The importance of environmental exposure history in forecasting Dungeness crab megalopae occurrence using J-SCOPE, a high-resolution model for the US Pacific Northwest

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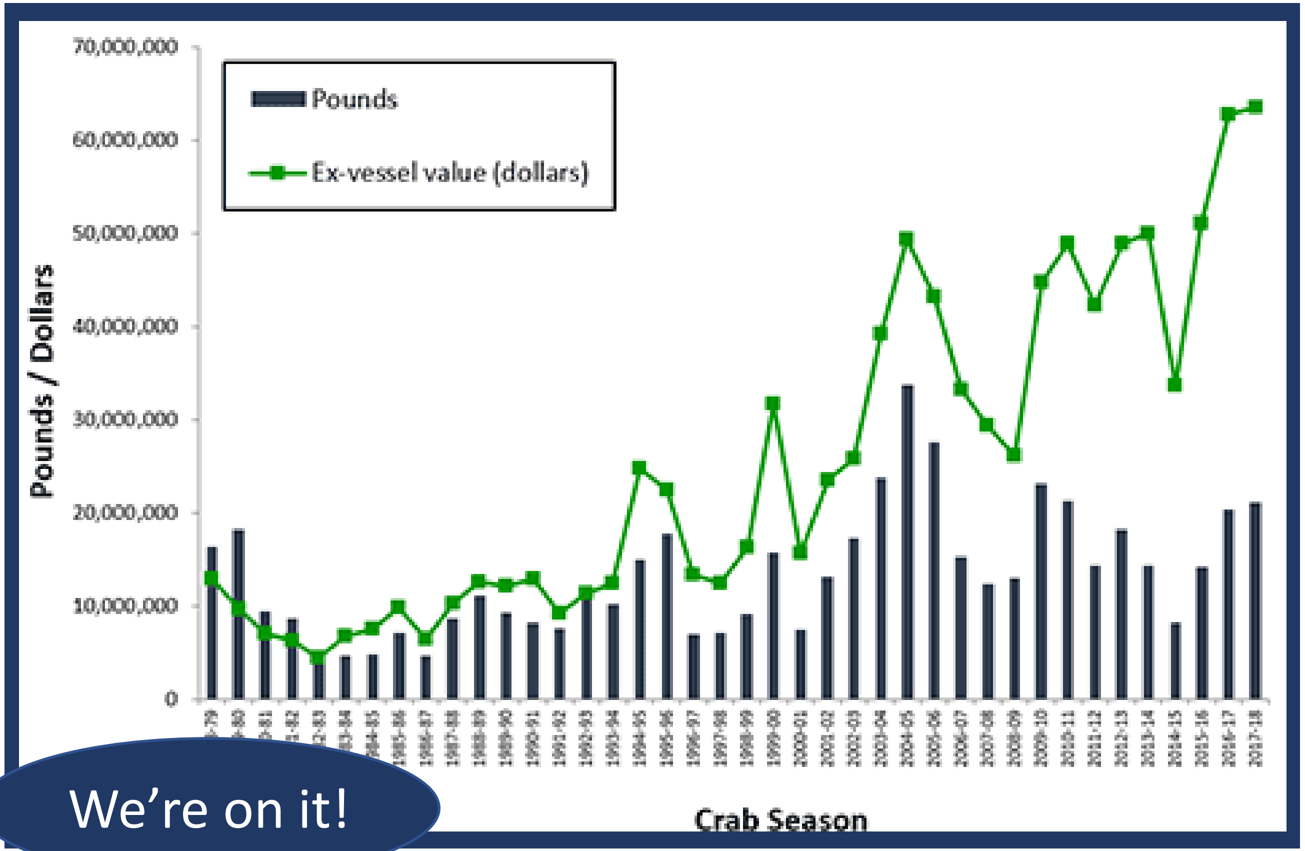
PICES Annual Meeting
October 22, 2019
Victoria, BC

Photo Credit: R. Norton

Dungeness Crab Fishery: Valuable but Variable

Historical Catch in Oregon



We're on it!

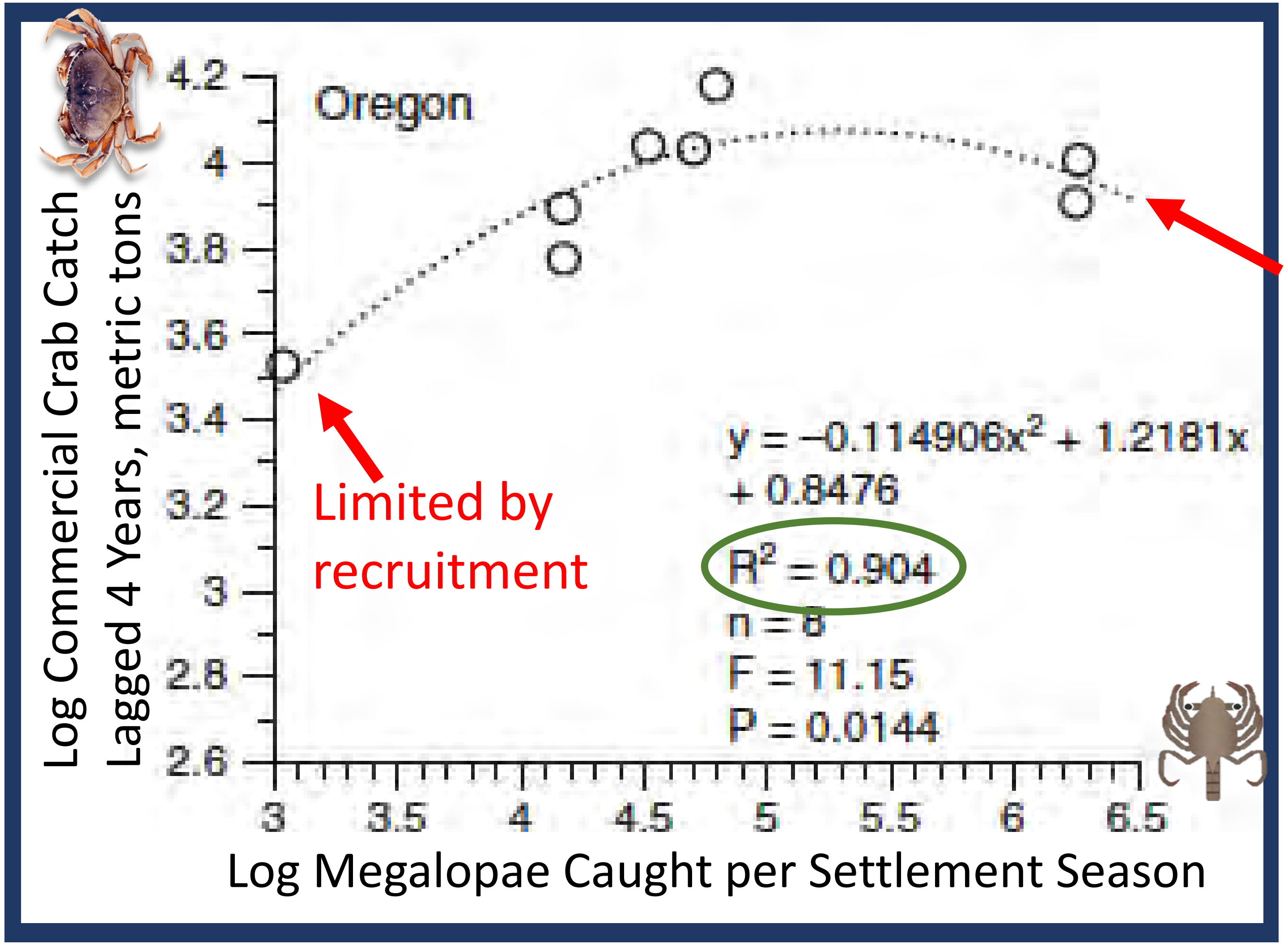
https://www.dfw.state.or.us/MRP/shellfish/commercial/crab/landings.asp

- One of the most valuable fisheries in the Pacific Northwest
- Interannual fluctuations
  - Driven by environmental variability
- Co-managed by State and Tribes

→ Managers are interested in forecasting tools

J-SCOPE

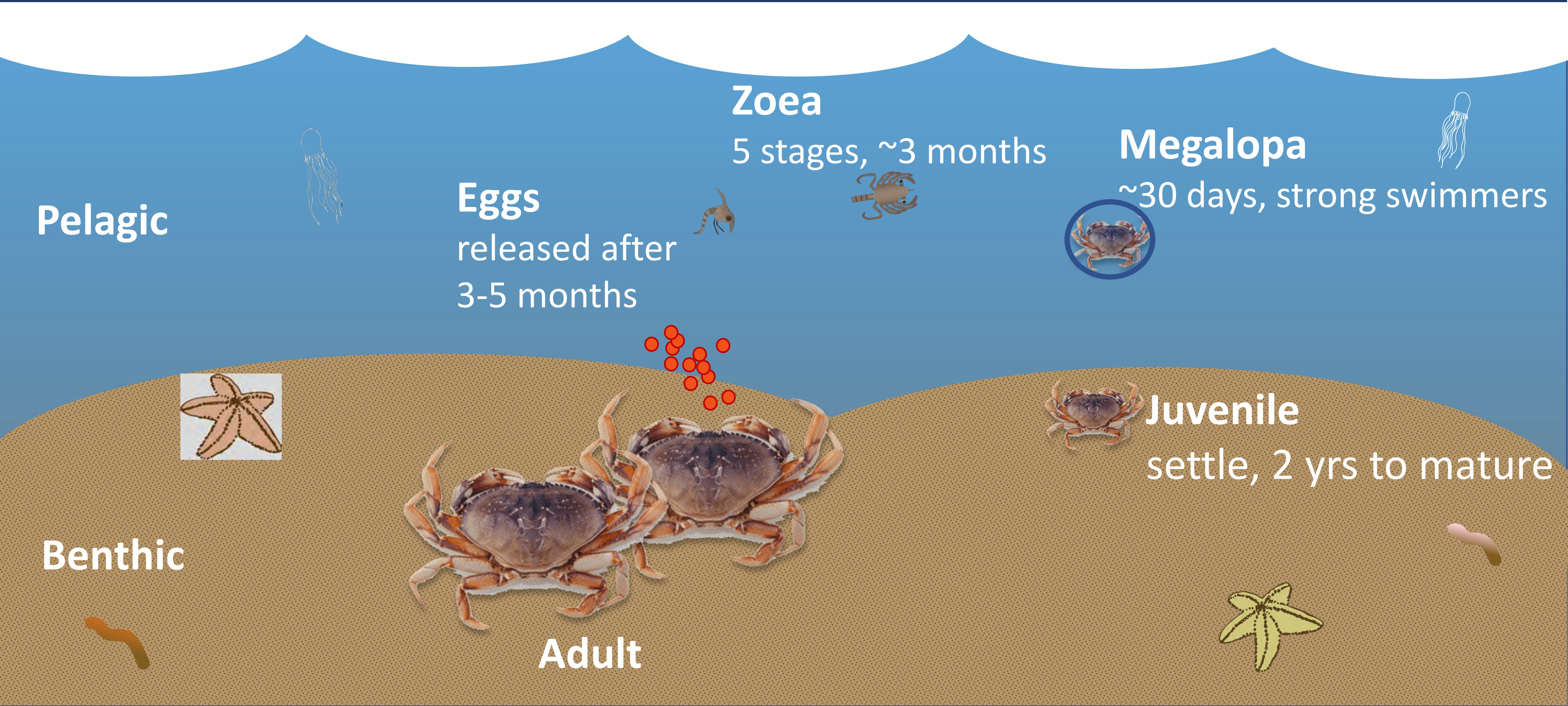
Megalopae Abundance Correlated with Adult Crab Fishery 4 Years Later



