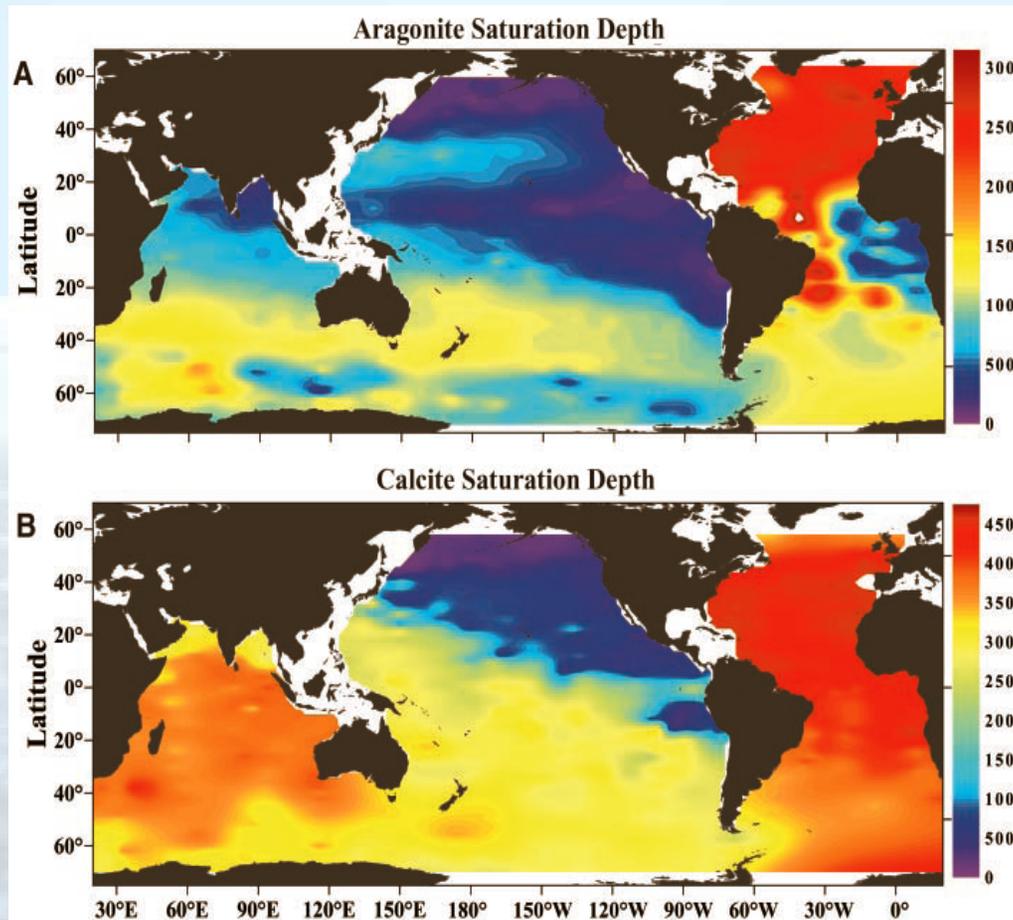


Fisheries Impacts of Ocean Acidification – Focus on Alaskan waters

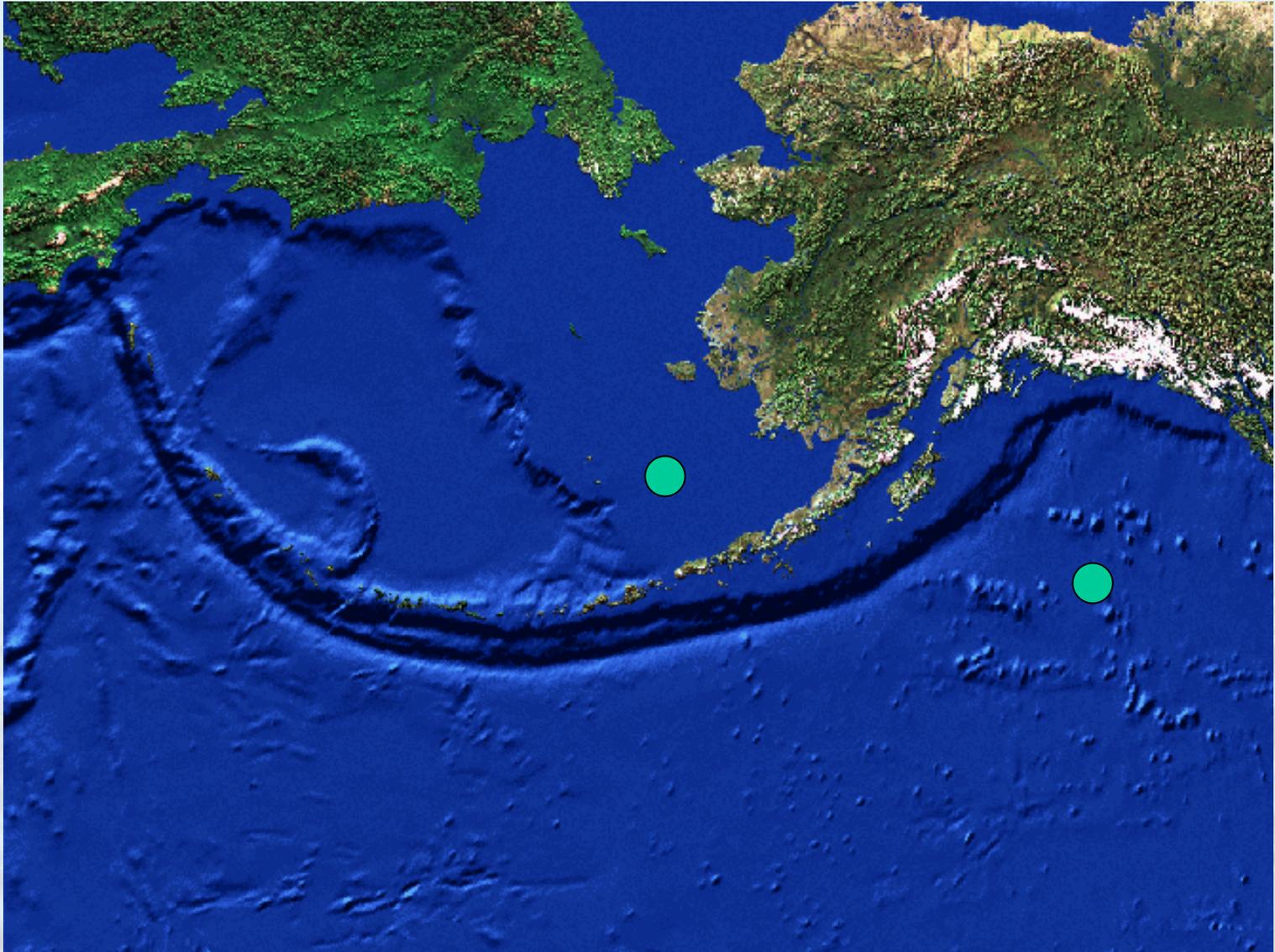


Sentinel Region

North Pacific Ocean, where carbonate saturation depth is relatively shallow.

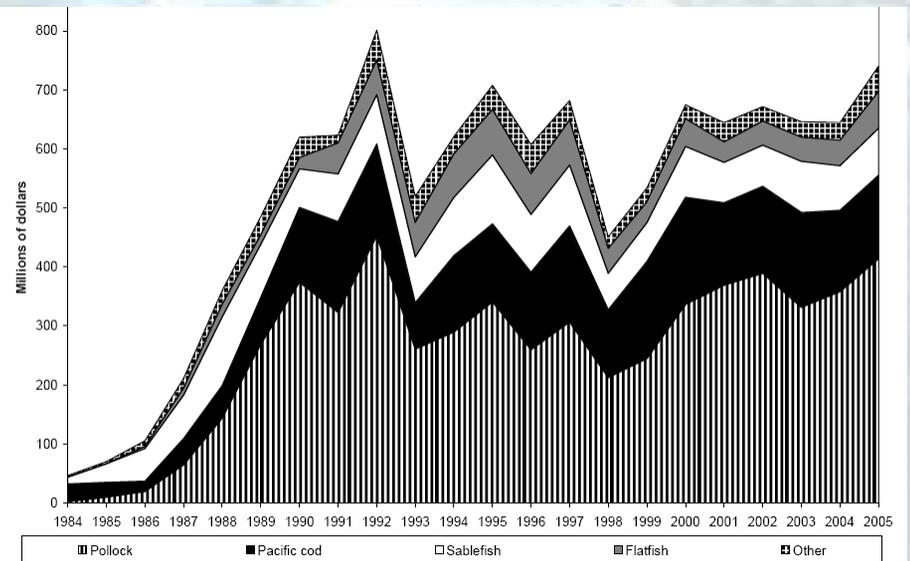
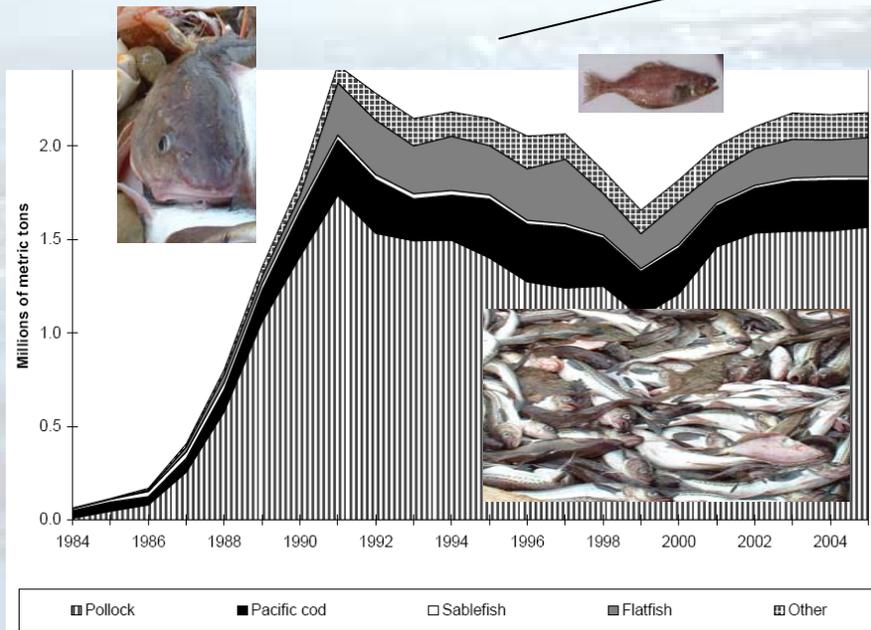
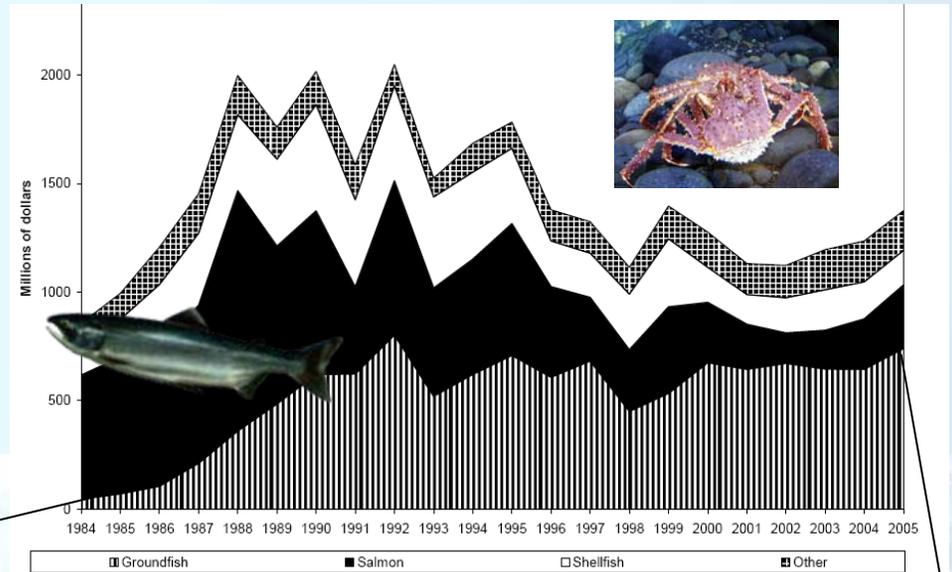


Feely et al. 2004. Impact of anthropogenic CO_2 on the CaCO_3 in the oceans. *Science* 305: 362-366.



