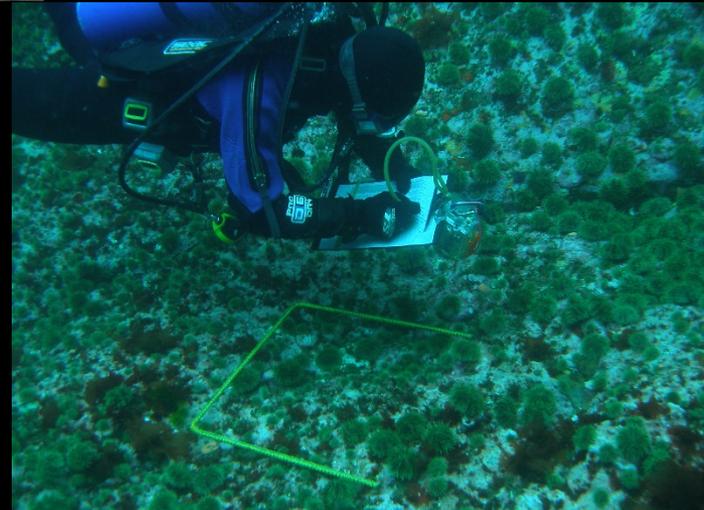
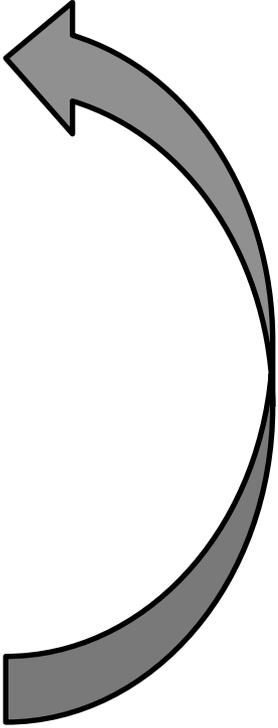
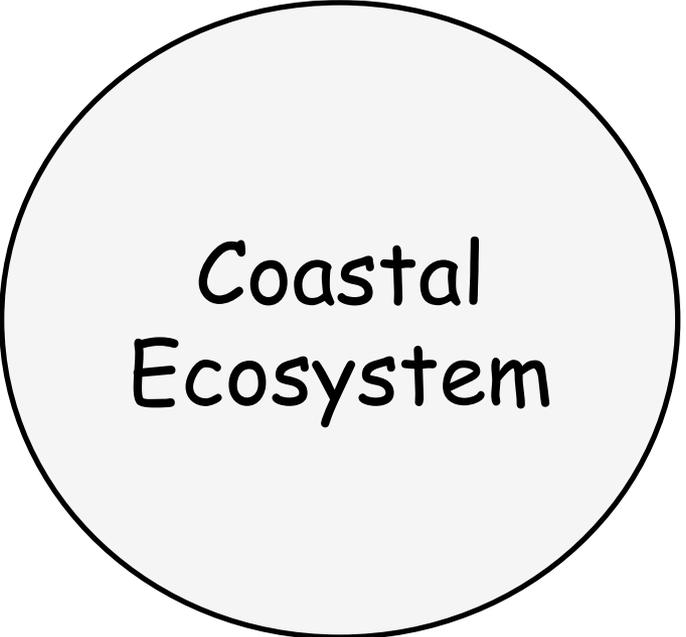
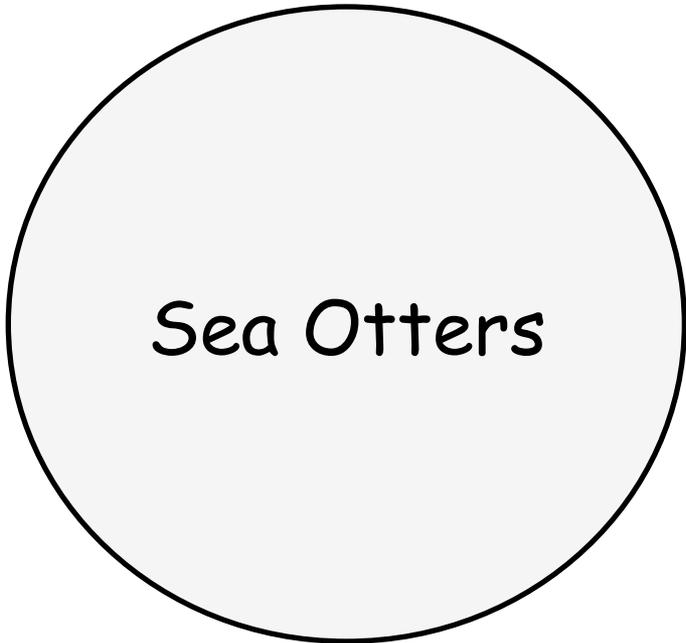


