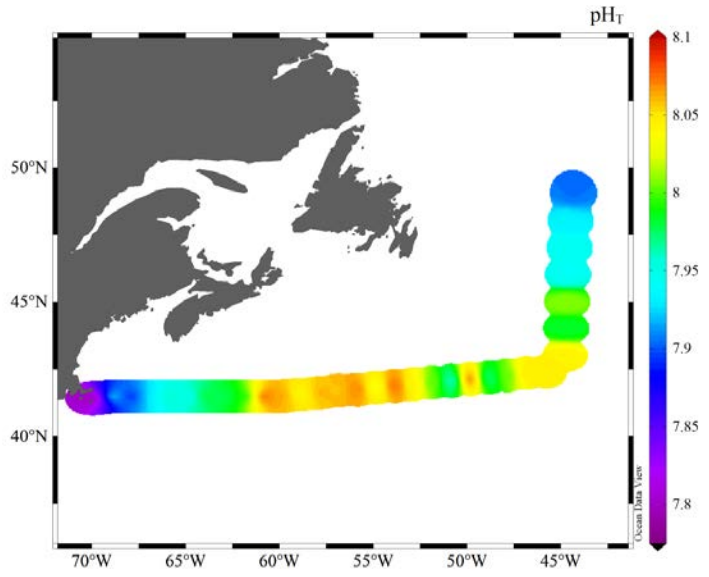


Underway Chemistry Observations

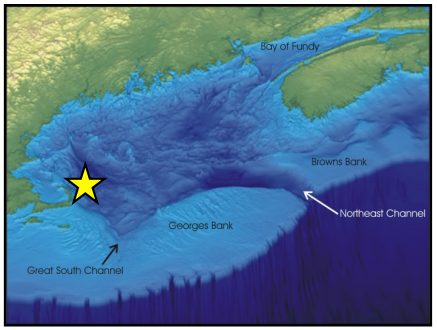
- Flow-through systems for carbonate chemistry

