Climate-driven changes in size-dependent overwintering success in age-0 Pacific cod

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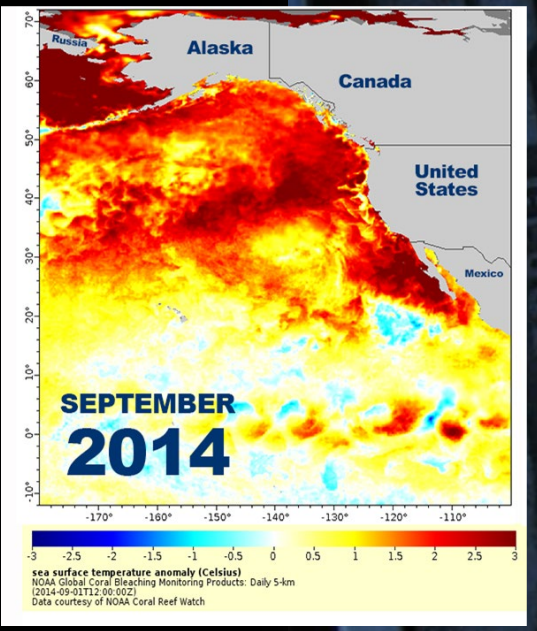
Cod fisheries in the wake of climate change



Gulf of Alaska Pacific cod (*Gadus macrocephalus*)

- Federal fishery closed in 2020

Bioenergetic stress during the marine heatwave

Gulf of Alaska Ecosystem Assessment (Zador et al 2017)

- Loss of productivity
- Lower trophic transfer efficiency
- Increased metabolic demand
- Seasonal interactions e.g., winter
- Evidence based on observations of summer diets (fullness, prey quality) and bioenergetic models

62 cm adult Pacific cod – Anton Larsen Bay, Kodiak
Photo by P. Iseri

But what about early life stages?

Early life stages determine population dynamics

Egg development (Late winter – early spring)

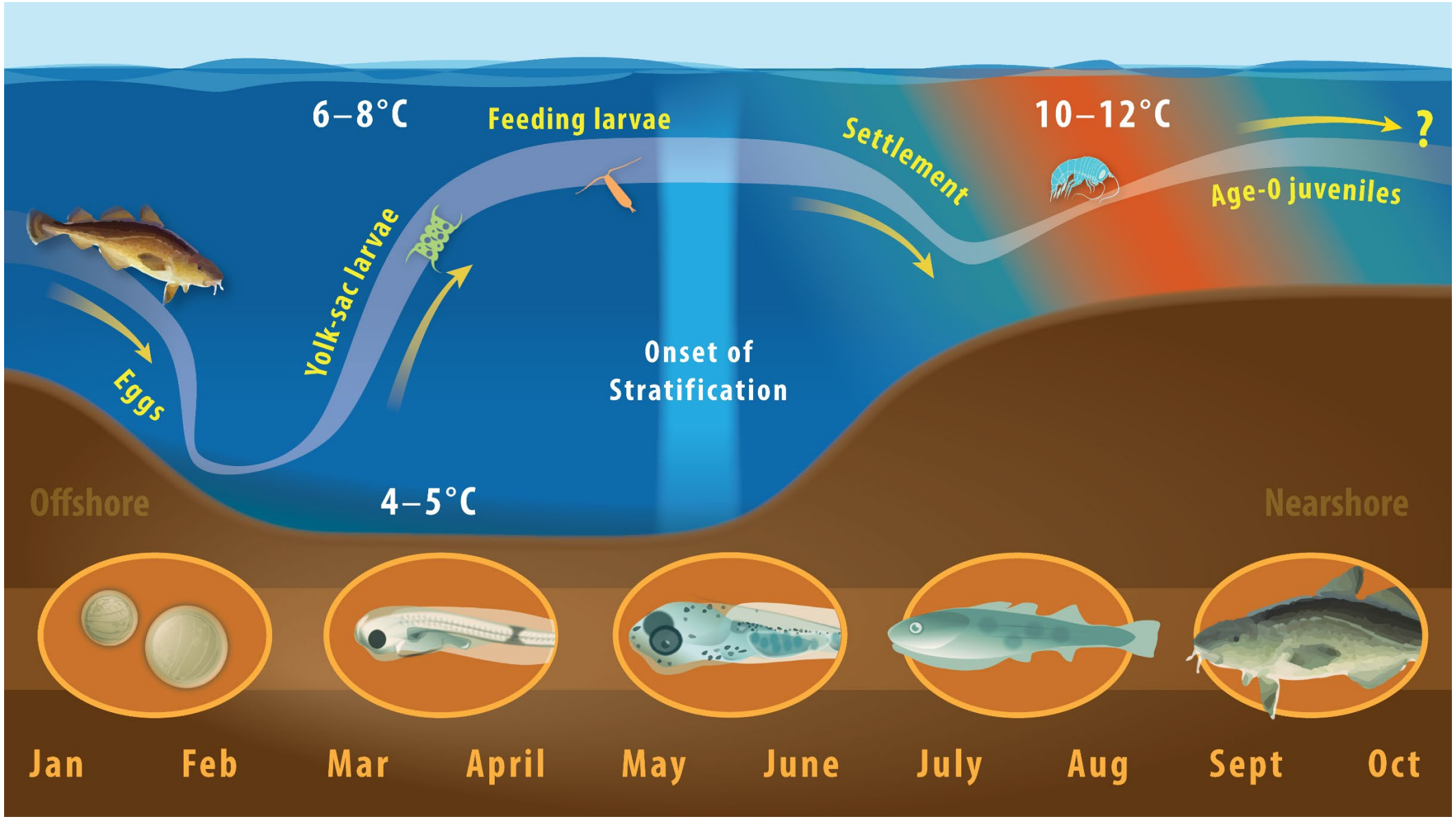
Larval period (Spring)

Settled juveniles (Summer –fall)