Highly productive shallow shelves, productive offshore regions (rearing and growth area for salmon)

Components of Alaskan fisheries



2006 Alaska Commercial Salmon Harvest Ex-vessel Values

Species	Avg. wt (lbs.)	Avg. Price/lb.	No. of Fish (thousands)	Lbs. of Fish (thousands)	Estimated Value USD (thousands)
Chinook	15.71	3.03	645	10,126	30,721
Sockeye	5.71	0.76	41,649	237,716	180,610
Coho	7.24	1.04	4,428	32,065	33,447
Pink	3.70	0.16	72,808	269,613	43,372
Chum	8.44	0.32	21,532	181,836	58,299
Totals			141,062	731,355	346,449

From <http://www.cf.adfg.state.ak.us/geninfo/finfish/salmon/salmoncatch.php> accessed 9/28/07

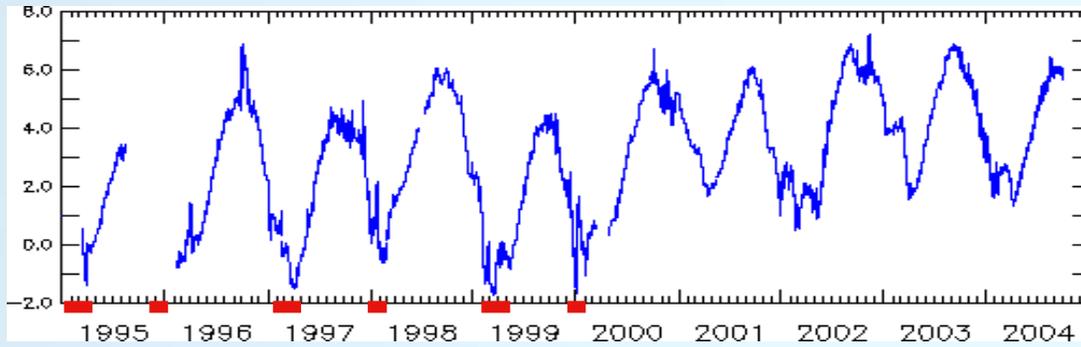
Does not include recreational value, or data from Japan, Russia, Canada, or Wa-Or-Ca



Rich biological relationships



Temperature and ice versus acidity?



Change in the nation's "fish basket"

Rising temperatures are transforming Alaska's Bering Sea, the source of half of America's seafood and the mainstay of Seattle's fishing industry. Crab, flatfish, walrus and seal populations are suffering while pollock and cod are on the rise.

A FROZEN WORLD

Ice provides habitat for mammals and birds and nurtures a food chain that favors bottom-feeding species like crab, flatfish and gray whales; it also creates a deep pool of near-freezing water that crab prefer and pollock avoid.

1. Walruses and seals give birth on sea ice and use it as a platform for hunting, as do seabirds like spectacled eiders.
2. In early spring, algae bloom under the sea ice.
3. Because the water is still very cold, few tiny animals, like copepods, are around to eat the algae.
4. The algae dies and falls to the bottom, providing food for worms, crabs and other small creatures that in turn feed crabs, walruses, bottom fish and diving birds. Gray whales feed on shrimplike animals called amphipods, which thrive in icy waters.

Gray whale populations are flourishing, but the big mammals are moving further north as amphipod numbers decline.

THAWING OUT

An ice-free sea favors species that live and feed in the water column, like pollock, cod and orcas.

1. When the water doesn't freeze, or the ice melts early, walruses and seals have fewer places to give birth. Forced into deeper waters further north where ice remains, walruses can't reach the bottom to forage for clams.
2. Without ice to provide a substrate, algae don't bloom until later in the spring.
3. In the warmer waters, zooplankton, including copepods, flourish, consuming the algae.
4. The zooplankton provide food for small fish, including juvenile pollock and cod, which also spread north as the pool of cold water shrinks; orca feed on the adult pollock and cod.
5. Less food reaches the bottom for crab and other bottom-feeders.

Species shown: Ribbon seal (*Phoca fasciata*), Walrus (*Odobenus rosmarus*), Spotted seal (*Phoca largha*), Spectacled eider (*Somateria fuscigera*), Algae, Copepods (*Calanus marshallae*), (juvenile) Walleye pollock (*Theragra chalcogramma*), (adult) Walleye pollock, Gray whales (*Eschrichtius robustus*), Pacific cod (*Gadus macrocephalus*), Orca (*Orcinus orca*), Amphipods (*Thermosia libellula*), Snow crab (*Chionoecetes opilio*), Blue king crab (*Paralithodes pinnigeryus*), Red king crab (*Paralithodes camtschaticus*), Yellowfin sole (*Limanda aspera*).

Sources: "A Major Ecosystem Shift in the Northern Bering Sea," Science, vol. 312, March 10, 2006. "BEST, Bering Ecosystem Study Science Plan," Bering Sea Research Consortium of the United States (ARCUS), 2004.



- Temperature
 - Direct temperature effects
 - Ice-related productivity
 - Winners and losers

- Acidity...any winners?

Acidity

- Direct stress
 - Crabs
 - Physiological effects on fish
- Habitat stress
 - Corals, effects on sheltering fish
- Trophic stress
 - Salmon dependent on pteropods
 - Shifting pathways in food web



Ocean Acidification - Shellfish

- Larval blue king crab, Kodiak Alaska, pilot experiment, 2006.
- Tested range of projected global ocean pH change over the current century.
- Reduced growth and survival.
- Contact: Bob Foy, AFSC Kodiak

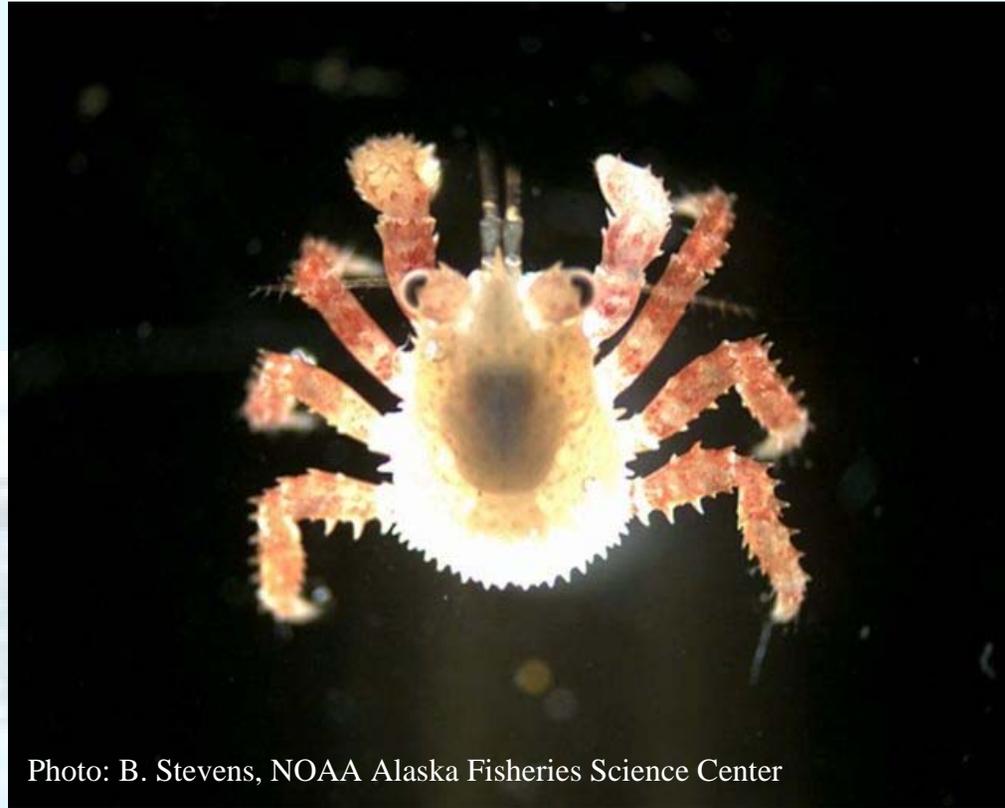
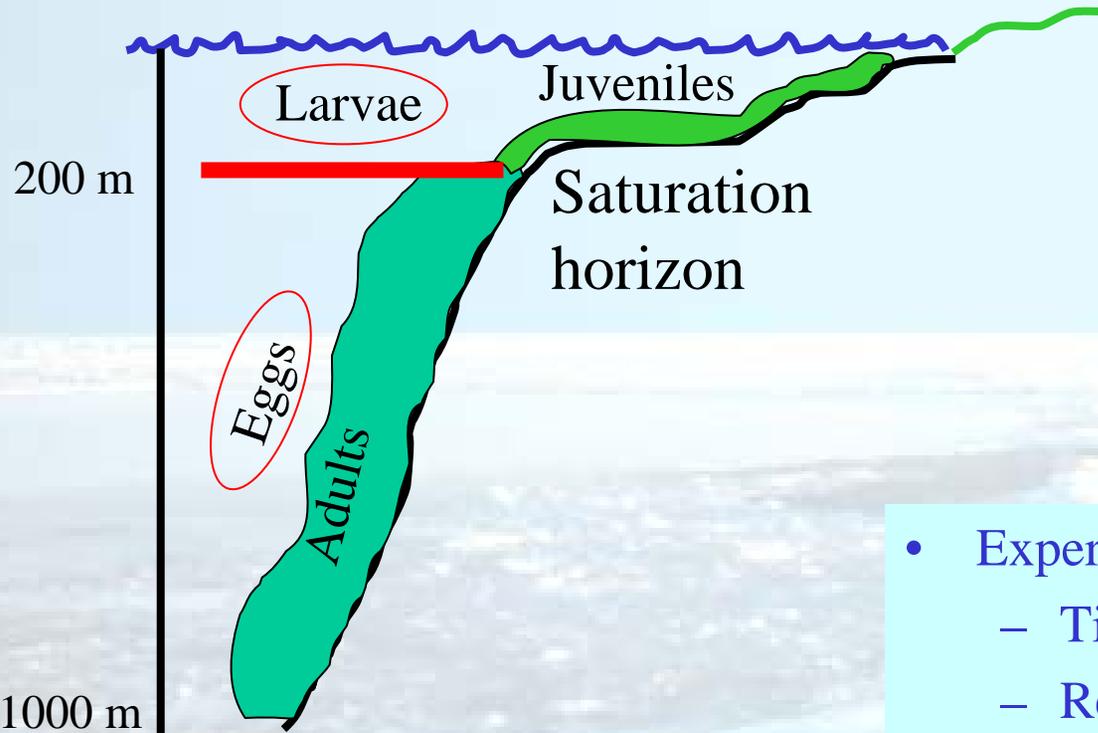


Photo: B. Stevens, NOAA Alaska Fisheries Science Center

Finfish in a Low Carbonate Environment – many do live.