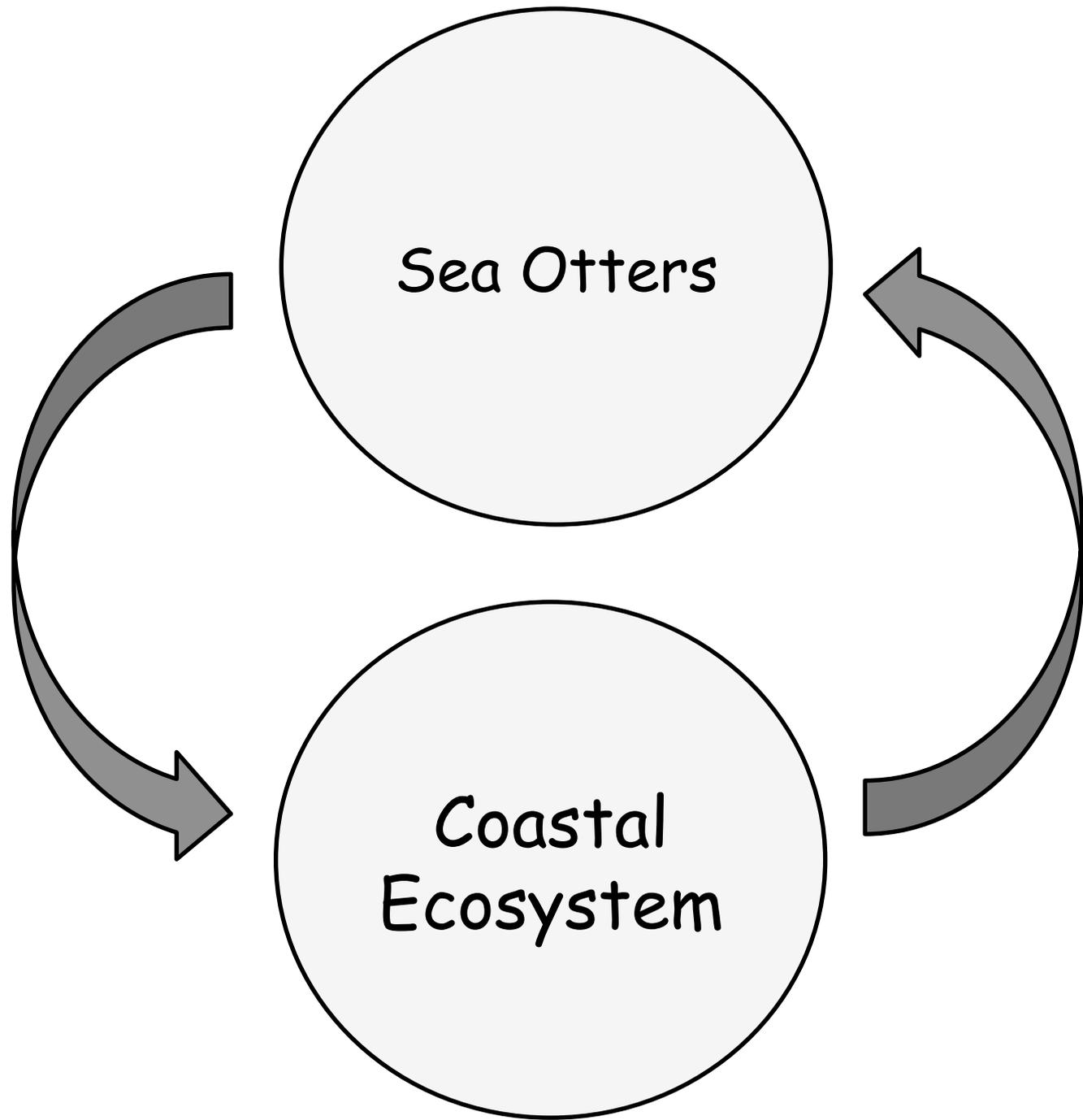
Sea otters and kelp forests: questions, approaches, and perspectives