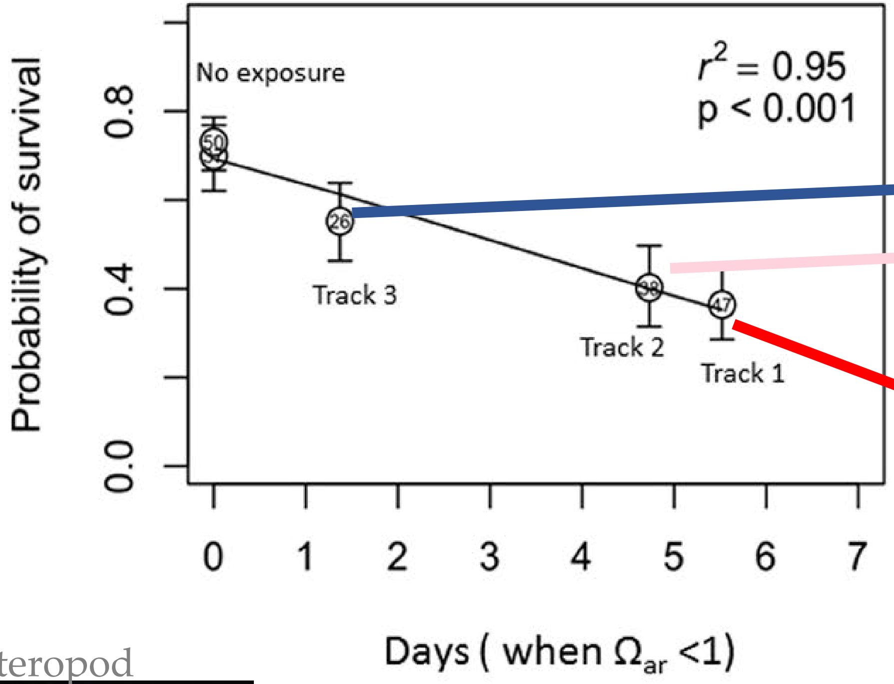
Aim: Forecast megalopae occurrence and habitat.

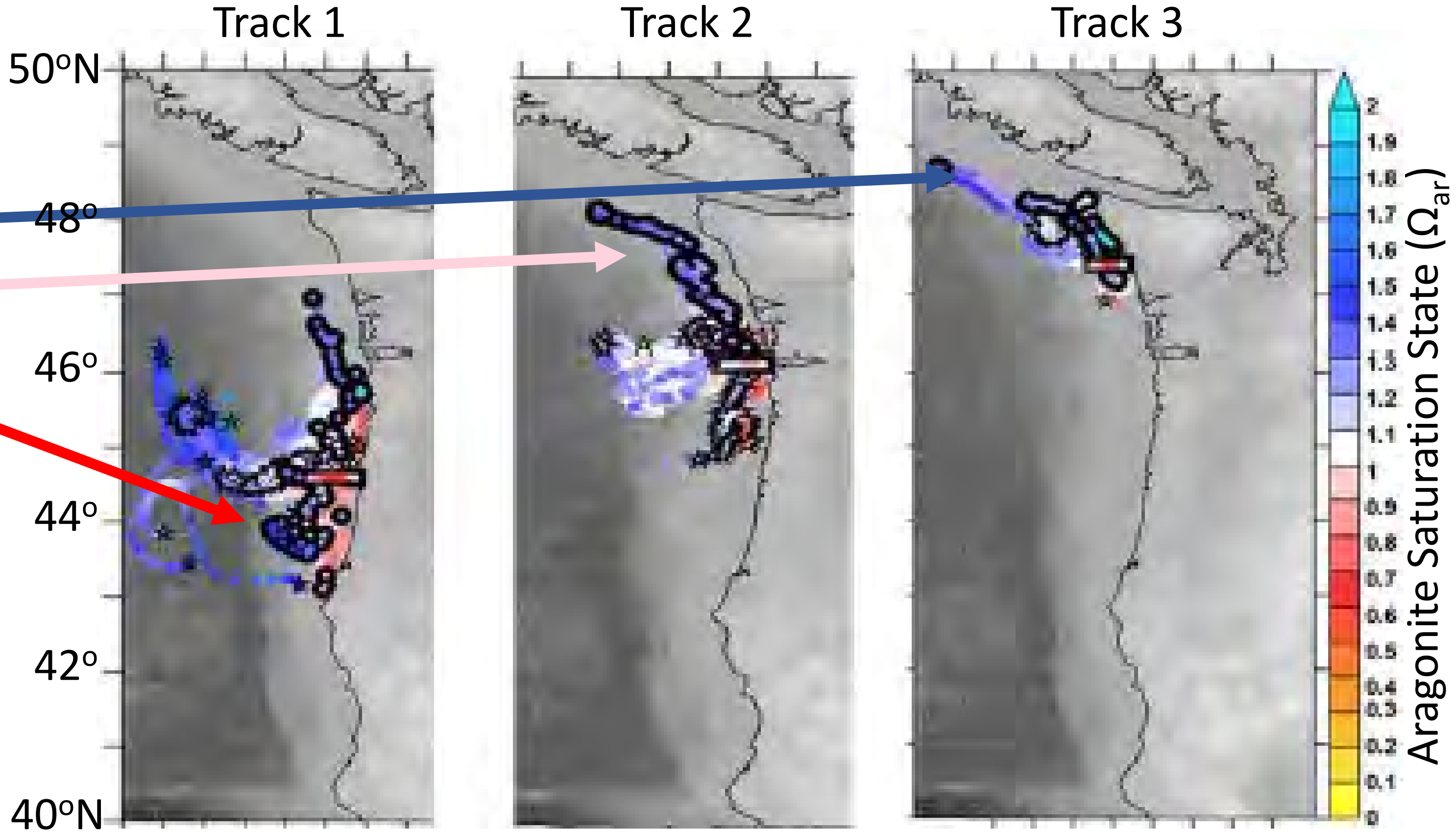
Fig. 6 in Shanks, 2013: *Fish. Oceanogr*. 22:4, 263-272

Dungeness Crab Life Cycle: Benthic and Pelagic Stages



Exposure History is Important for Some Pelagic Organisms: Pteropod Survival





Pteropod

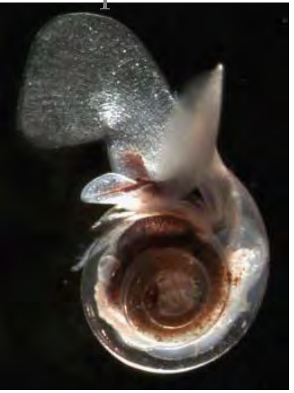


Photo: R. Hopcroft

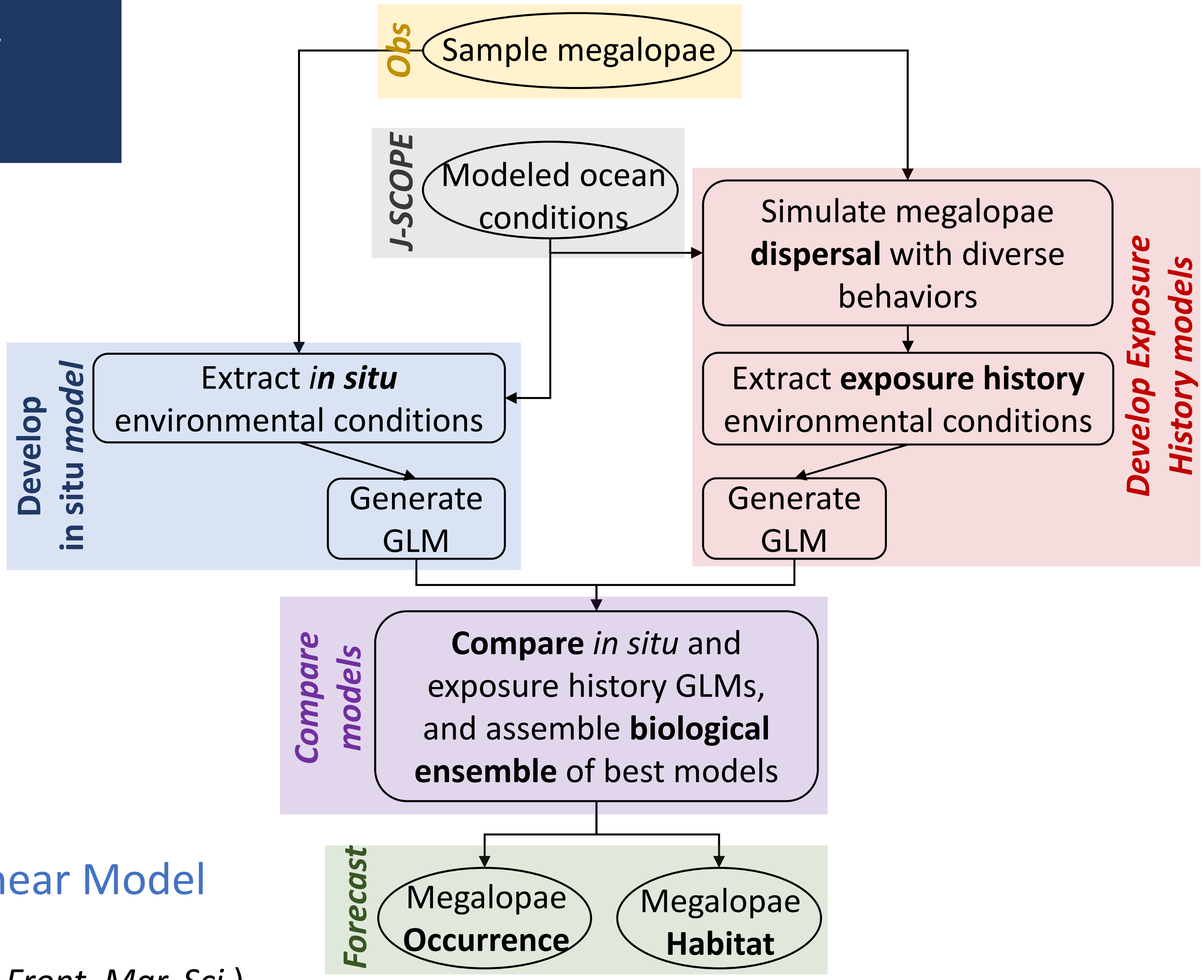
- Particles initialized at sampling locations with vertical migration behavior
- Dispersal simulations run forward and backward for 30 days to estimate undersaturation days