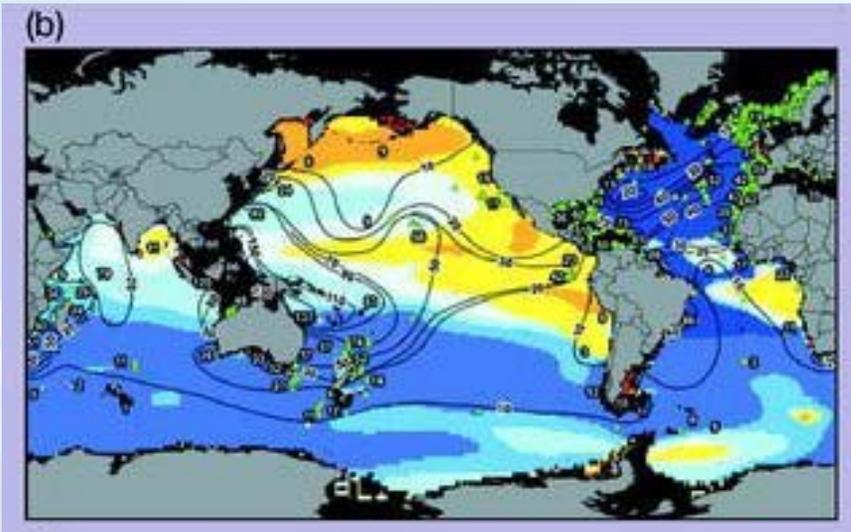
Alaska Sablefish



- Experimental effects
 - Tissue acidosis
 - Reproduction
- Experimental concentrations generally higher than considered reasonable given projected CO₂ concentrations
- Considerable planning on further experiments – Mike Sigler

Ocean Acidification - Corals

Deep-sea bioherm forming corals



Guinotte, JM, J. Orr, S. Cairns, A. Freiwald, L. Morgan, and R. George. 2006. Will human-induced changes in seawater chemistry alter the distribution of deep-sea scleractinian corals? *Front. Ecol. Environm.* 4:141-146. Green triangles are locations of deep-sea bioherm forming corals.

Depth distribution of Aleutian corals.

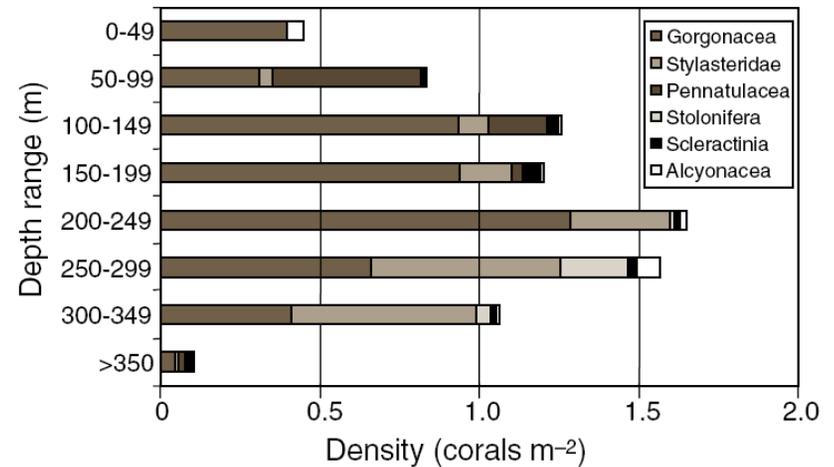
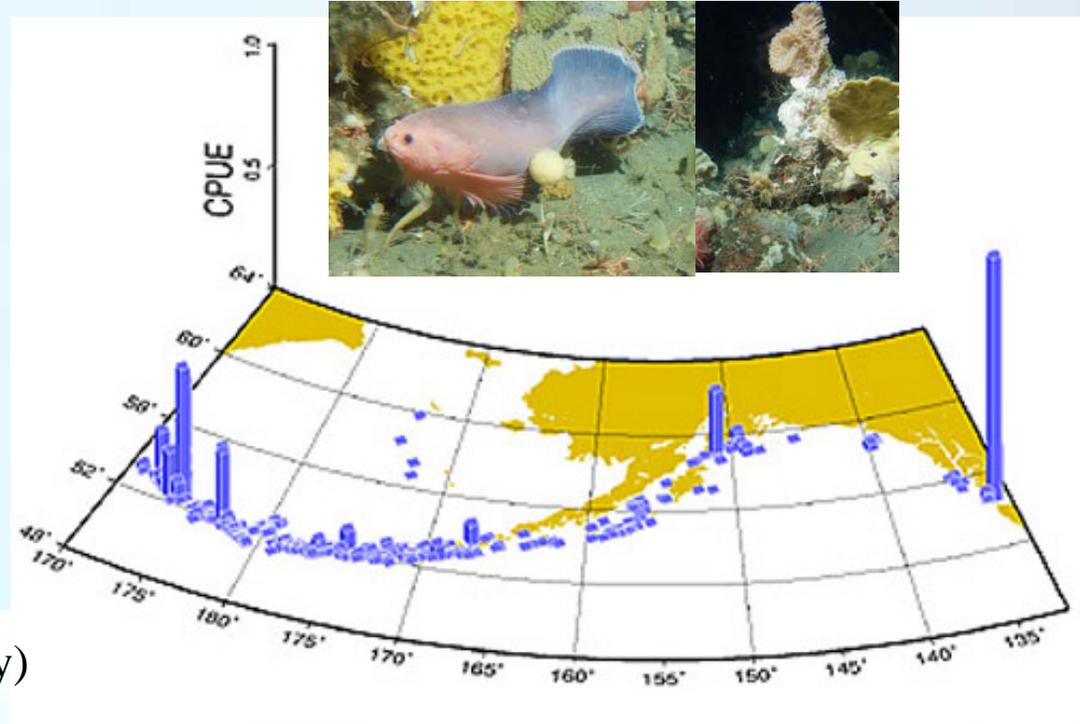


Fig. 3 Density of corals observed in 50-m depth zones with the submersible 'Delta'

Stone, R. P. 2006. Coral habitat in the Aleutian Islands off Alaska: Depth distribution, fine-scale species associations, and fisheries interactions. *Coral Reefs* 25:229-238.

Coral gardens

- Shelter for juvenile rockfish



(Jonathan Heifetz, Auke Bay Laboratory)



Ocean Acidification - Calcareous plankton, the base of the food web.

Coccolithophores (phytoplankton)

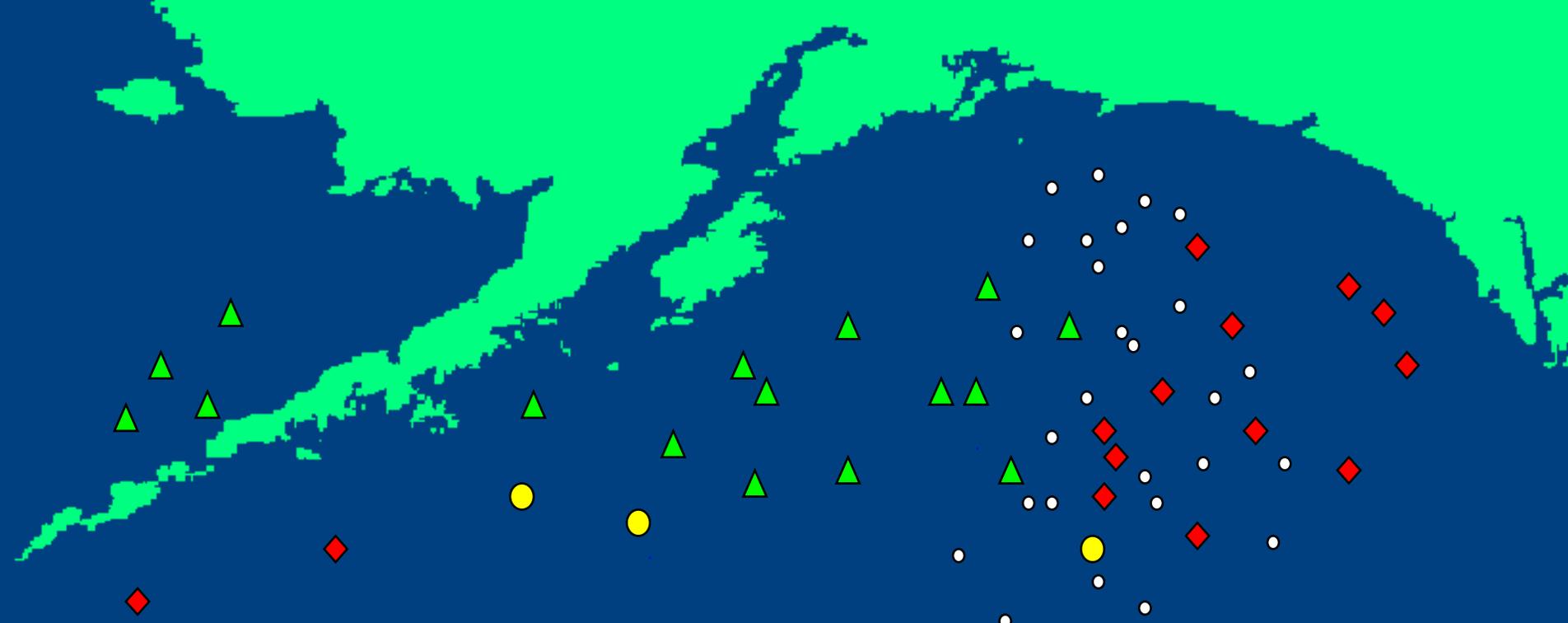


Foraminifera
(protist)



Pteropods (snail)