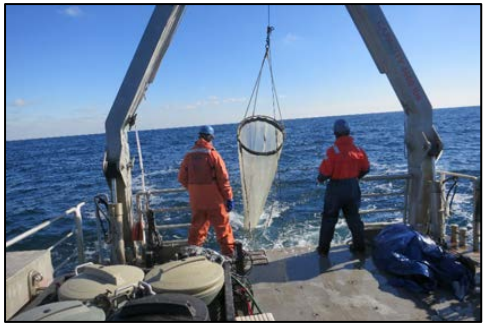


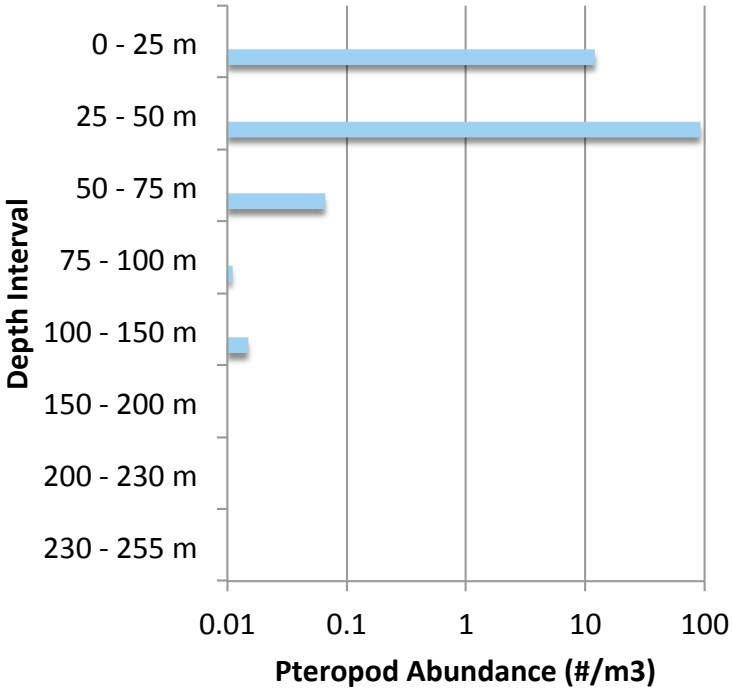


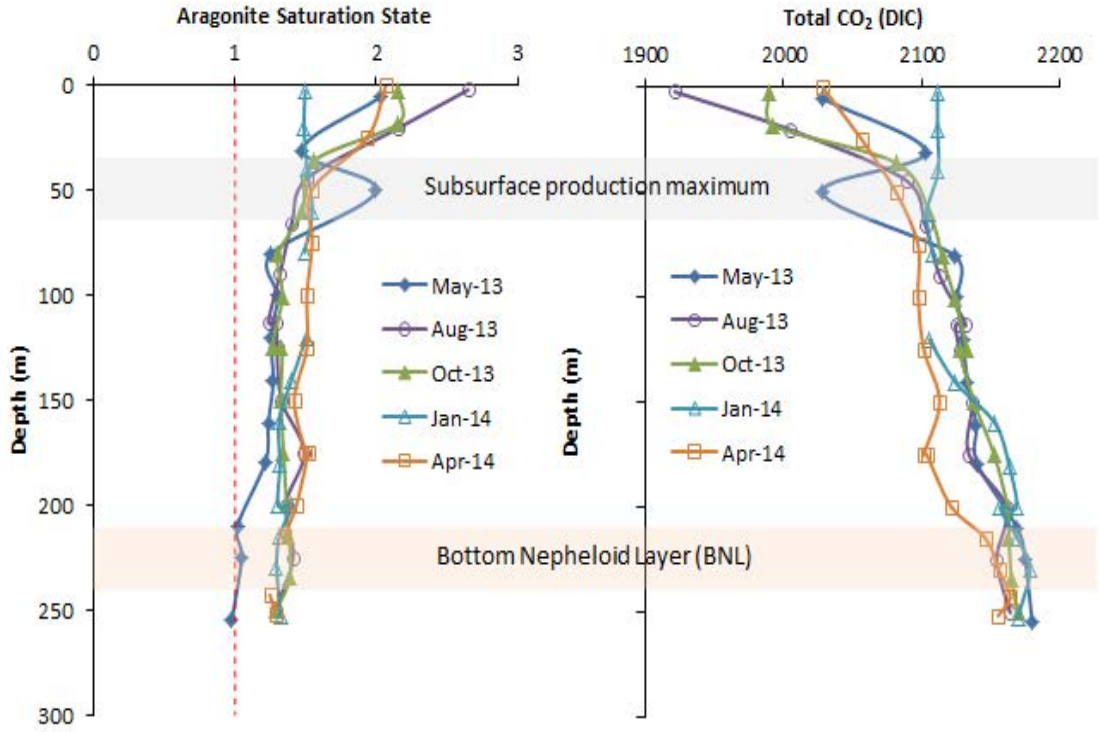


Field Studies

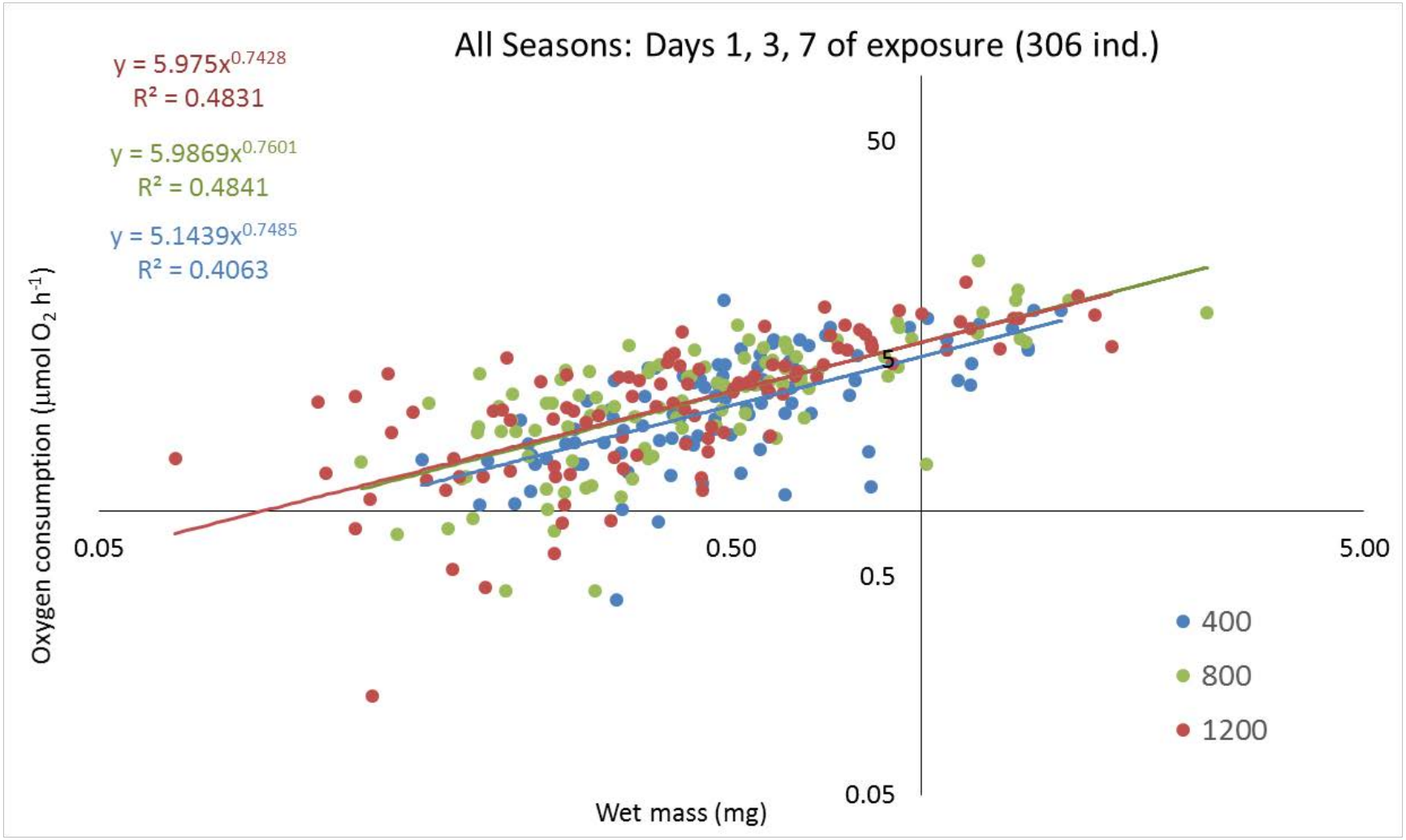




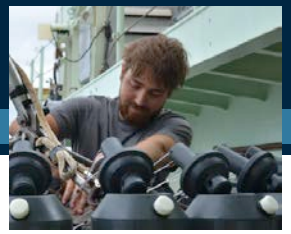




Differences in rate due to CO2 exposure



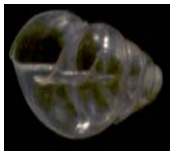
Shell Condition

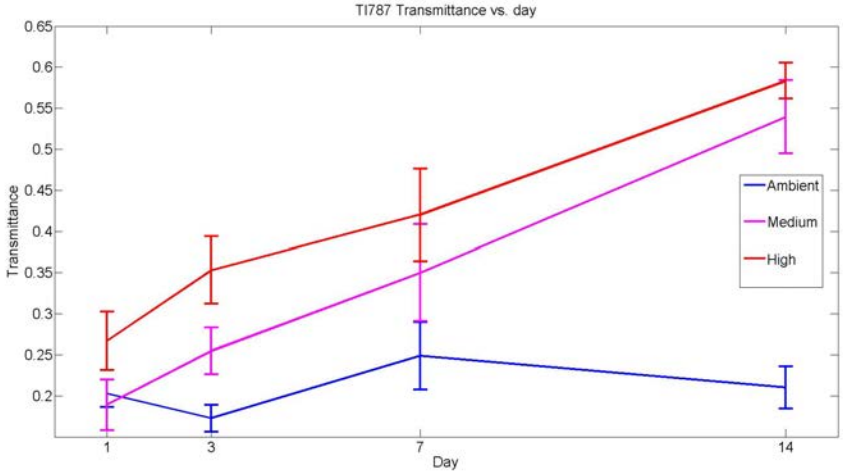


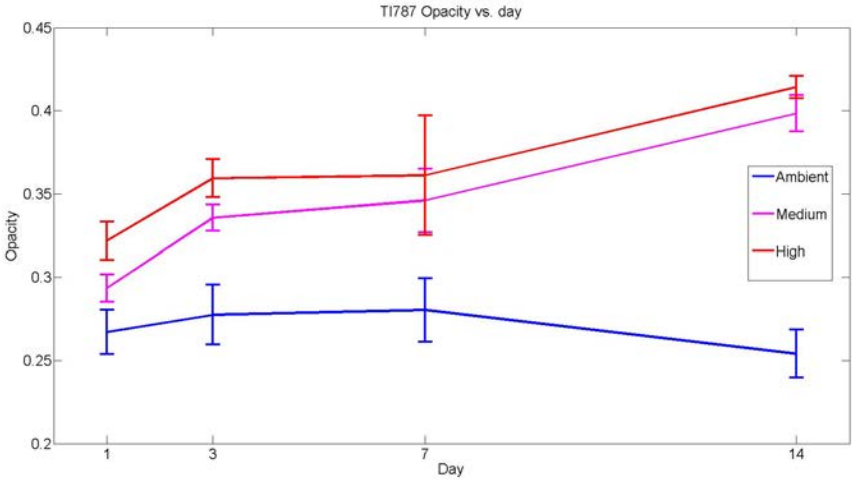
Alexander Bergan
PhD Student

Transparency and Opacity

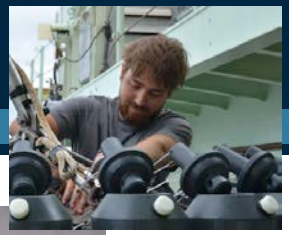
- A quantitative interpretation of the Limacina Dissolution Index (eg. Gerhardt *et al*. 2000)
- Images from a dissecting microscope at 2.5x magnification with transmitted and opaque lighting
- Cropping is used such that the operculum and any holes are removed from grayscale analysis (any single layer of shell)





