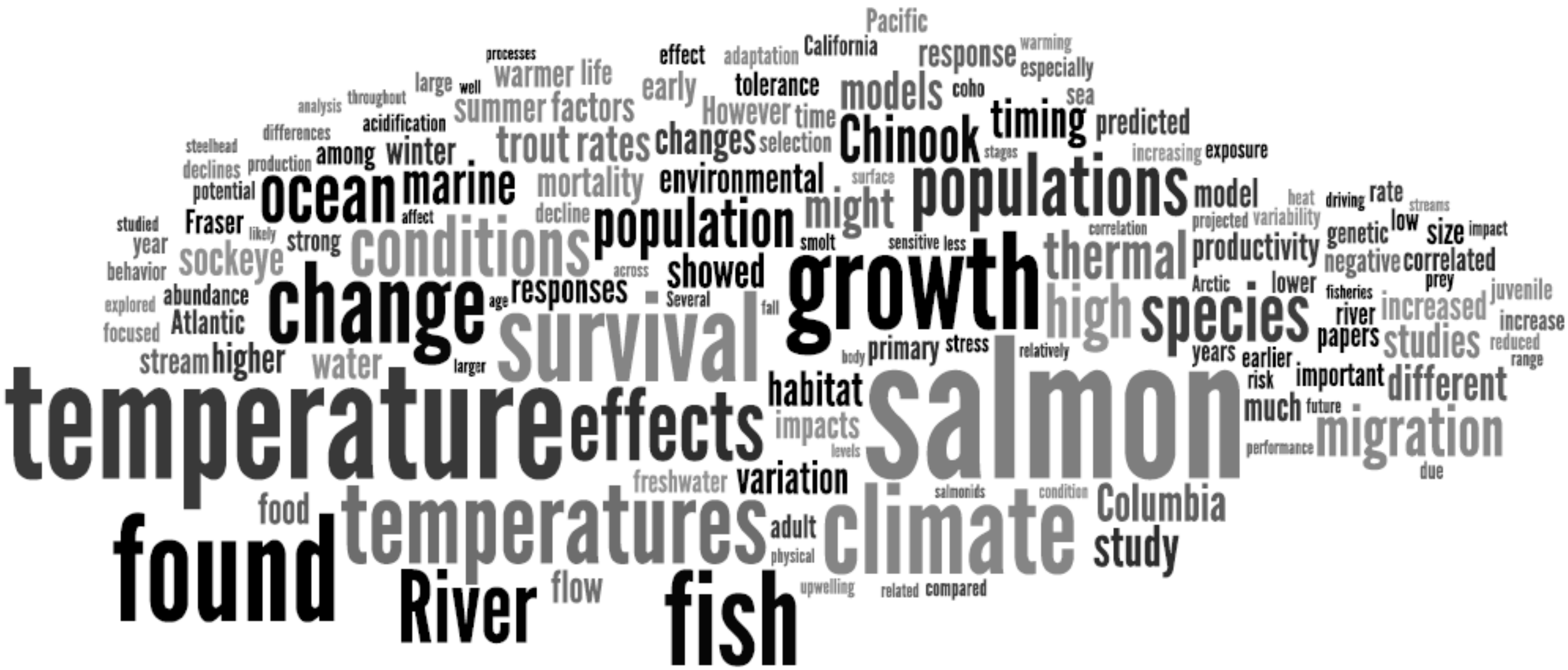
A Review of 1100 Papers on Climate Impacts on Salmon: What Have We Learned in the Last 5 Years?

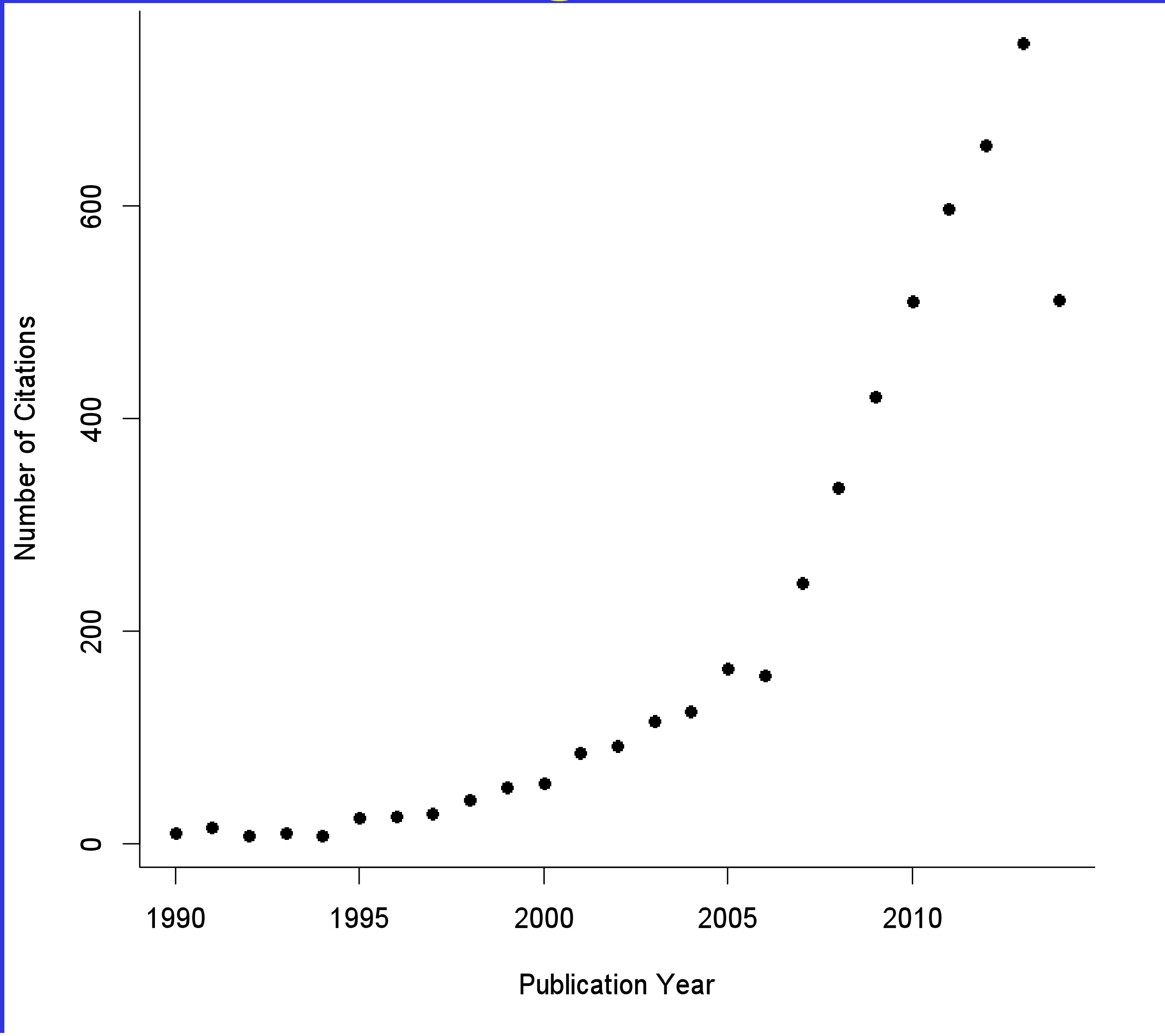


Lisa Crozier NOAA-Fisheries, Seattle

5th Annual PNW Climate Science Conference

September 9-10, 2014, University of Washington, Seattle

Web of Science search: “climate change” and “salmon”



2013: 753

2012: 657

2011: 597

History of my literature review

Endangered Species Act
Section 7(a)(2) Consultation
Supplemental Biological Opinion

Supplemental Consultation on Remand for Operation of the Federal Columbia River Power System,
11 Bureau of Reclamation Projects in the Columbia Basin and ESA Section 10(a)(I)(A) Permit for Juvenile Fish Transportation Program

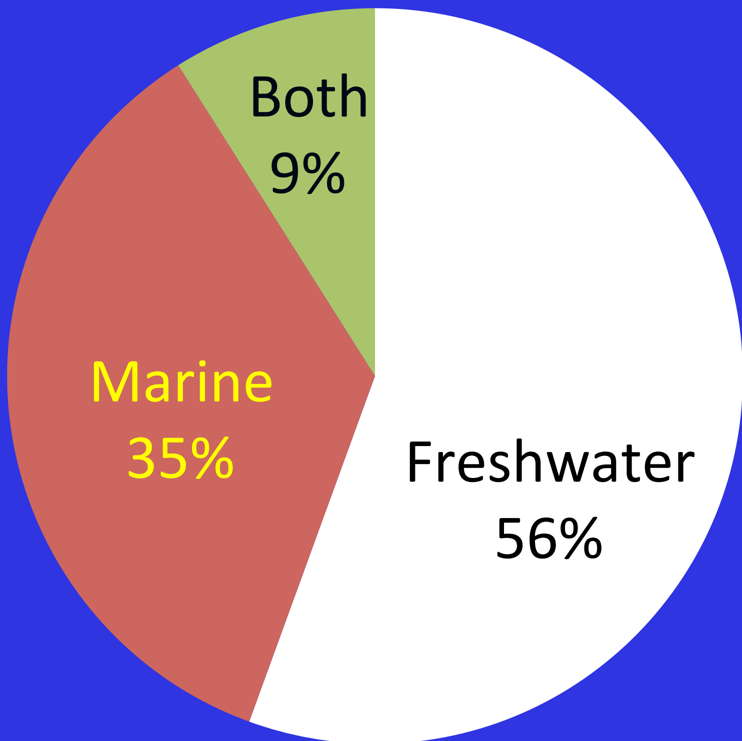
NOAA-Fisheries 2010:
2.2.1 Climate Change and Ocean Conditions
Annual updates of new information

- 303 in 2007-2010 Supplemental Report
- 227 in 2010
- 135 in 2011
- 224 in 2012
- 202 in 2013