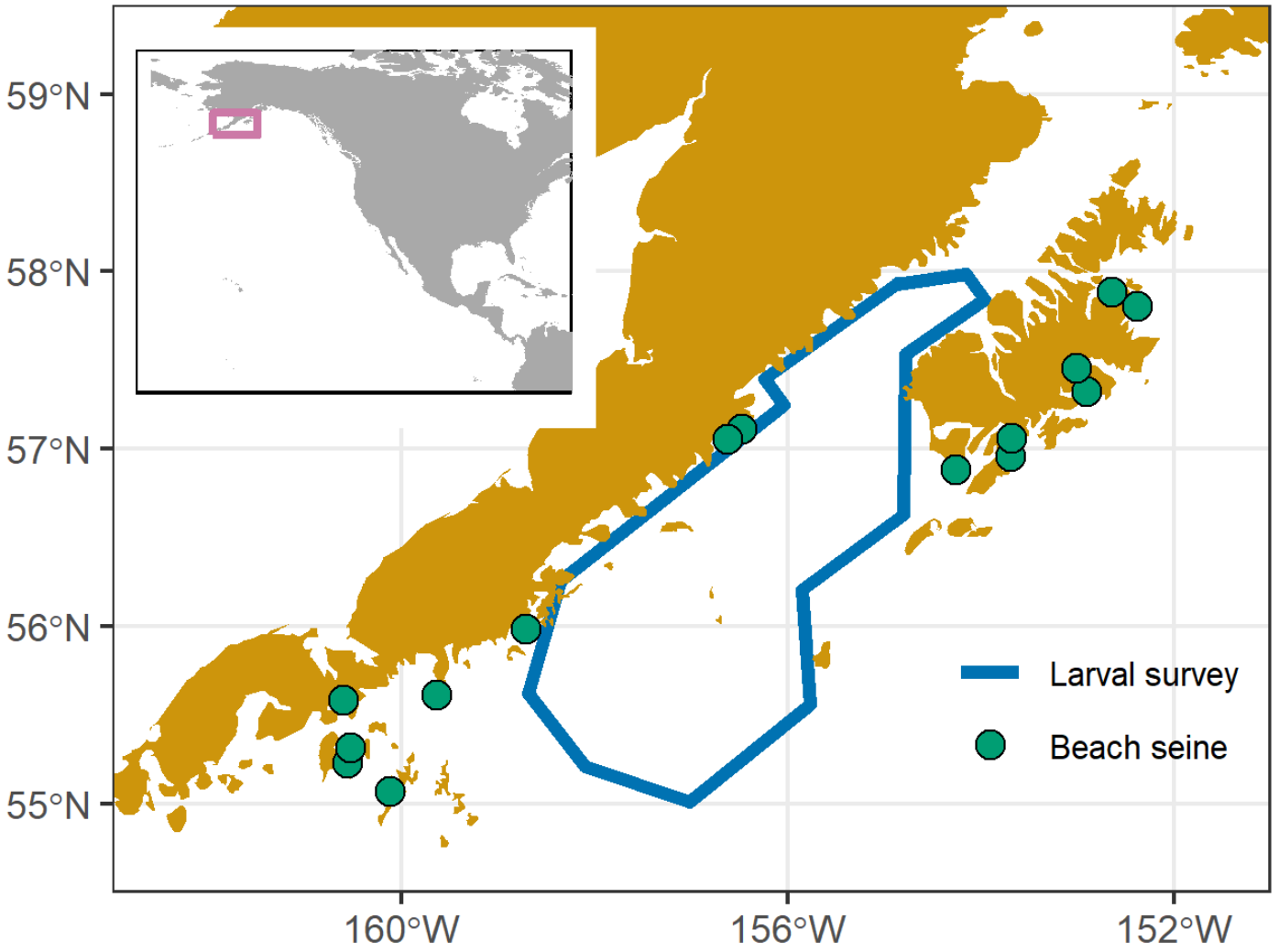
1st overwintering

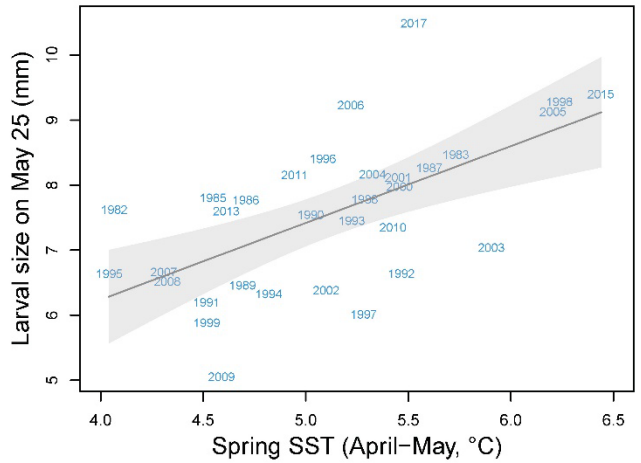
Johan Hjort

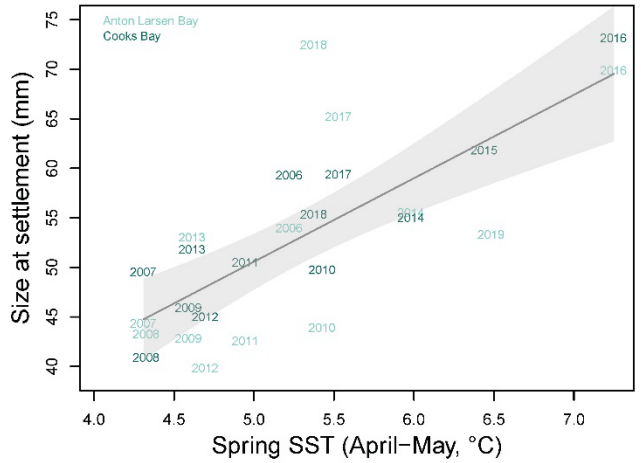
Review of early life stages

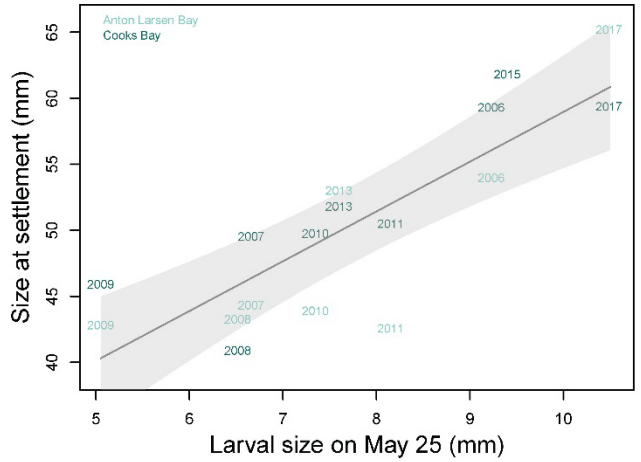


Warming results in bigger larvae and age-0 juvenile cod

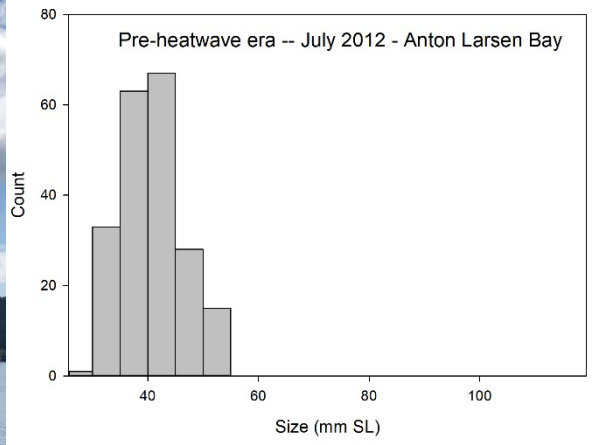


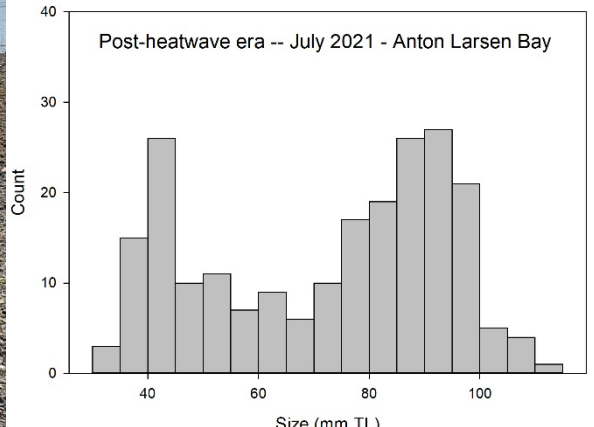






Changes in age-0 juvenile size structure in the post-heatwave era



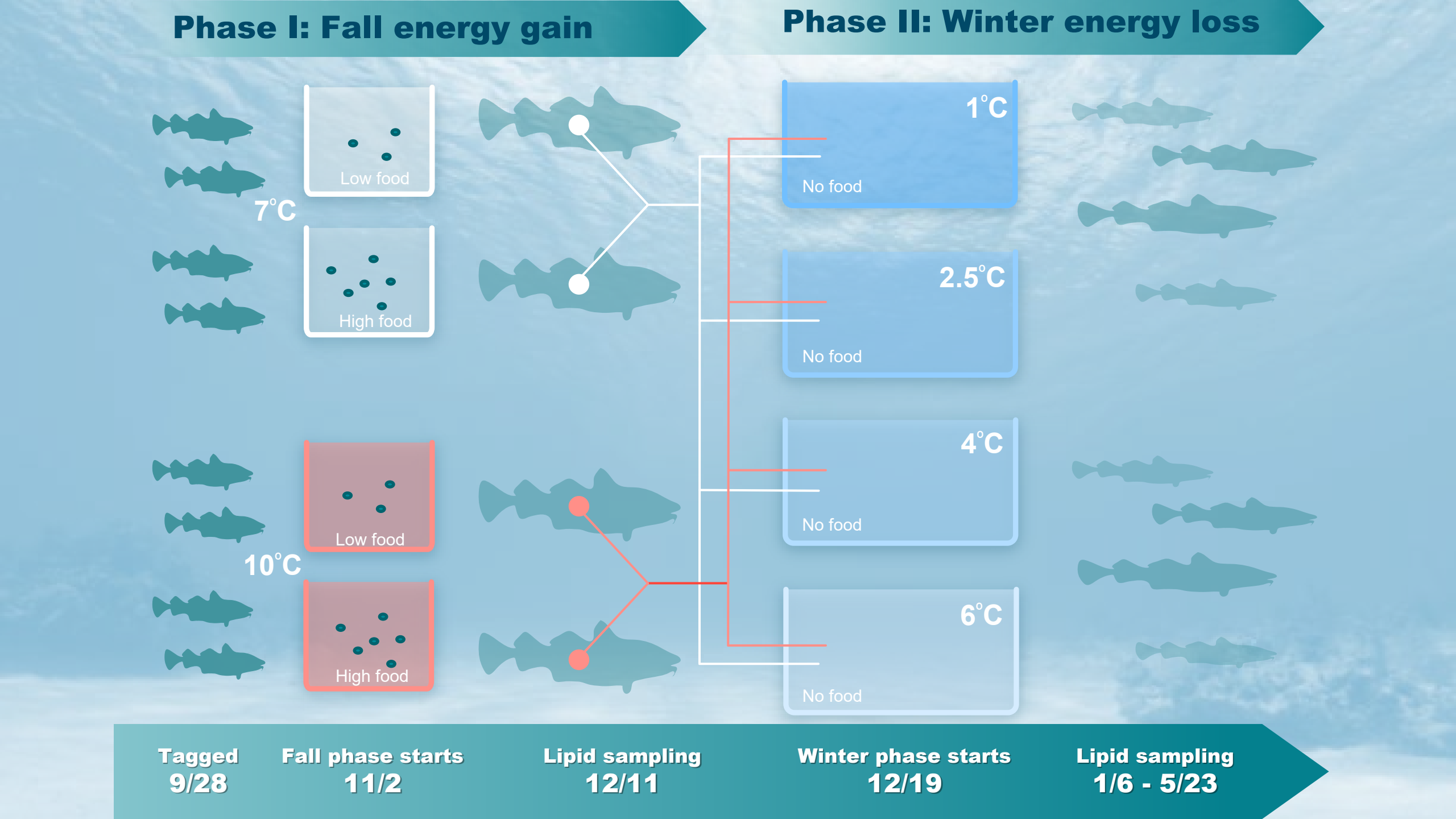


Will changes in size structure impact first winter survival?

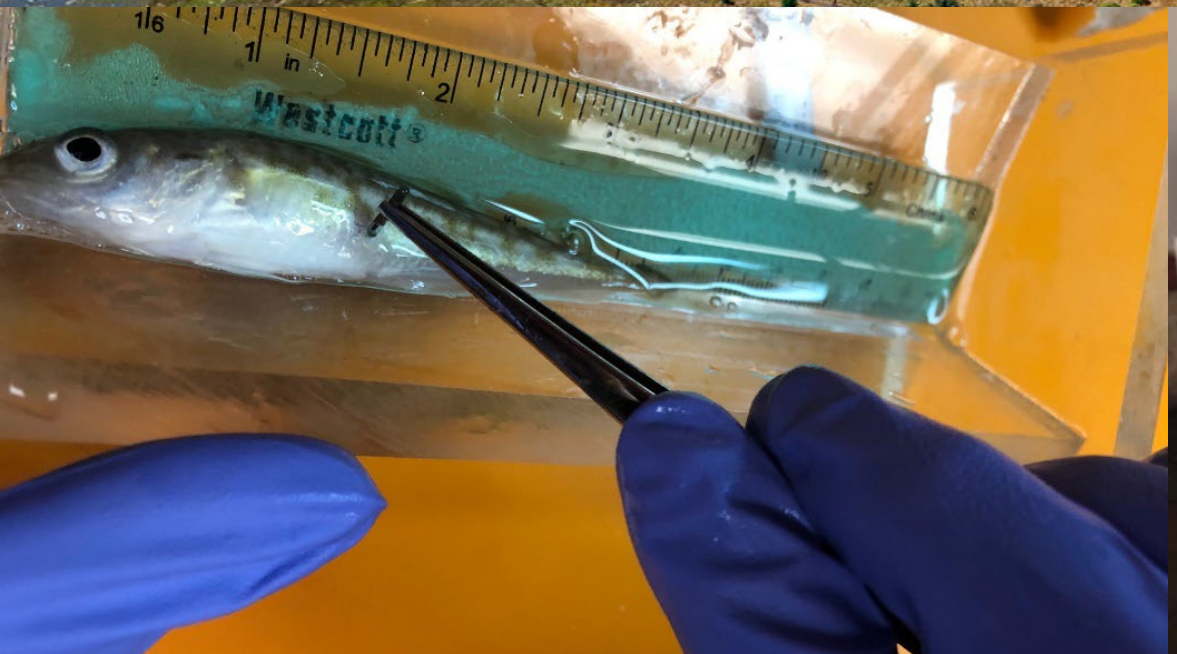
- In freshwater, overwintering survival is higher in larger juveniles (Post and Evans, 1989; Bystrom et al. 2006; Huss et al 2008).
    - Weight specific standard metabolic rates (Jobling 1990)
    - Lower energy storage in smaller individuals (Hunter and Post 1990; Lankford and Targett 2001)
- In marine systems, overwintering survival is more poorly understood (Hurst 2006)
    - Pre-winter energetic condition and feeding conditions (Heintz et al 2013)
    - Can be size independent and/or linked to fall growth (Geissinger et al. 2021; Geissinger et al in review)
- Overwintering success rests on many assumptions on environmental conditions (e.g., predators, thermal habitat, food availability).
- Climate change likely to change overwintering success by way of a number of mechanisms in unpredictable ways

Questions

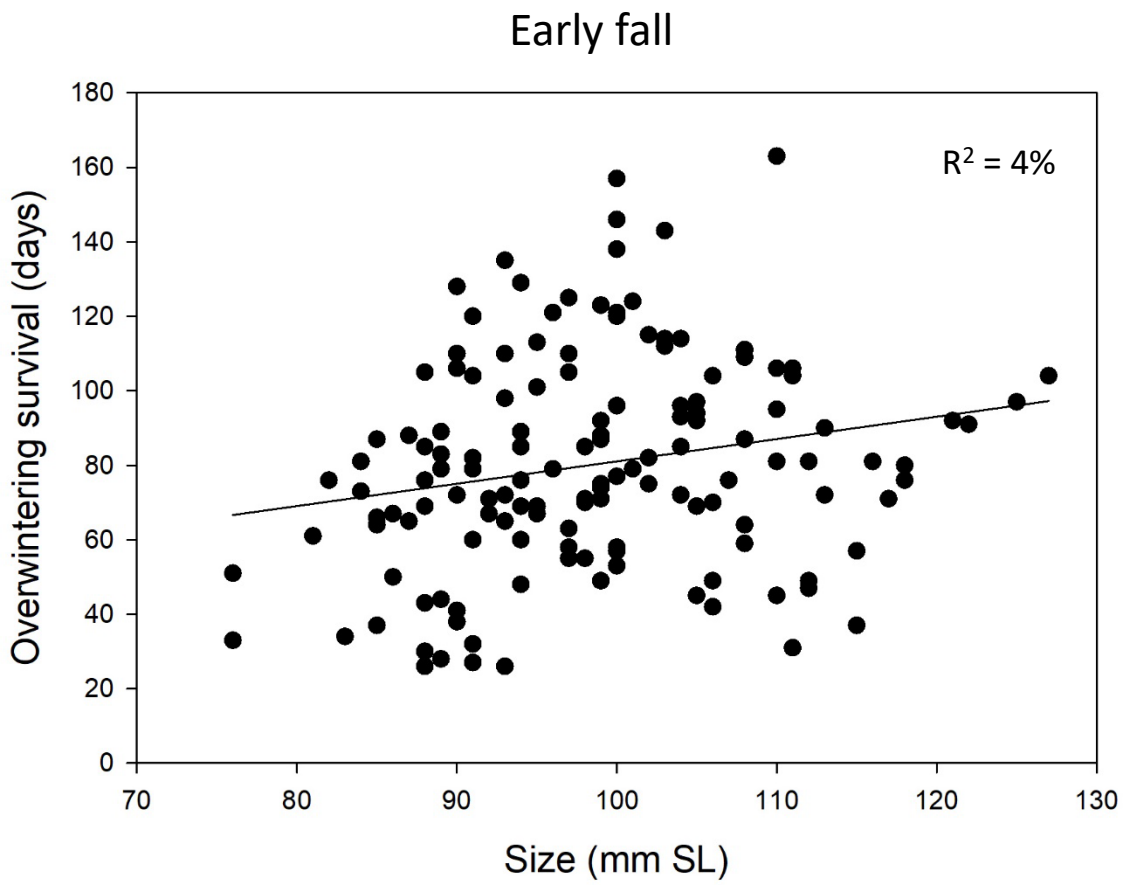
- 1) Can overwintering success be predicted from late summer cohort demographics e.g. size-at-capture?
- 2) To what degree does feeding and thermal experience in the fall impact winter survival?
- 3) Do condition metrics based on growth and lipid energy improve predictions of winter survival?
- 4) Will warmer thermal regimes (warm falls coupled with warm winters) amplify overwintering mortality in age-0 Pacific cod?