Fig. 3 in Bednaršek et al., 2017. *Sci. Rep.* 7, 4526

Project Overview

Hypothesis:

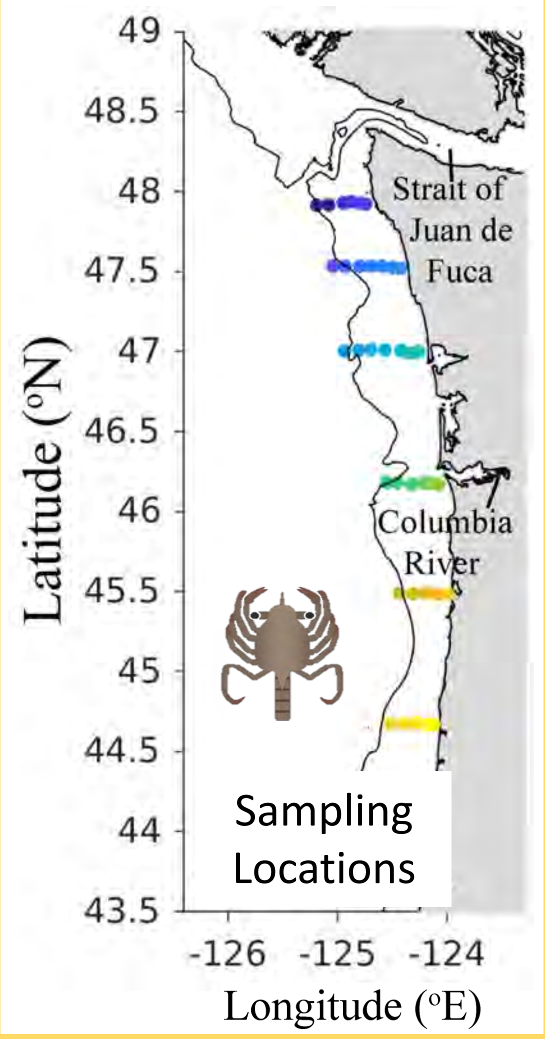
Including environmental exposure history will improve our ability to predict megalopae occurrence and habitat compared to using only co-occurring environmental conditions (‘*in situ*’).



GLM = Generalized Linear Model

Norton et al., 2019 (submitted, *Front. Mar. Sci.*)

Dungeness Megalopae Occurrence Data



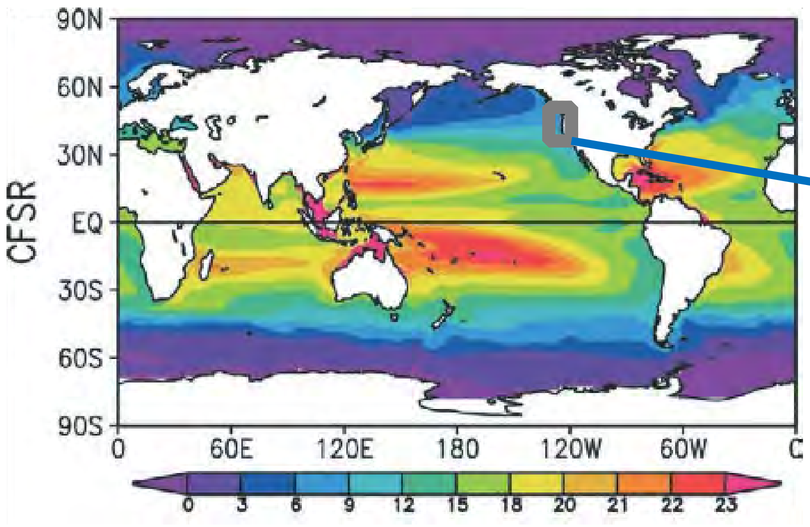
- 13 surveys from nine years
  - 2009-2016: develop GLMs
  - 2017: test GLM performance
- 37 sampling locations
- May + June surveys
- Oblique bongo tows 0-30m
- Dungeness megalopae identified and counted

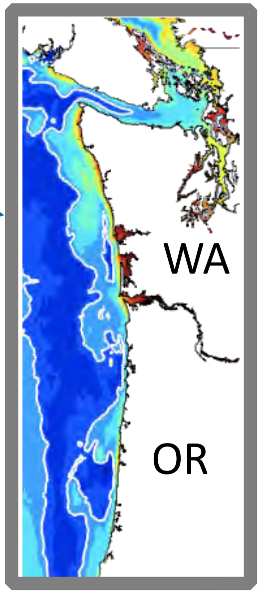
Thanks to C. Morgan for providing data; sampling conducted by Bonneville Power Administration and Northwest Fisheries Science Center (NOAA)

Norton et al., 2019 (submitted, *Front. Mar. Sci.*)

J-SCOPE (JISAO's Seasonal Coastal Ocean Prediction of the Ecosystem)

Forecasts Seasonal Coastal Marine Conditions for PNW

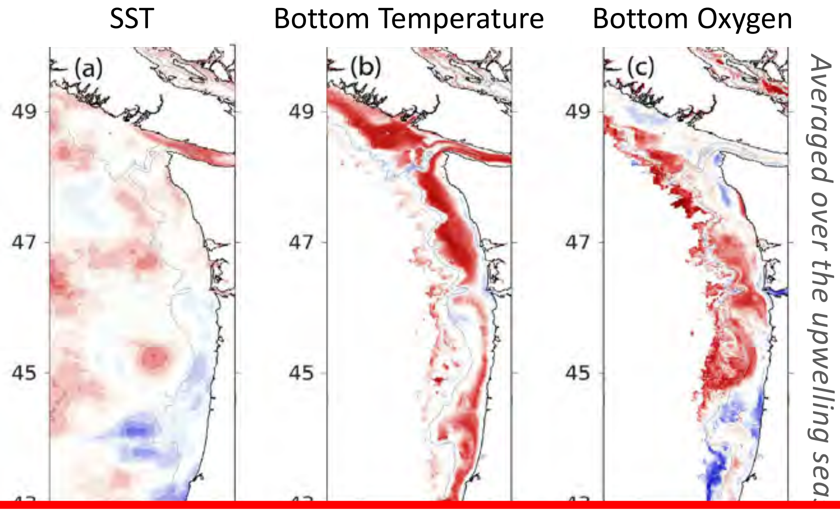




- NOAA's Climate Forecast System (CFS) – global coupled air/sea/land model – used for boundary and atm forcing of ROMS-based regional model with biogeochemistry (Cascadia domain, ~1.5 km res)
- Empirically-derived relationships applied to modeled fields to predict additional quantities (e.g. pH and fish)

Currently forecasting:

- T, S, O, NO_3, Chl a, pH, Ω
- Sardine Habitat (Kaplan et al., 2016)
- *in prep:* OA specific indices for adult crab, shellfish, pteropods; and hake habitat (Malick et al., *in prep*)



Anomaly Correlation Coefficient for seasonal forecast vs. hindcast

Siedlecki et al., 2016.

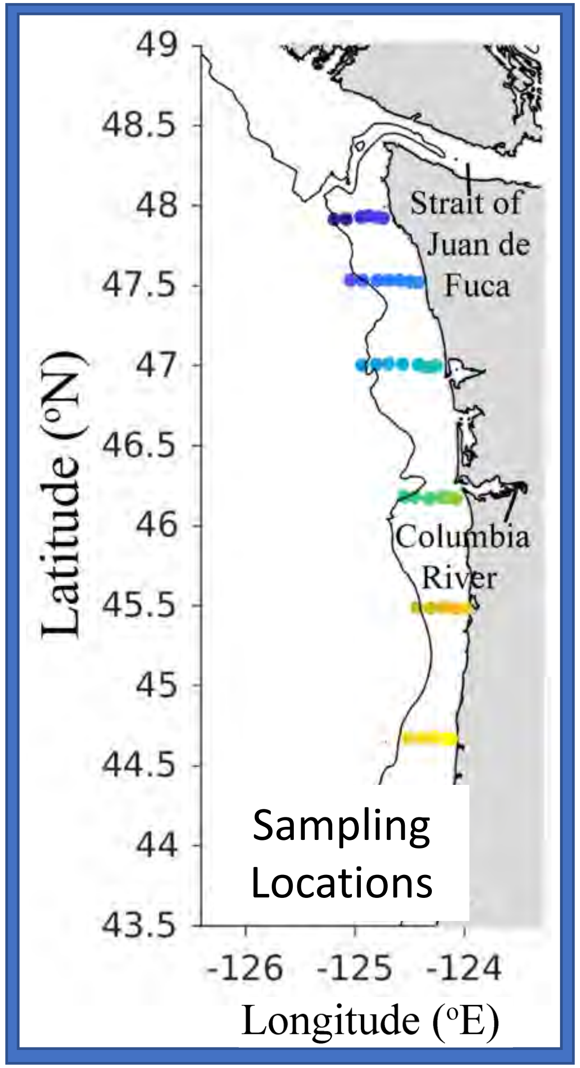
Next talk: Skill and uncertainty of environmentally driven forecasts of Pacific hake distribution