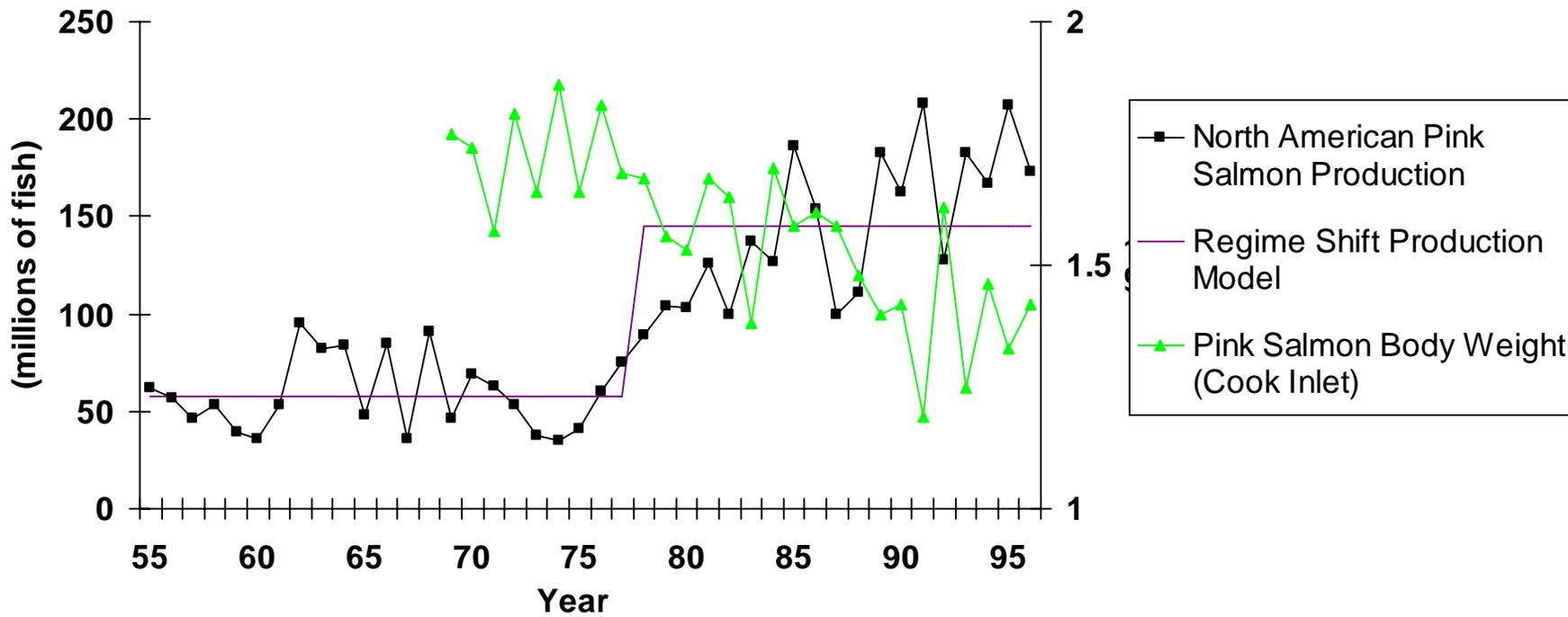


- ▲ Western Alaskan Sockeye
- ◆ British Columbia Sockeye
- Central Alaskan Pink
- Japanese Chum

Pacific Salmon Carrying Capacity



- Stock competition
- Salmon may be forage limited
- Habitat linked to water temperature



Trends in production and growth

Model linkages

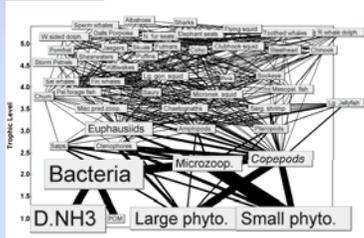


Pink salmon bioenergetics model, predicts daily pink salmon growth and numerical mortality based on input ration.

Pink salmon body weight and numbers used to set Ecosim biomass for predator and prey equations in next timestep.

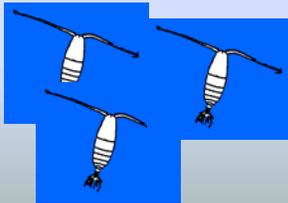
Consumption and mortality rates for Pink salmon based on predator and prey biomass.

Ecosim (ecosystem biomass dynamics model), run on a daily timestep.



*No direct feedback to NEMURO:
Ecosim parameters for predatory zooplankton (euphausiids) tuned to match NEMURO predictions for same species.*

Daily biomass density of phytoplankton, microzooplankton, large zooplankton



NEMURO (nutrient-phytoplankton-zooplankton-detritus): 1-dimensional water column model integrated on an hourly timestep.

Salmon Food Habits Analysis: Study Areas (Nancy Davis)

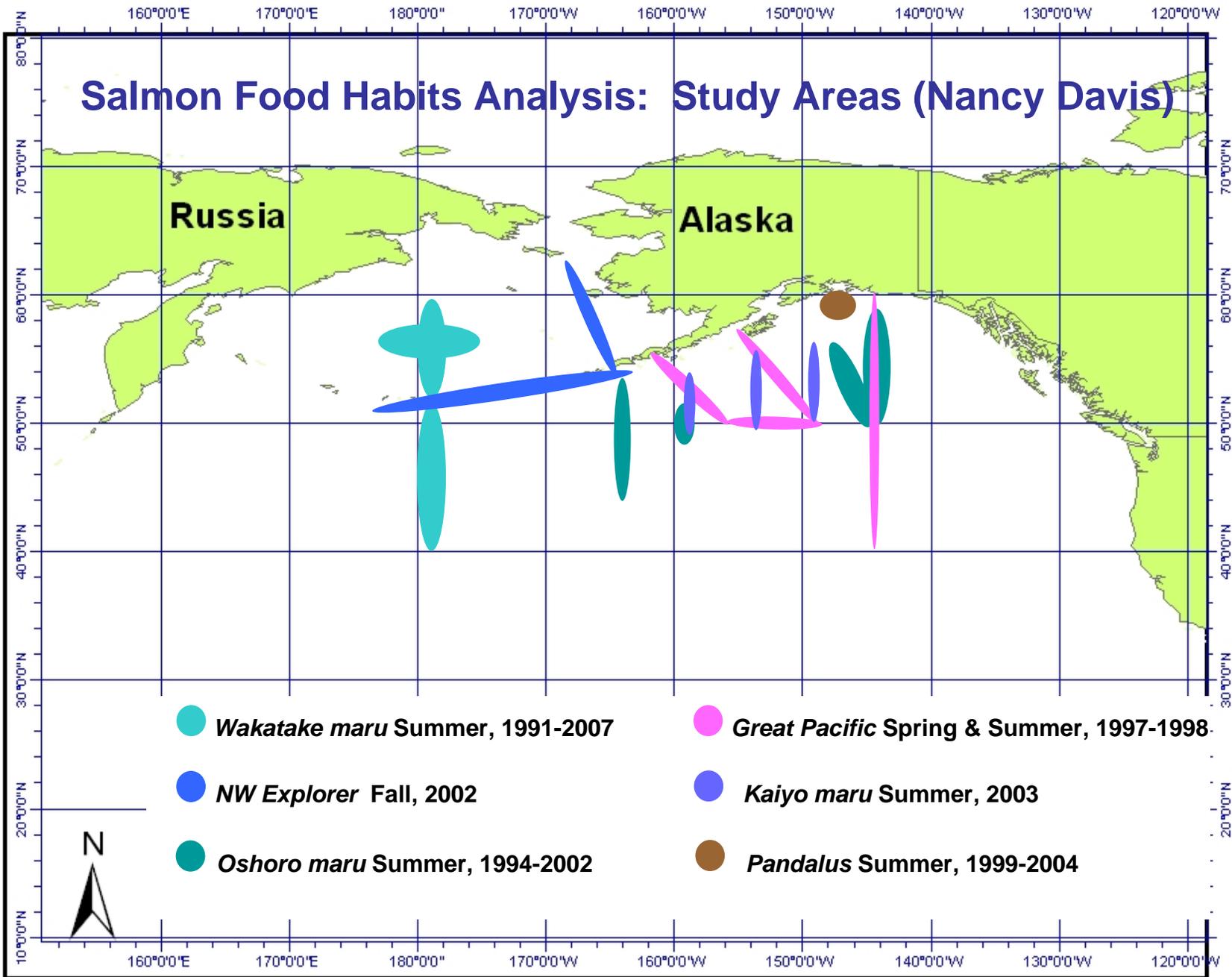
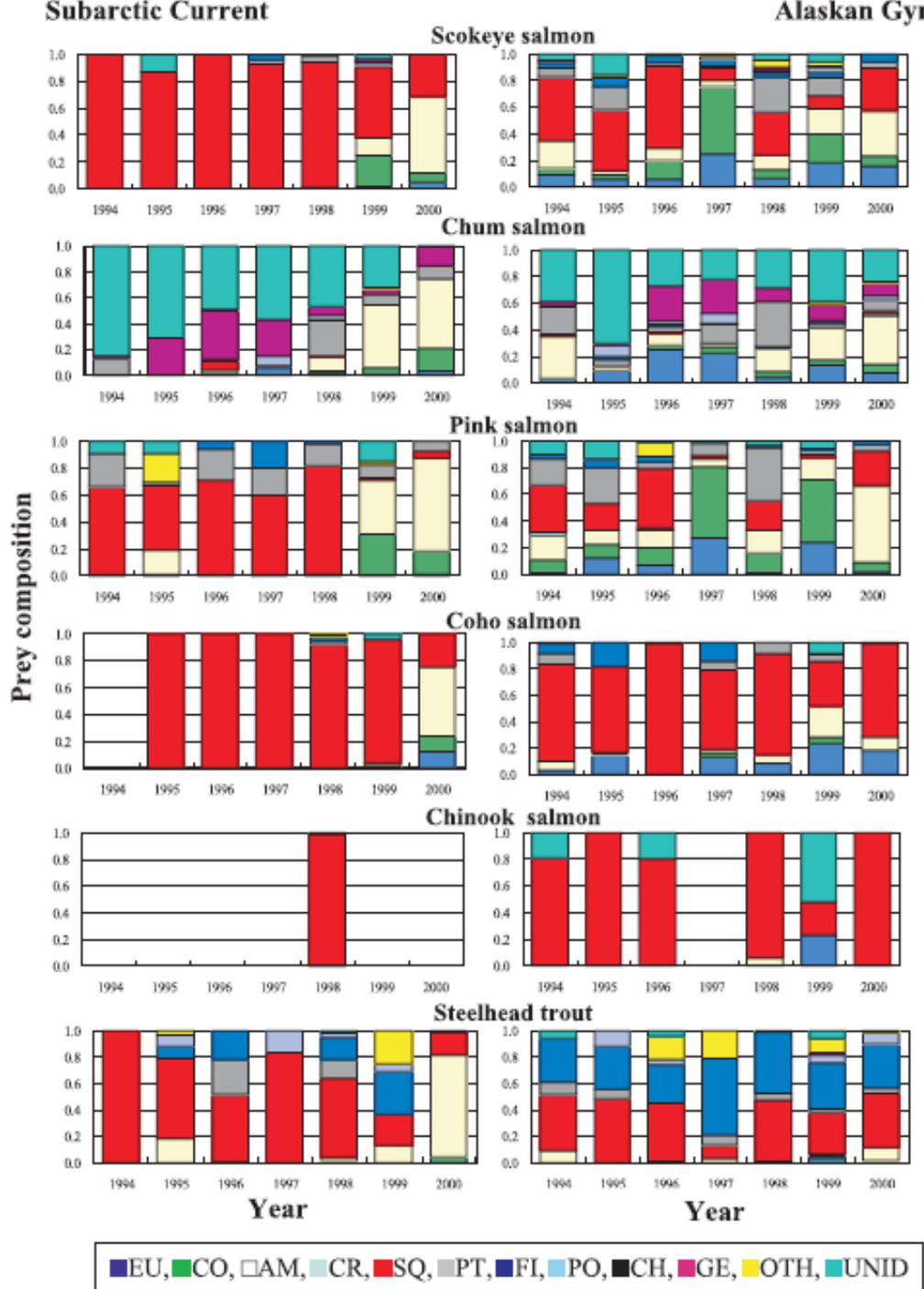