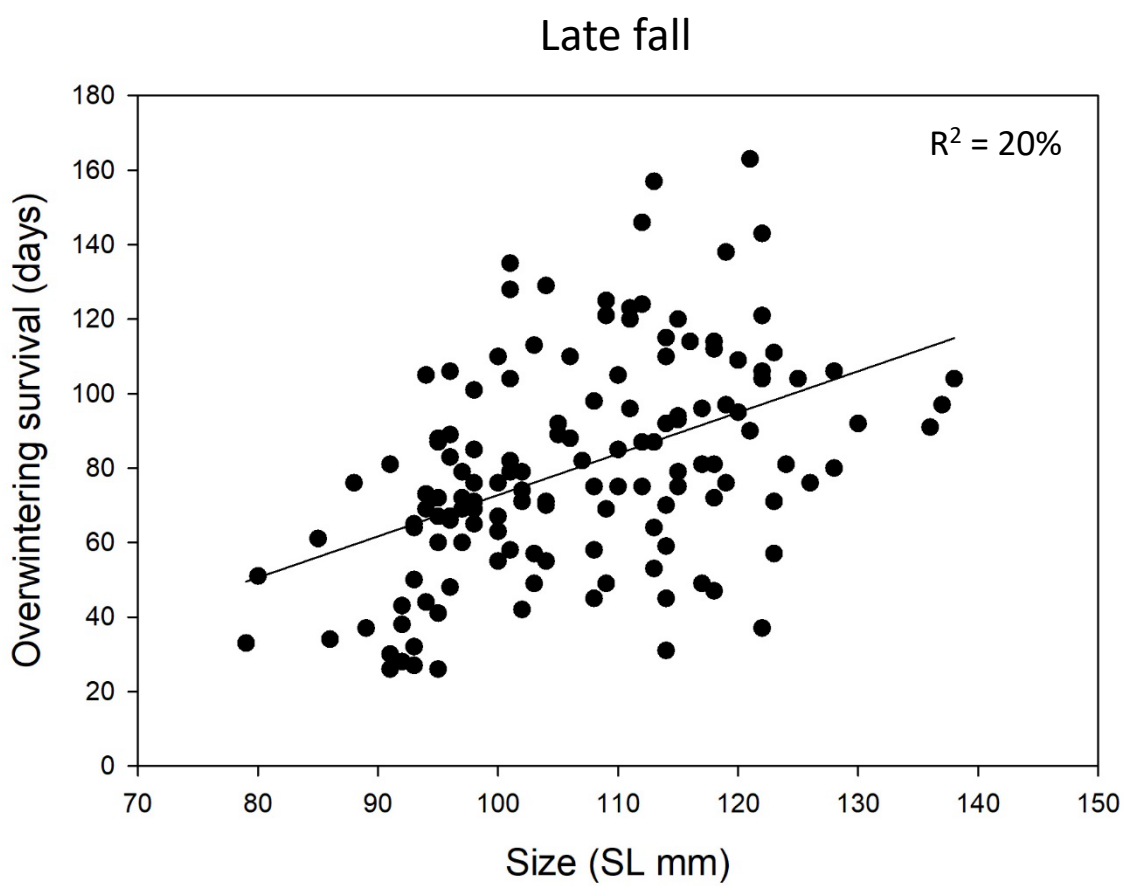

Phase I: Fall energy gain
Phase II: Winter energy loss
7°C
Low food
High food
10°C
Low food
High food
1°C
No food
2.5°C
No food
4°C
No food
6°C
No food
Tagged
9/28
Fall phase starts
11/2
Lipid sampling
12/11
Winter phase starts
12/19
Lipid sampling
1/6 - 5/23

Hatfield Marine Science Center – Newport, OR

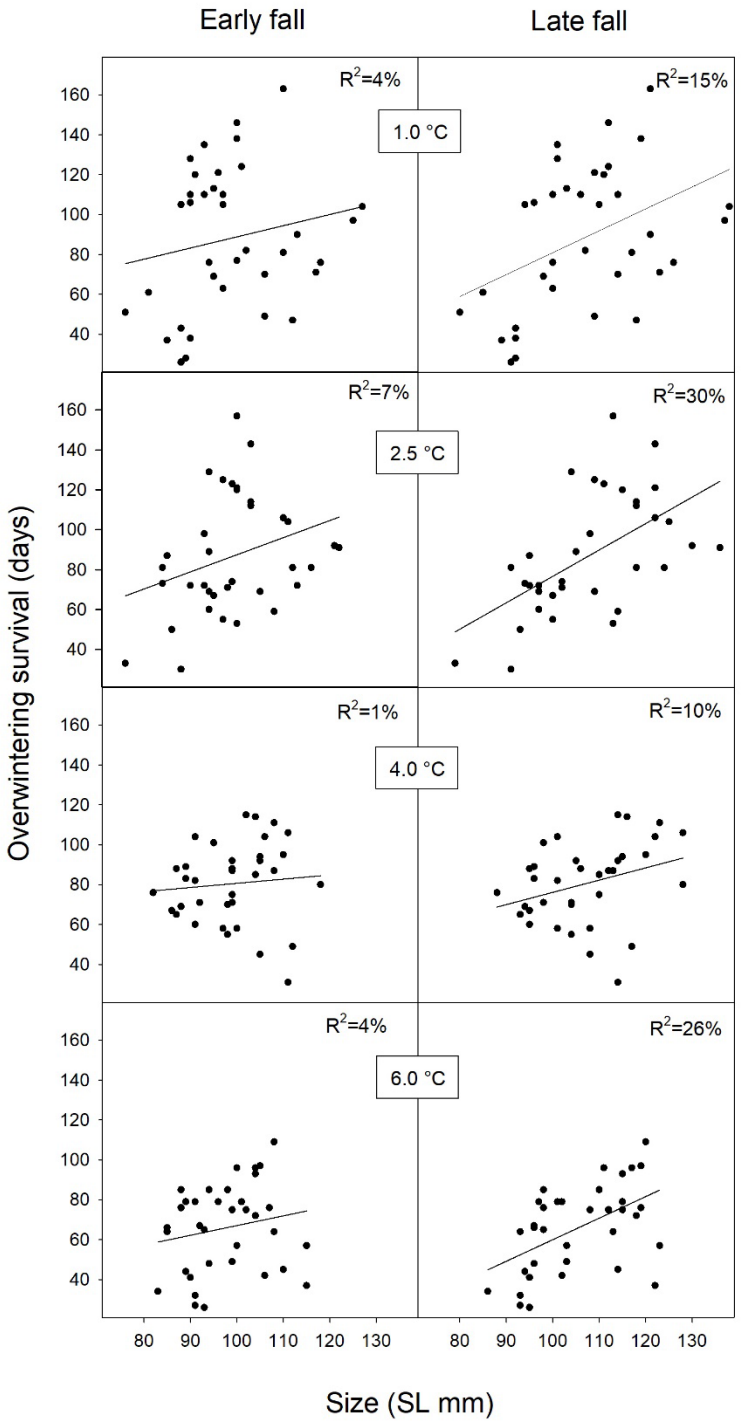


Size is a weak predictor of overwintering survival but improves when measured just before winter onset

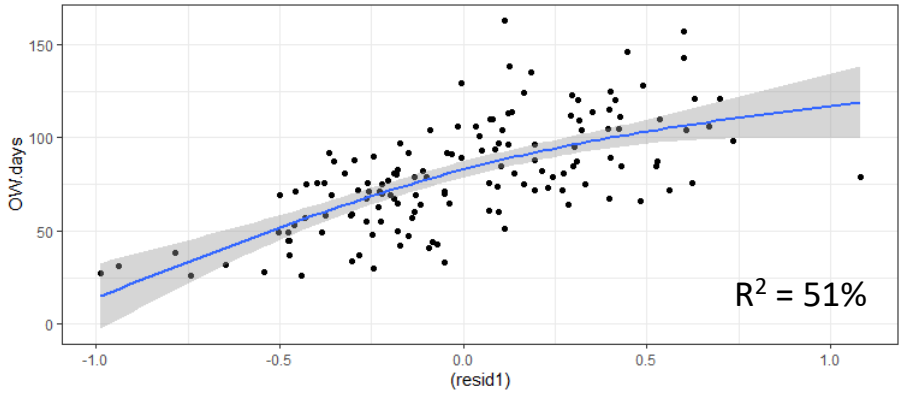




Size is still a weak predictor of overwintering survival even when thermal winter conditions are known



Fall growth experience impacts winter survival



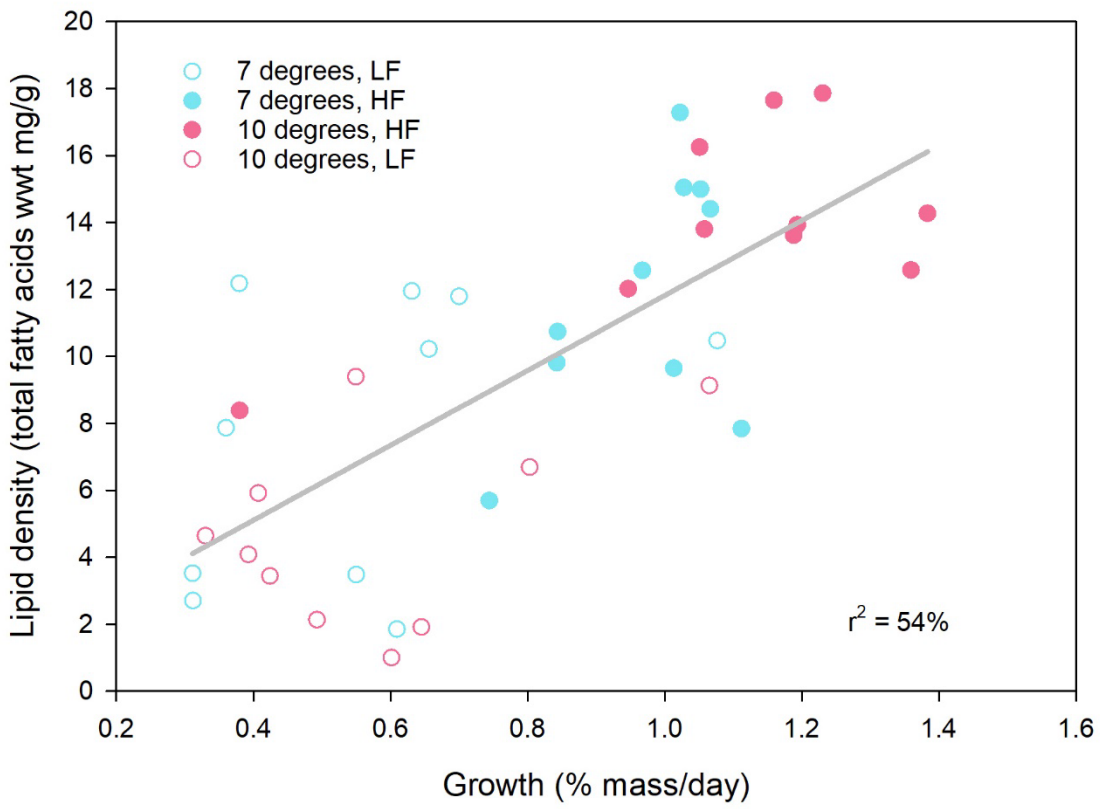
Fall growth predicts overwintering survival without knowing fall/winter environmental experience