Check out our websit

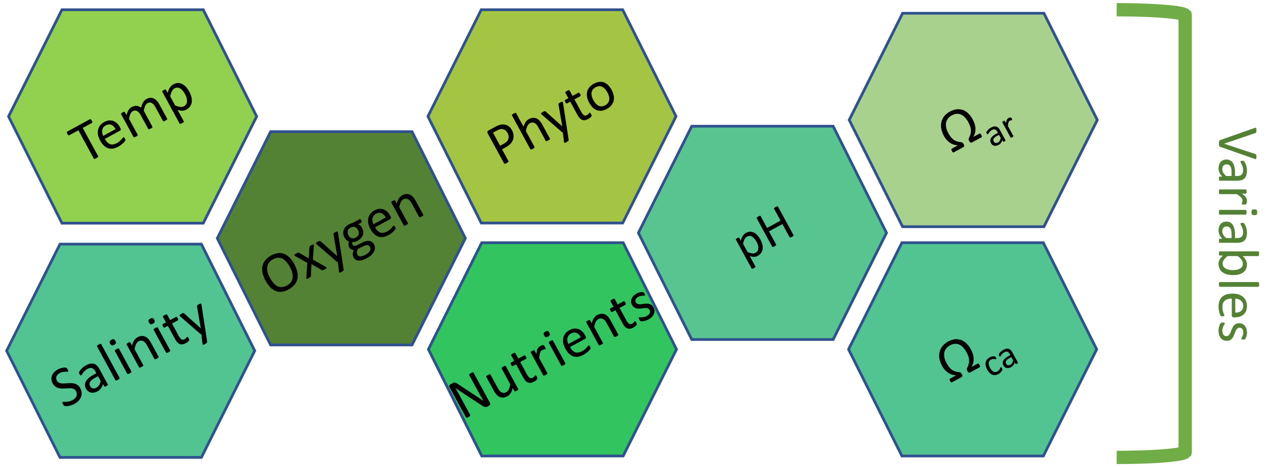
http://www.nanoos.org/products/j-scope/home.php

Develop *in situ model*

"*in situ*" Variable Extractions



- From J-SCOPE at times and locations concurrent with megalopae sampling (37 stations, 2009-2016)
- Averaged over sampling depth (0-30m depth)

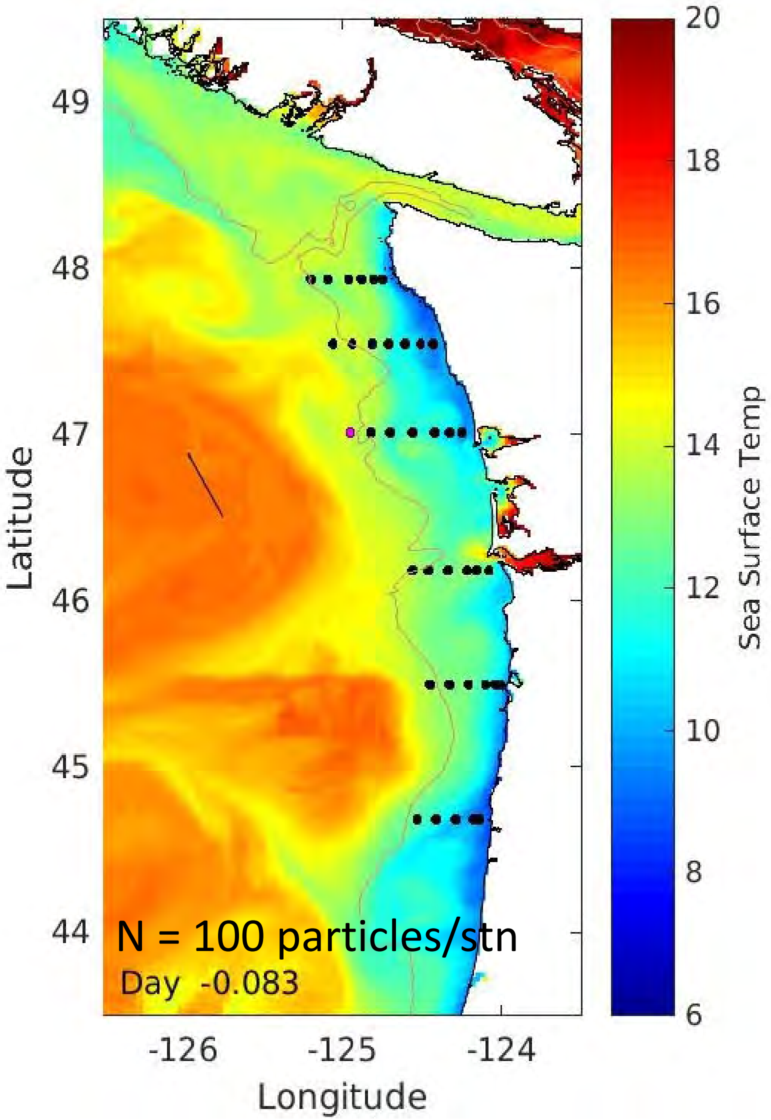


Estimating **exposure history** is more complicated...

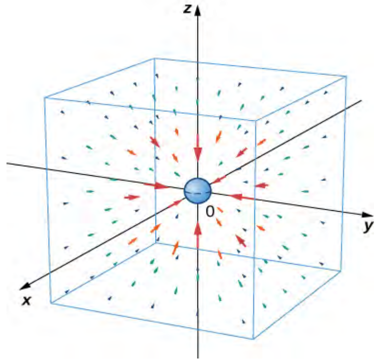
Norton et al., 2019 (submitted, *Front. Mar. Sci.*)

Develop EH models

Exposure History: Particle Dispersal Tracked Backward for 30 Days with LTRANSv2b[1]

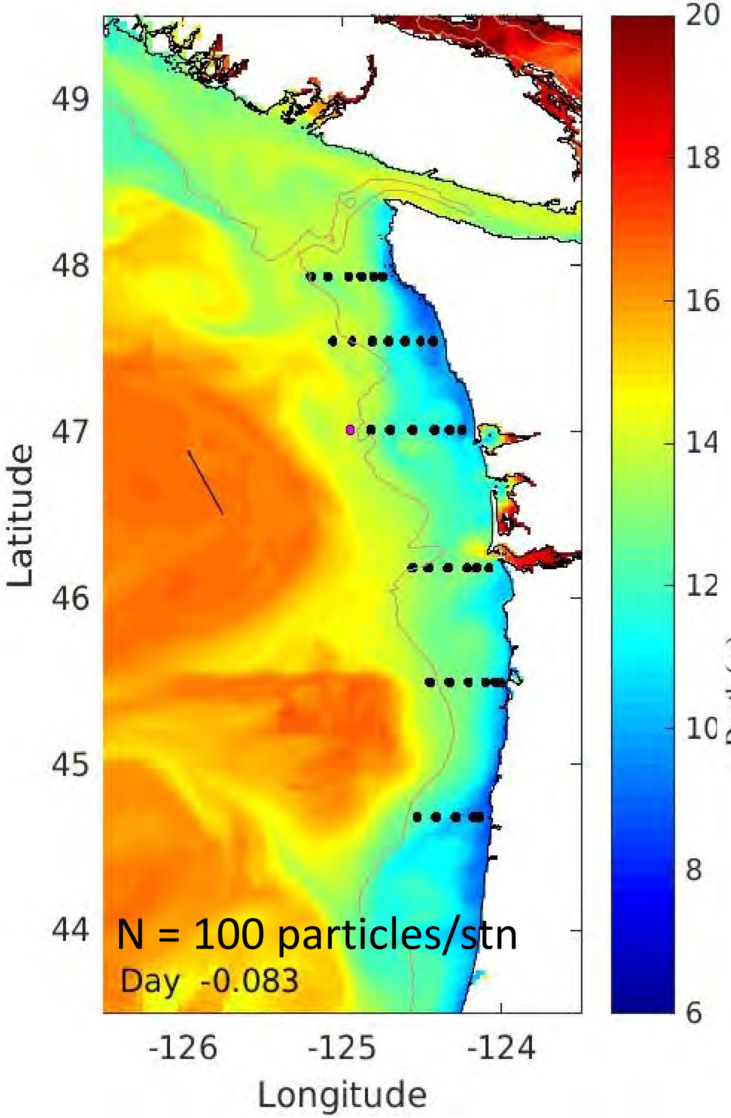


1. Advection and **environmental conditions** from J-SCOPE



[1]North et al., 2008; 2011; Schlag and North, 2012

Exposure History: Particle Dispersal Tracked Backward for 30 Days with LTRANSv2b[1]



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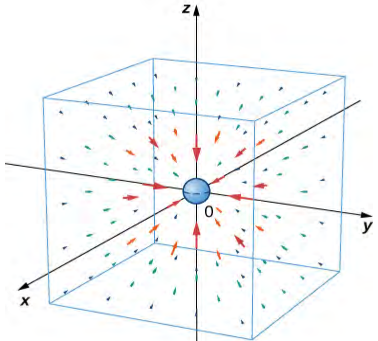
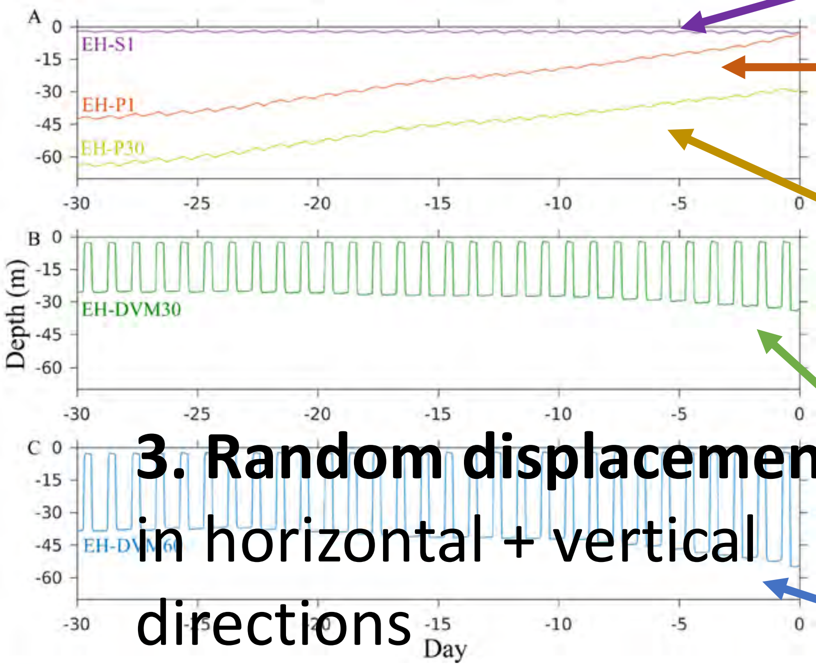