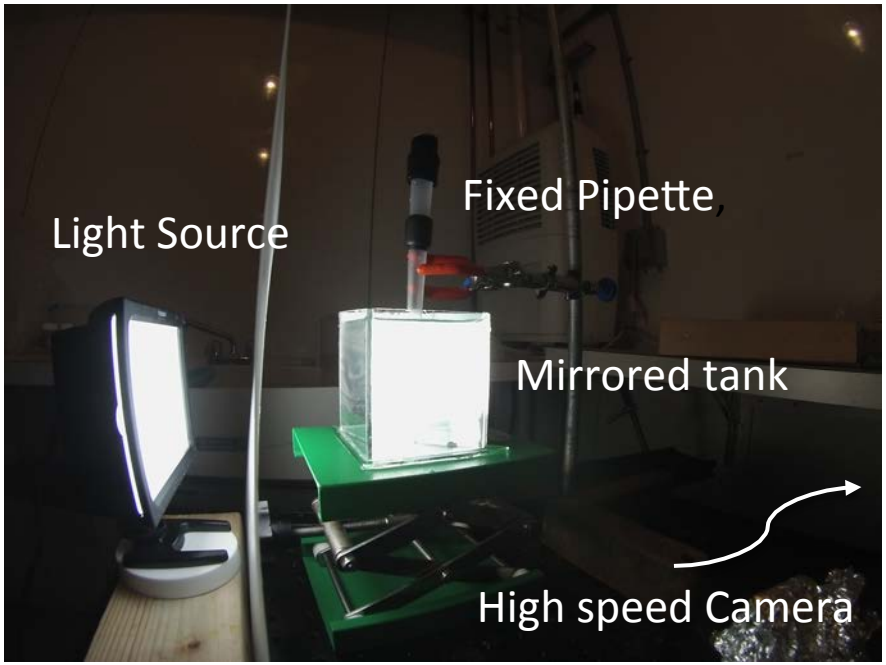


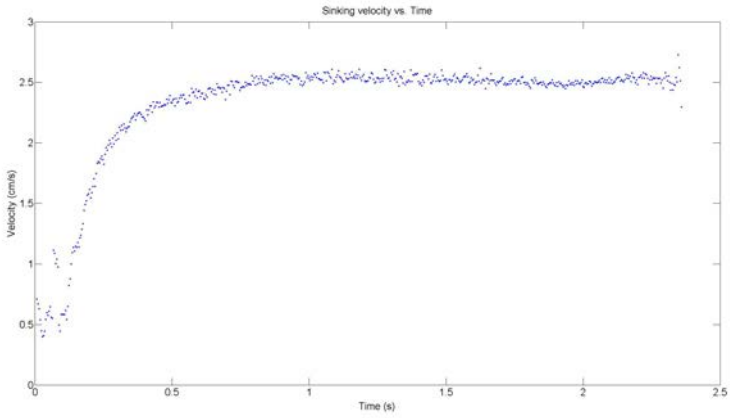
Sinking



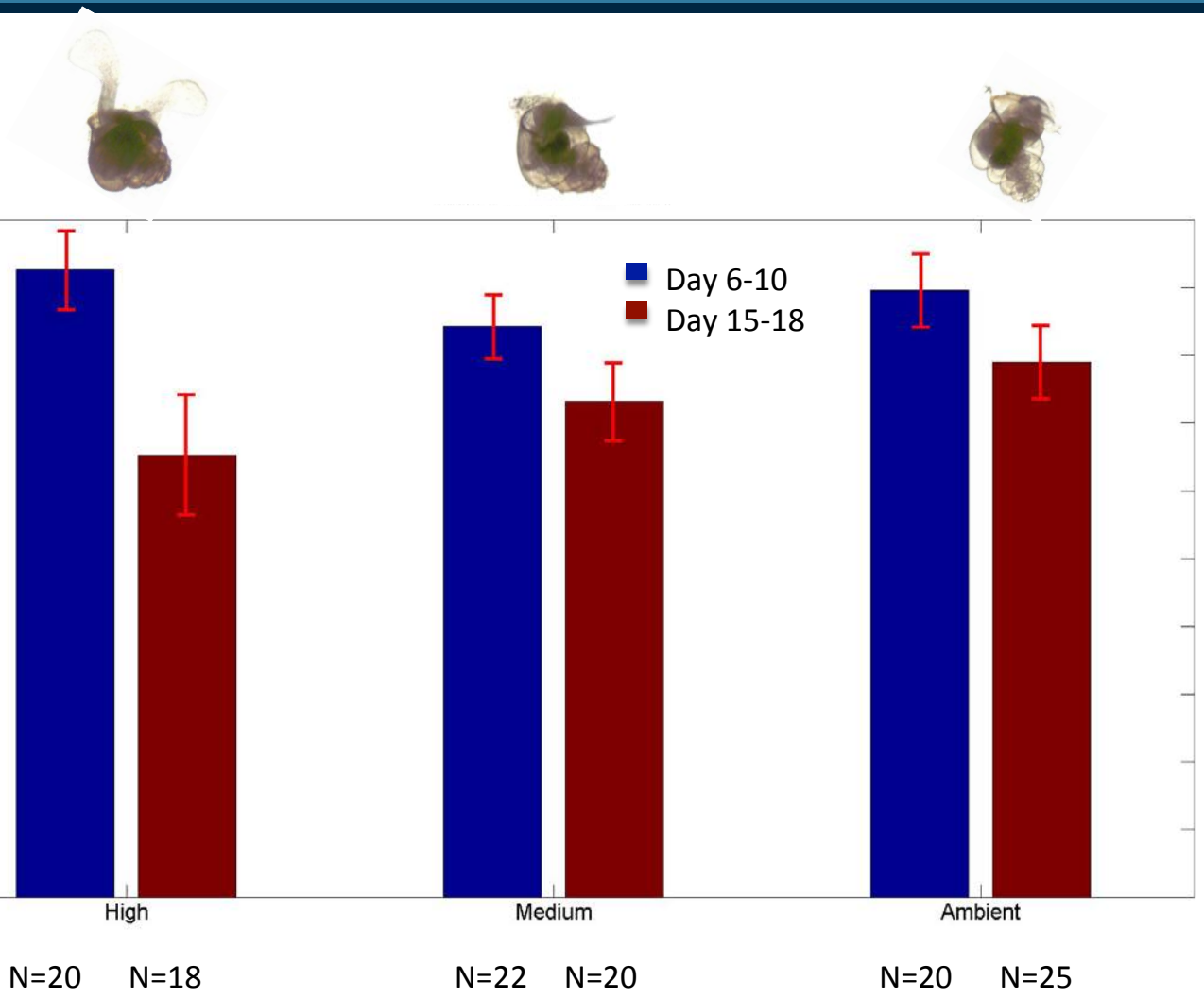
Alexander Bergan
PhD Student

- *Limacina retroversa* reared in seawater bubbled with 400 ppm CO_2, 800 ppm CO_2, and 1200 ppm CO_2
- Video taken in mirrored tank at 500 frames per second, giving 3D path and velocity of the animals