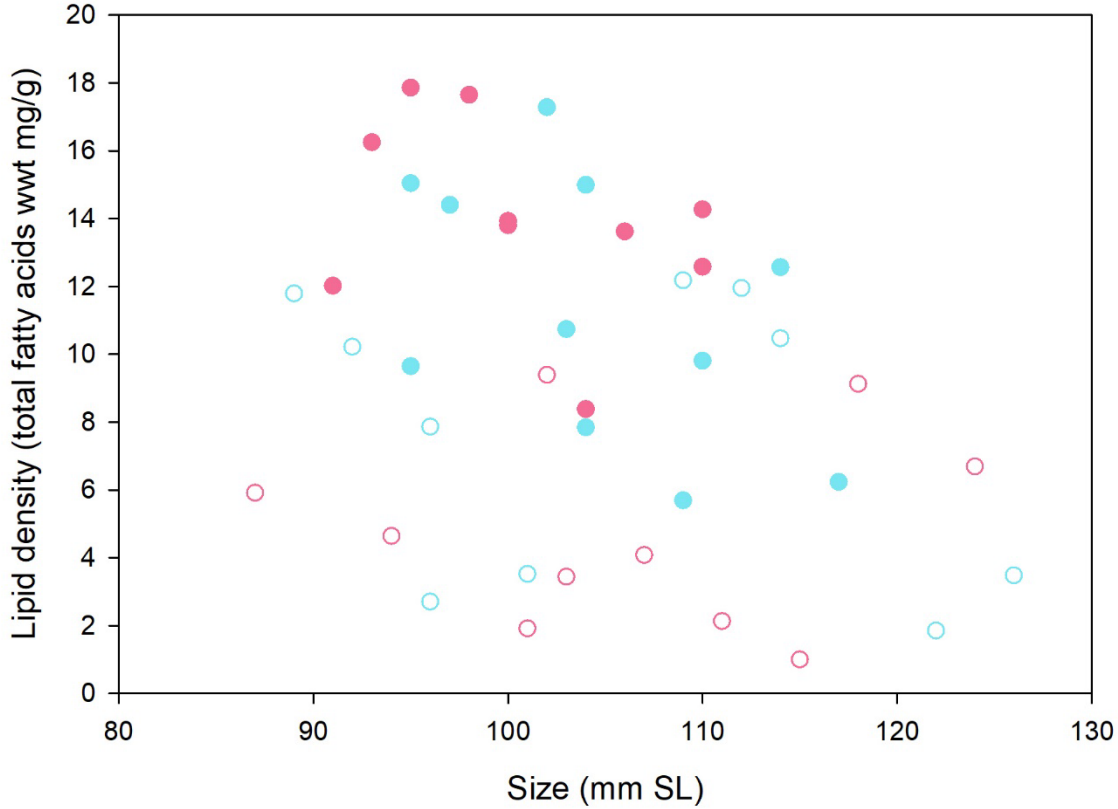
Fish under high food conditions in the fall grew faster and survived longer

Warm conditions in the fall reduce growth potential under low food conditions

Winter survival depends more on winter temperature for high fed fish in contrast to growth for low fed fish

Growth is a proxy for lipid density…….. but size is not!.





Conclusions

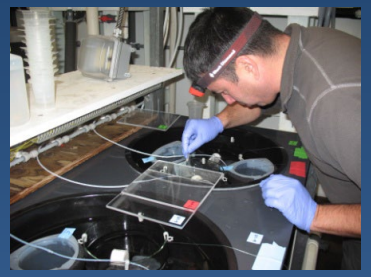
- 1) Can overwintering success be predicted from late summer/early fall size-at-capture?
  - Sometimes but need to know both fall and winter environments. Size is not a predictor of lipid density.
- 2) To what degree does feeding and thermal experience in the fall impact winter survival?
  - Fall food availability is very important to winter survival, especially under warm fall conditions
- 3) Do condition metrics based on growth and lipid energy improve predictions of winter survival?
  - Yes!
- 4) Will warmer thermal regimes (warm falls coupled with warm winters) amplify overwintering mortality in age-0 Pacific cod?
  - Likely, as there is an increased demand on fall/winter food availability

Management implications

- Fall age-0 surveys would greatly improve our ability to predict overwintering success (late estimates of CPUE, characterize food/thermal environments, measurements of fish condition, size etc)
- In the absence of fall surveys, real-time management could integrate metrics/proxies of fall/winter environments with summer surveys. Age-1 growth histories (e.g., otoliths) could potentially be used for hindcast analyses.
- Survival trajectories based on size/growth/condition will change as winter/fall environments change