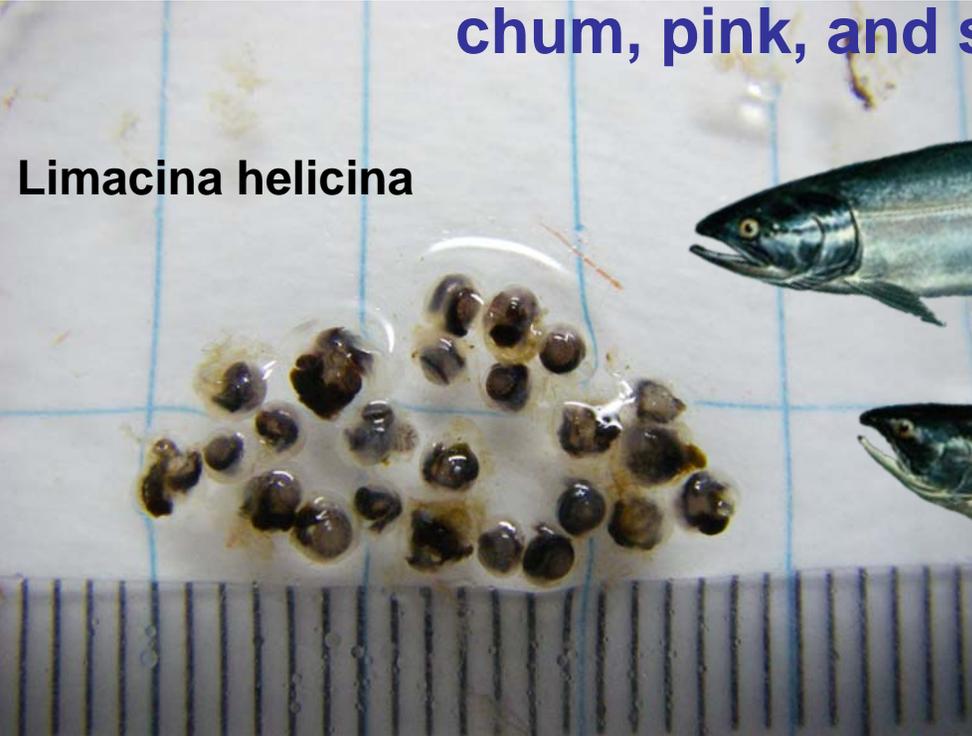
Table 1. Prey animals and food items of Pacific salmon in the Gulf of Alaska.

Food items	Species
Euphausiids (EU)	<i>Thysanoessa longipes</i>
	<i>Thysanoessa inermis</i>
	<i>Thysanoessa</i> spp.
	<i>Euphausia</i> spp.
	Other euphausiids
Copepods (CO)	<i>Neocalanus cristatus</i>
	<i>Eucalanus bungii</i>
	Other copepods
Amphipods (AM)	<i>Hyperia medusarum</i>
	<i>Hyperia</i> spp.
	<i>Themisto pacifica</i>
	<i>Themisto japonica</i>
	<i>Themisto</i> spp.
	<i>Primno macrops</i>
	<i>Phronima sedentaria</i>
Other amphipods	
Decapods (DE)	Decapods
Squids (SQ)	<i>Beryteuthis anonychus</i>
	<i>Gonatus middendorffi</i>
	Other squids
Pteropods (PT)	<i>Limacina</i> spp.
	<i>Clio</i> spp.
	<i>Clione</i> spp.
Fishes (FI)	<i>Anoplopona fimbria</i>
	Myctophids
	Other fish eggs and larvae
Polychaetes (PO)	Polychaetes
Chaetognaths (CH)	Chaetognaths
Gelatinous zooplankton (GE)	Coelenterates
	Ctenophores
	Salps
	Other animals (OT)
Other animals (OT)	Halocypridids
	Cumacea
	Octopoda
	Ostracods
	Barnacles
	Debris
	UI



Pteropods are consumed by juvenile, immature, and maturing chum, pink, and sockeye salmon

Limacina helicina

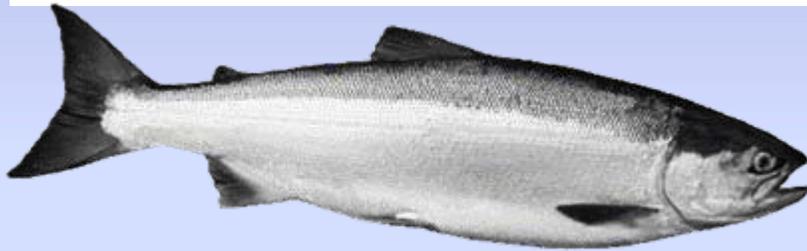
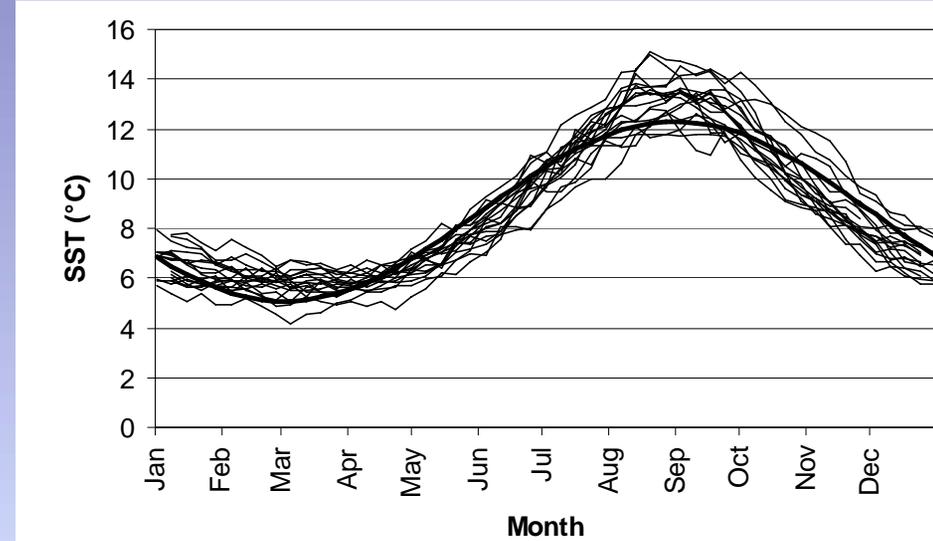
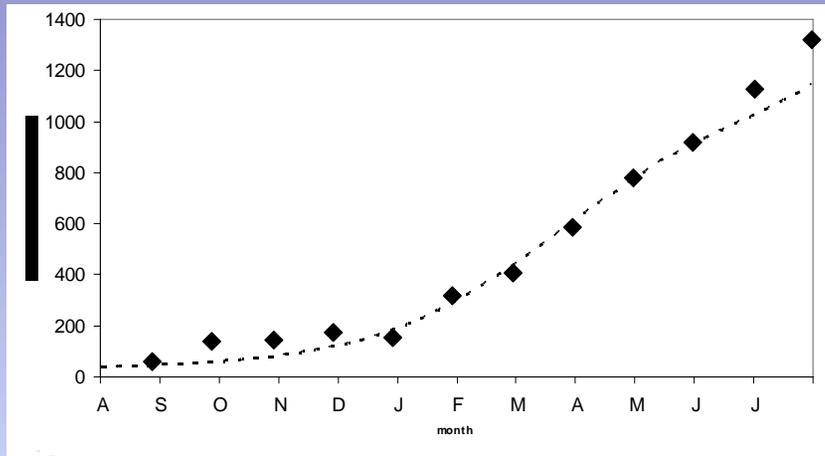