James A. Estes
University of California
Santa Cruz



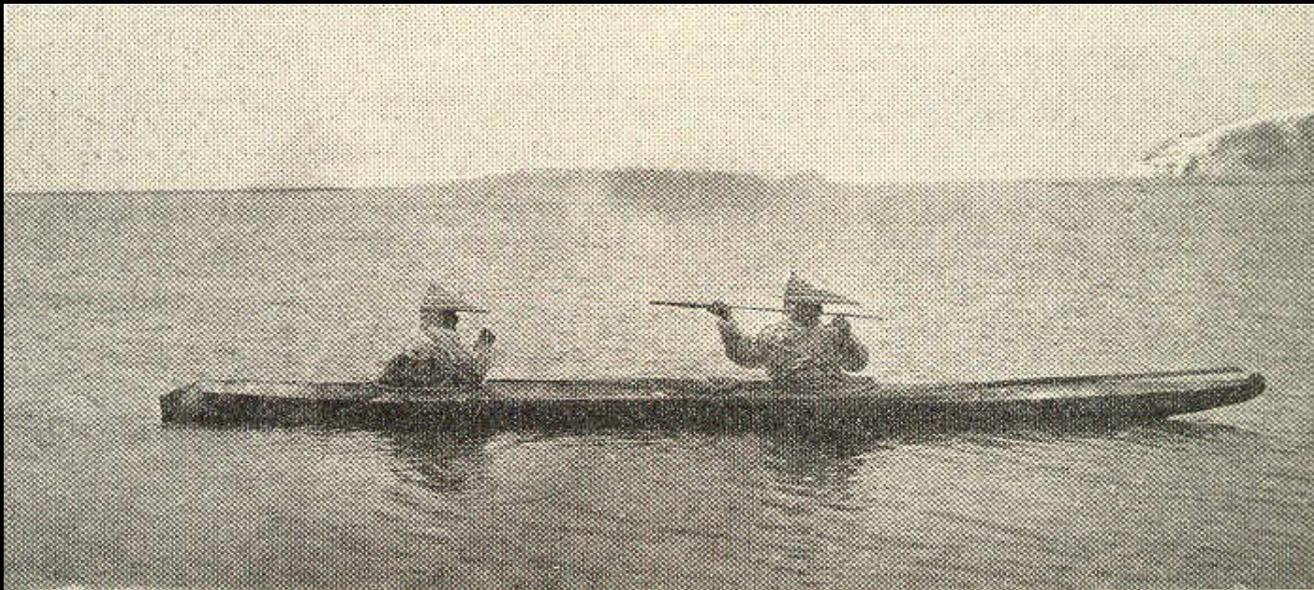




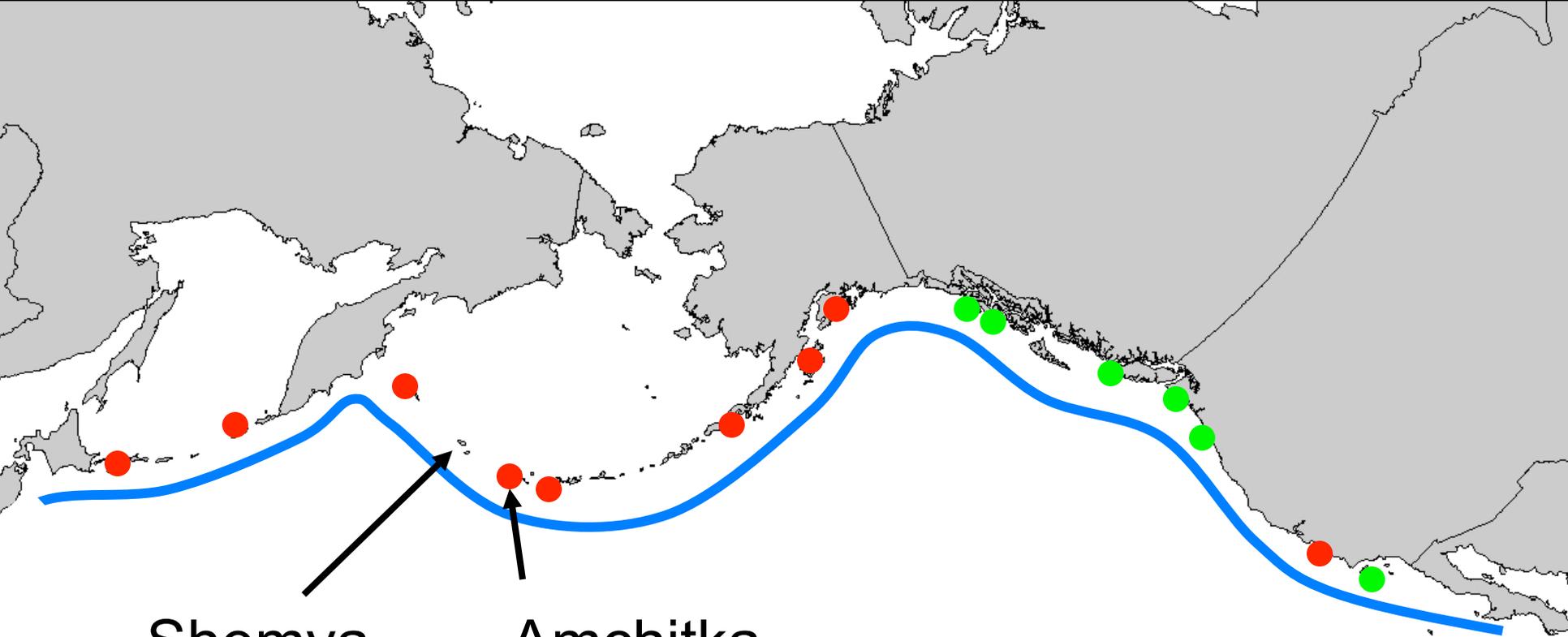
Sea Otters

Coastal
Ecosystem

Pacific Maritime Fur Trade



A perturbation



Shemya

Amchitka



— Historical range (1741)

● Surviving remnant population

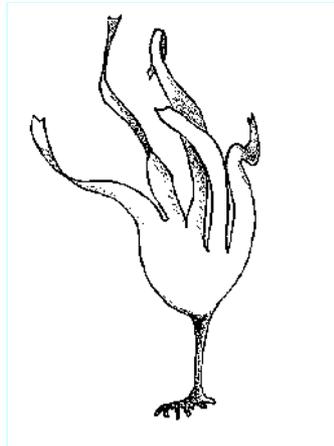
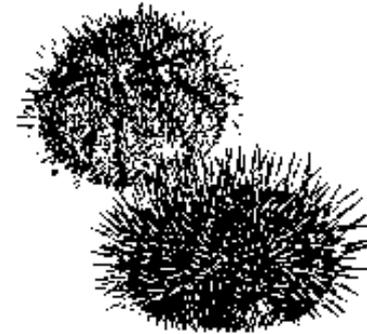
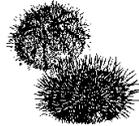


Amchitka



Shemya

A “trophic cascade”



Amchitka

Shemya

Questions

- Generality
- Transitional patterns and dynamics
- Broader ecosystem effects
- Evolutionary consequences
- Inter-ecosystem connectivity