The Pcod team in Newport, OR

Chris Magel



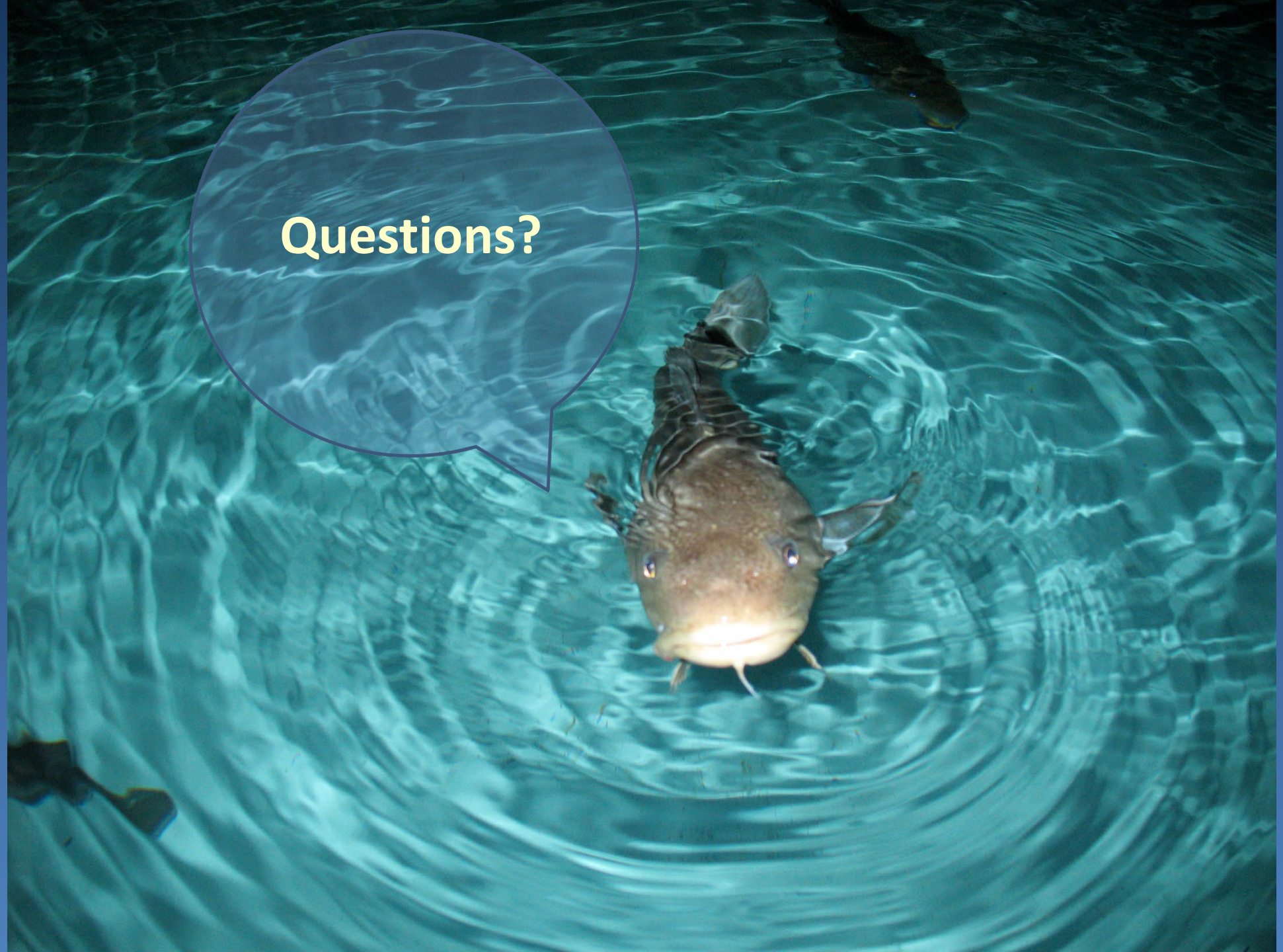
Paul Iseri

Mara Spencer

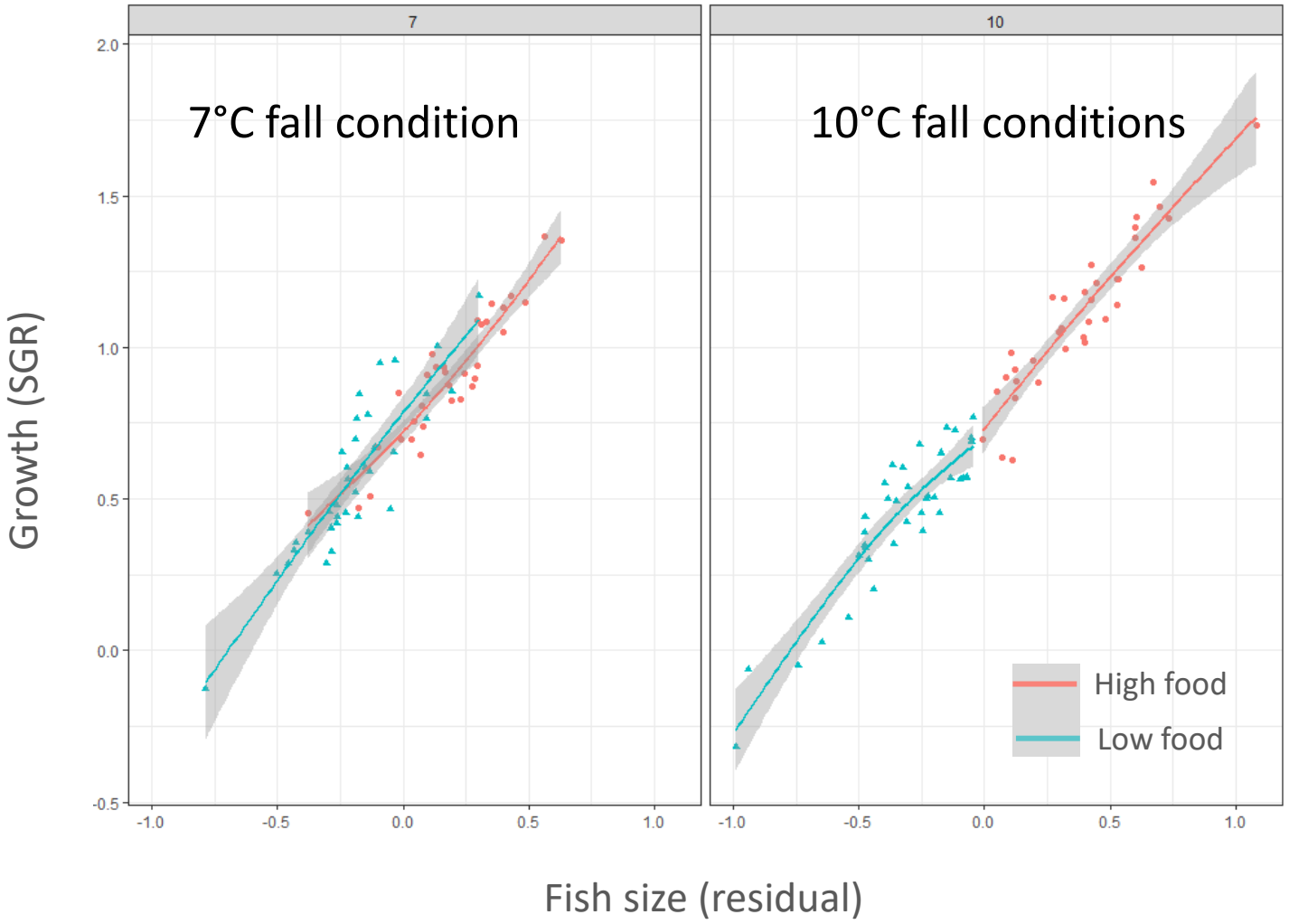
Tom Hurst

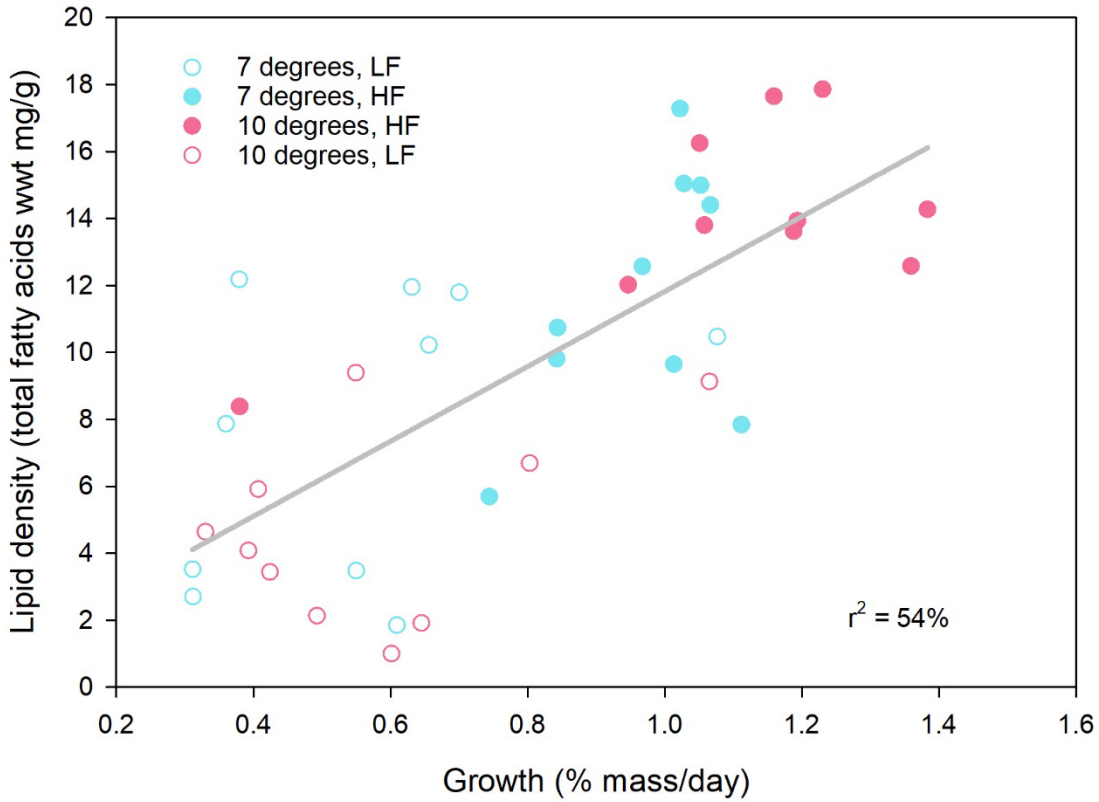
Michele Ottmar

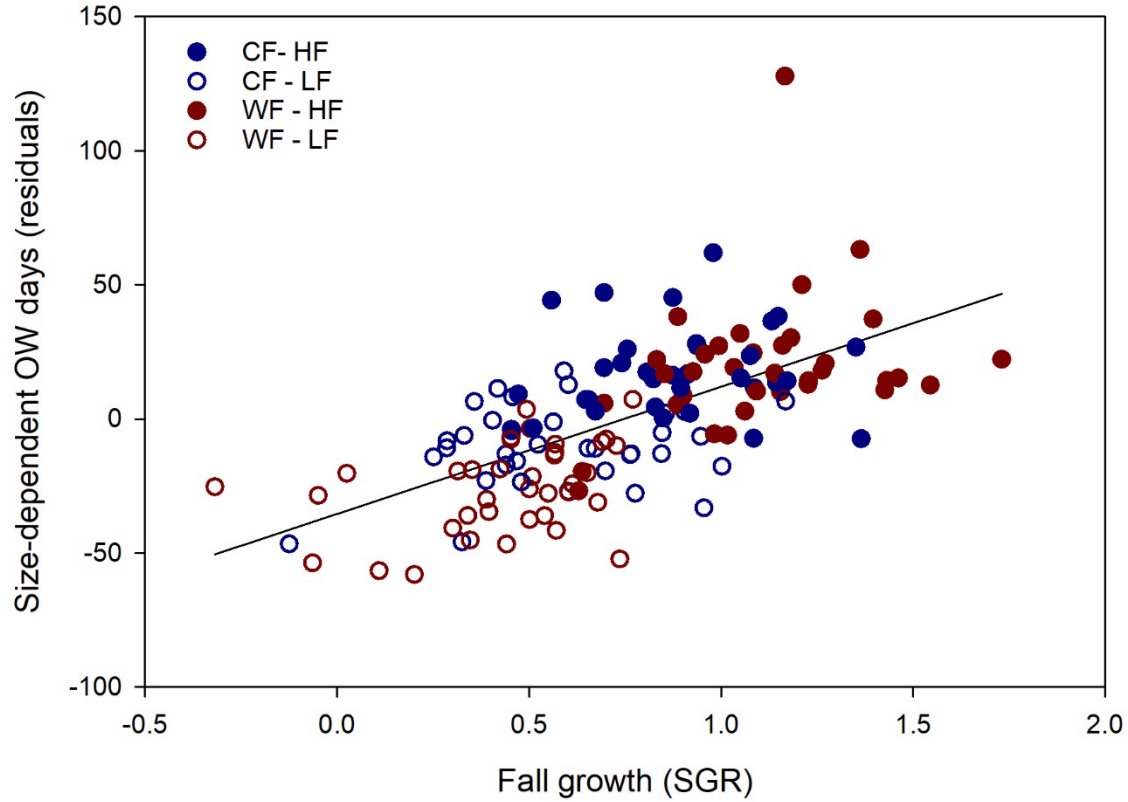
And Jessica Andrade and Michelle Stowell too!

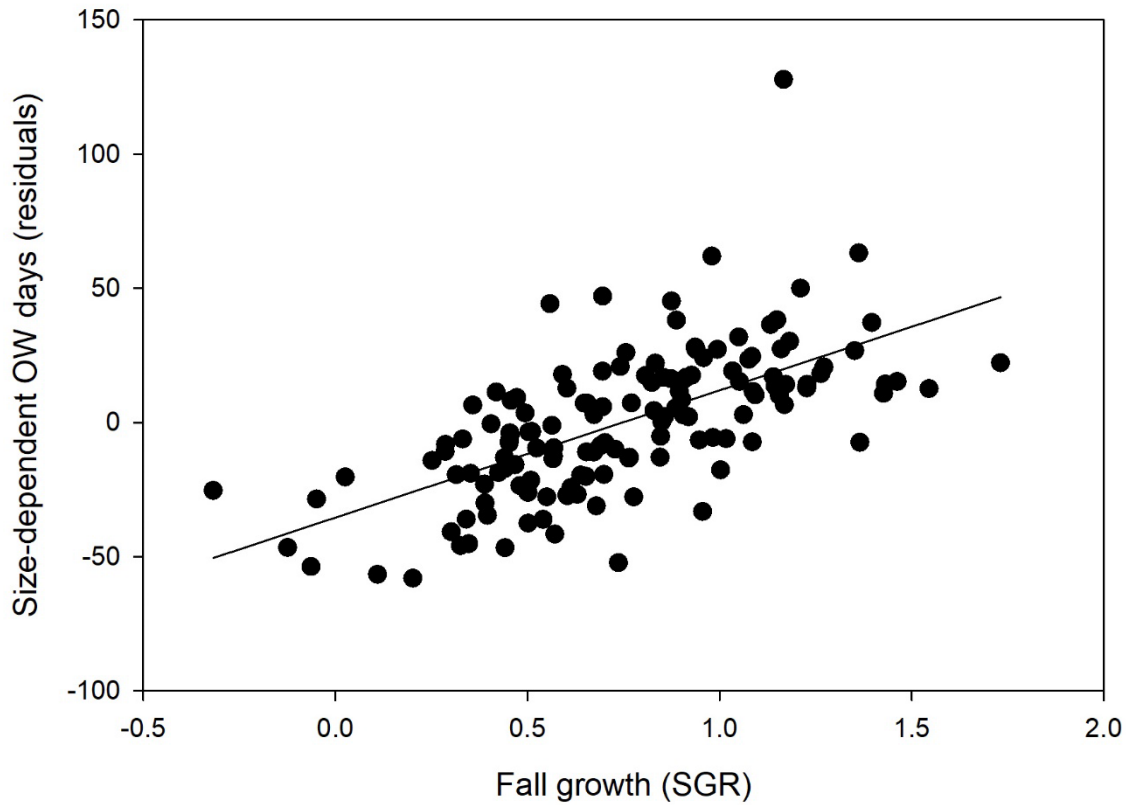

Questions?

Food availability impacts growth during warm fall conditions




Lipid density (total fatty acids wwt mg/g)
Growth (% mass/day)
7 degrees, LF
7 degrees, HF
10 degrees, HF
10 degrees, LF
r2 = 54%
0
2
4
6
8
10
12
14
16
18
20
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6


Size-dependent OW days (residuals)
Fall growth (SGR)
CF- HF
CF - LF
WF - HF
WF - LF
-100
-50
0
50
100
150
-0.5
0.0
0.5
1.0
1.5
2.0


150
100
50
0
-50
-100
-0.5
0.0
0.5
1.0
1.5
2.0
Size-dependent OW days (residuals)
Fall growth (SGR)

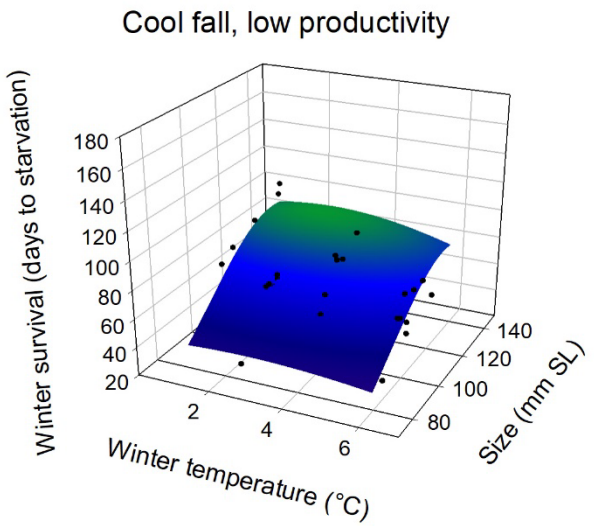
Background

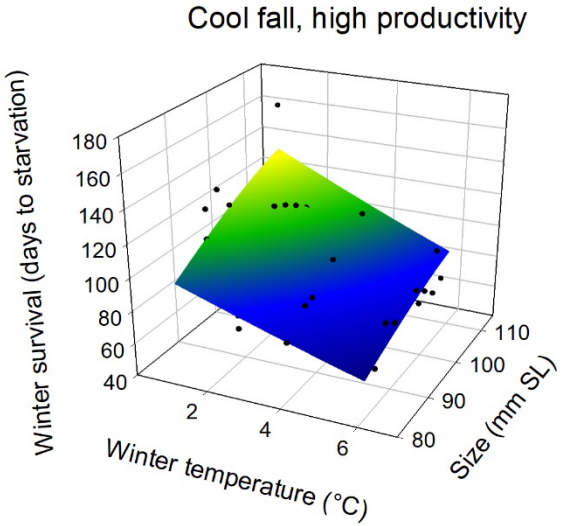
- Early life stages of marine fish are highly sensitive to temperature, but are undergoing varying rates of thermal stress across ecosystems
- The rapid decline of Pacific cod biomass following the 2014-16 Gulf of Alaska marine heatwave has prompted a review of 1st year of life biology for this species, as well as management tools to better prepare for recruitment failure
- We use observational data and thermal habitat models to examine contemporary and historical distributions in an effort to isolate important critical periods under varying climate stress