2. Larval Behavior



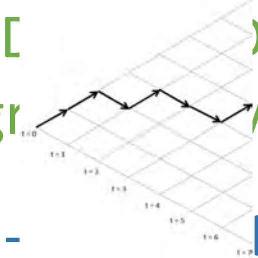
EH-S1: Surface-following

EH-P1: Passive dispersal initialized at 1m

EH-P30: Passive initialized 30m

EH-D iel vertical migr /M) 0-30m

EH- DVM 0-60m



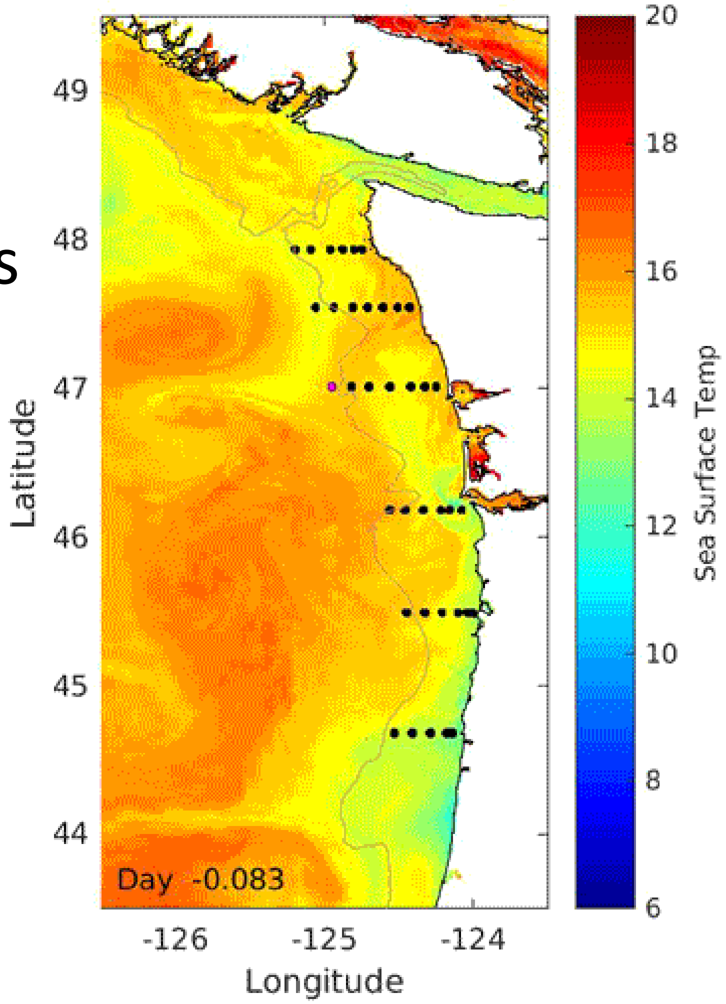
3. Random displacement in horizontal + vertical directions

[1]North et al., 2008; 2011; Schlag and North, 2012

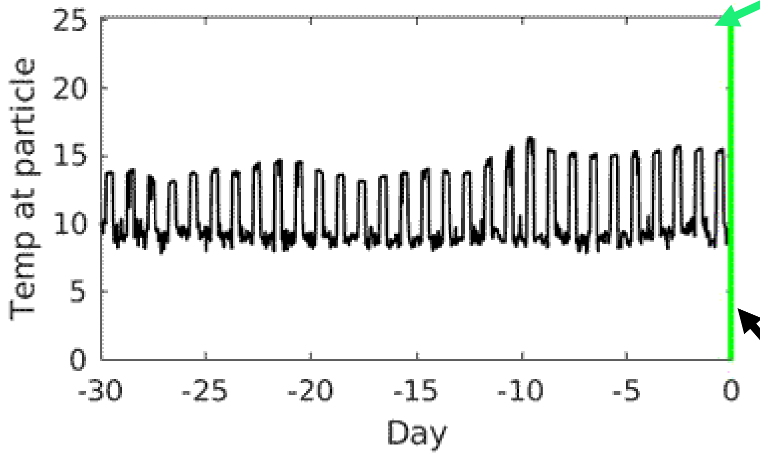
Develop EH models

Environmental Conditions Extracted Along Particle Trajectories

Particle tracks over SST field

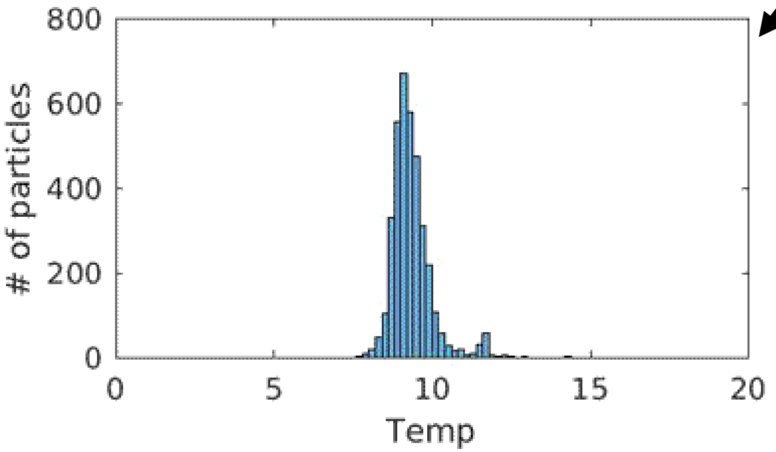


Day in simulation



Temperature at one particle

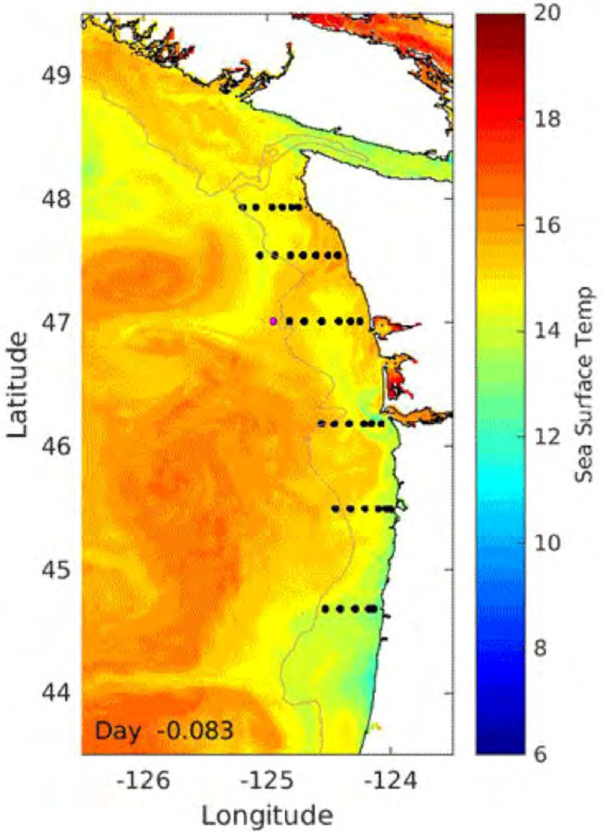
Indicative of DVM

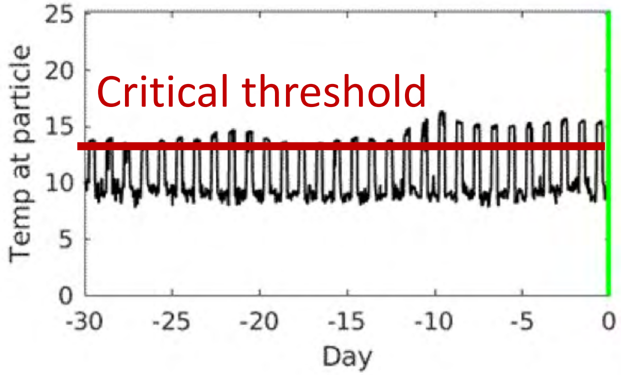


Temperature histogram for all particles

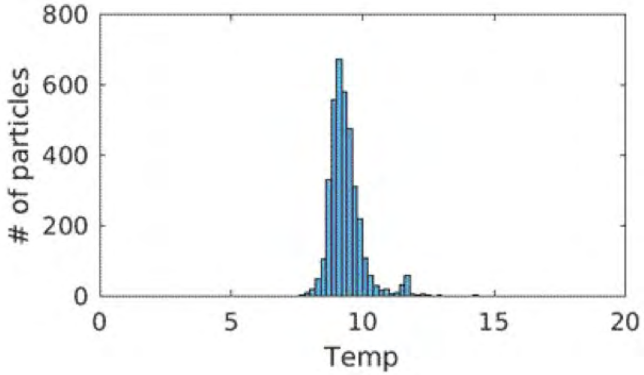
Norton et al., 2019 (submitted, *Front. Mar. Sci.*)

Calculated Two Types of Exposure Histories Variables

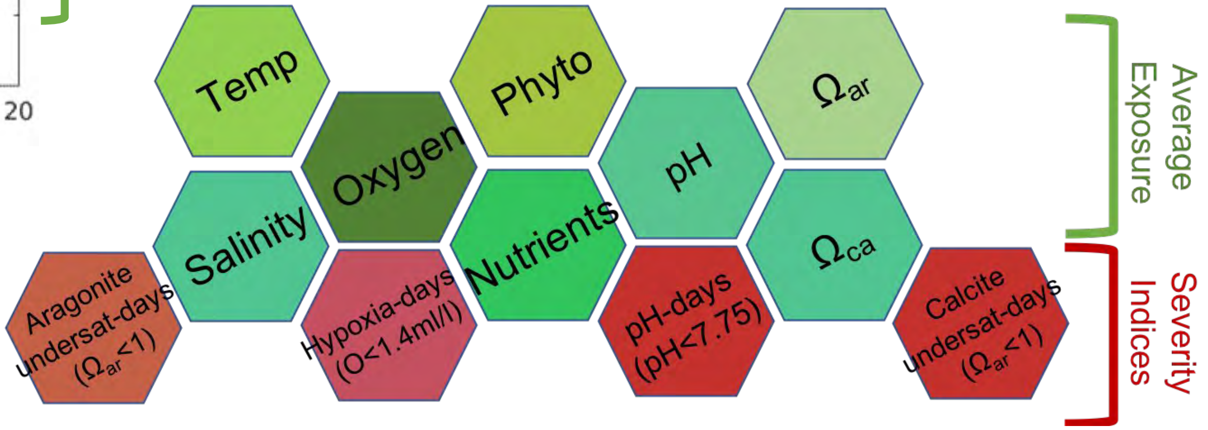




2. **Severity Index**: Time and degree by which a threshold was surpassed



1. **Average** conditions



J-SCOPE

Norton et al., 2019 (submitted, *Front. Mar. Sci.*)