Generality



Aleutian
archipelago

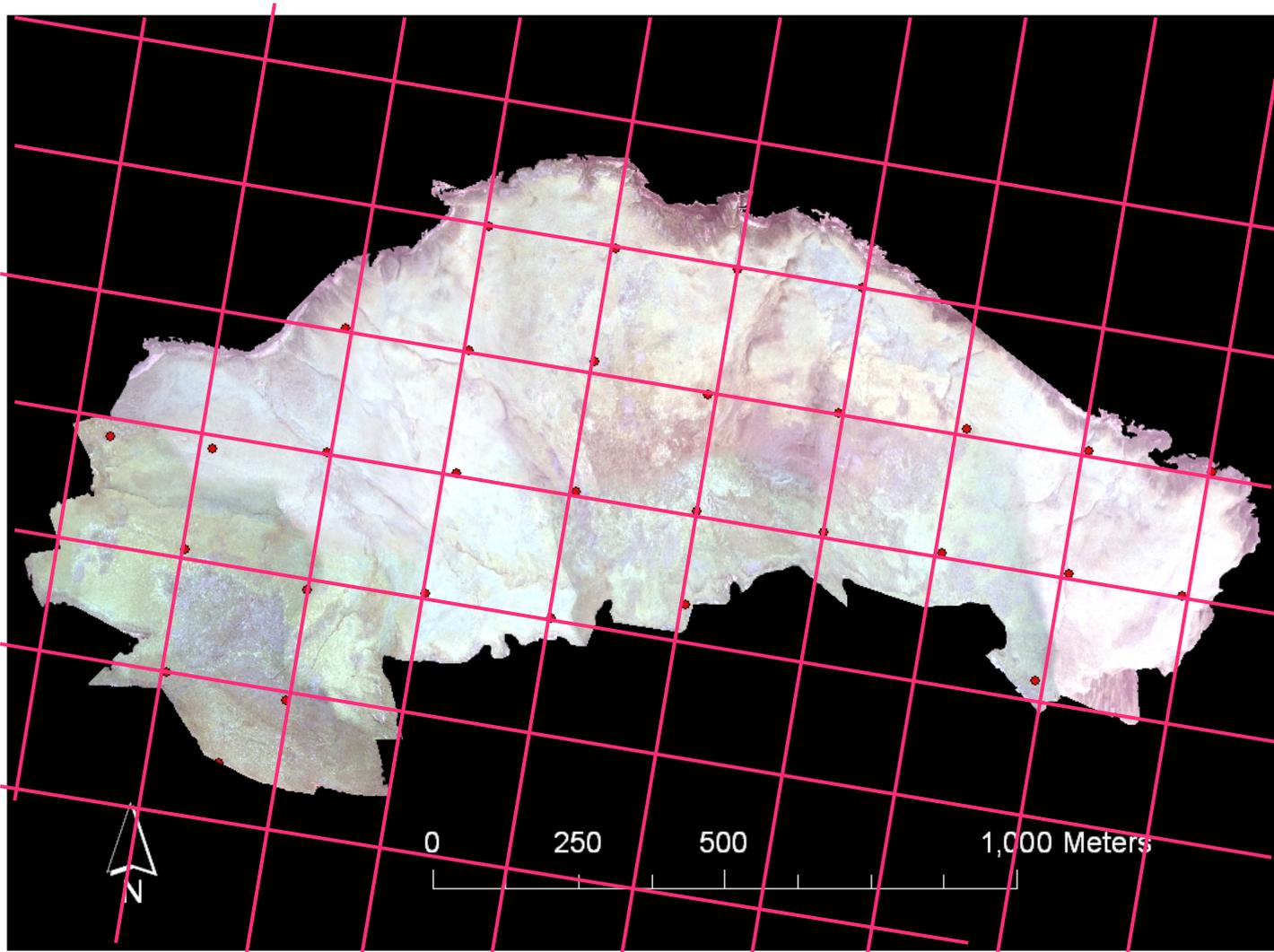
Southeast
Alaska