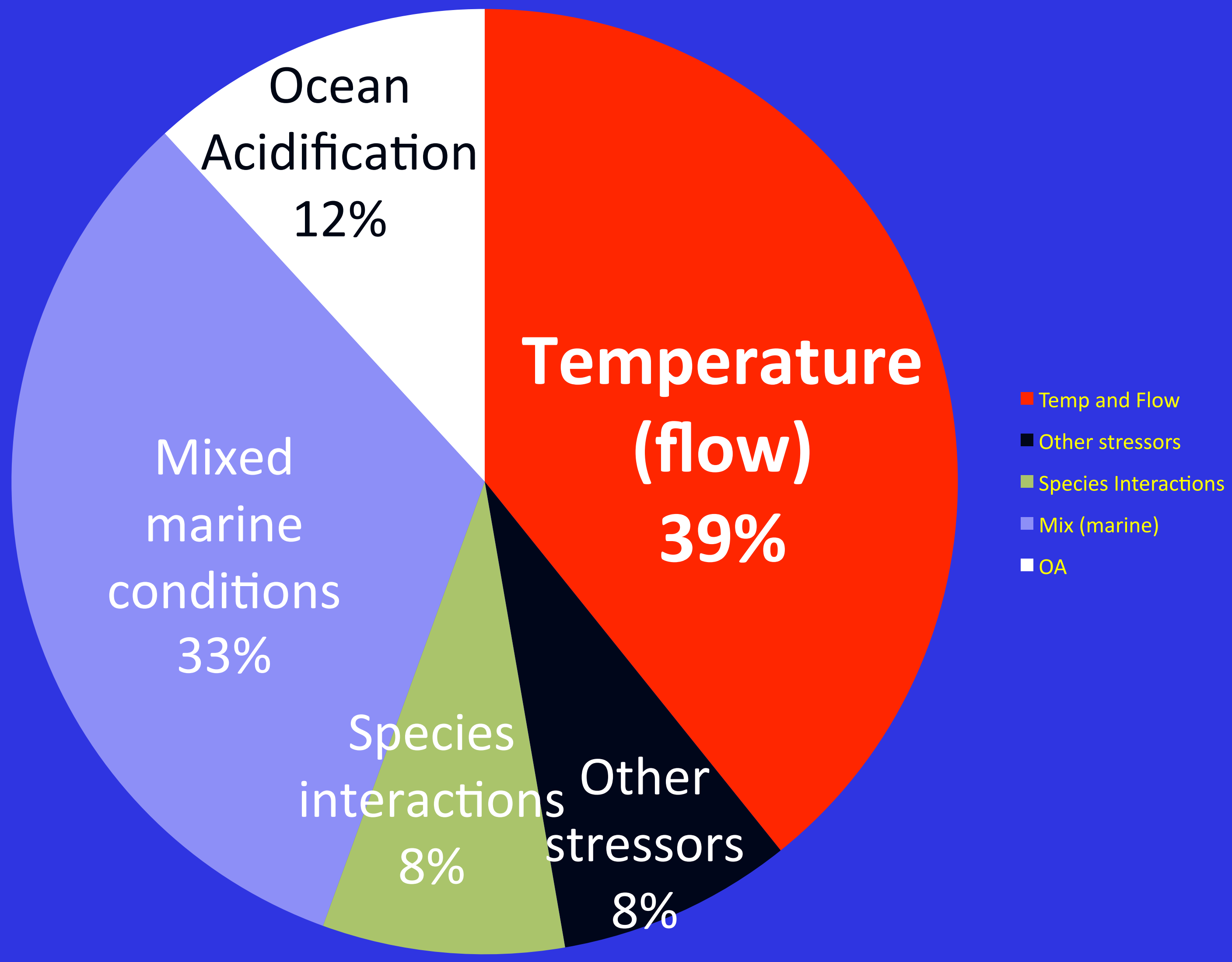
➢ 1091 papers summarized

Reports available at
http://www.nwfsc.noaa.gov/trt/lcm/freshwater_habitat.cfm

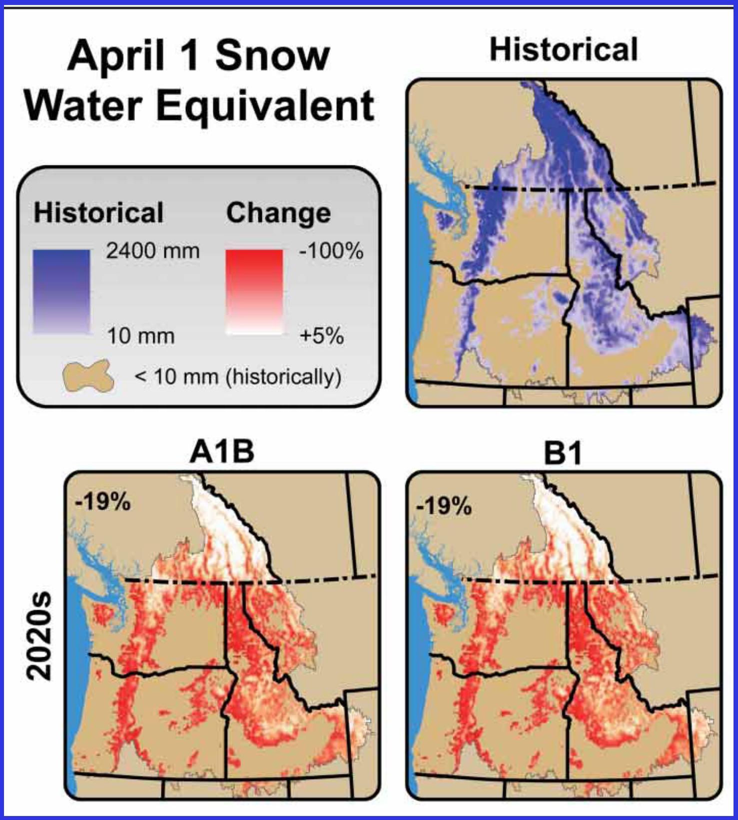
Relative habitat representation

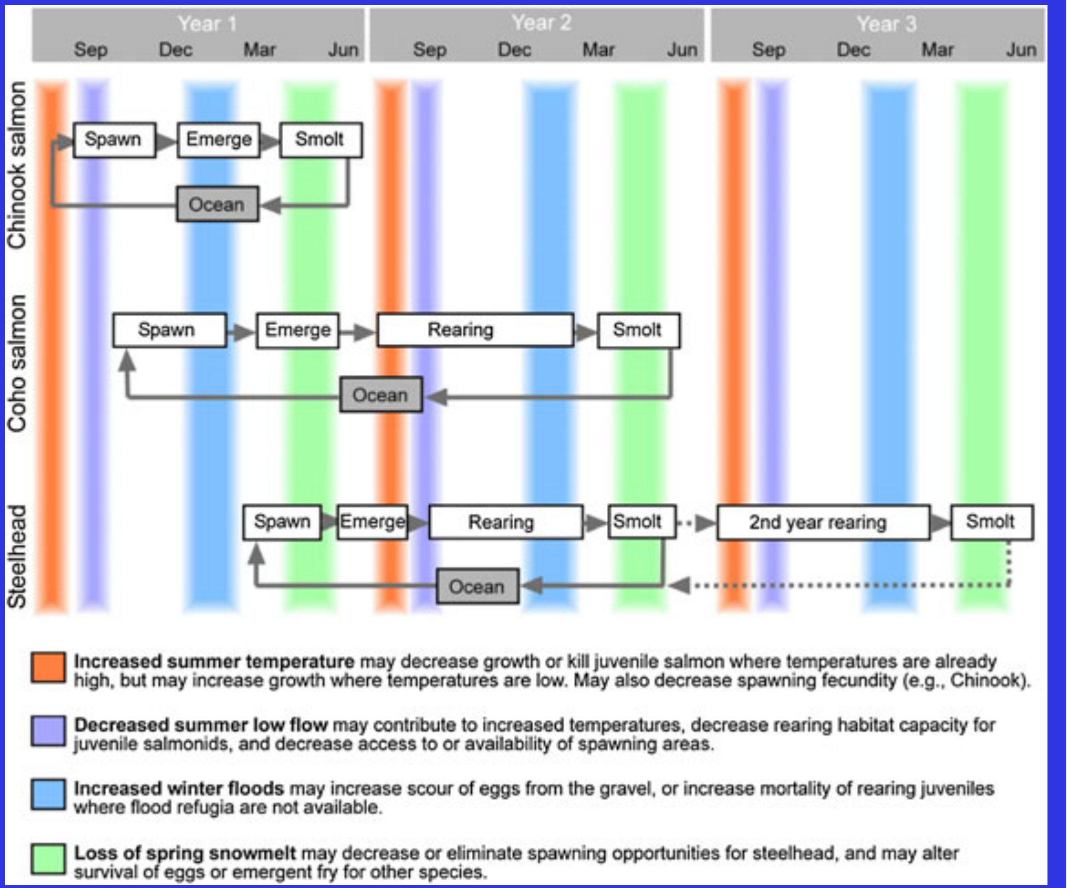


Representation of drivers



Spatial and biological variability in impacts





Hamlet et al 2013

Beechie et al 2013
River Research and Applications

Major threats:
Temperature stress and new flow regime

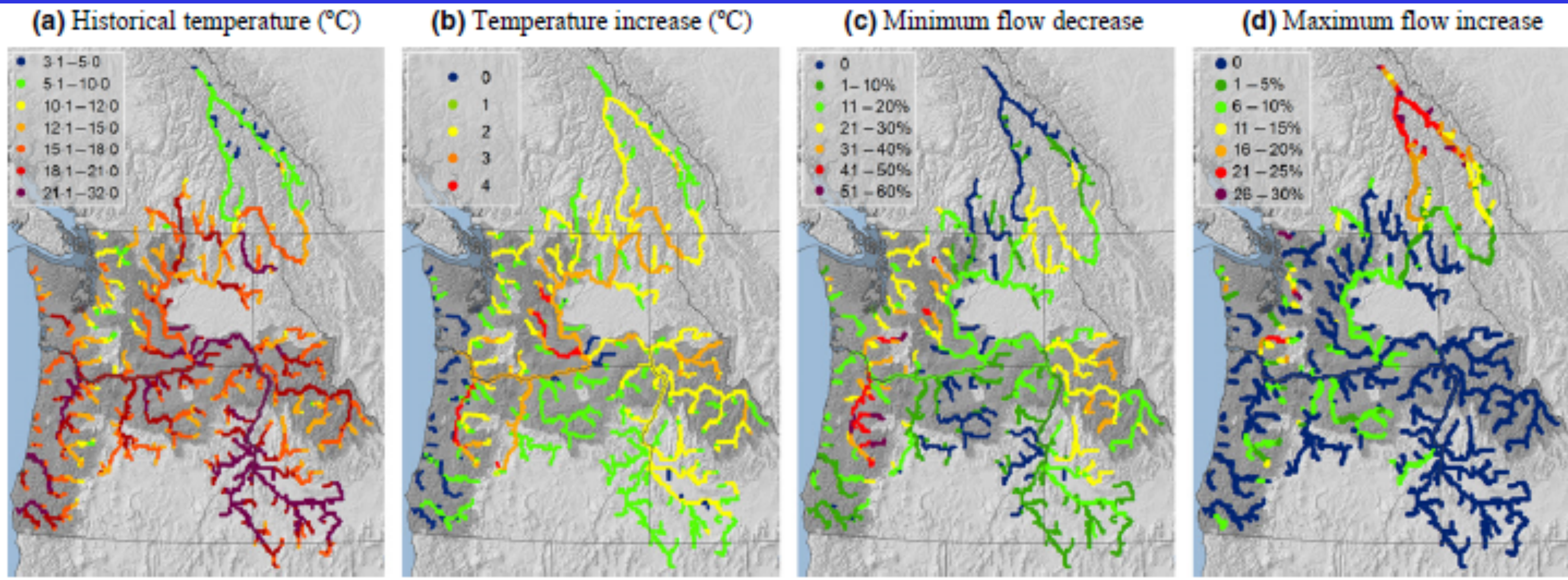


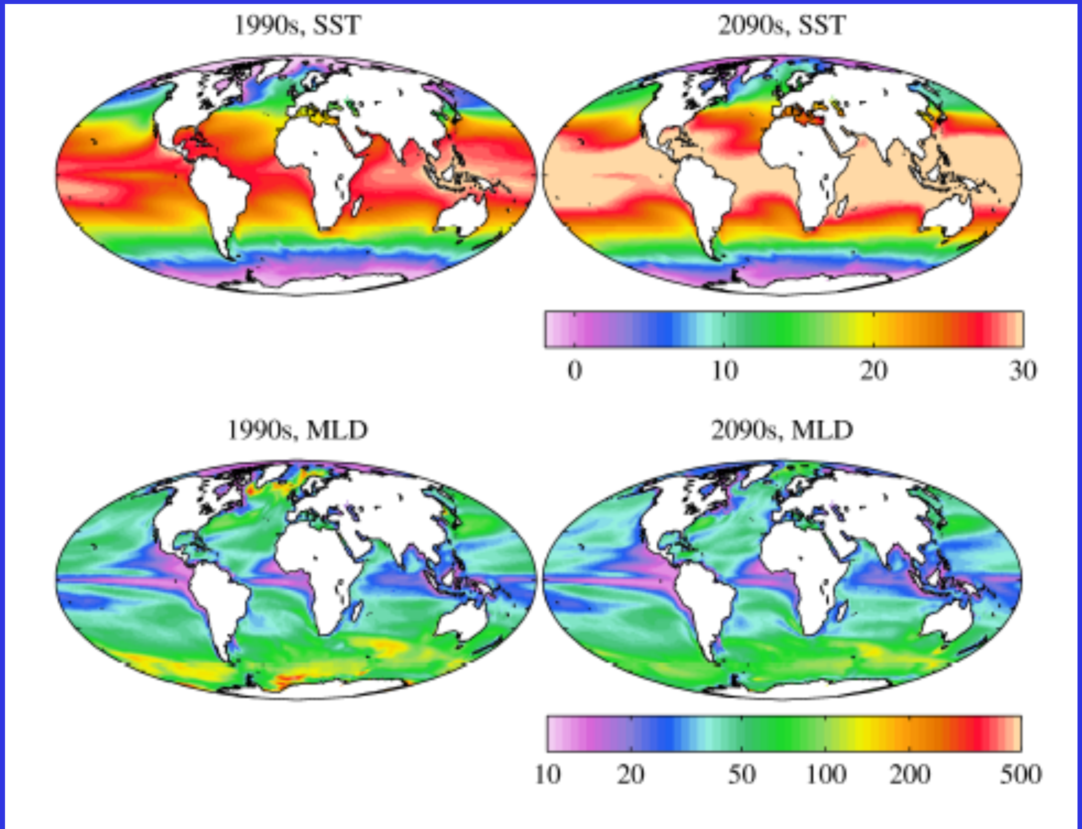
Fig. 3. Historical and projected climate metrics for the Pacific Northwest. Modelled historical water temperature [maximum weekly mean (°C) from 1970–1999] (a), modelled increases in temperature between the historical period and 2030–2059, rounded to the nearest