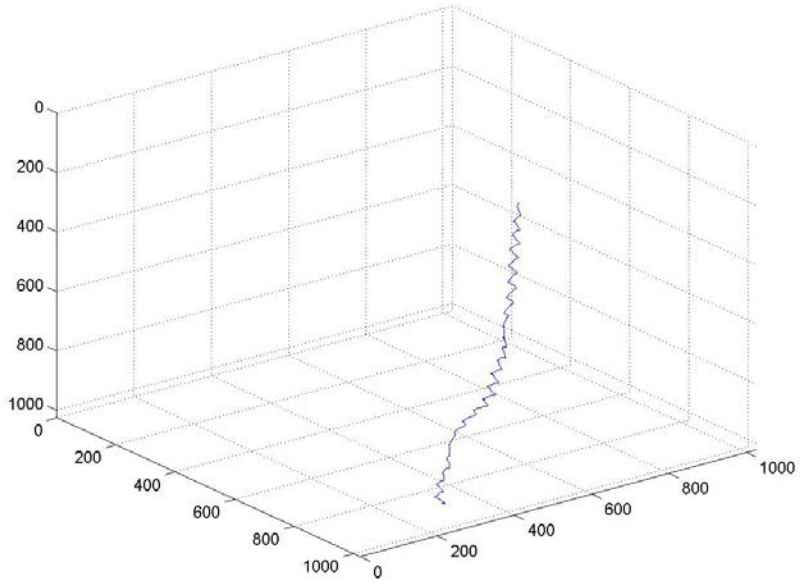
Sinking



Before 2 weeks: p=0.091, One way ANOVA

After 2 weeks: p=0.02*, One way ANOVA

Swimming

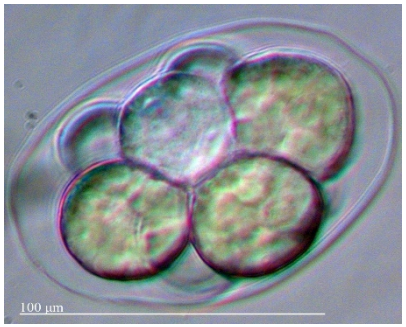

0
200
400
600
800
1000
0
200
400
600
800
1000
0
200
400
600
800
1000

Early Life Stages

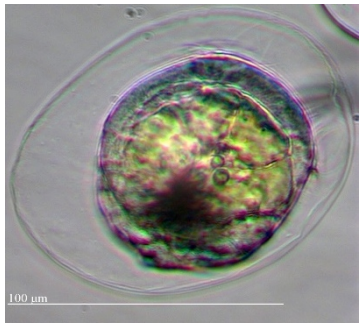
1- cell

2- cell

4- cell

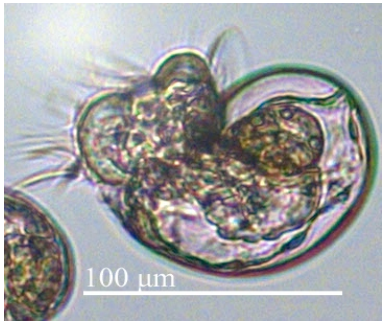


8- cell