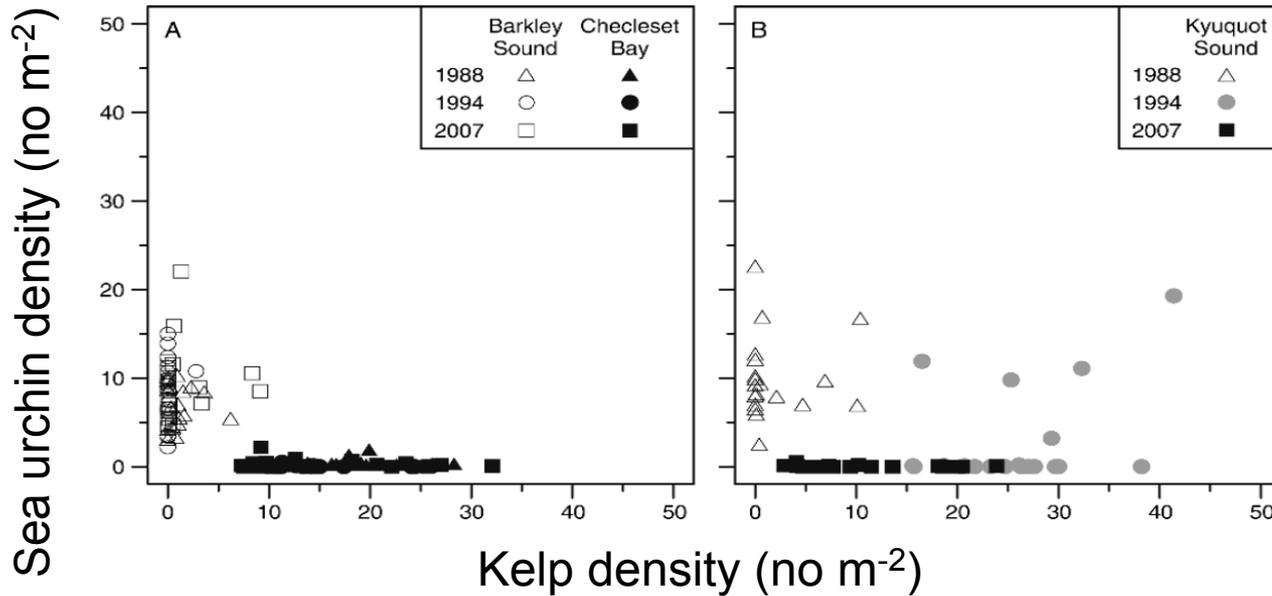
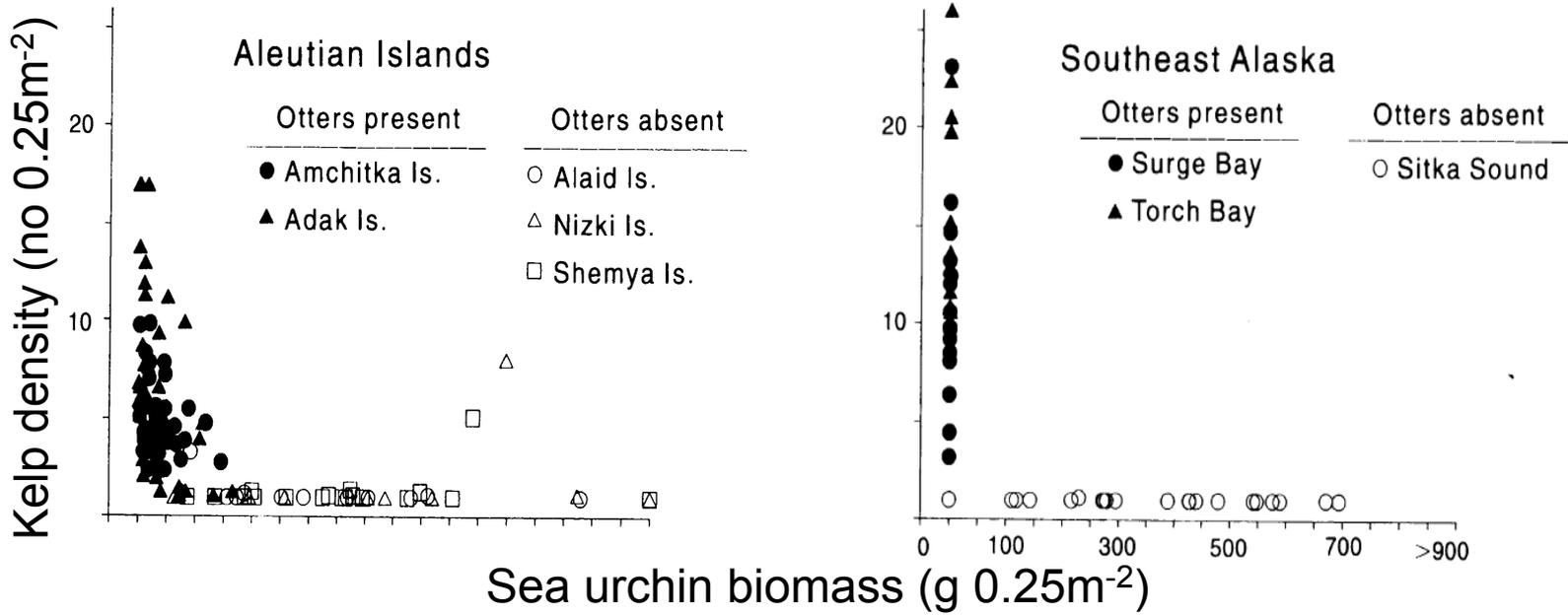
Vancouver
Island