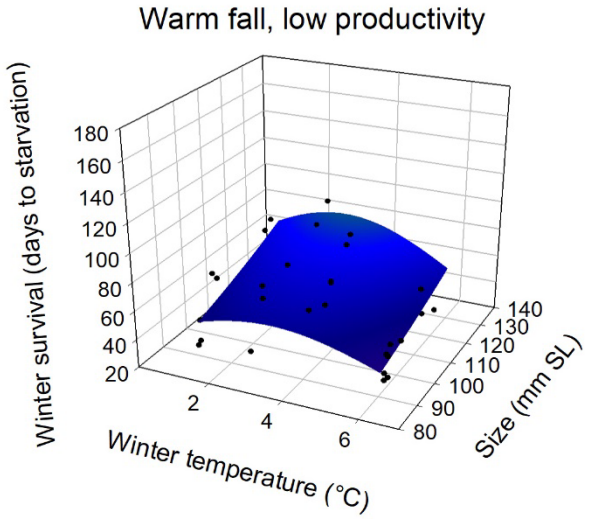
Fisheries research labs

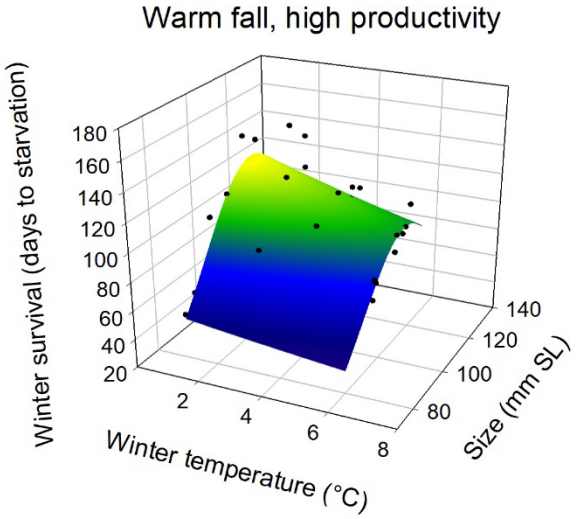
Fisheries management

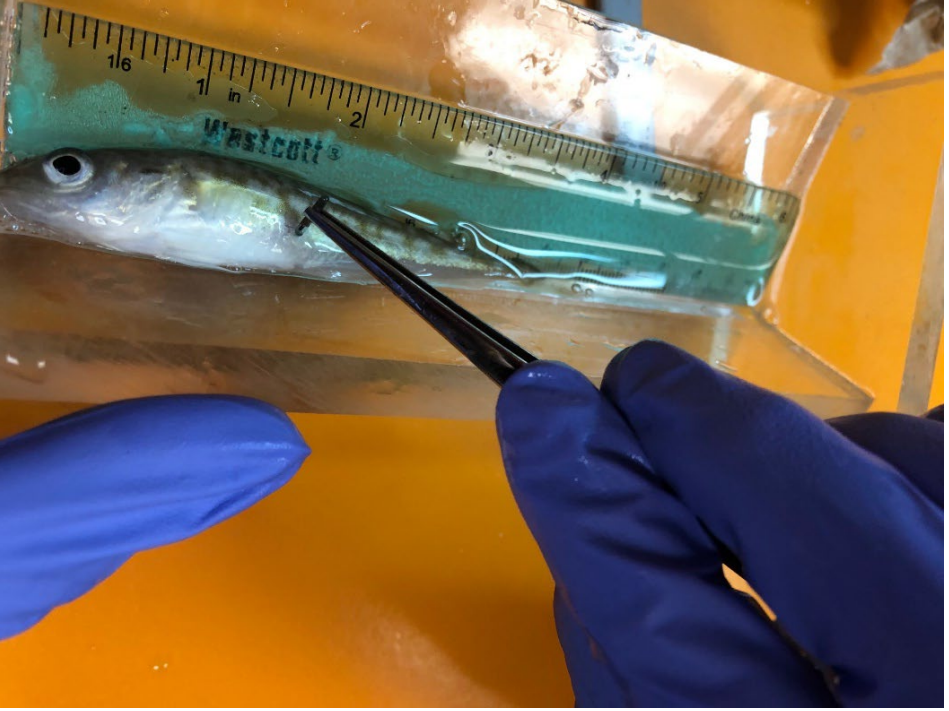
Size only predicts winter survival under certain environmental conditions