Late gastrula

Trochophore larva



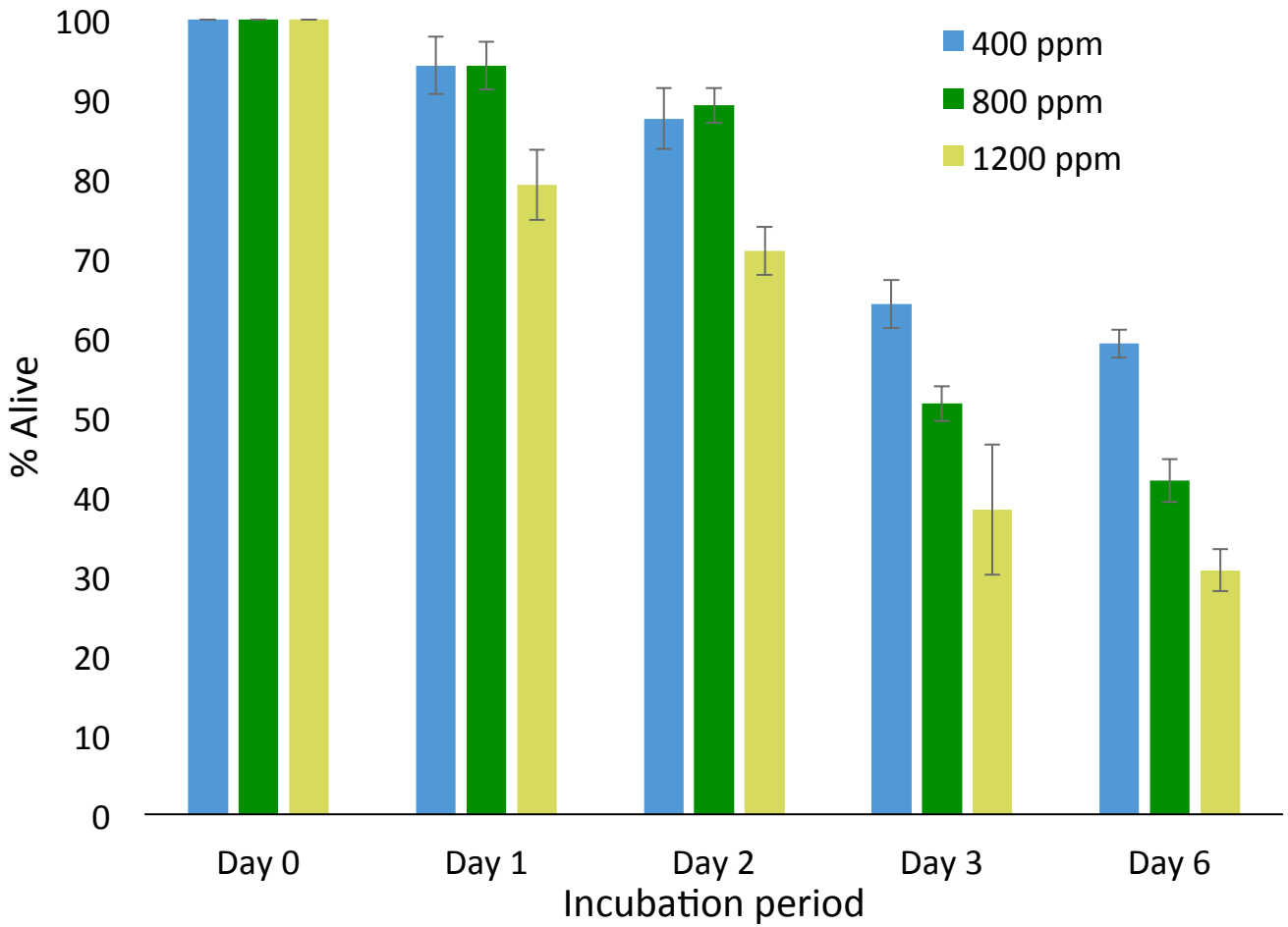
1 week veliger larvae

3 week veliger larva

Reproductive adult

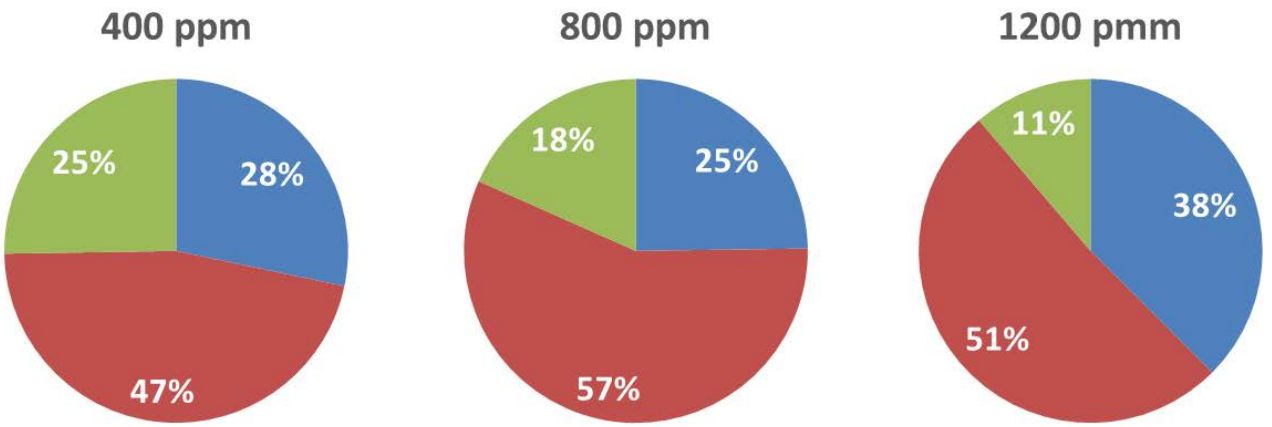
Stage	Time
Spawning	0 h
2-cell	4 h
4-cell	6 h
8-cell	9 h
16-cell	11 h
Blastula	16 h
Gastrula	24 – 72 h
Hatching	3 days
Trochophore	3-6 days
Veliger	6-7 days
Juvenile	1-2 month
Reproductive Adult	3 months
Life Span	6 months