Clione limacina



Additional data

OSP temperature

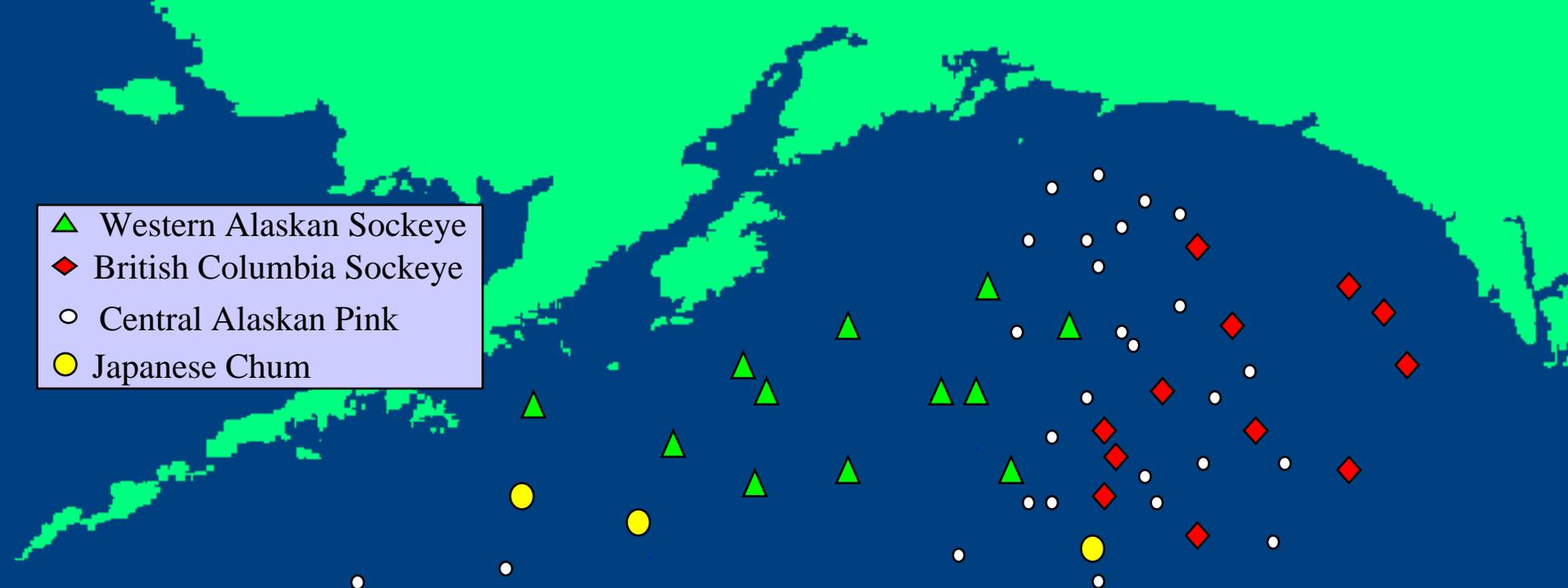


Prey quality

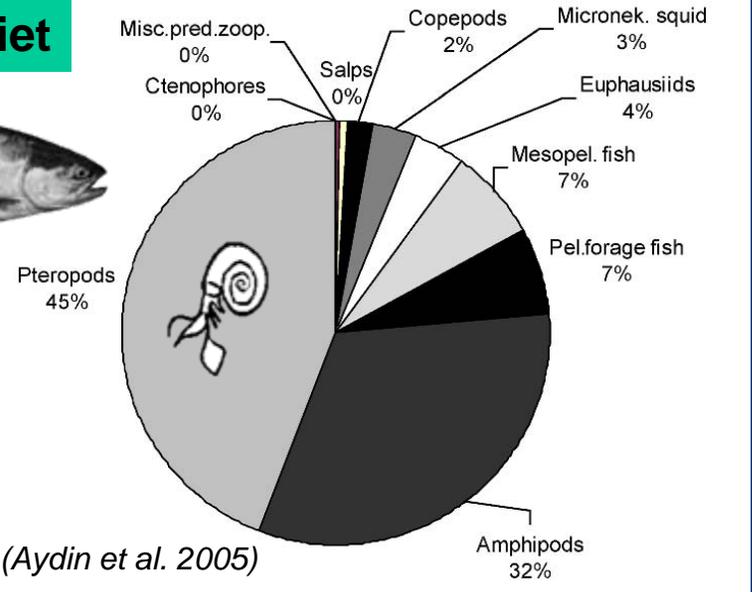
Mixed-layer dynamics

Prey group	cal/g wet weight	species and range
Copepods	700	<i>Neocalanus cristatus</i> ; 627-748
Euphausiids	1000	<i>Thysanoessa</i> spp., <i>Euphausia</i> spp., 840-1050
Pteropods	650	<i>Limacina helicina</i> ; 624-940
Amphipods	800	<i>Parathemisto pacifica</i> ; 852-1010
Ctenophores	50	<i>Beroe</i> sp., 47
Salps	36	<i>Salpa</i> sp., 36
Chaetognaths	450	<i>Sagitta elegans</i> ; 455-488
pelagic forage fish	1200	<i>Gasterosteus aculeatus</i> ; 1166-1533
mesopelagic forage fish	2000	<i>Stenobranchius leucopsarus</i> ; <i>Tarletonbeania crenularis</i> ; <i>Leuroglossus schmidti</i> ; 2041-2365 (Bering Sea)
Micron. squid	1500	<i>Berryteuthis anonychus</i> ; 1307-1737 (increases with increasing mantle length).

- ▲ Western Alaskan Sockeye
- ◆ British Columbia Sockeye
- Central Alaskan Pink
- Japanese Chum



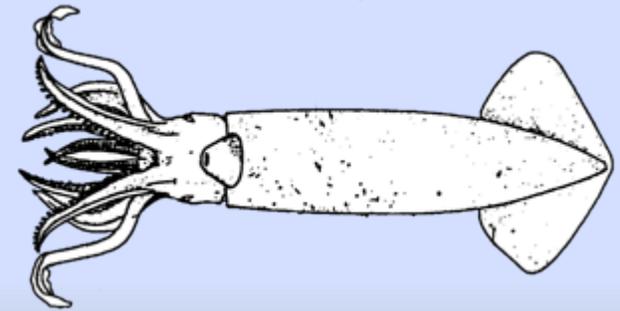
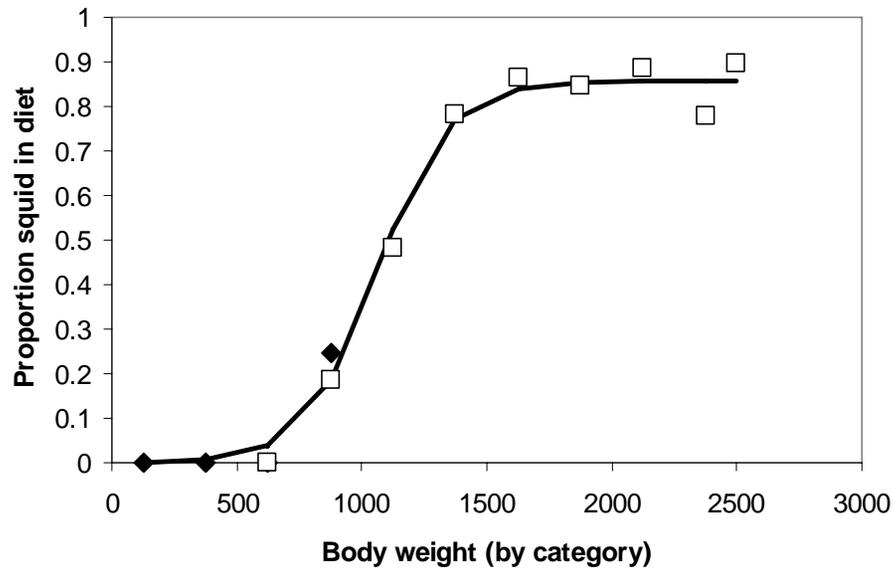
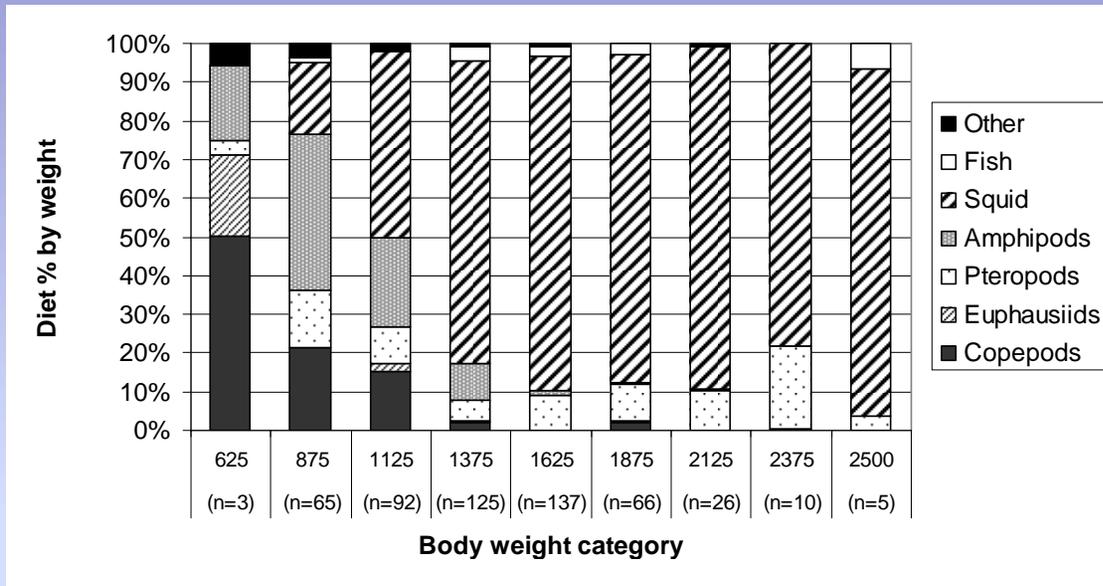
Pink salmon diet



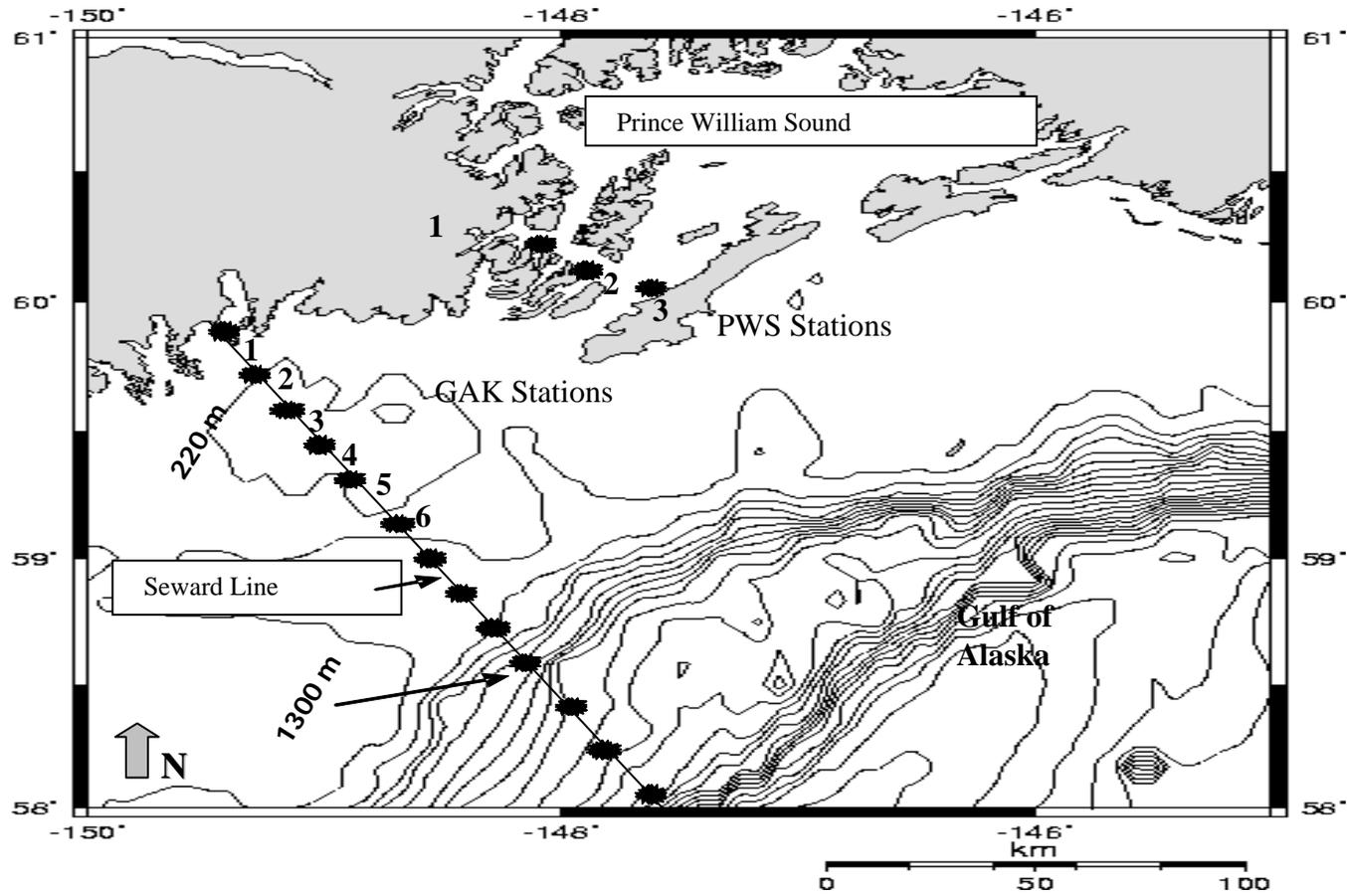
Predicted effect of climate change on pink salmon growth:

- 10% increase in water temperature leads to 3% drop in mature salmon body weight (physiological effect).
- 10% decrease in pteropod production leads to 20% drop in mature salmon body weight (prey limitation).