degree (b), percentage decrease in minimum weekly flow (c) and percentage increase in maximum weekly mean flow (d) (cubic feet per second) between the historical period and 2030–2059. Historical temperatures and changes in temperature and flow for each analytical unit are in Table S3 (Supporting information).

Wade et al 2013 Journal of Applied Ecology

Most relevant ocean impacts not as simple

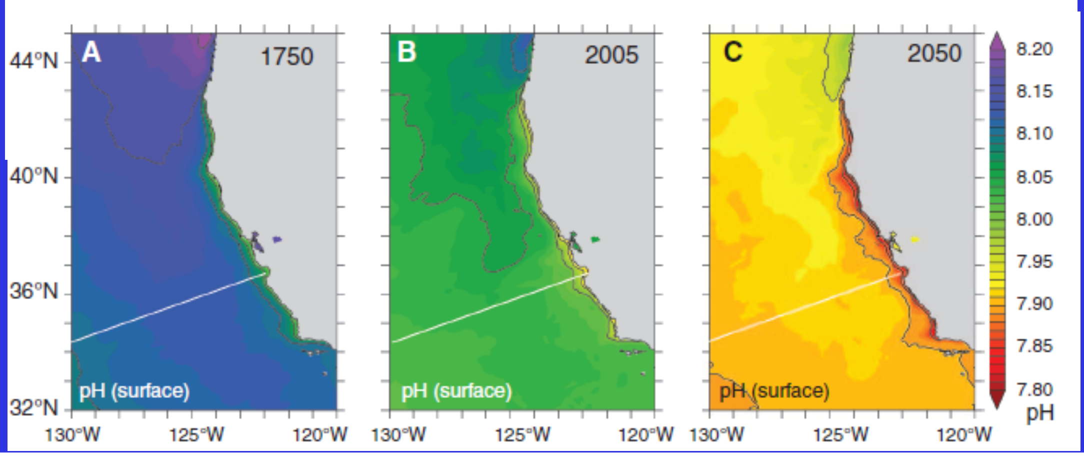
Temperature

Mixing



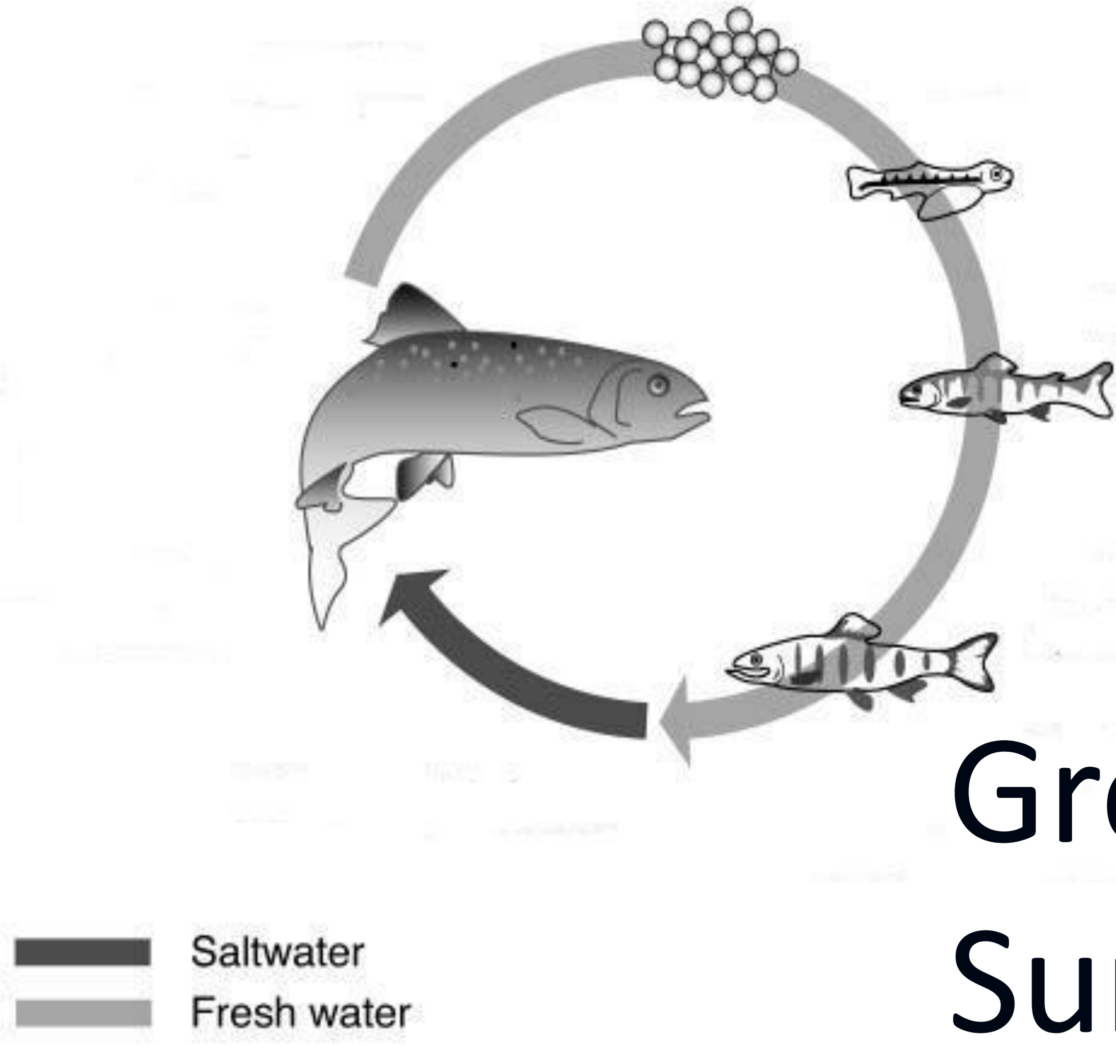
Yool et al 2013

pH



Gruber et al 2013

Results:
Population persistence depends on

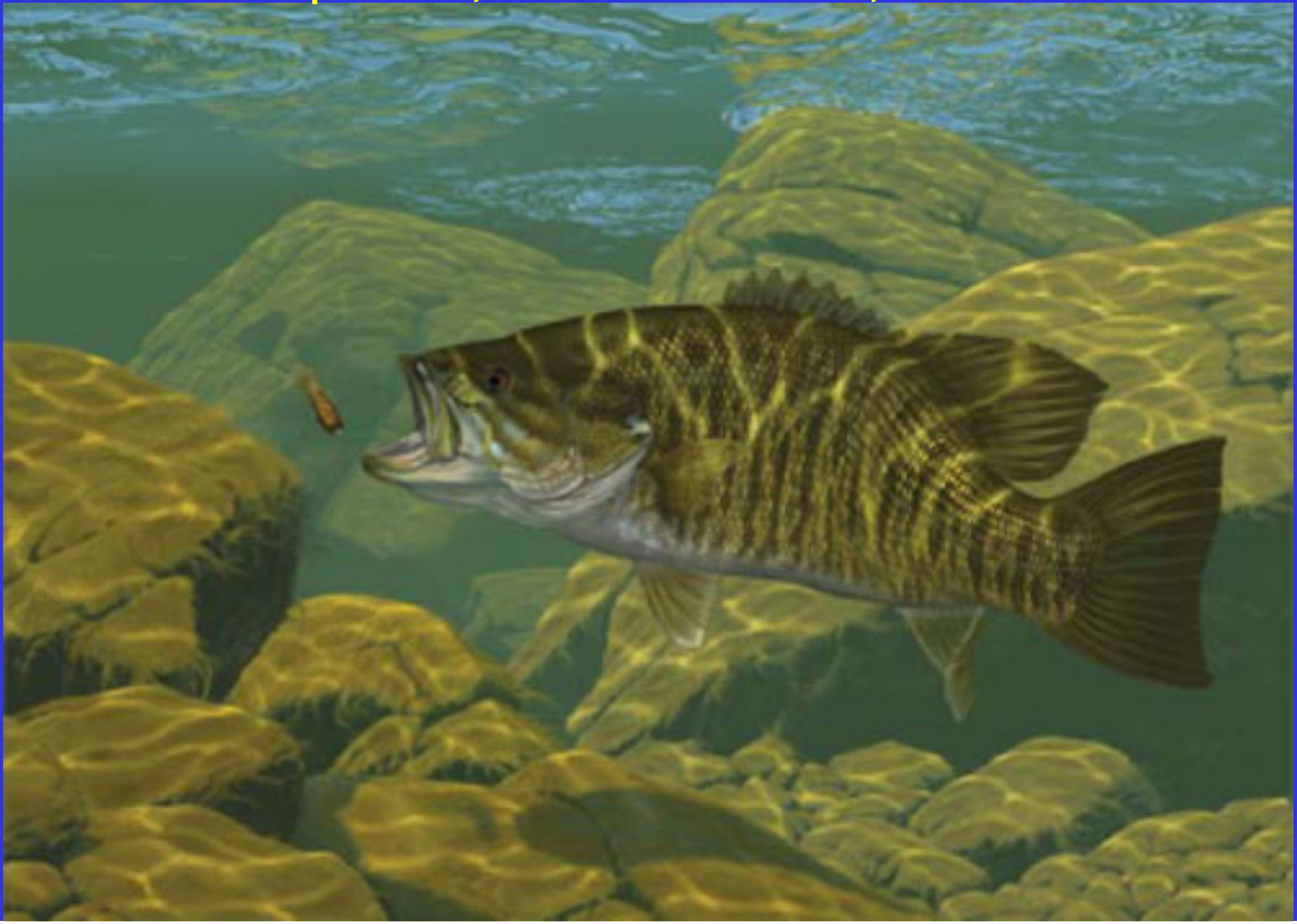


Growth

Survival

Survival – competition and predation

invasive species, bass and shad, various trout



LIFE HISTORY AND PHENOLOGY

Timing of juvenile and adult migration, spawning, etc.