Approach:

- With vs. without otters
- Before vs. after otters

Sampling methodology for kelp and sea urchins



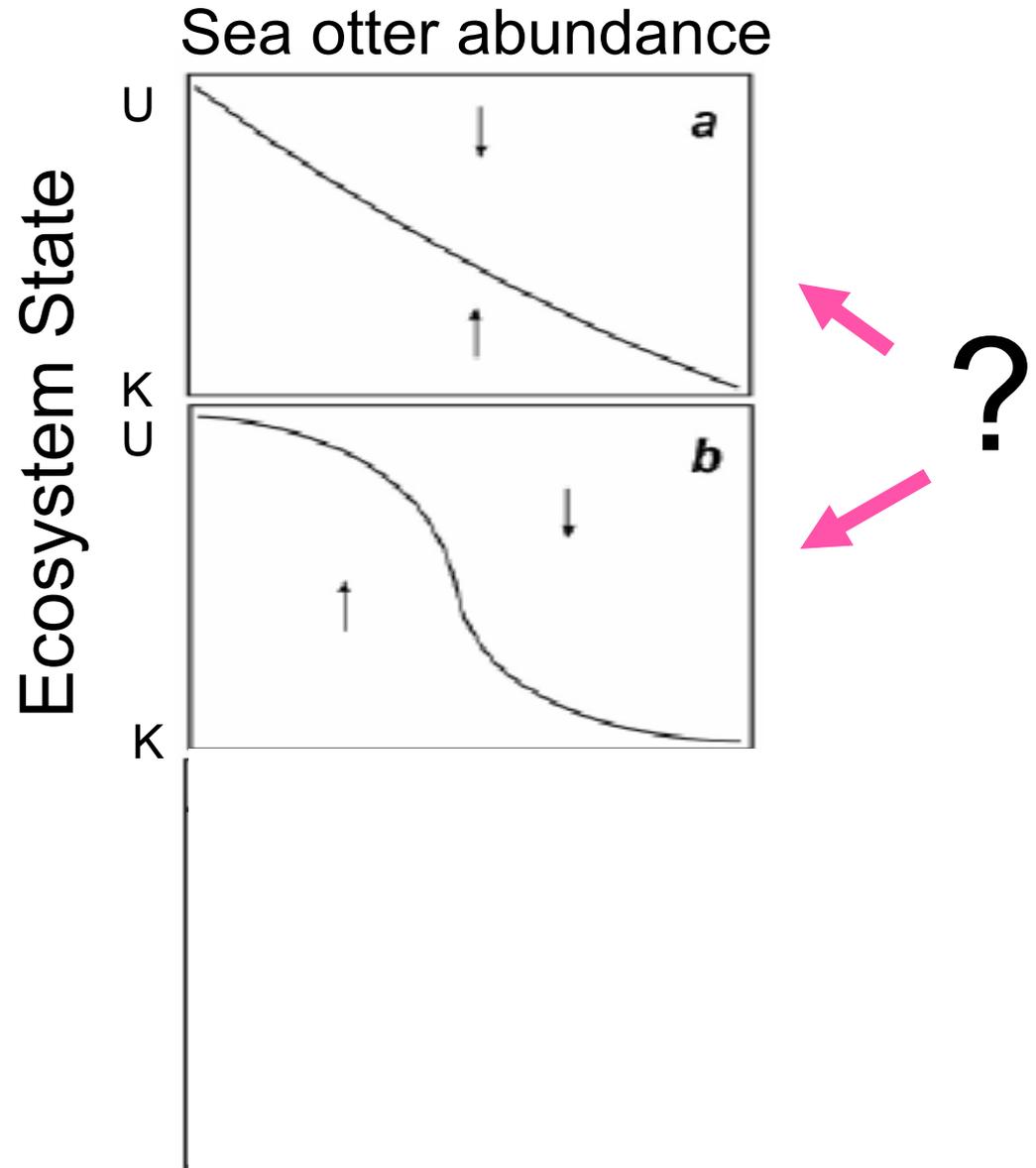