Diet switching?

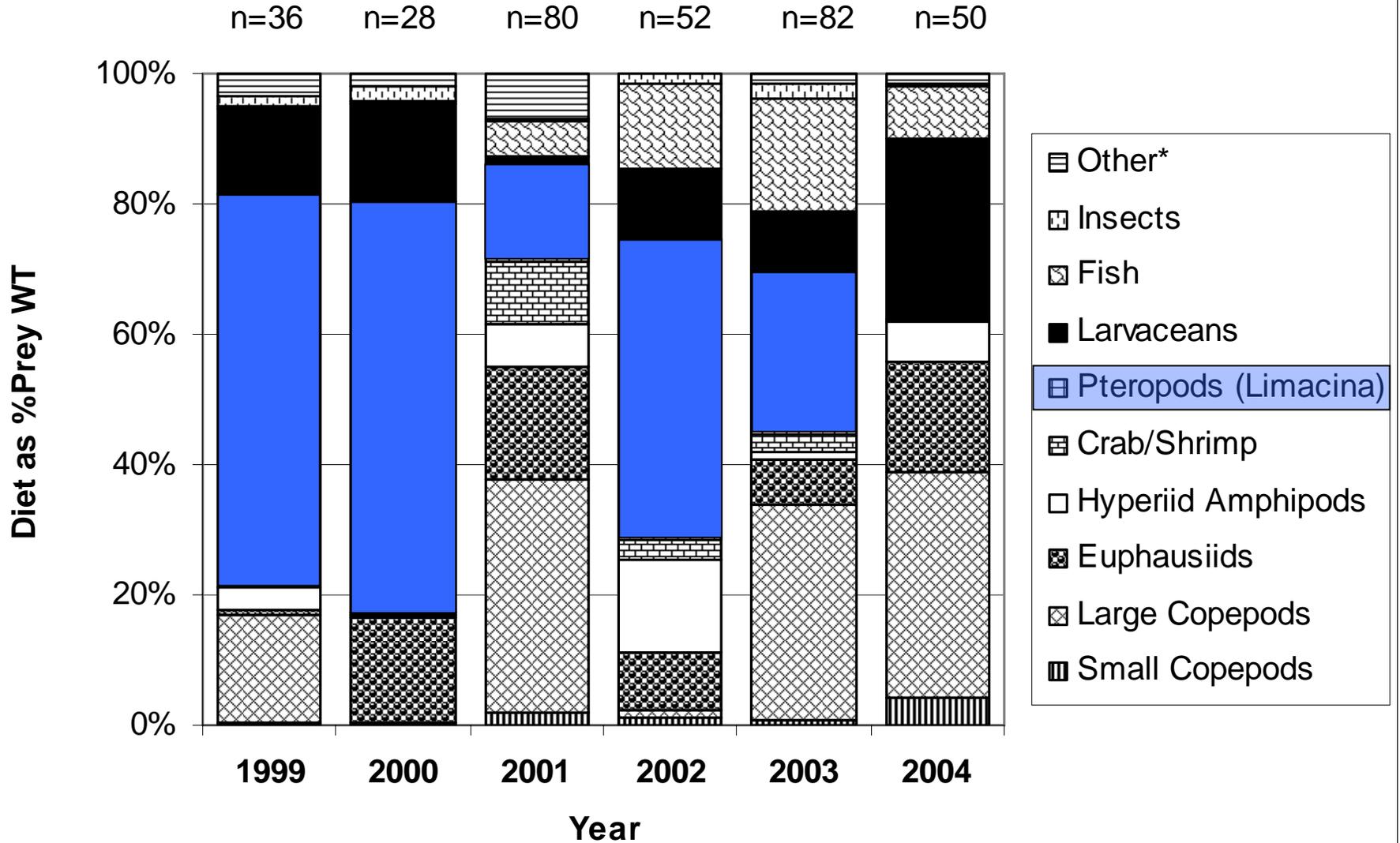


Prince William Sound and northern GOA (Seward Line) sample sites for collection of juvenile pink salmon 1999-2004

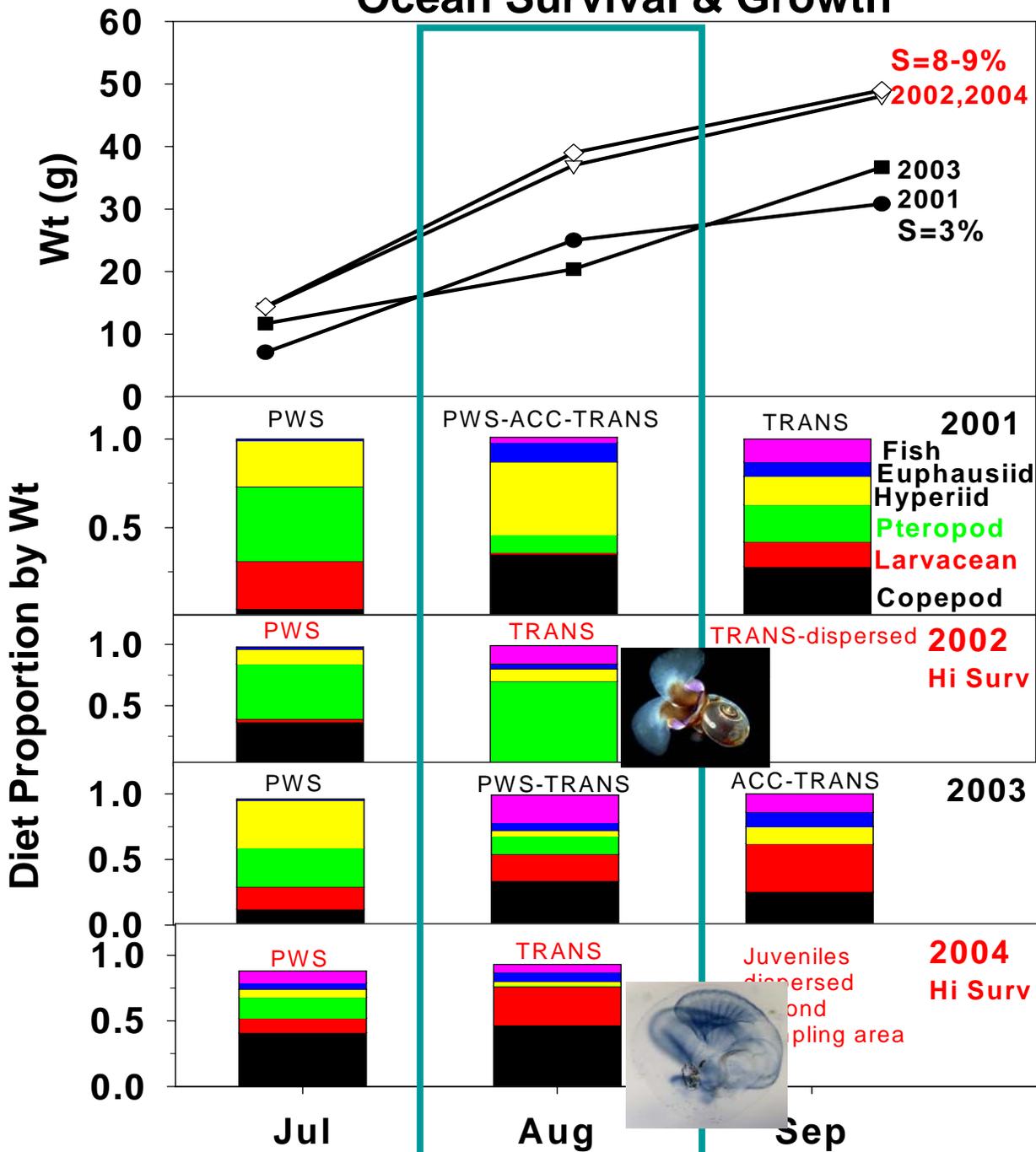


Juvenile Pink Salmon

Interannual Diet Comparison: August GAK 1-6



Ocean Survival & Growth



GROWTH:

Higher survival associated with Larger juveniles

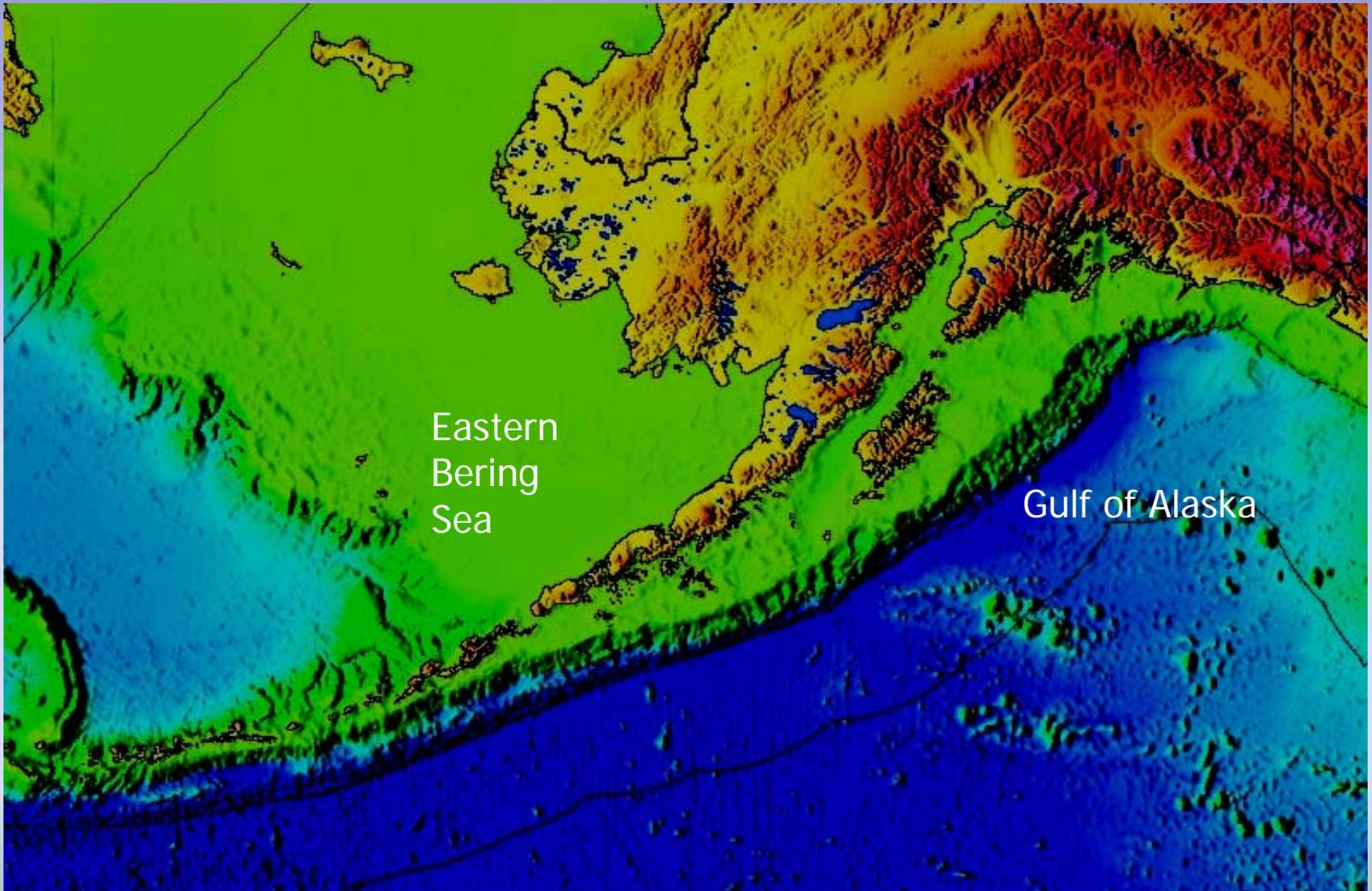
DISTRIBUTION:

Higher survival associated with Earlier, wider dispersal during Aug-Sep

DIET:

Diet composition Highly variable Among months & Years. Non-Crustaceans Important during Critical period in August

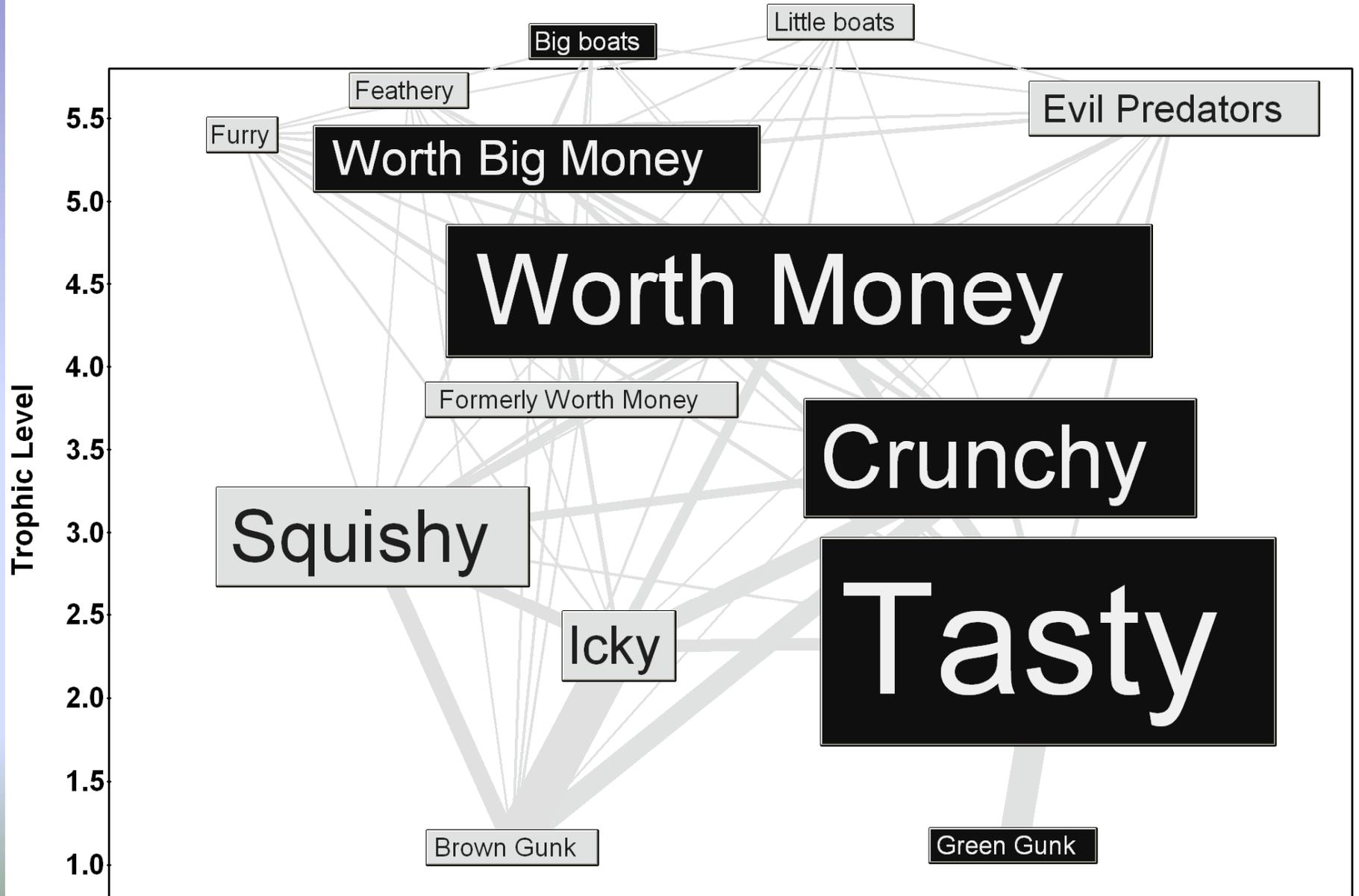
FOOD WEB EFFECTS



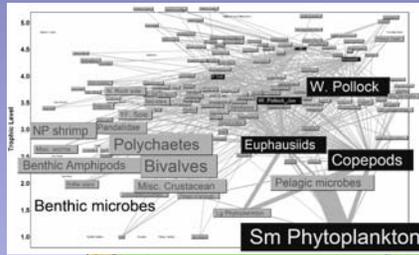
Rich biological relationships



Complexity vs. management reality

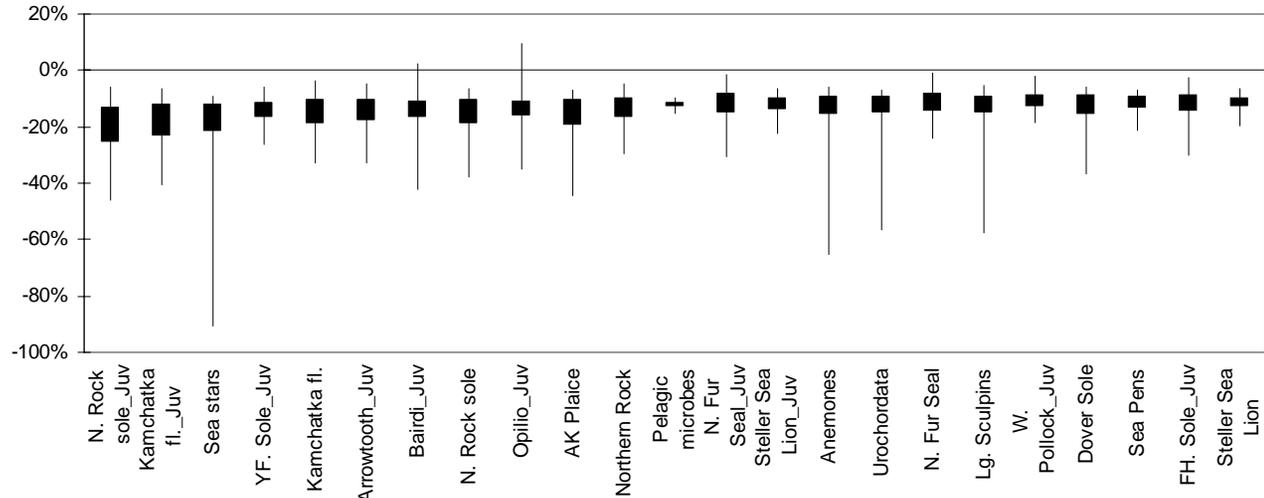
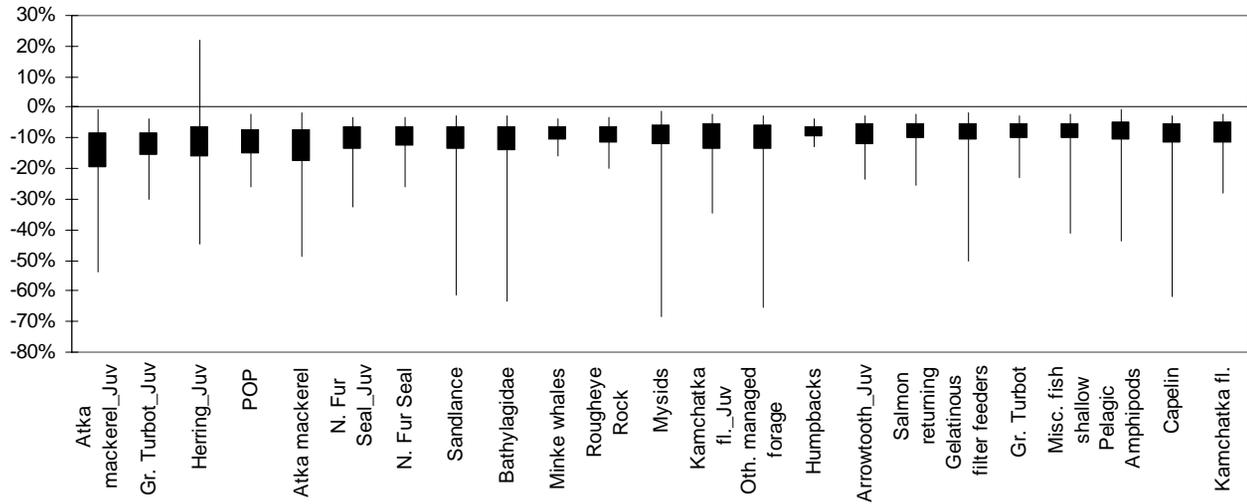


FOOD WEB EFFECTS - simulated



Decrease in large phytoplankton

Decrease in micro-phytoplankton



A key to upper trophic levels is THRESHOLD effects

- *Current data (summer-dominated) indicates that pteropods are a relatively low percentage of fish diets.*
- *HOWEVER* (for example), during fall BASIS surveys, *L. helicina* comprised up to 25% of prey wet weight for age-0 pollock in oceanic influenced waters that move through the Aleutian passes into the SE Bering Sea (L. Eisner pers. comm.).



Research Goals for Understanding Biological Impacts – Alaska Fisheries Science Center



M. Jones, NMFS



- Measure species-specific physiological responses
- Understand impacts on fish, marine mammals and seabirds
- Forecast fisheries and subsistence impacts
- Contact:
Mike.Sigler@noaa.gov