Early Life Stages

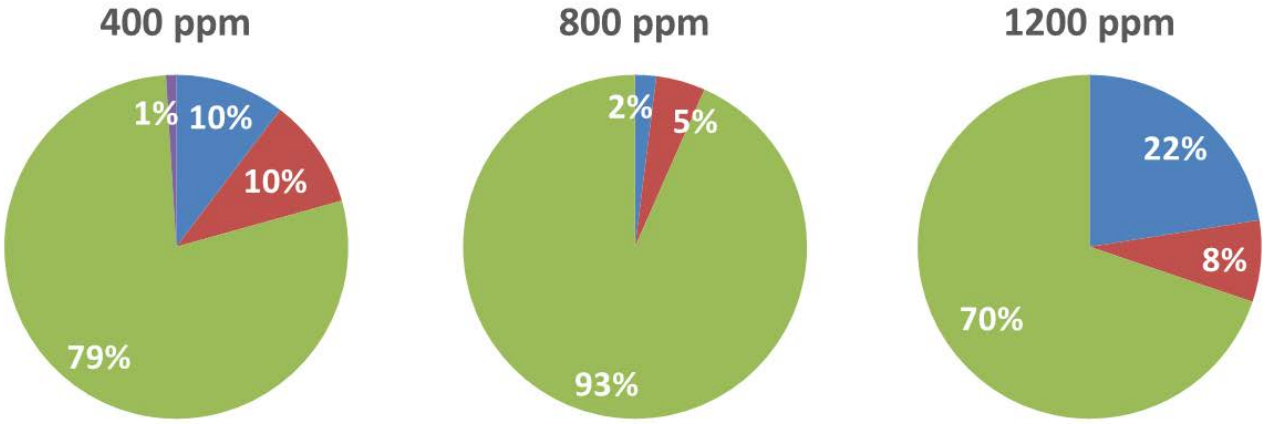


Early Life Stages

Day 2



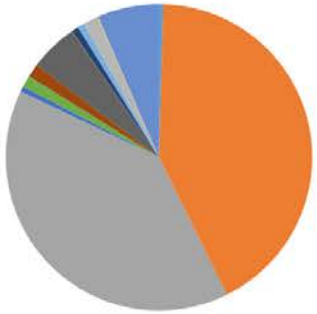
Day 6

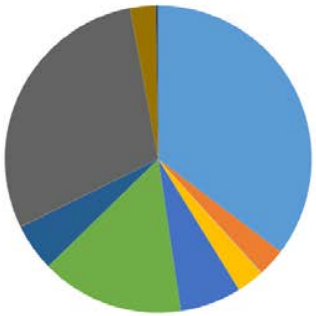


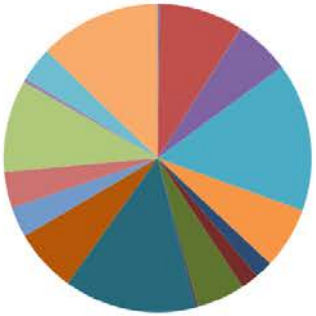
Gastrula (non-moving)
Gastrula (moving)
Trochophore
Veliger

Limacina retroversa transcriptome

	Limacina retroversa	*Clio pyramidata*
Bioproject	PRJNA260534	PRJNA231010
Transcriptome	GBXC00000000	GAWL00000000
# transcripts (isoforms)	270,317	45,802
# components (gnes)	125,222	30,853
N50	1,699	851
% Blast ID	~31%	~23%