Age at smolting
Age at return migration
Residency in steelhead
Precocial males
Probability of repeat spawning

Evidence of
evolutionary or plastic responses to recent climate change: literature review

Crozier, L. G. and J. A. Hutchings (2014).
"Plastic and evolutionary responses to climate change in fish."
Evolutionary Applications **7**(1): 68-87

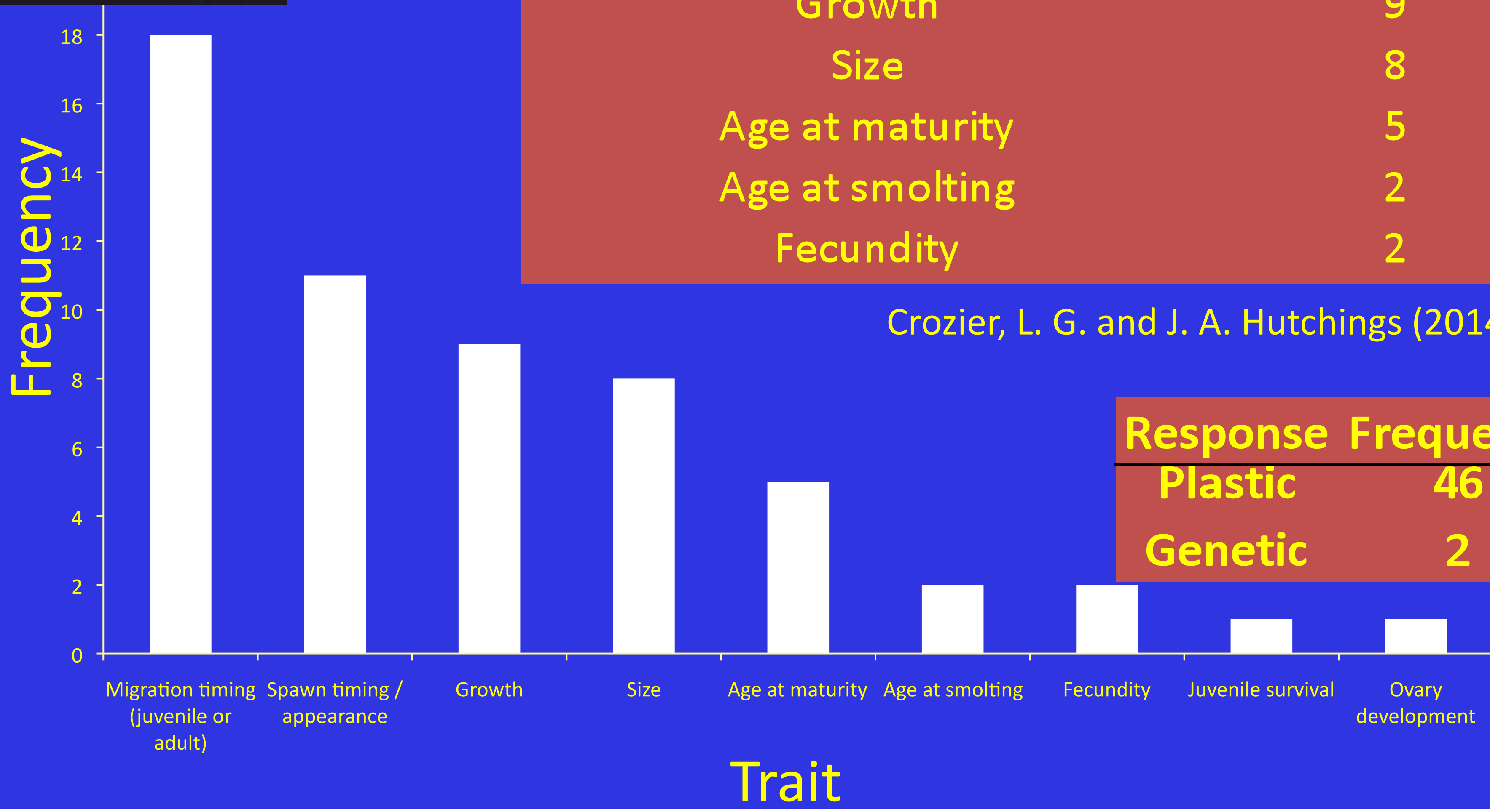
Trait representation

25 species of fish, but mostly salmon

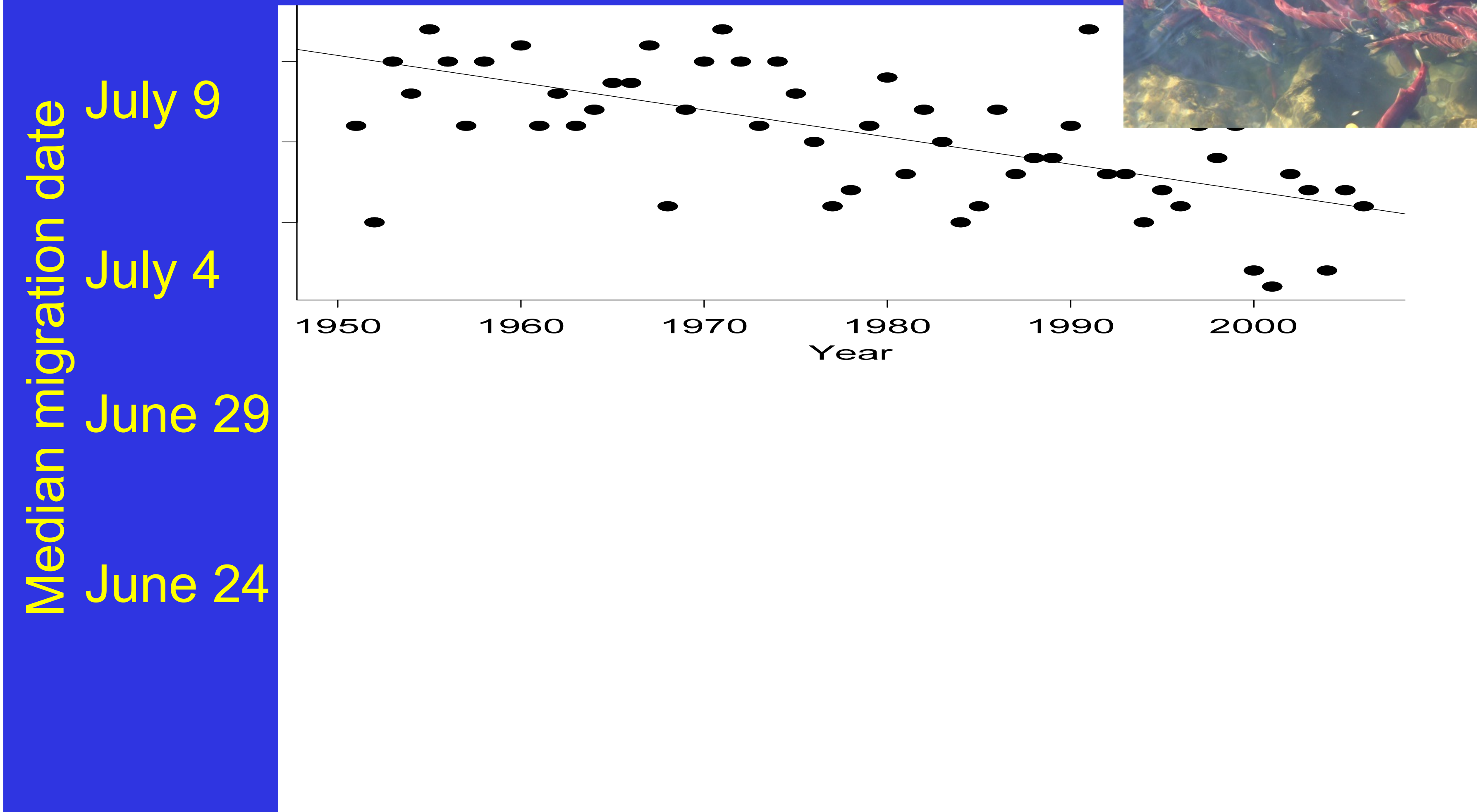
Trait	Count of trait
Migration timing (juvenile or adult)	18
Spawn timing/appearance	11
Growth	9
Size	8
Age at maturity	5
Age at smolting	2
Fecundity	2

Crozier, L. G. and J. A. Hutchings (2014).