Compare models

Exposure History Models Show Better Fit and Performance Than *in situ* Model

Relative Model Fit (0 is best)

Experiment	Predictor Variables (**bold p<0.05**)	ΔAIC	in-sample AUC
in situ	-**N**	11.8	0.602
EH-P1	+**S**, +**O**	0.0	0.658
EH-P30	+P, -**SI Ωar**	1.9	0.625
EH-DVM30	+**O**	4.7	0.644
EH-DVM60	+**S**, +**O**	5.3	0.650
EH-S1	-T, -**N**, -SI **Ωca**	7.9	0.645

Model Performance (0→1, higher is better)

Worst model fit *and* performance

4 EH models have good fit *and* performance

→Assemble "**biological ensemble**"

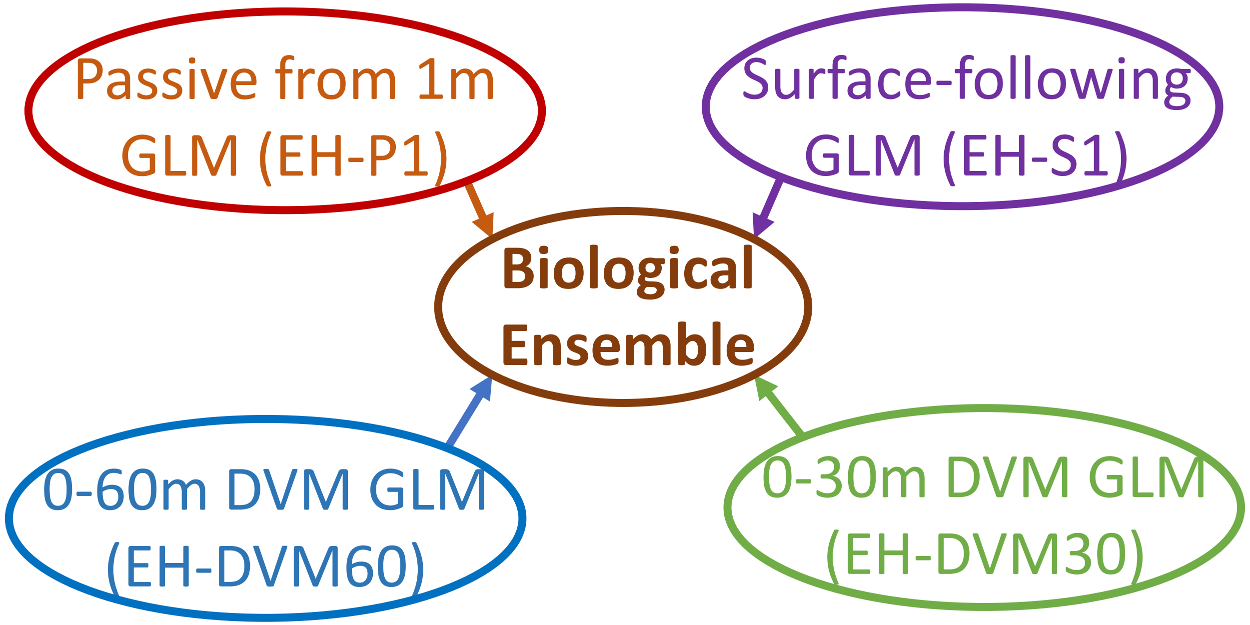
Predictor(s) in GLM with direction (-/+) of correlation to megalopae occurrence

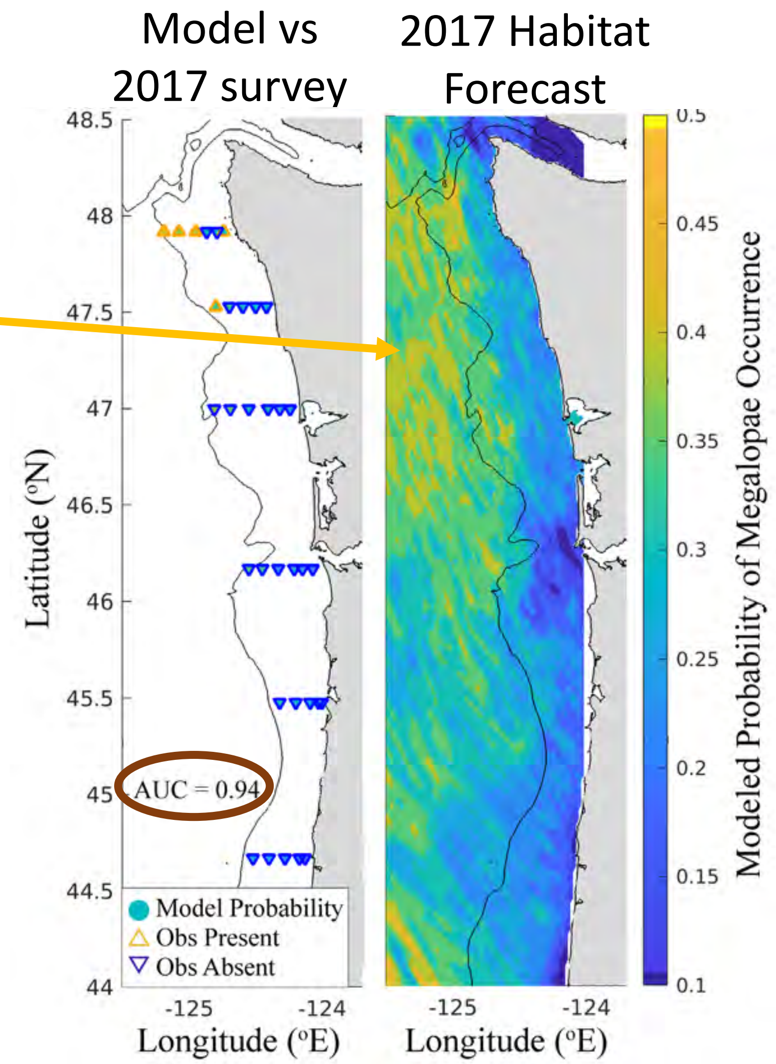
J-SCOPE

Norton et al., 2019 (submitted, *Front. Mar. Sci.*)

Biological Ensemble Skillfully Forecasts Megalopae Occurrence

- Biological ensemble represents multiple behaviors
- 94% agreement with 2017 megalopae survey
- Predicts habitat on outershelf and northern areas





Norton et al., 2019 (submitted, *Front. Mar. Sci.*)

Conclusions

- Prediction of pelagic habitat for Dungeness megalopae is possible with a combination of tools: ocean conditions model, particle tracking, statistical modeling
- Models that include exposure history outperform those that solely rely on *in situ* conditions
- Simulated behavior affects depth habitat and ultimately drives environmental exposure
- Best prediction was the result of a biological ensemble that includes multiple behaviors

J-SCOPE

Norton et al., 2019 (submitted, *Front. Mar. Sci.*)

Acknowledgements

Funding for this project provided by NOAA Ocean Acidification Program. Funding for J-SCOPE provided by NOAA MAPP and NOAA OAP.

Thanks to Bonneville Power Administration, NOAA NWFSC, and *F/V Frosti* crew for sample collection.

NOAA OCEAN ACIDIFICATION PROGRAM

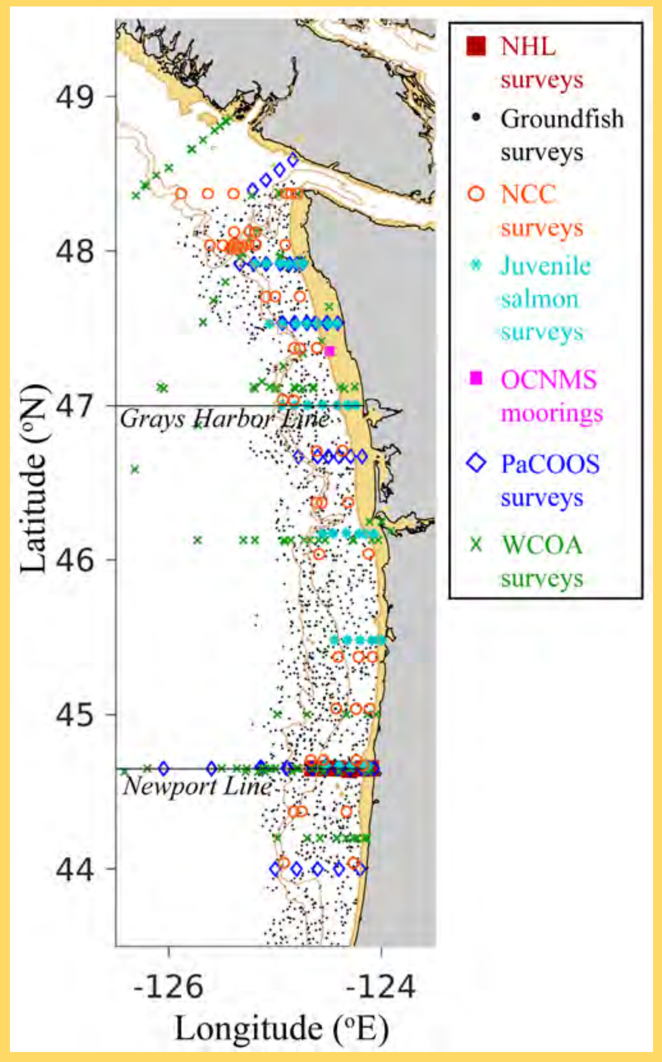
For more information, check out our website:
http://www.nanoos.org/products/j-scope/home.php

Photo Credit: R. Norton

Ocean Condition Observations for J-SCOPE Skill Assessment

- Surface, seafloor, and water column measurements
- Moorings and cruises
- 2009-2017