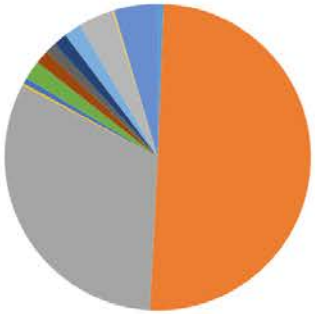


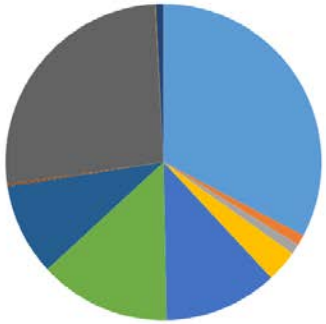
Molecular Function

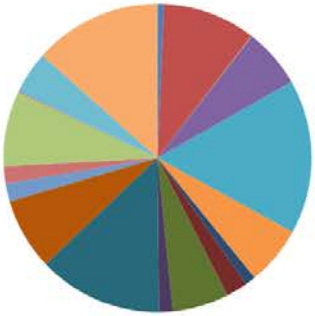
Cellular Component

Biological Process

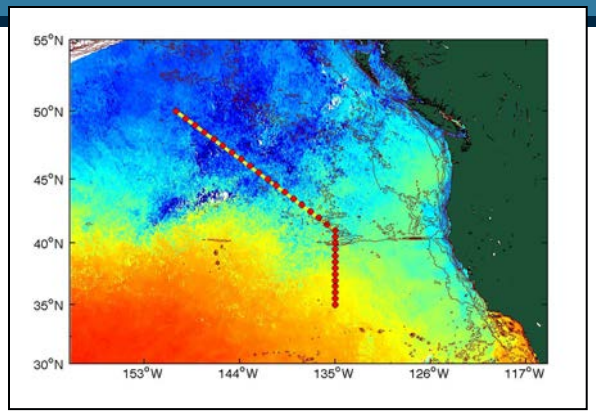
GO term classifications

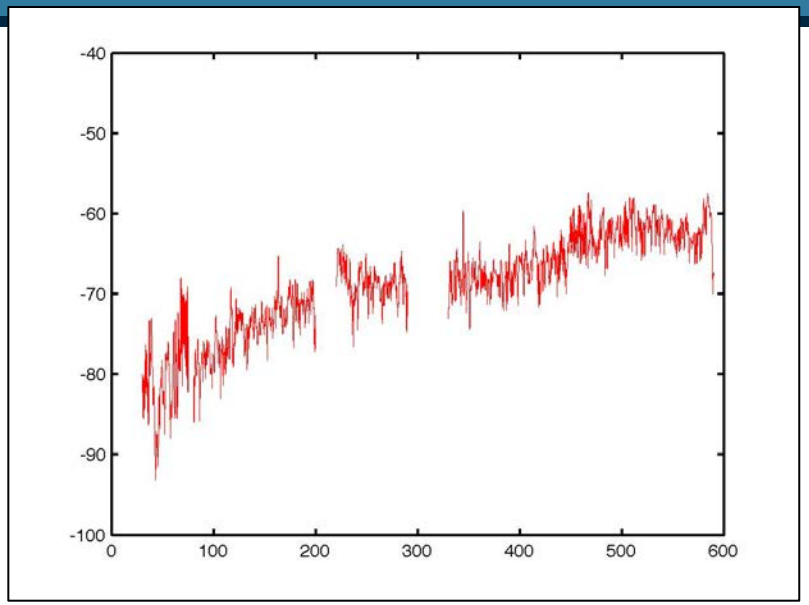


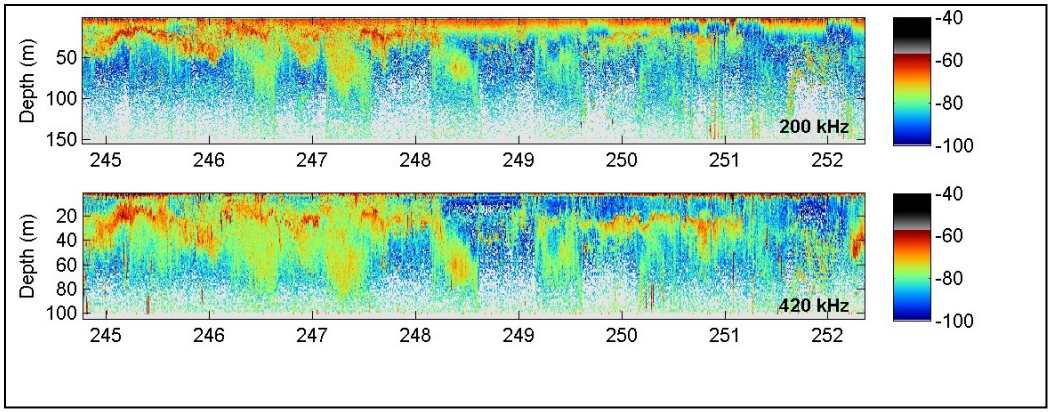


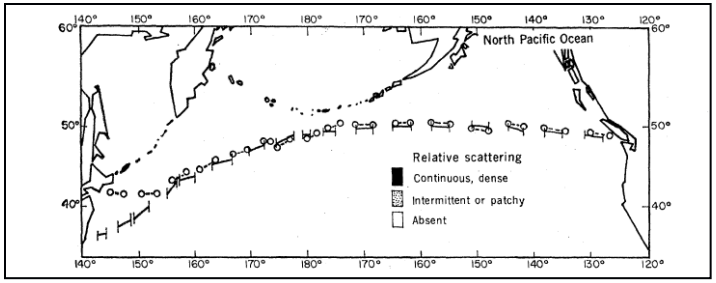


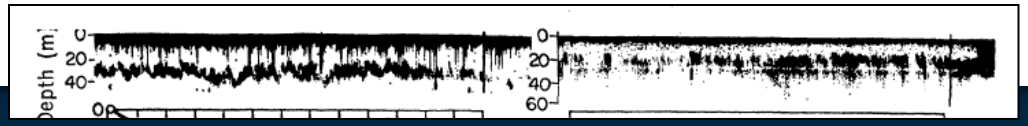
OAPS – Pacific 2012











- Dominant scattering feature was a non-migratory shallow layer
- Additional analyses and comparison to net samples are required

Art-Science Collaboration