Response	Frequency
Plastic	46
Genetic	2

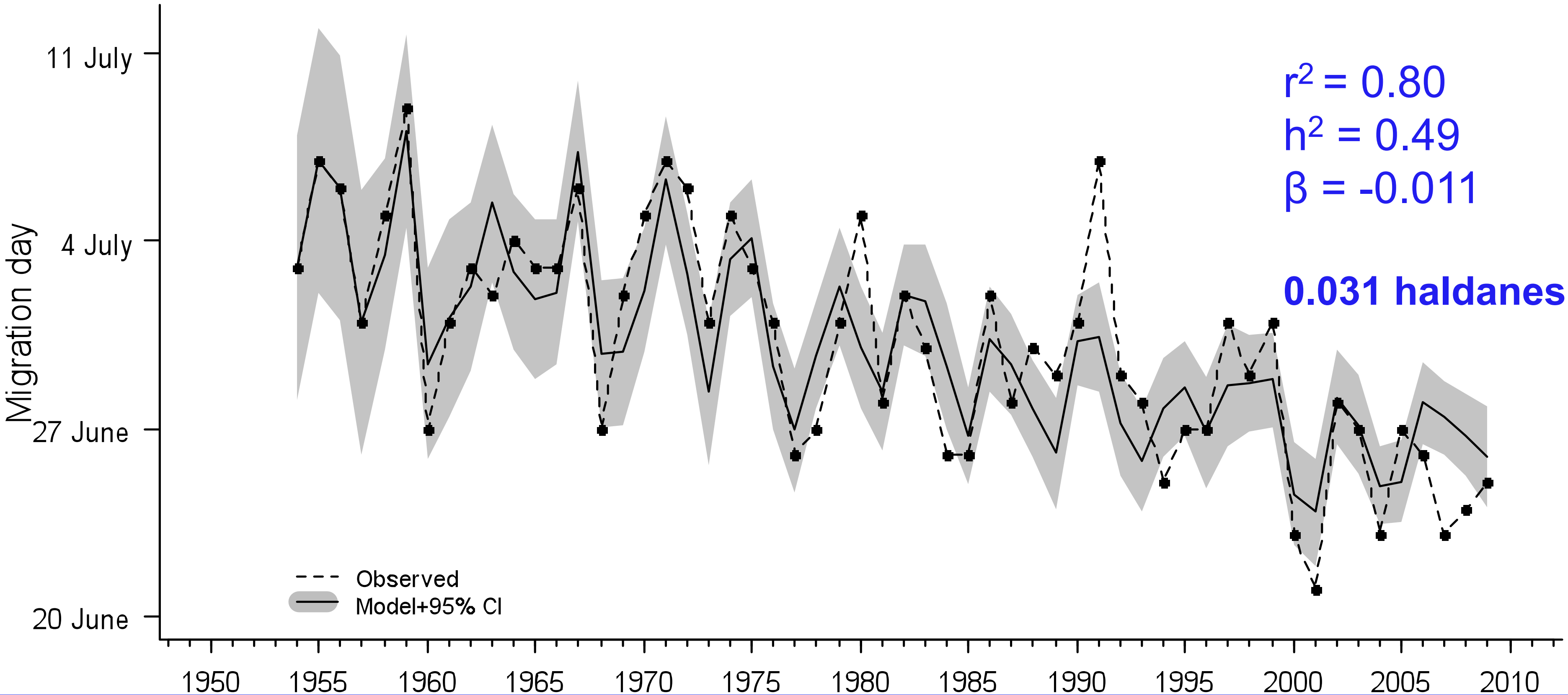


Sockeye migrate ~10.3 days earlier than in the 1940s



Quinn and Adams 1996
Crozier et al 2008
Crozier et al 2011

Model prediction plasticity + evolution



$r^2 = 0.80$
$h^2 = 0.49$
$\beta = -0.011$

0.031 haldanes

Additional topics

- Sex determination, sex ratios
- Skeletal and muscle morphology – swimming

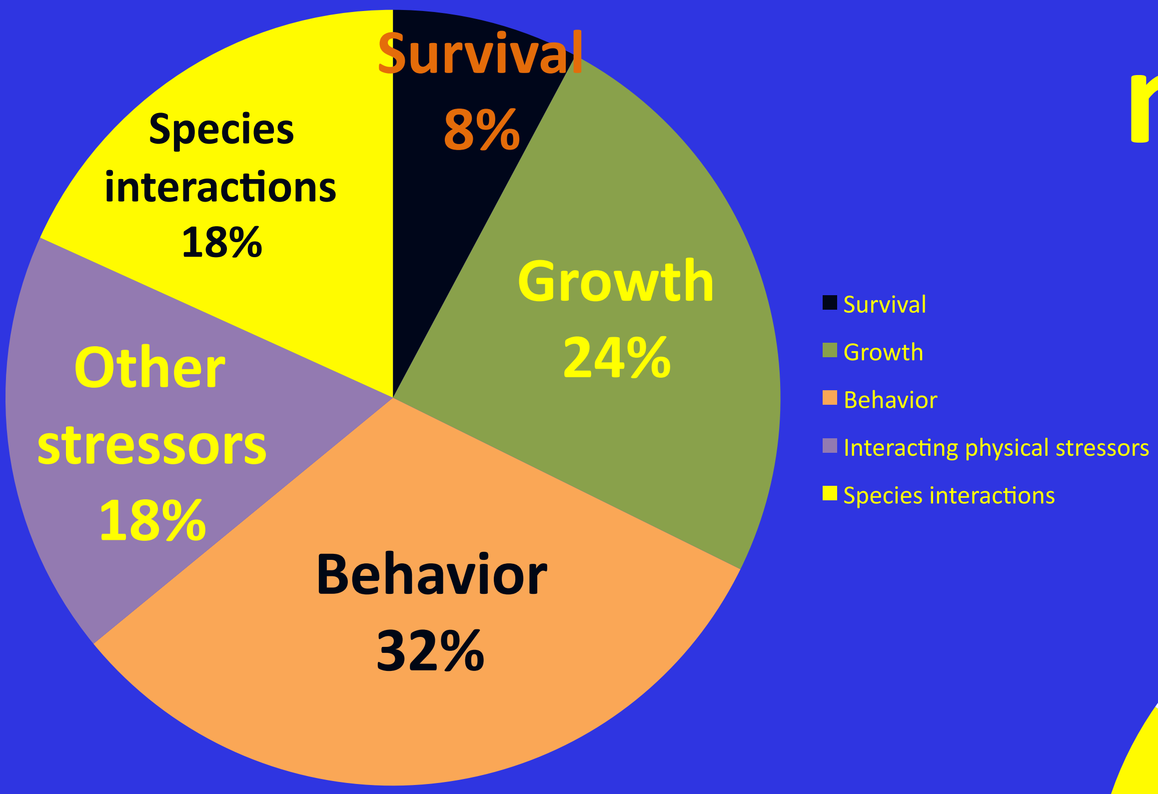
- Various behaviors
  - Avoidance of predators -- boldness
  - Habitat use
  - Activity levels
  - Migration blockages, straying

Interacting stressors

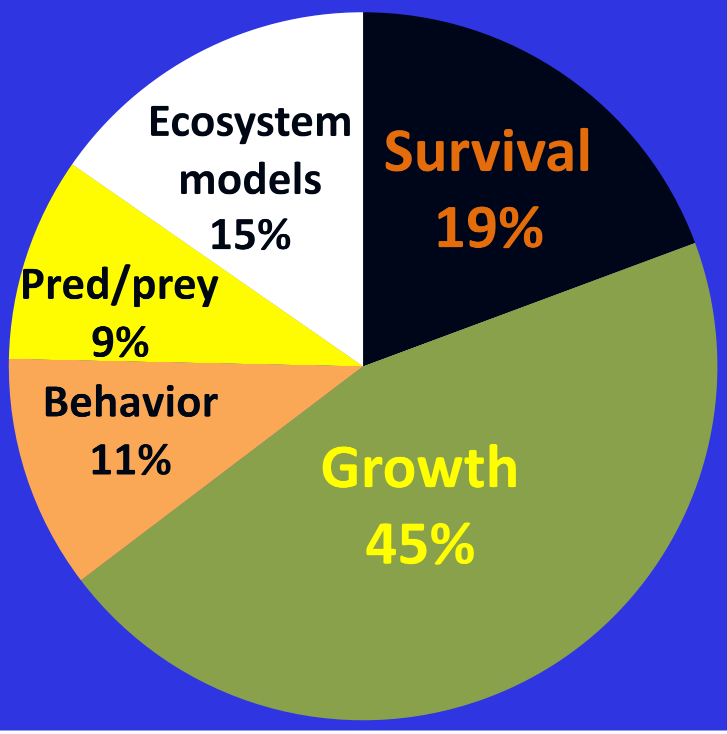
- Hypoxia
- Contaminants
- Handling/interception by fishery
- Change prey availability, energy density
- Disease
  - ***Ceratomyxa shasta***
  - ***myxozoan parasite Parvicapsula minibicornis***
  - **proliferative kidney disease**

Traits measured

Freshwater Responses



Marine Responses



Behavior:

Migration/spawn timing
Performance (e.g., swimming ability)
Life history (age at smolting, age at maturation)
Habitat usage, movement data

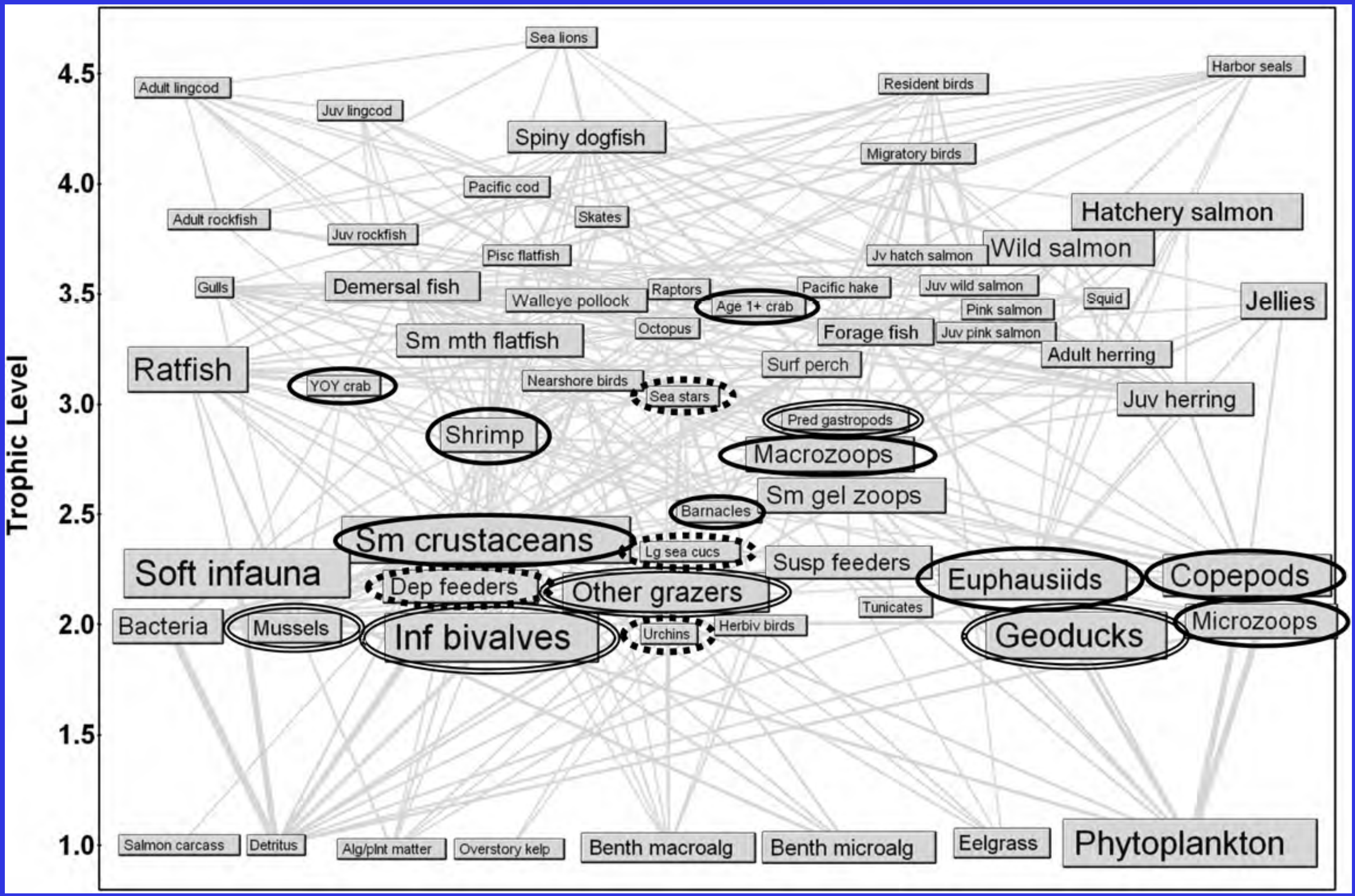
Taxa	Response	Mean Effect
 Calcifying algae	Survival	
	Calcification	
	Growth	
	Photosynthesis	−28%
	Abundance	−80%
 Corals	Survival	
	Calcification	−32%
	Growth	
	Photosynthesis	
	Abundance	−47%
 Coccolithophores	Survival	
	Calcification	−23%
	Growth	
	Photosynthesis	
	Abundance	
 Mollusks	Survival	−34%
	Calcification	−40%
	Growth	−17%
	Development	−25%
	Abundance	
 Echinoderms	Survival	
	Calcification	
	Growth	−10%
	Development	−11%
	Abundance	
 Crustaceans	Survival	
	Calcification	
	Growth	
	Development	
	Abundance	
 Fish	Survival	
	Calcification	
	Growth	
	Development	
	Abundance	
 Fleshy algae	Survival	
	Calcification	
	Growth	+22%
	Photosynthesis	
	Abundance	
 Seagrasses	Survival	
	Calcification	
	Growth	
	Photosynthesis	
	Abundance	
 Diatoms	Survival	
	Calcification	
	Growth	+17%
	Photosynthesis	+12%
	Abundance	

Not tested or too few studies
Enhanced <25%
95% CI overlaps 0
Reduced <25%
Reduced >25%

Ocean acidification primarily affects calcifying organisms, but responses very idiosyncratic