Observation Locations

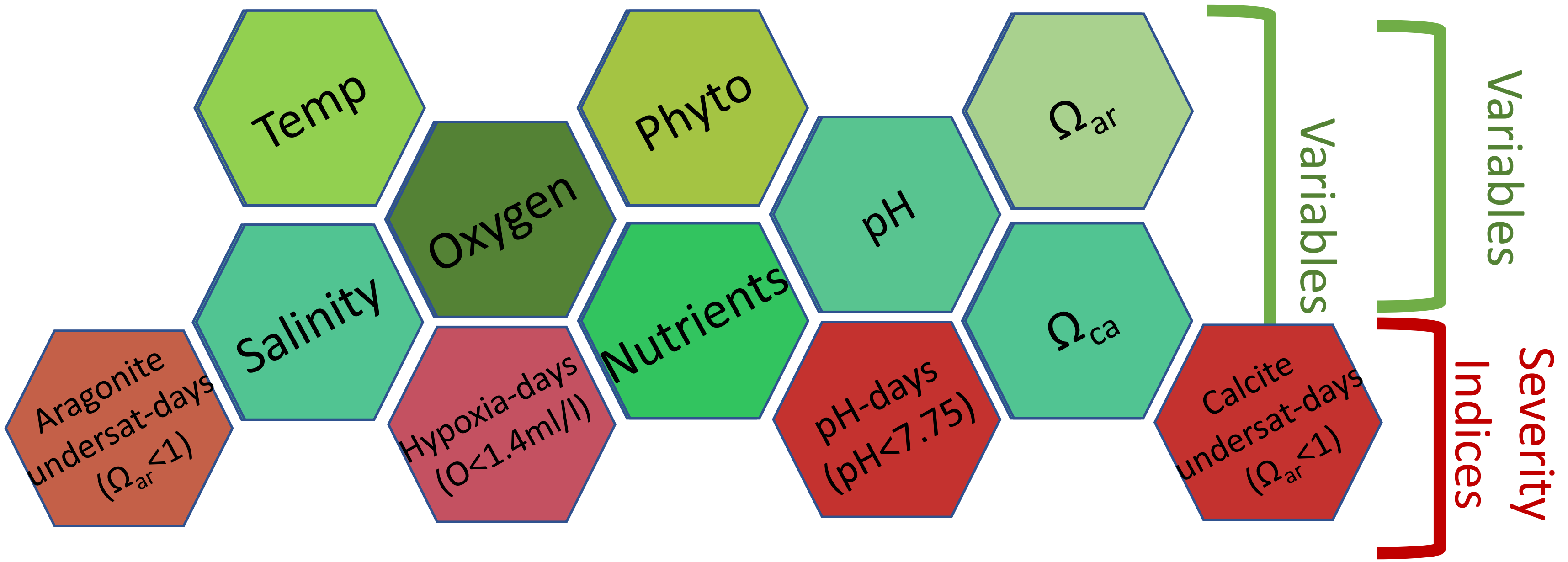


Select Environmental Variables to Consider for Occurrence Model

Criterion 1: Reported as important for megalopae in the literature

1b: Critical thresholds exist to calculate severity indices

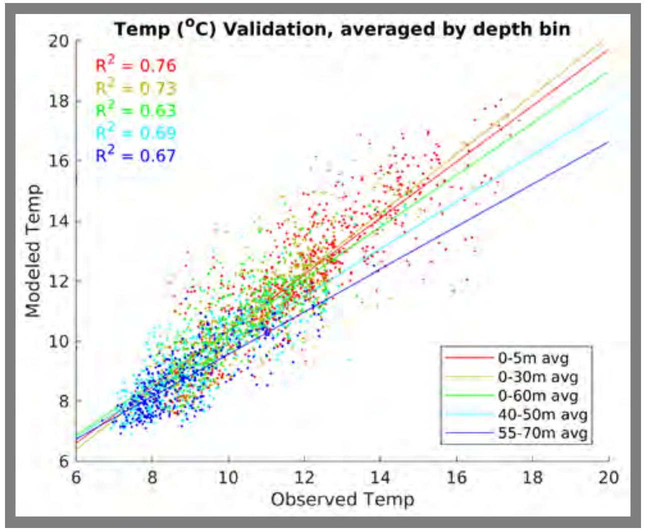
Criterion 2: Modeled by J-SCOPE (or could be derived from modeled variables)



Assess Skill of Modeled Variables

Motivation: Variable skill will influence performance of occurrence models
→ investigate patterns of J-SCOPE skill

- Paired modeled and observed variables within specific depth habitats and seasonal windows:
  1) Pearson's Correlation Coefficient ($r>0.5$)
  2) Normalized Root Mean Square Error ($-1<NRMSE<1$)

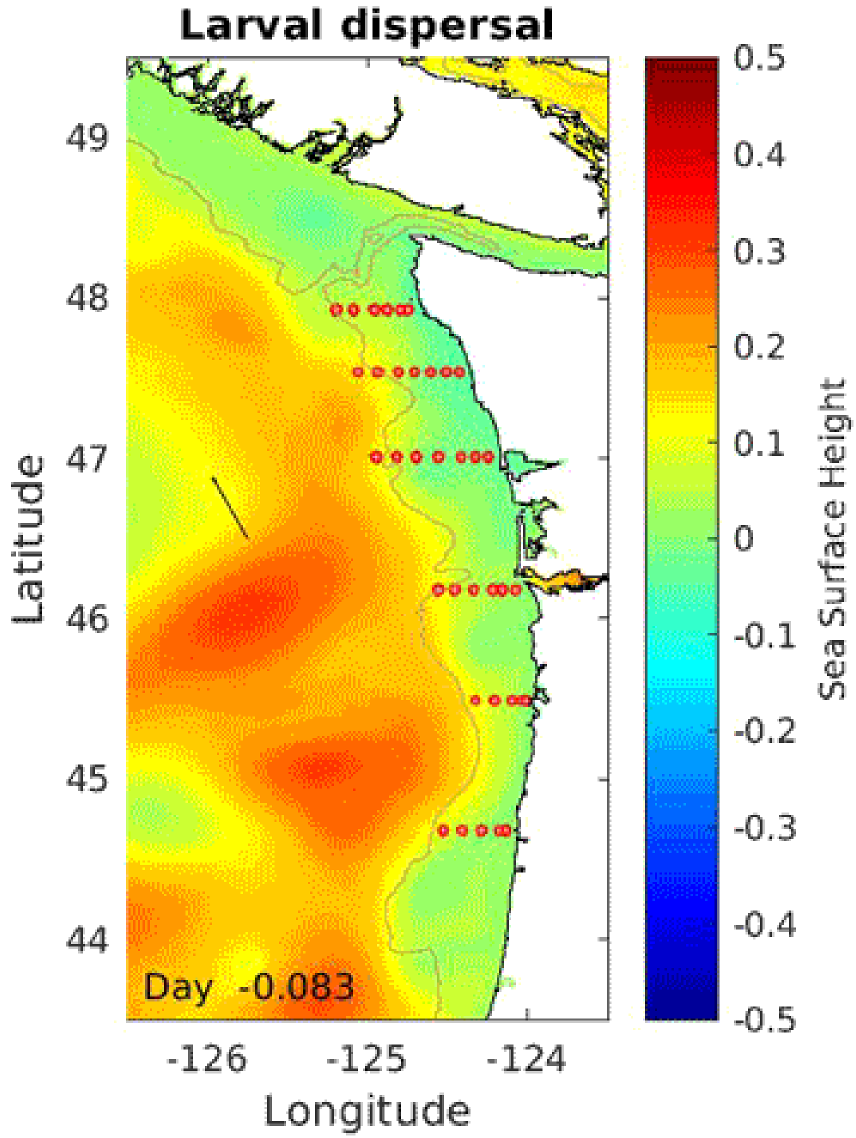


Experiment	Depth Habitat (m)	Temperature (°C)	Salinity	Oxygen (mmol m^{-3})	Nitrate (mmol m^{-3})	Phytoplankton (mmol m^{-3})	pH	Ω_{ar}	Ω_{ca}
EH-P1	40-50	0.87	0.66	0.71	0.75	0.04	0.72	0.73	0.77
		-0.59	-0.85	-0.94	2.63	-1.14	-0.90	-0.84	-0.77
		(2403)	(2403)	(2348)	(33)	(2353)	(2165)	(2165)	(2165)
EH-P30	55-70	0.89	0.61	0.54	N/A	0.09	0.58	0.56	0.72
		-0.51	-0.92	-1.25		-1.57	-1.13	-1.13	-0.88
		(2729)	(2729)	(2665)	(0)	(2689)	(2409)	(2409)	(2409)
EH-DVM30/ *in situ*	0-30	0.88	0.76	0.71	0.61	0.10	0.71	0.75	0.78
		0.58	-0.66	0.79	1.01	1.56	-0.77	-0.70	0.67
		(8391)	(8391)	(8189)	(860)	(8105)	(7516)	(7516)	(7516)
EH-DVM60	0-60	0.91	0.79	0.75	0.62	0.09	0.75	0.77	0.80
		0.51	-0.63	0.82	1.19	-1.30	0.78	0.73	0.68
		(14832)	(14832)	(14482)	(906)	(14398)	(13287)	(13287)	(13287)
EH-S1	0-5	0.82	0.74	0.50	0.62	0.50	0.56	0.72	0.76
		0.76	-0.70	-0.92	-0.84	2.71	-0.88	-0.72	-0.69
		(1335)	(1335)	(1302)	(625)	(1255)	(1195)	(1195)	(1195)