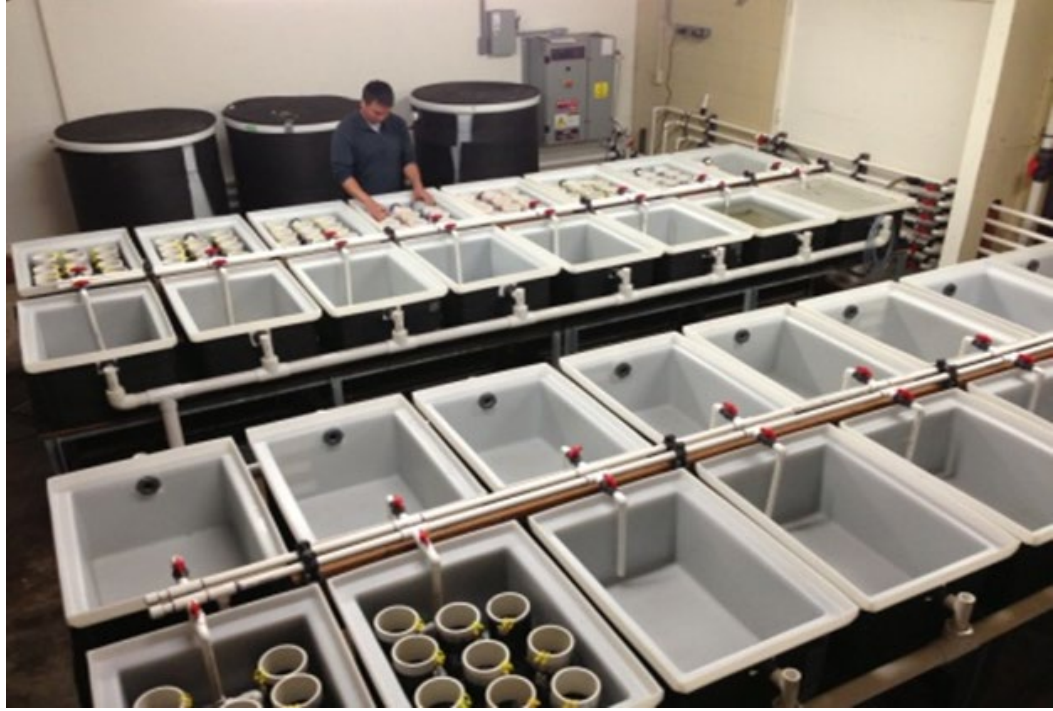




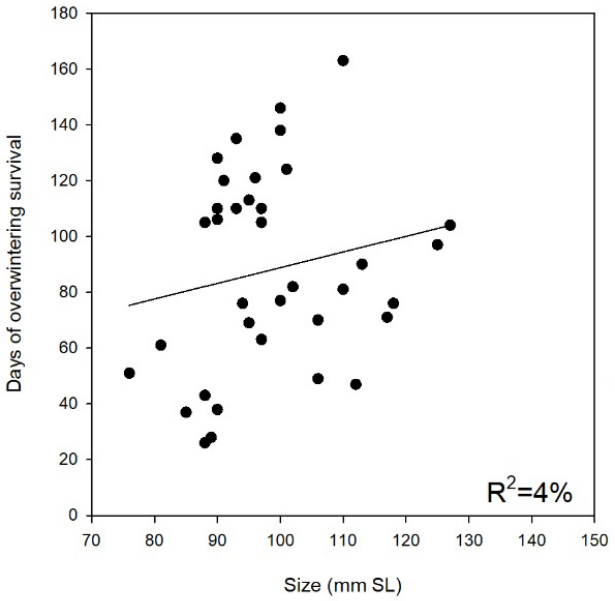




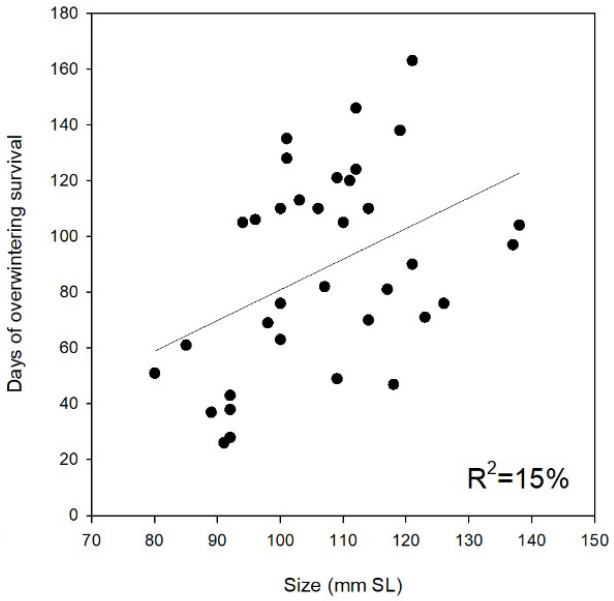




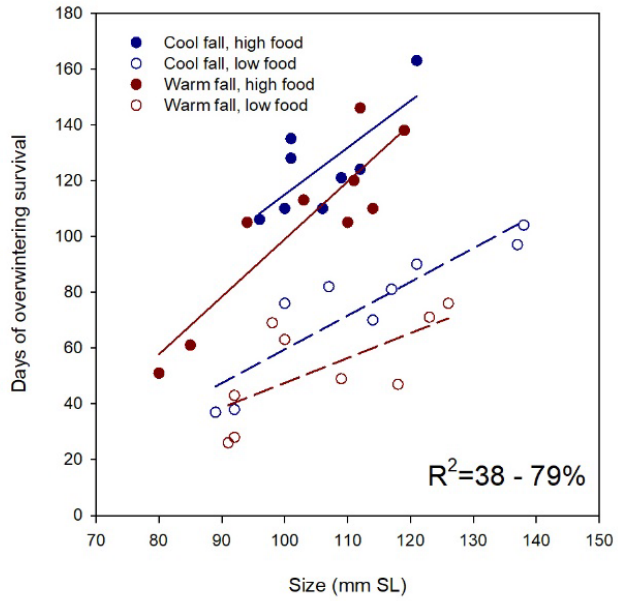
Late summer size



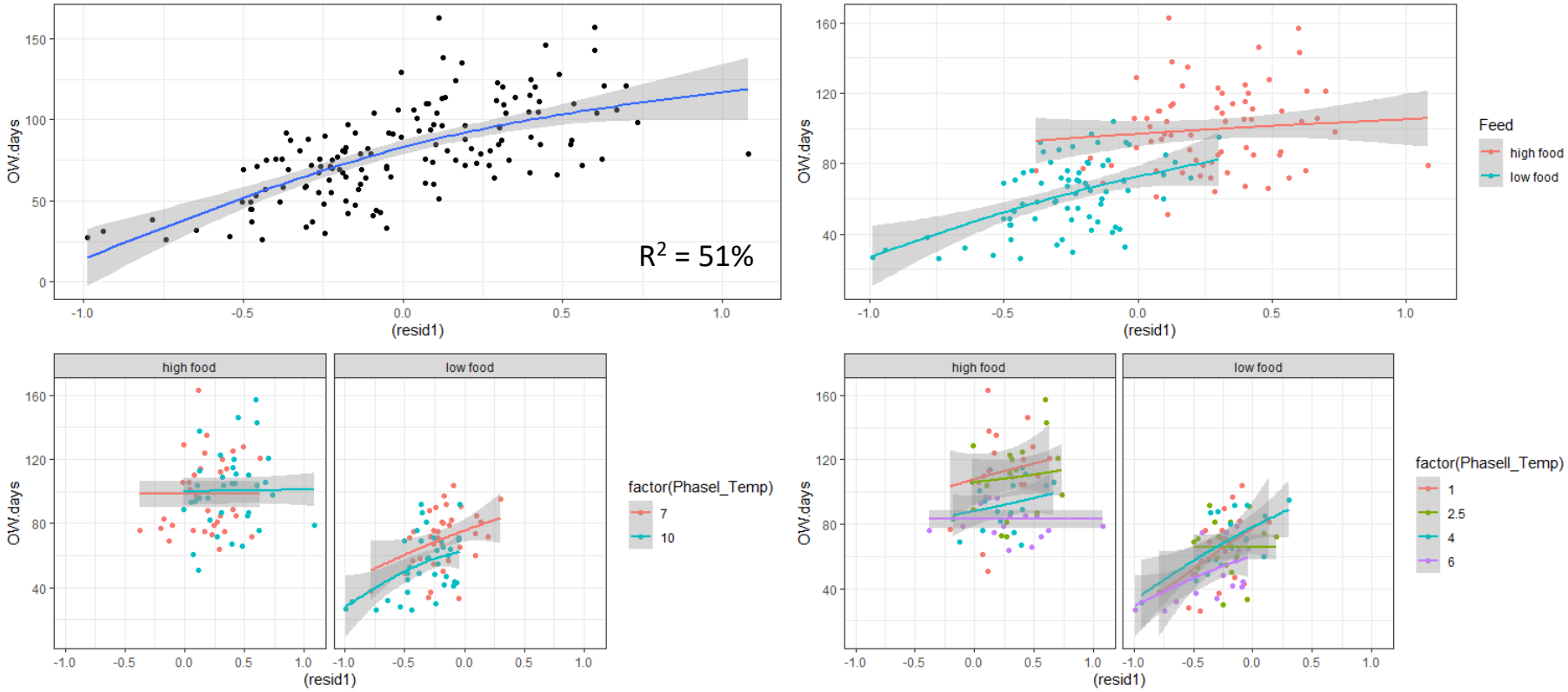
Late fall size



Late fall size + fall environmental conditions



Fall growth experience impacts winter survival



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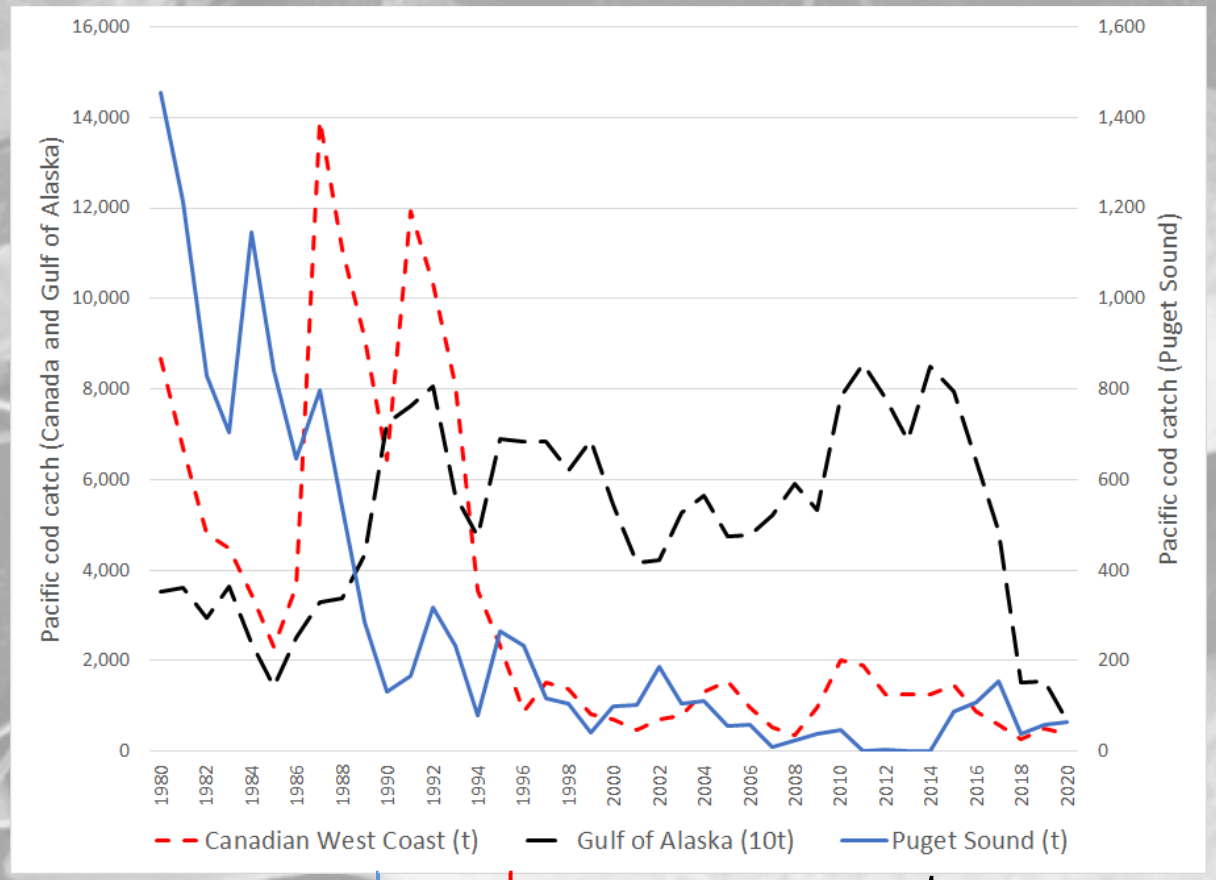
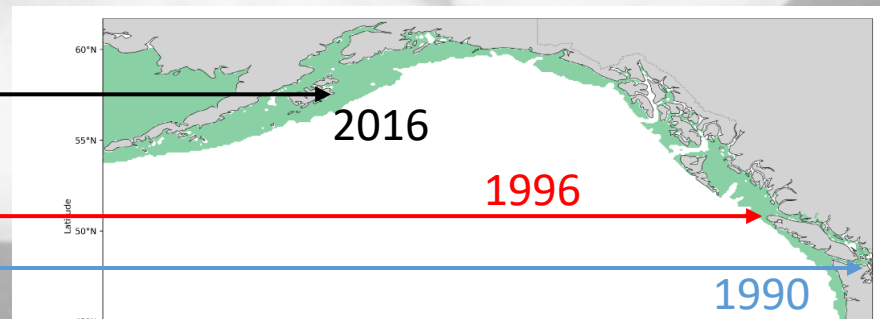
A latitudinal progression of population decline…





Background

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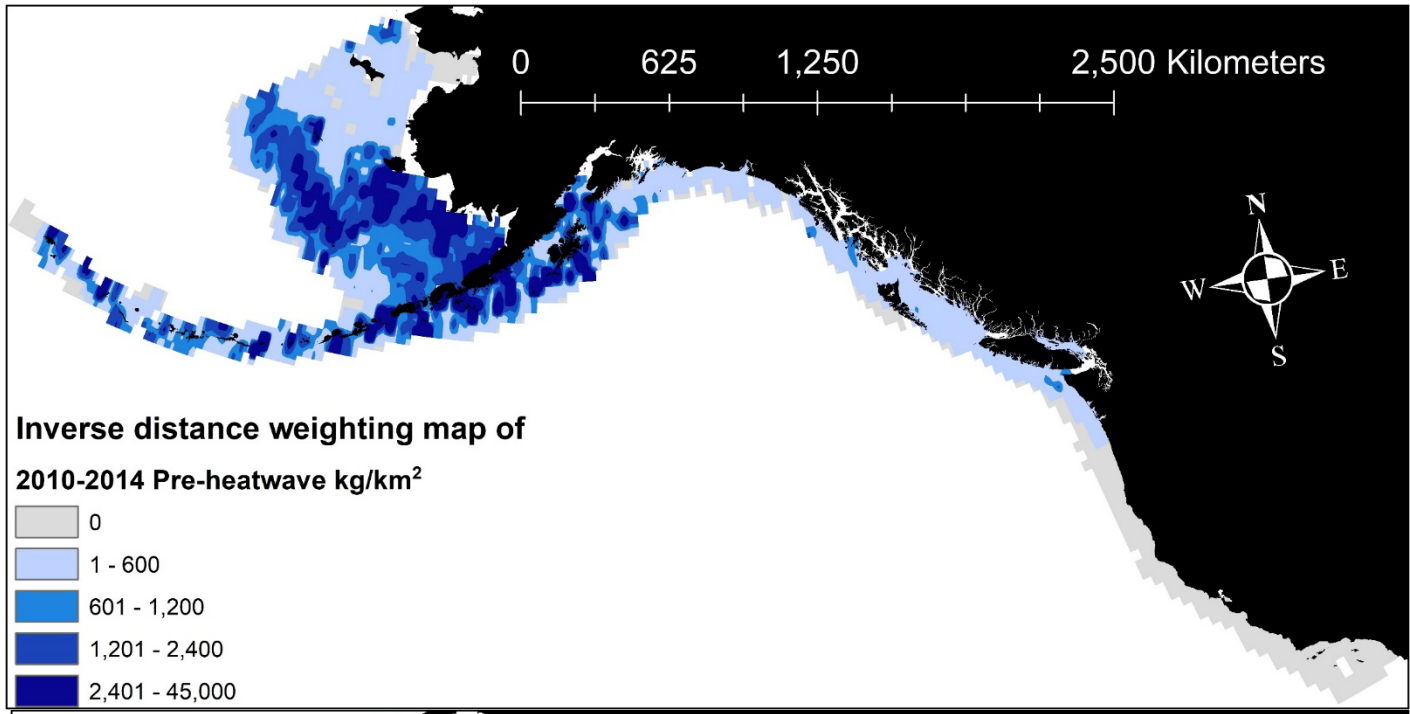
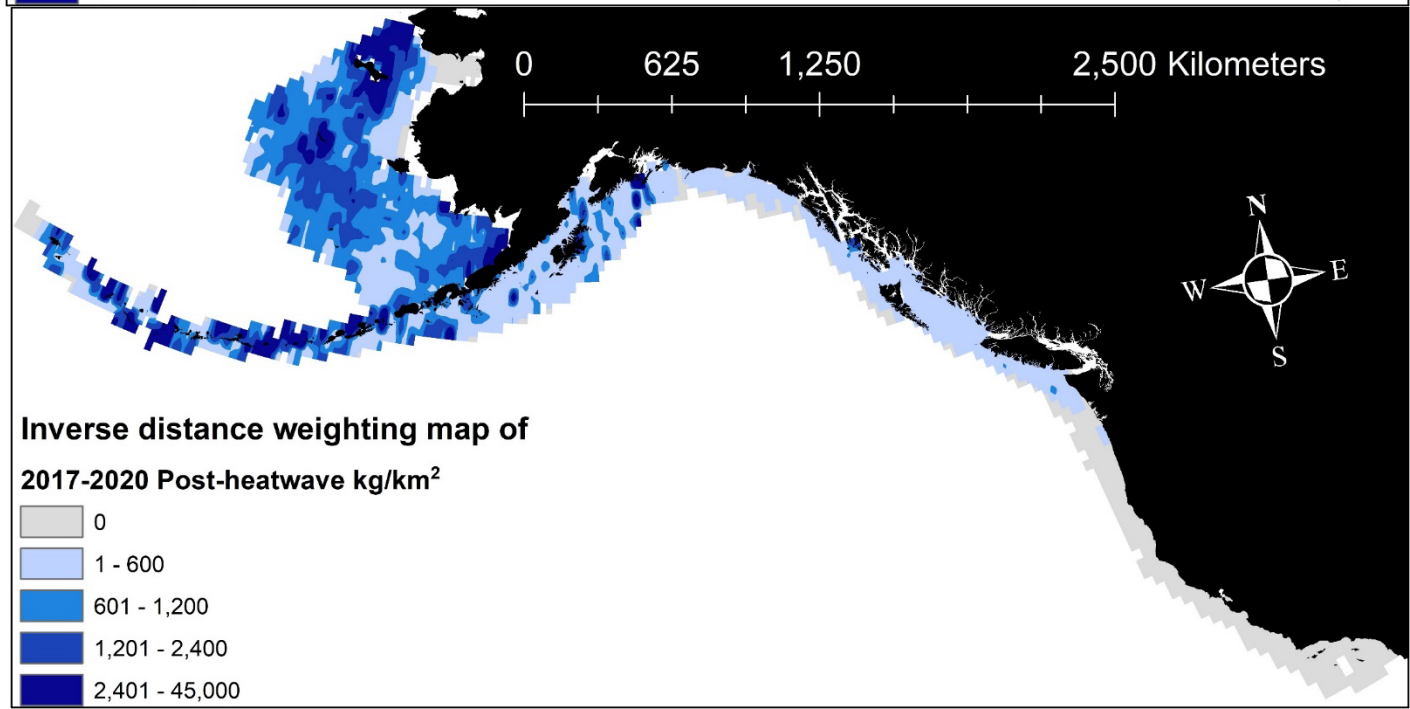
- The rapid decline of Pacific cod biomass following the 2014-16 Gulf of Alaska marine heatwave has prompted a review of 1st year of life biology for this species, as well as management tools to better prepare for recruitment failure
- We use observational data and thermal habitat models to examine contemporary and historical distributions in an effort to isolate important critical periods under varying climate stress