Kroeker et al 2103. Global Change Biology

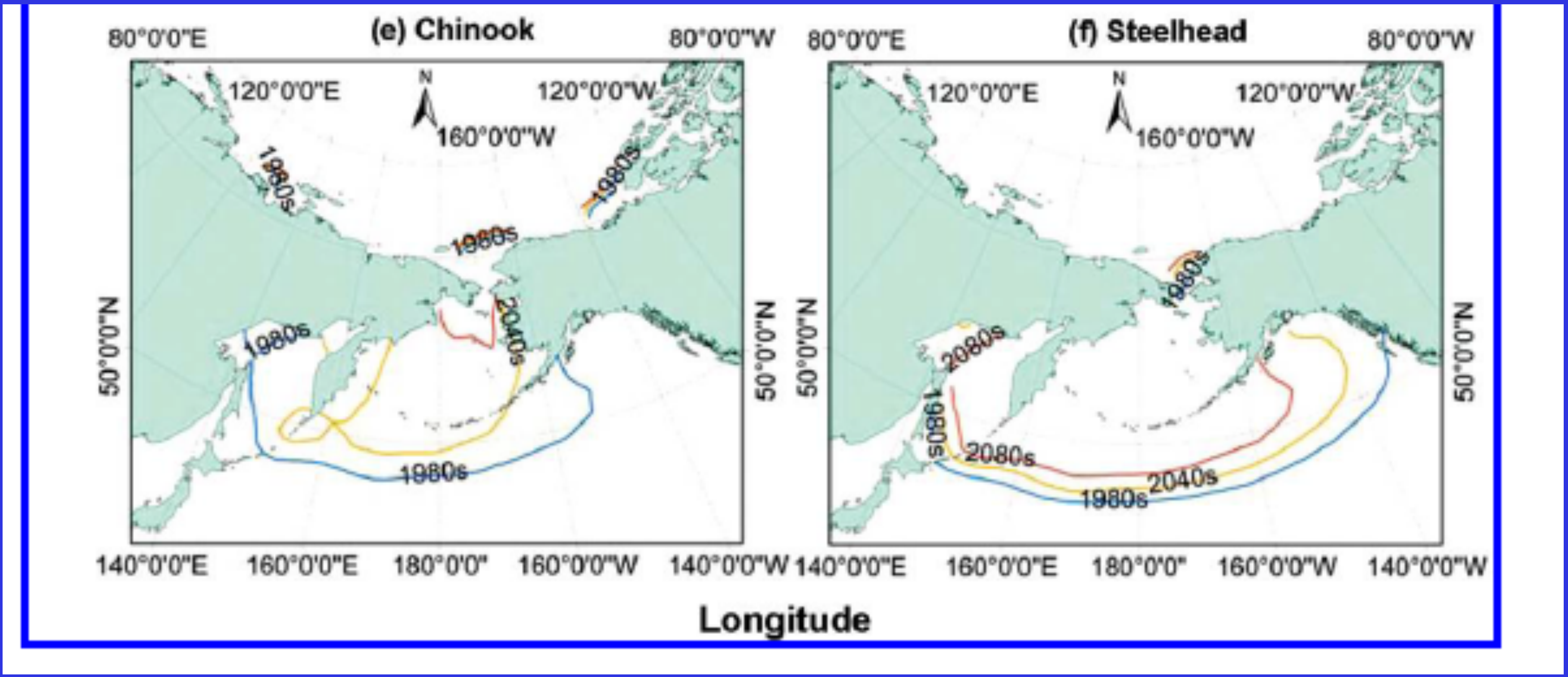
Ocean acidification



Busch, Harvey and McElhany,
Potential impacts of ocean acidification on the Puget Sound food web
Ices Journal of Marine Science, 2013

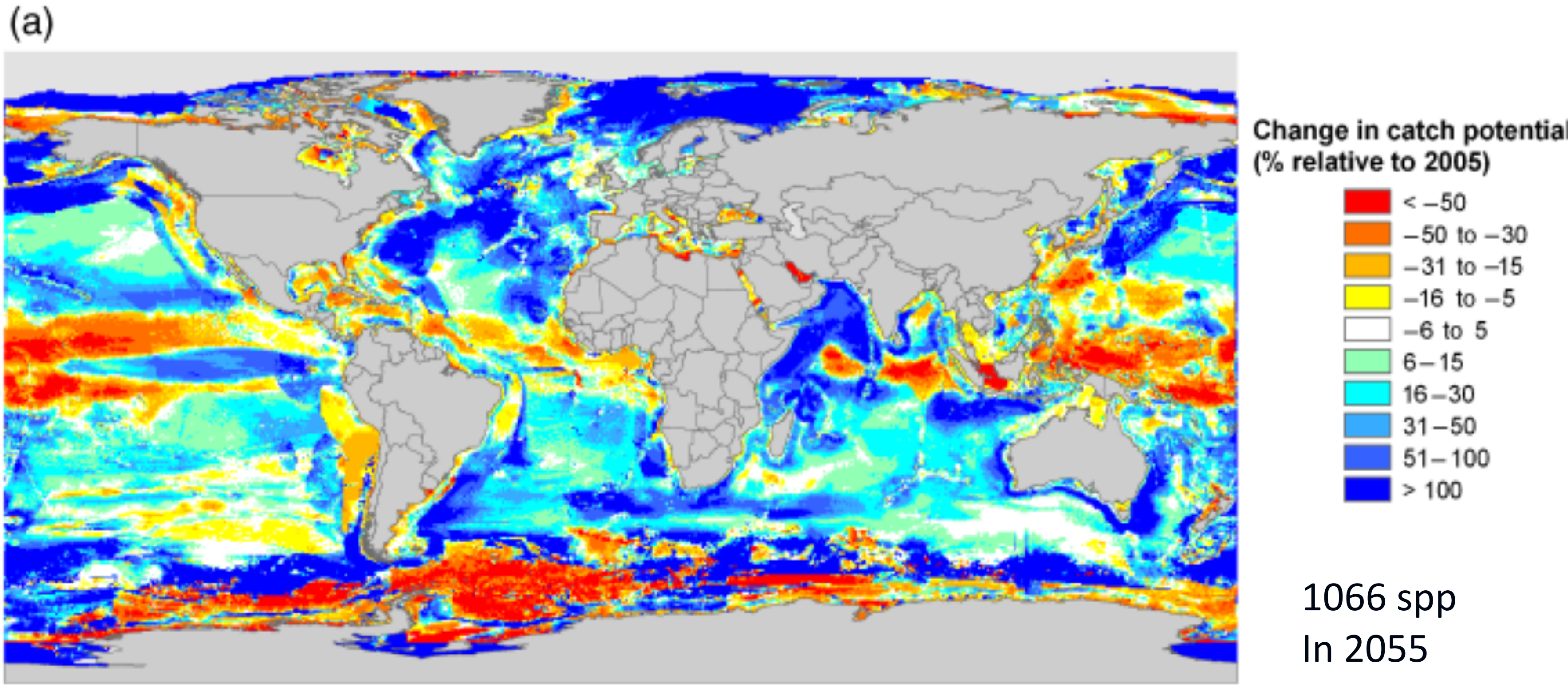
"Impacts of OA were imposed on all heterotrophic functional groups dominated by calcifiers (Table 1, Figure 1)."

Projected ocean habitat ~ SST



Abdul Aziz et al 2012 CJFAS

Fisheries catch ~ ocean productivity



1066 spp
In 2055

Cheung et al 2010

Major uncertainties

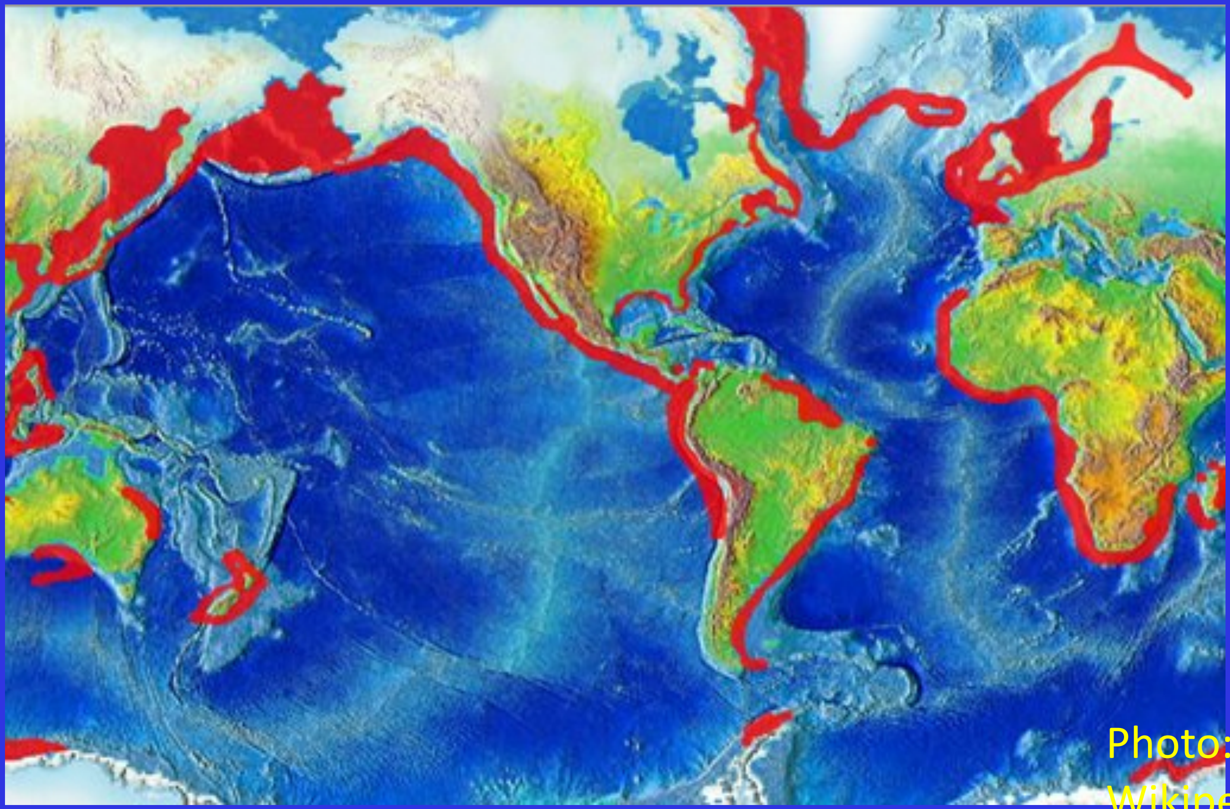
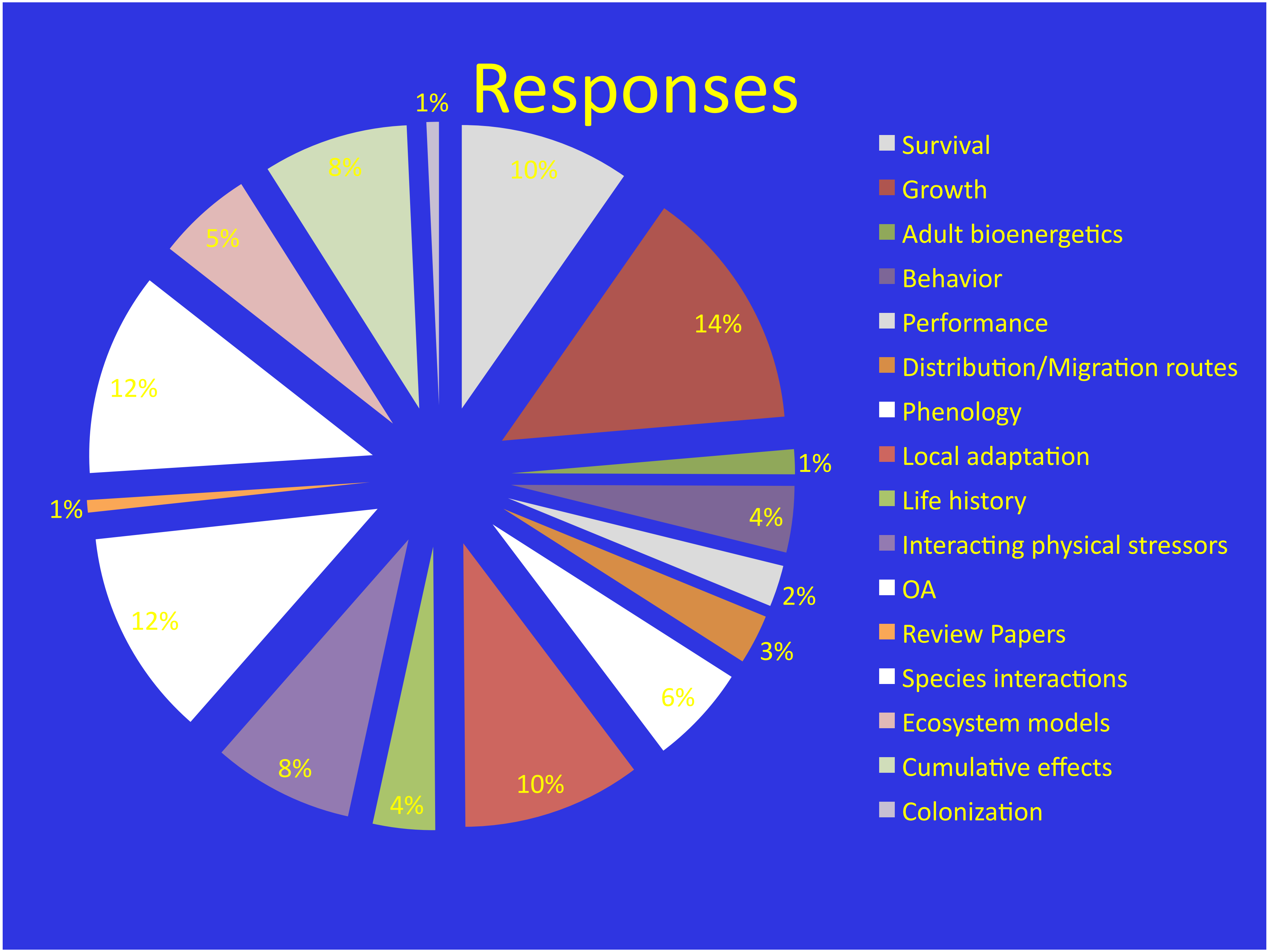