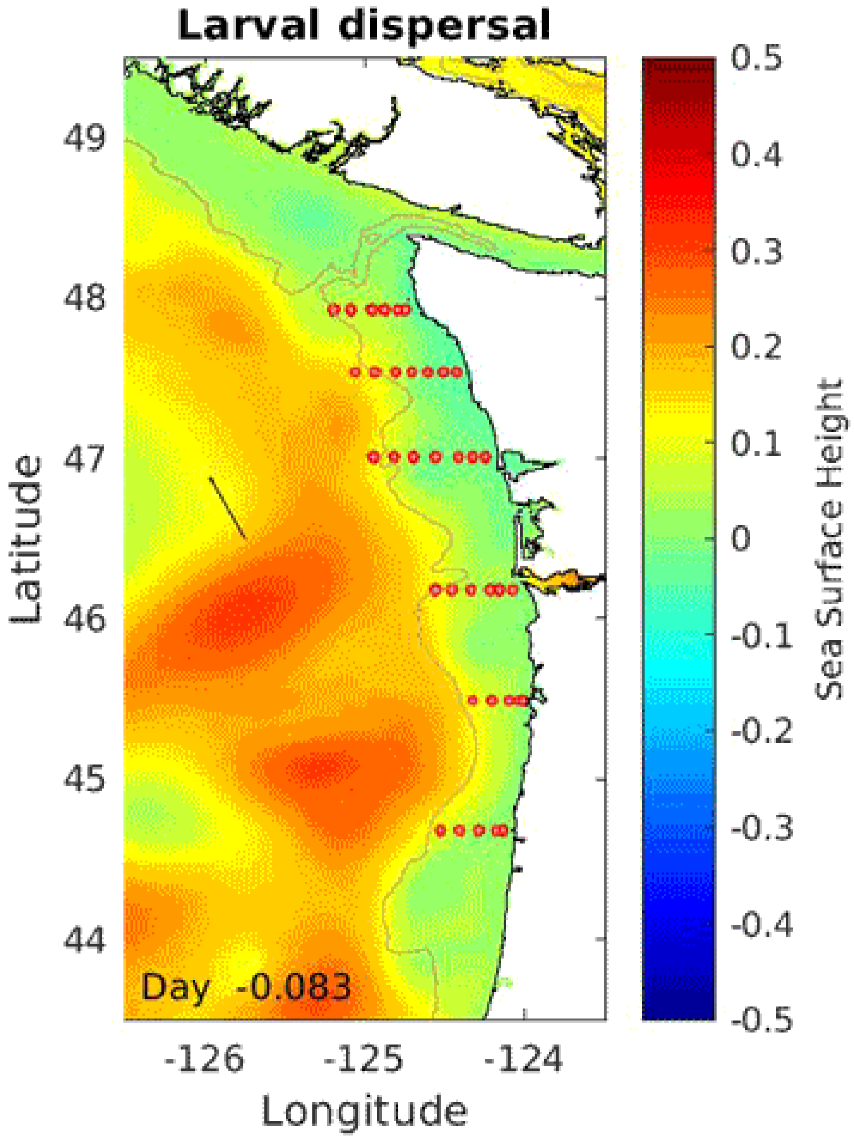
➔ Significant skill for most variables; skill increases subsurface

Results: Particle tracking simulations

Passive Dispersal

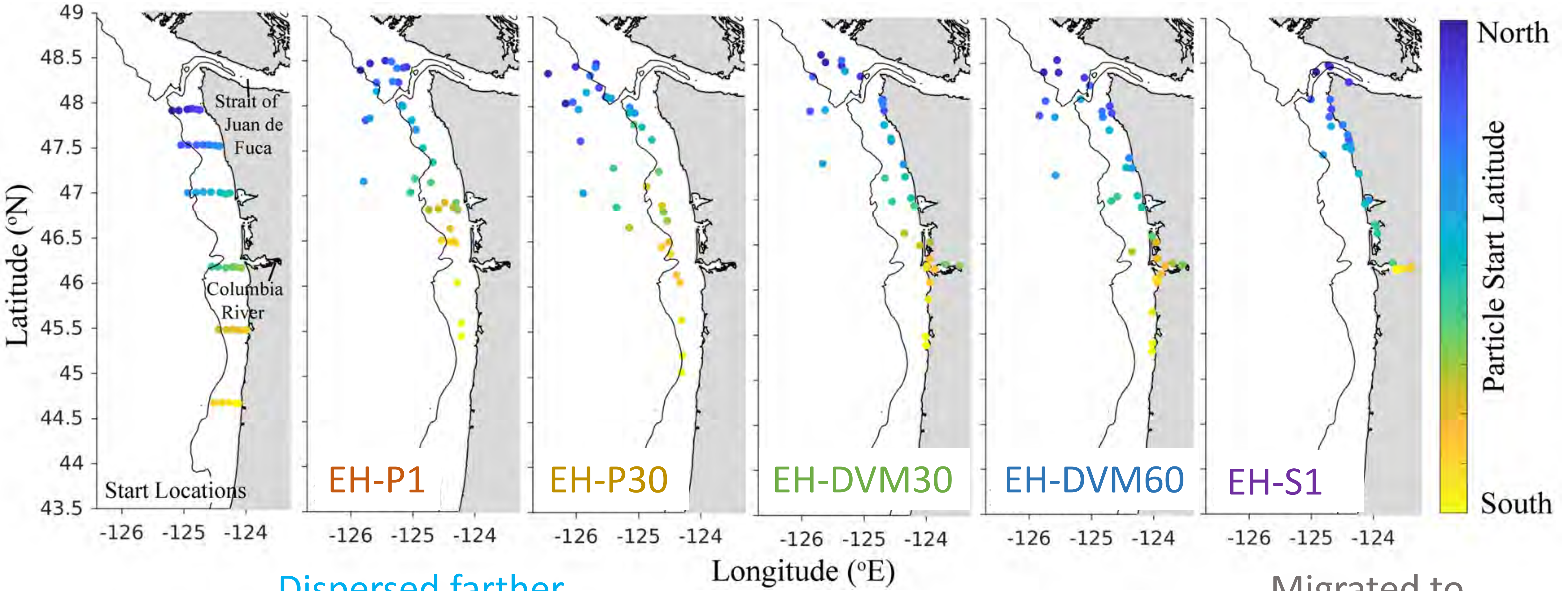


DVM Behavior



Develop EH models

Behavior and Initialization Depth Affect Dispersal Trajectory

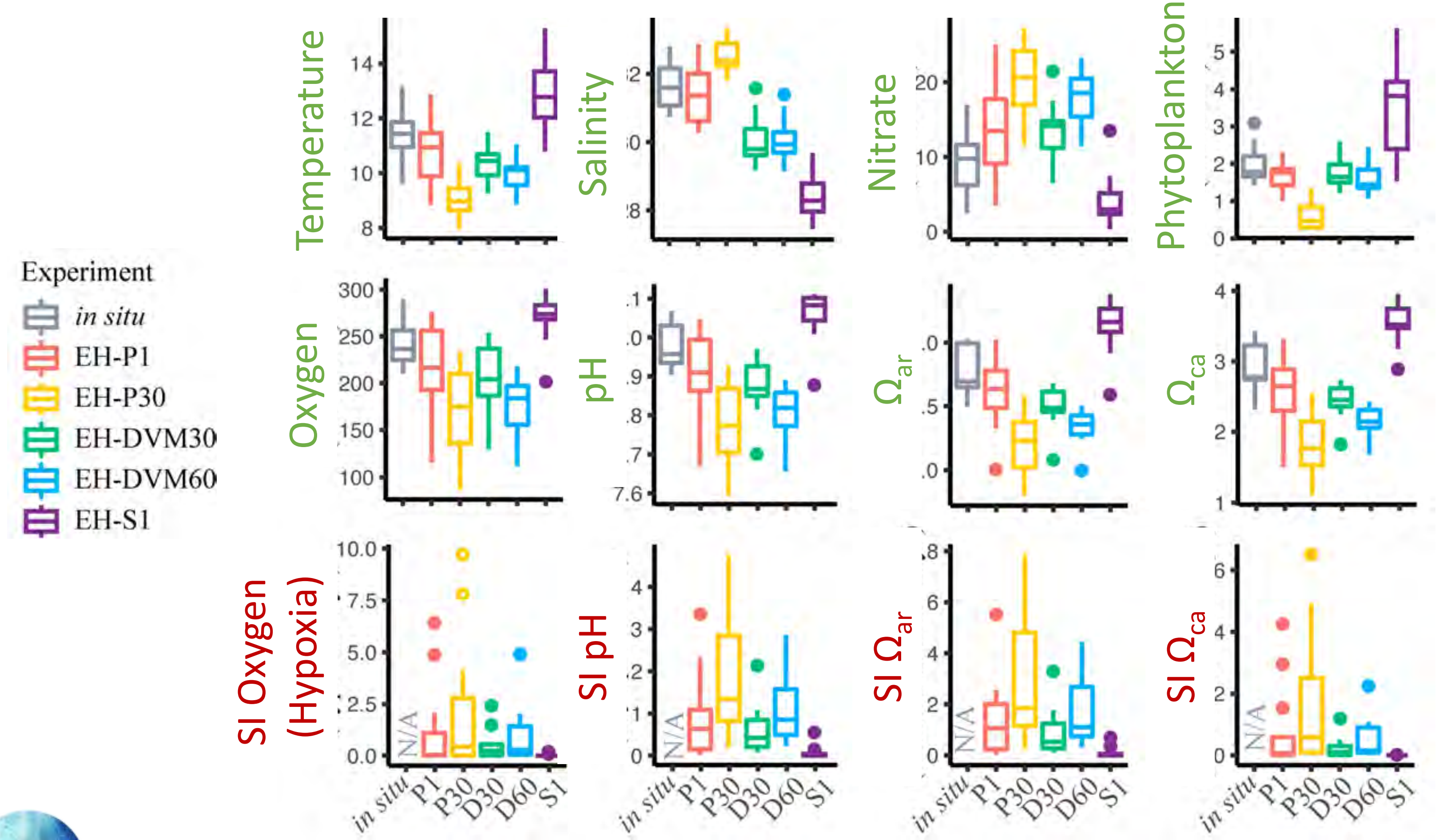


Dispersed farther offshore → Migrated to shore

Norton et al., 2019 (submitted, *Front. Mar. Sci.*)

Develop EH models

Environmental Exposure Influenced by Depth Habitat



1. Averages: **Depth habitat** drives exposure patterns – shallow (EH-S1) and deep (EH-P30) habitats are most divergent

2. Severity Indices: Severe conditions experienced in deep habitats (EH-P30, DVM60)

J-SCOPE

Norton et al., 2019 (submitted, *Front. Mar. Sci.*)

Compare models

Develop GLMs Using *in situ* and Exposure History Variables

Recall Aim: Model megalopae occurrence using in situ vs. exposure history variables

- Binomial distribution ('present' or 'absent') requires logit link function

$$Probability\ of\ Presence = log\left(\frac{\mu}{1-\mu}\right)$$

where

$$\mu = \frac{e^{X_b}}{1+e^{X_b}}$$

X_b is linear combinations of predictor variables

- Considered all variables as potential predictors
  - Selected best combination of variables based on lowest AIC score

Biological ensemble – 2017 performance

Experiment	Equation **(bold p<0.05)**	2017 AUC
EH-P1	-11.0 + 0.248***S** + 0.0111***O**	0.914
EH-DVM30	-3.01 + 0.109***O**	0.814
EH-DVM60	-6.42 + 0.132***S** + 0.00988***O**	0.936
EH-S1	1.77 - 0.157*T - 0.0994***N** - 79.5*(SI Ωca)	0.757
Biological Ensemble:		0.936

11:50a – 12:10p: 15 min talk + 5 min Q