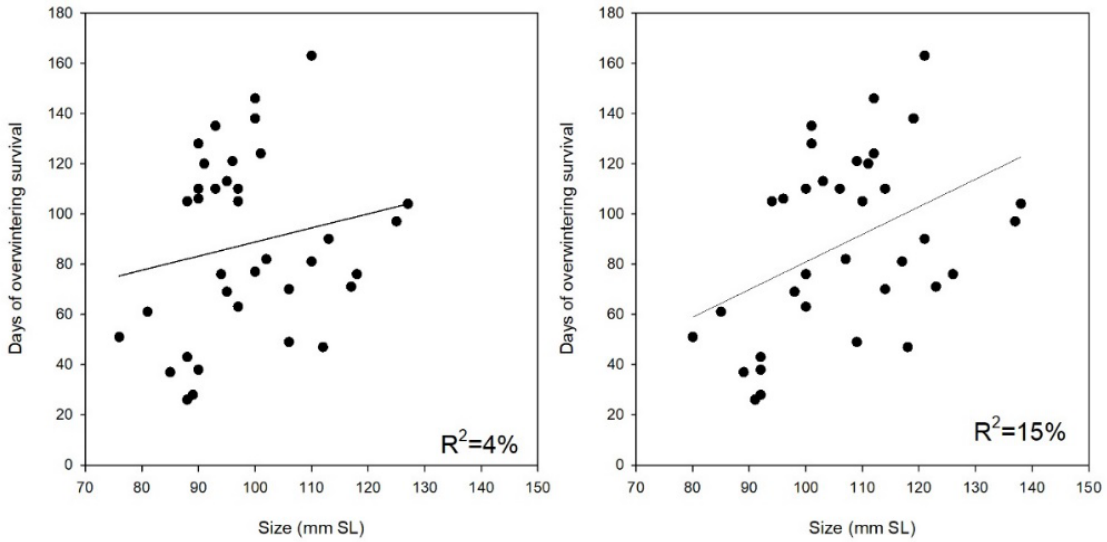
A poleward shift in the last decade

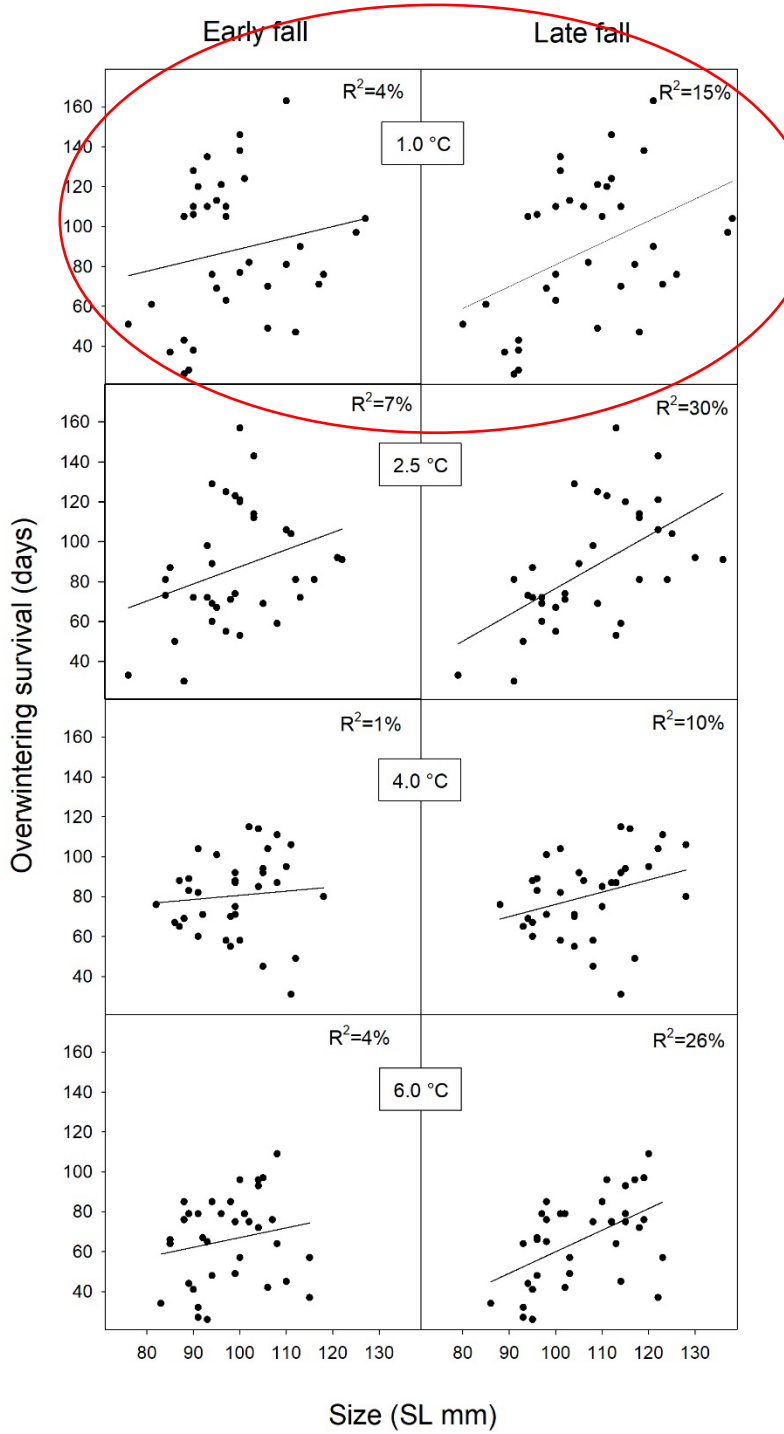




Data on adult distributions and abundance were from bottom trawl surveys conducted by the Alaska Fisheries Science Center in the Eastern and Northern Bering Sea (annual 2010-2019; Lauth et al., 2019); Aleutian Islands (biannual 2010-2018; von Szalay & Raring, 2020) and Gulf of Alaska (biannual 2011-2019; Von Szalay & Raring, 2018), by the Department of Fisheries and Oceans for the West Coast Vancouver Island (biannual 2010-2018; Williams et al., 2020b), West Coast Haida Gwaii (biannual 2010-2018; Williams et al., 2020a), Hecate Strait (biannual 2011-2019; Williams, 2018), West Coast Queen Charlotte Islands (biannual 2011-2019; Workman et al., 2008), and Strait of Georgia (2012 and 2015; Olsen & Workman, 2013), and by the Northwest Fisheries Science Center for the west coast of the United States (annual 2010-2019; Keller et al., 2017).

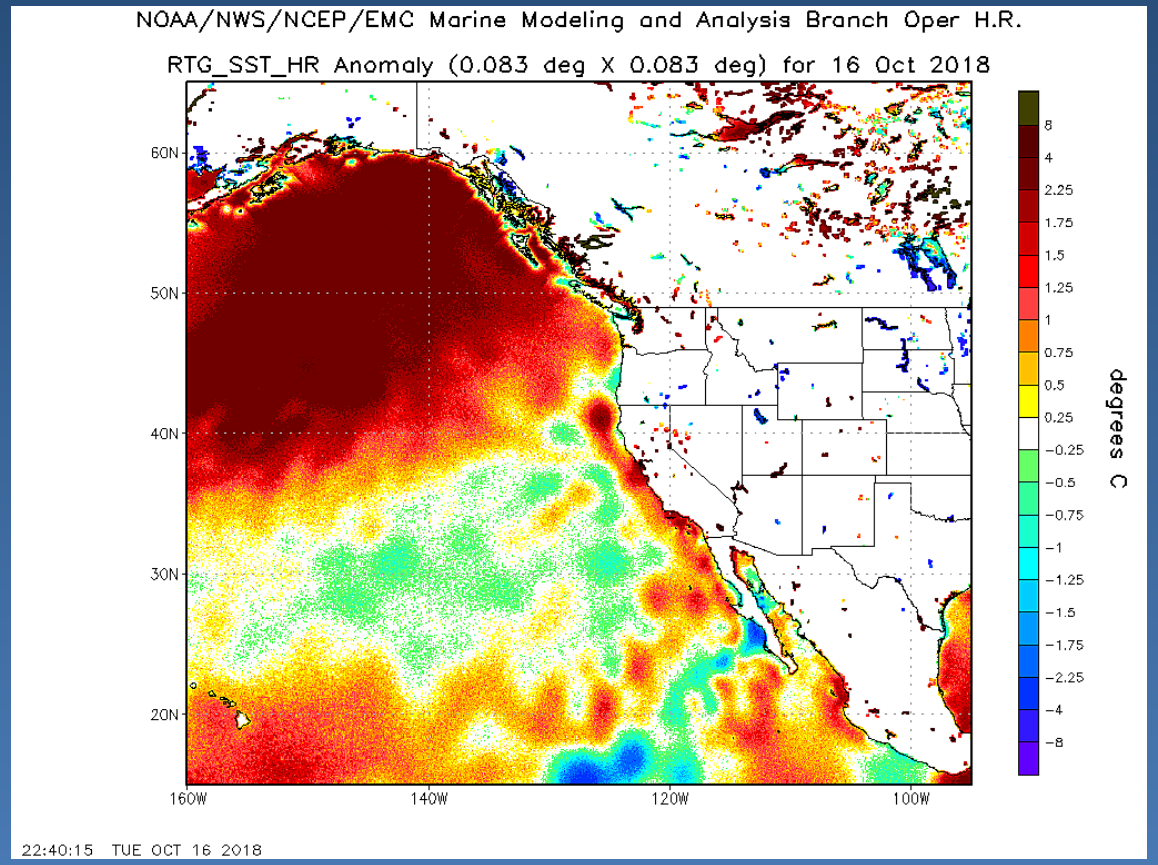
Size is still a weak predictor of overwintering survival even when thermal winter conditions are known






Gulf of Alaska

2019 Marine heatwave



http://cliffmass.blogspot.com/2018/10/the-son-of-blob-is-back.html

>2°C temperature anomalies over much of the Gulf of Alaska in October 2018