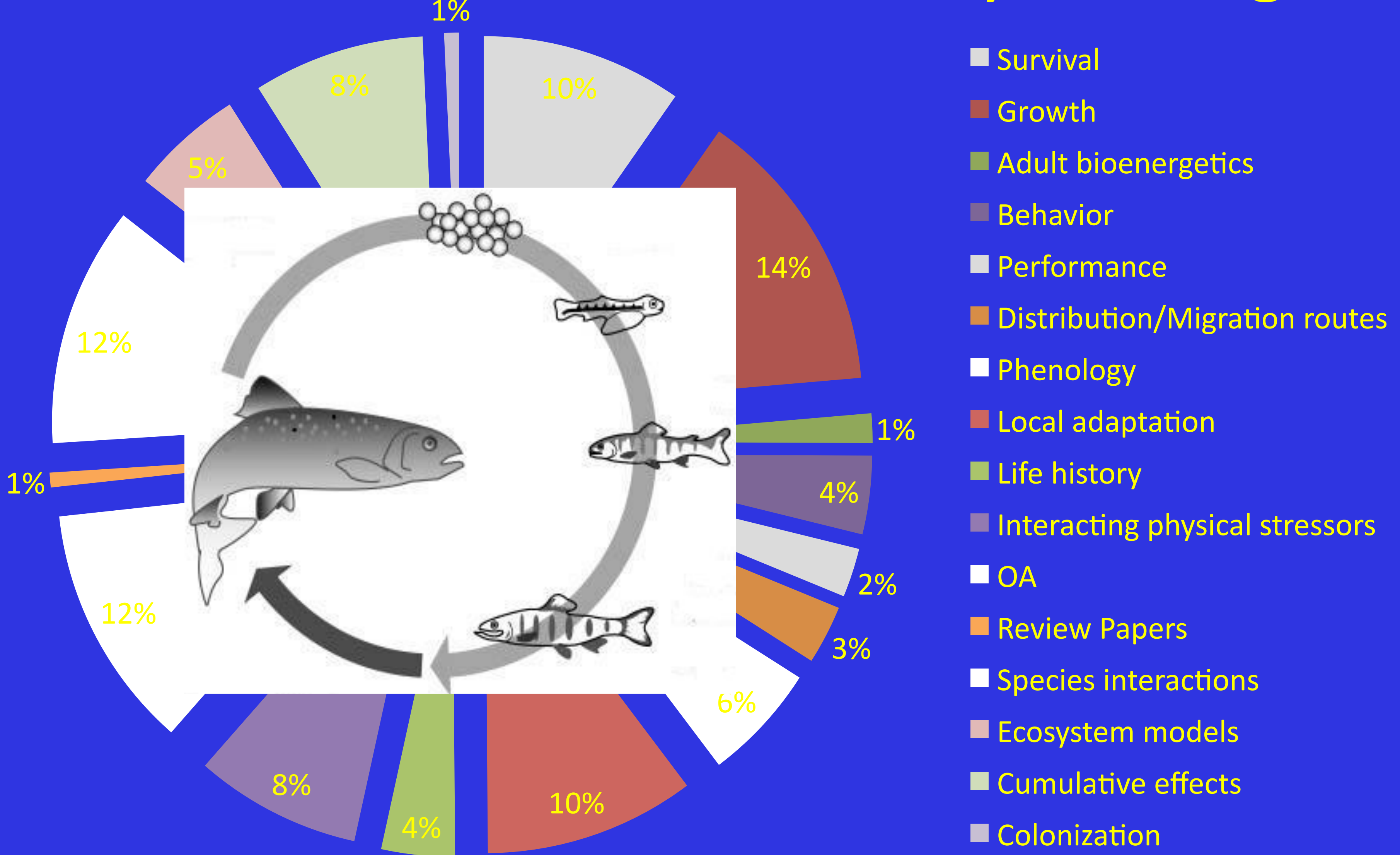
Photo:
Wikipedia: upwelling

Upwelling zones drive most productive ocean habitats
Intensity ↑ or ↓?
Importance of timing shifts?
General ocean changes and impacts on salmon?

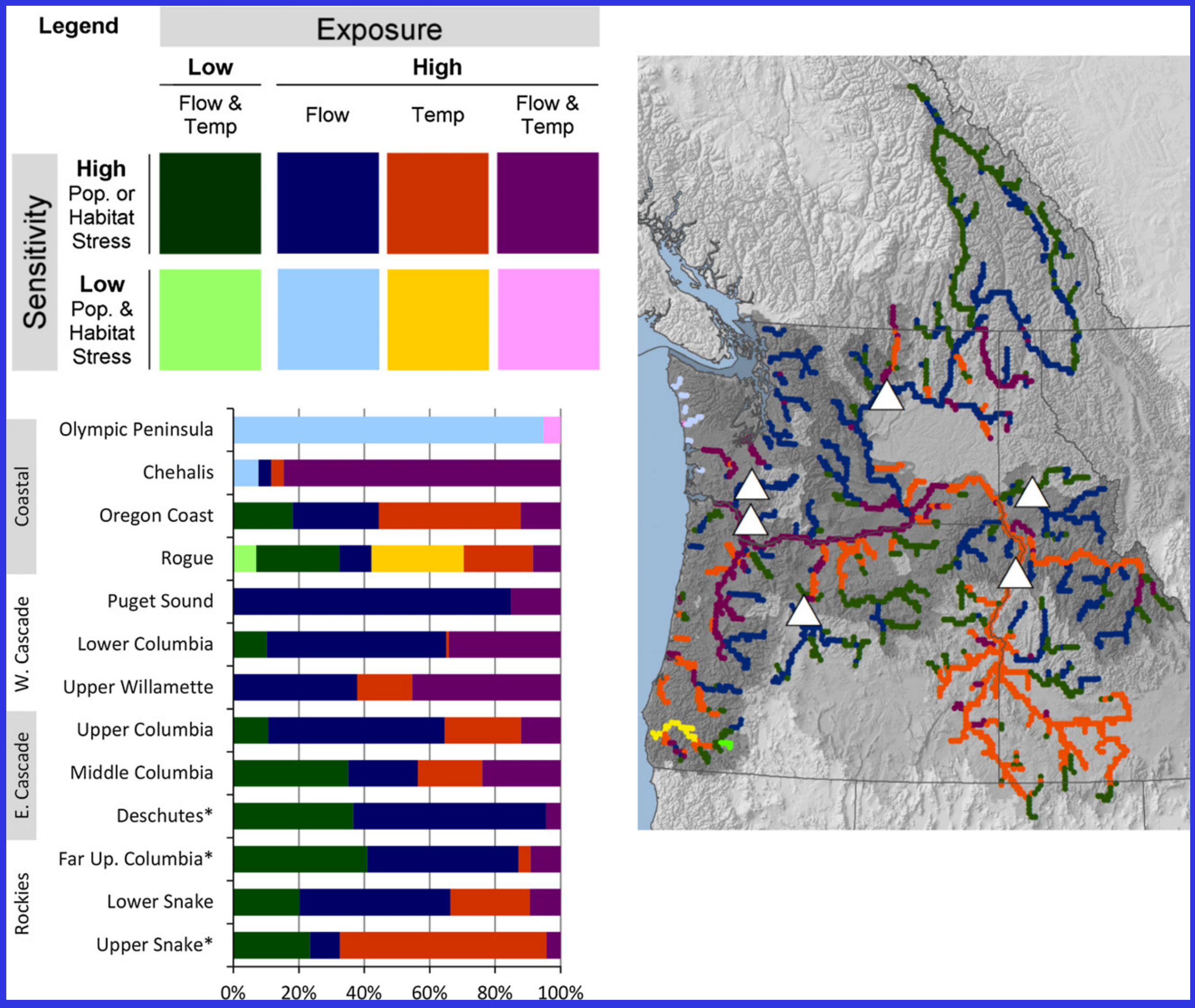


Responses
1%
10%
14%
1%
4%
2%
3%
6%
10%
4%
8%
12%
1%
12%
5%
8%
Survival
Growth
Adult bioenergetics
Behavior
Performance
Distribution/Migration routes
Phenology
Local adaptation
Life history
Interacting physical stressors
OA
Review Papers
Species interactions
Ecosystem models
Cumulative effects
Colonization

Results: Climate affects every life stage



Steelhead vulnerability assessment



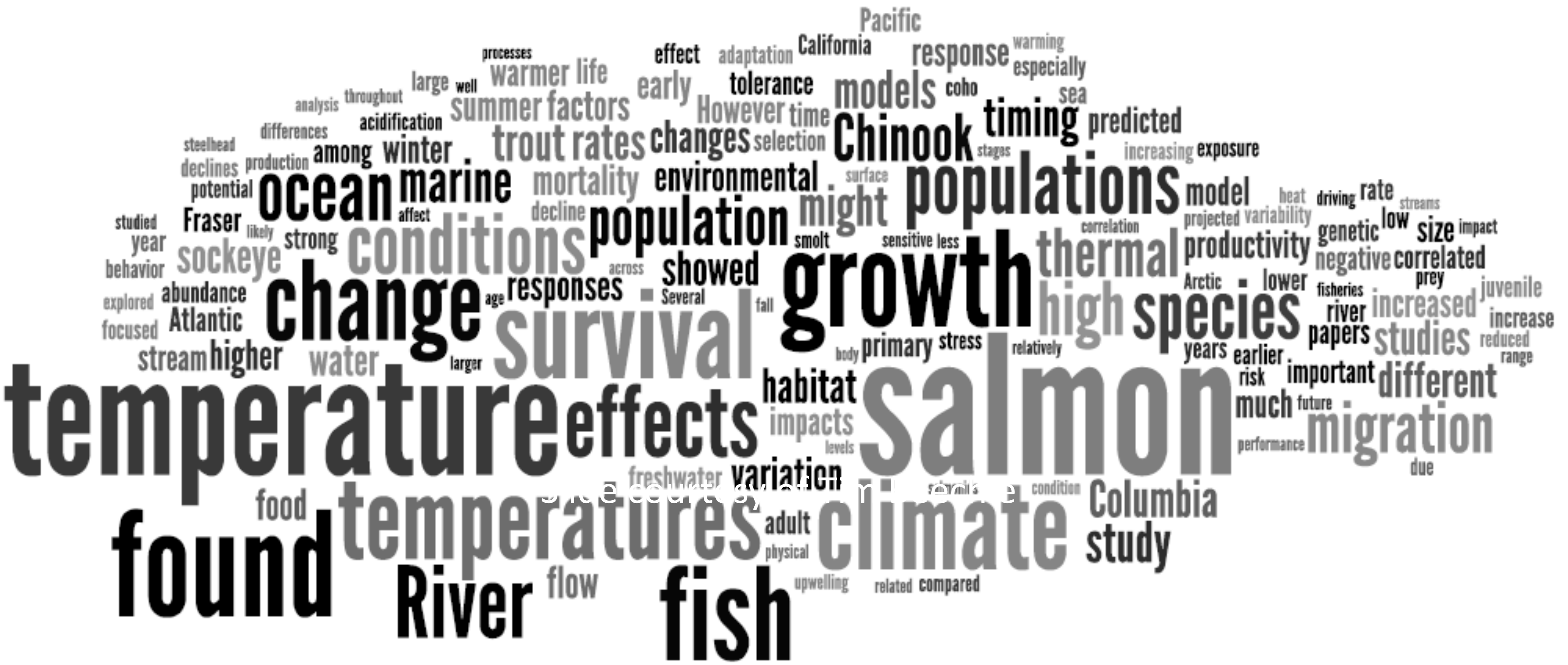
Wade et al 2013. Journal of Applied Ecology

Restoration actions and climate change

Restoration action	Does action reduce a climate change effect?		
	Temperature increase	Low flow decrease	Peak flow increase
Restore incised channel	Y	Y	Y
Floodplain connectivity	Y	N	Y
Restore in-stream flow	Y	Y	N
Riparian rehabilitation	Y	N/Y	N
Road rehabilitation	N	N	N/Y
In-stream habitat	N	N	N
Nutrient enrichment	N	N	N

Slide courtesy of Tim Beechie

Conclusions



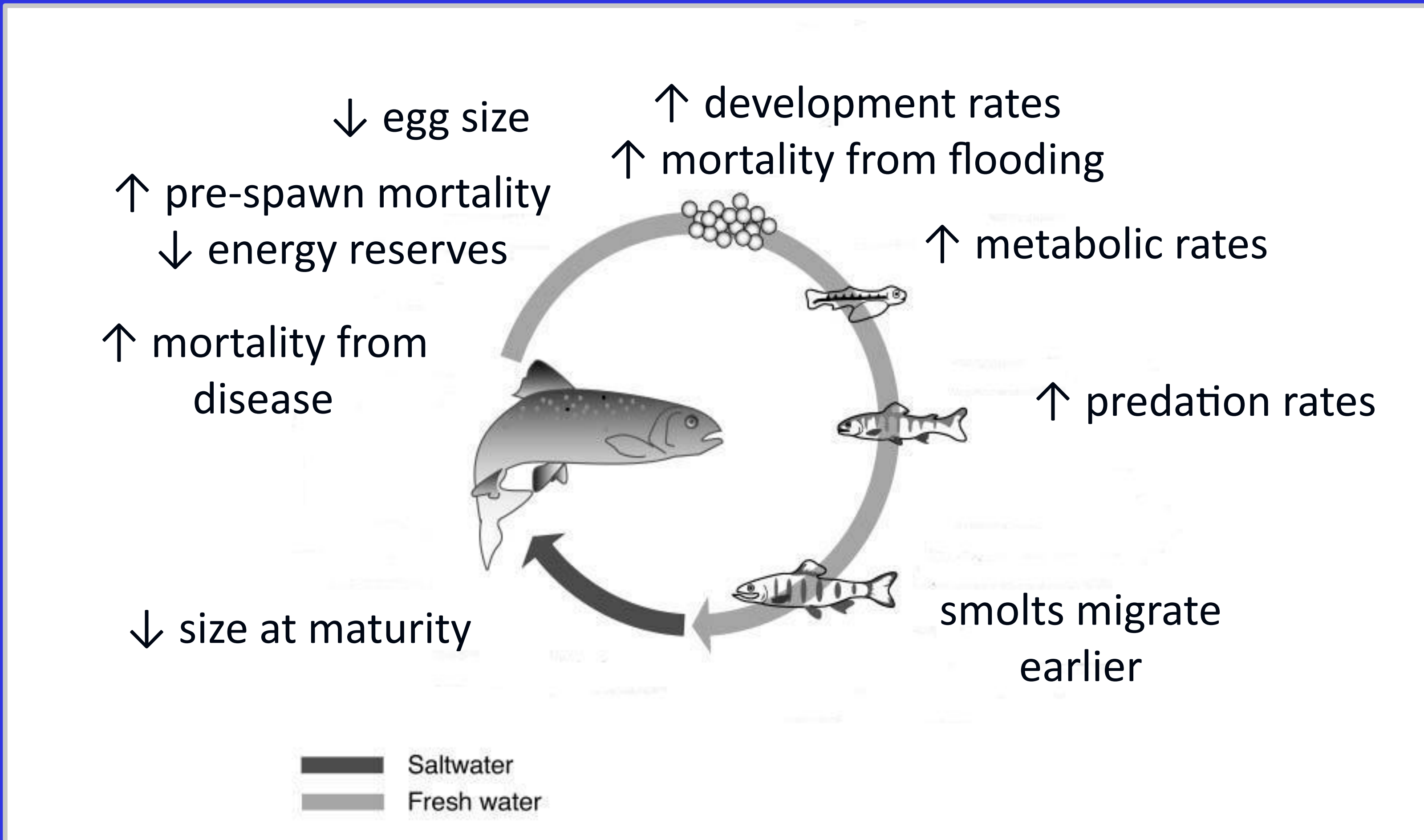
1. Different information about marine and freshwater ecosystems
2. Interactions among stressors and across ecosystems important
3. Restoration actions relatively clear – human impacts ~ climate change

Reports available at
http://www.nwfsc.noaa.gov/trt/lcm/freshwater_habitat.cfm

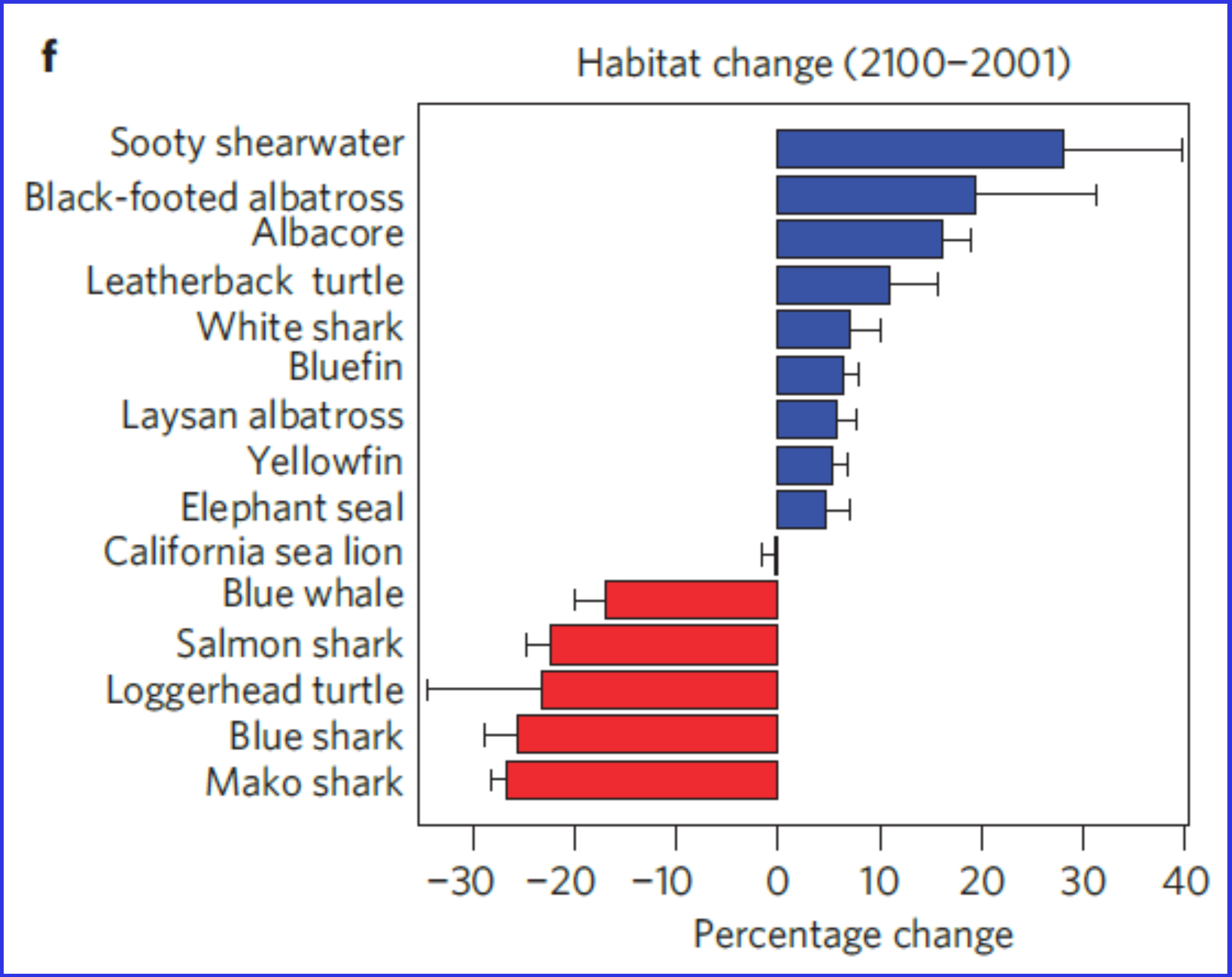
Acknowledgments

Chris Toole, NOAA-Fisheries
Rich Zabel, NOAA-Fisheries
Tim Beechie, Nate Mantua,
Tom Wainwright, Bill Peterson many other reviewers!!!

In warmer water,



Changes in marine top predators



Hazen et al 2012. Nature Clim. Change