Vancouver Is., BC
 Watson & Estes, *Ecol Monog* 2011

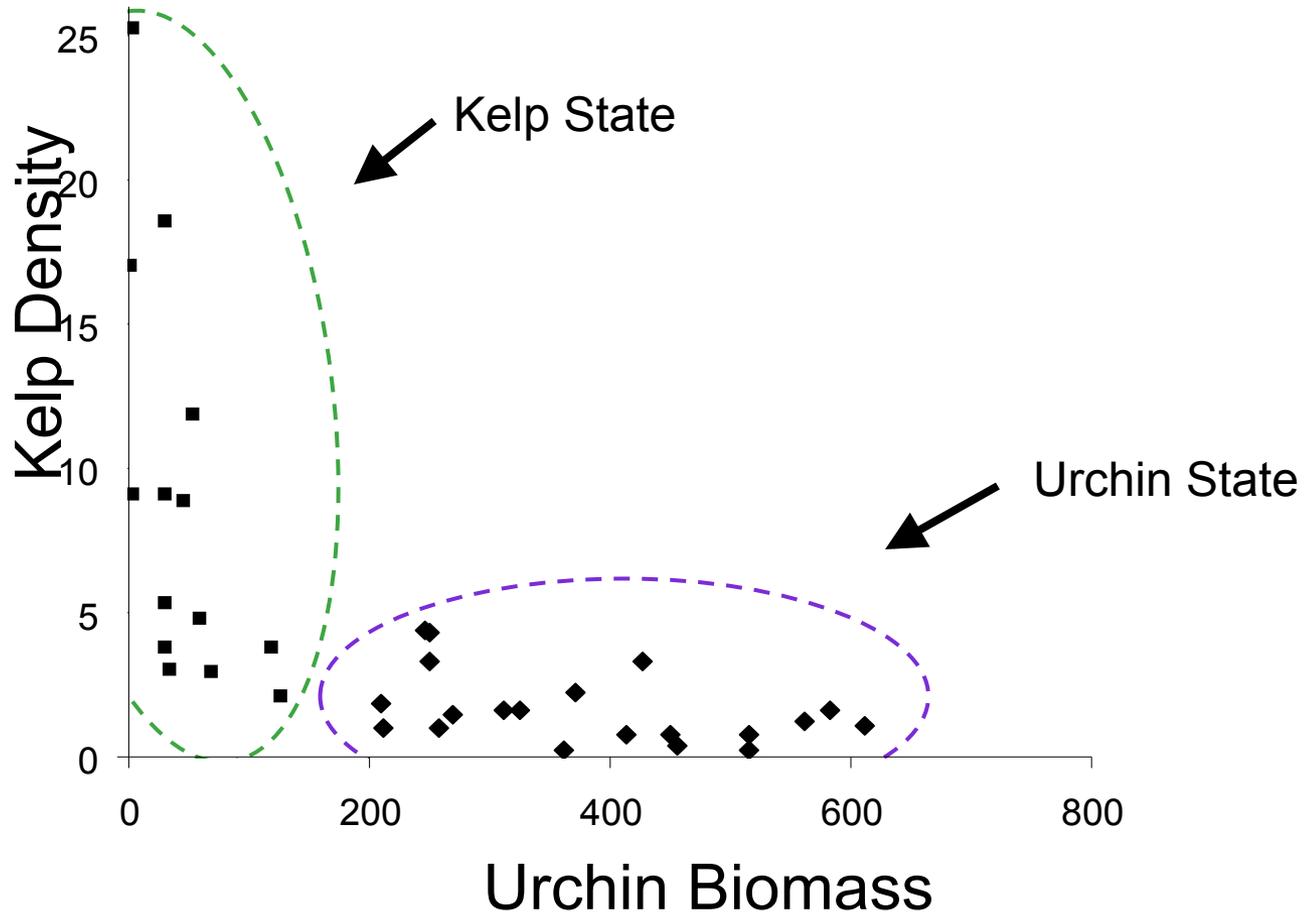
Transitional patterns and dynamics

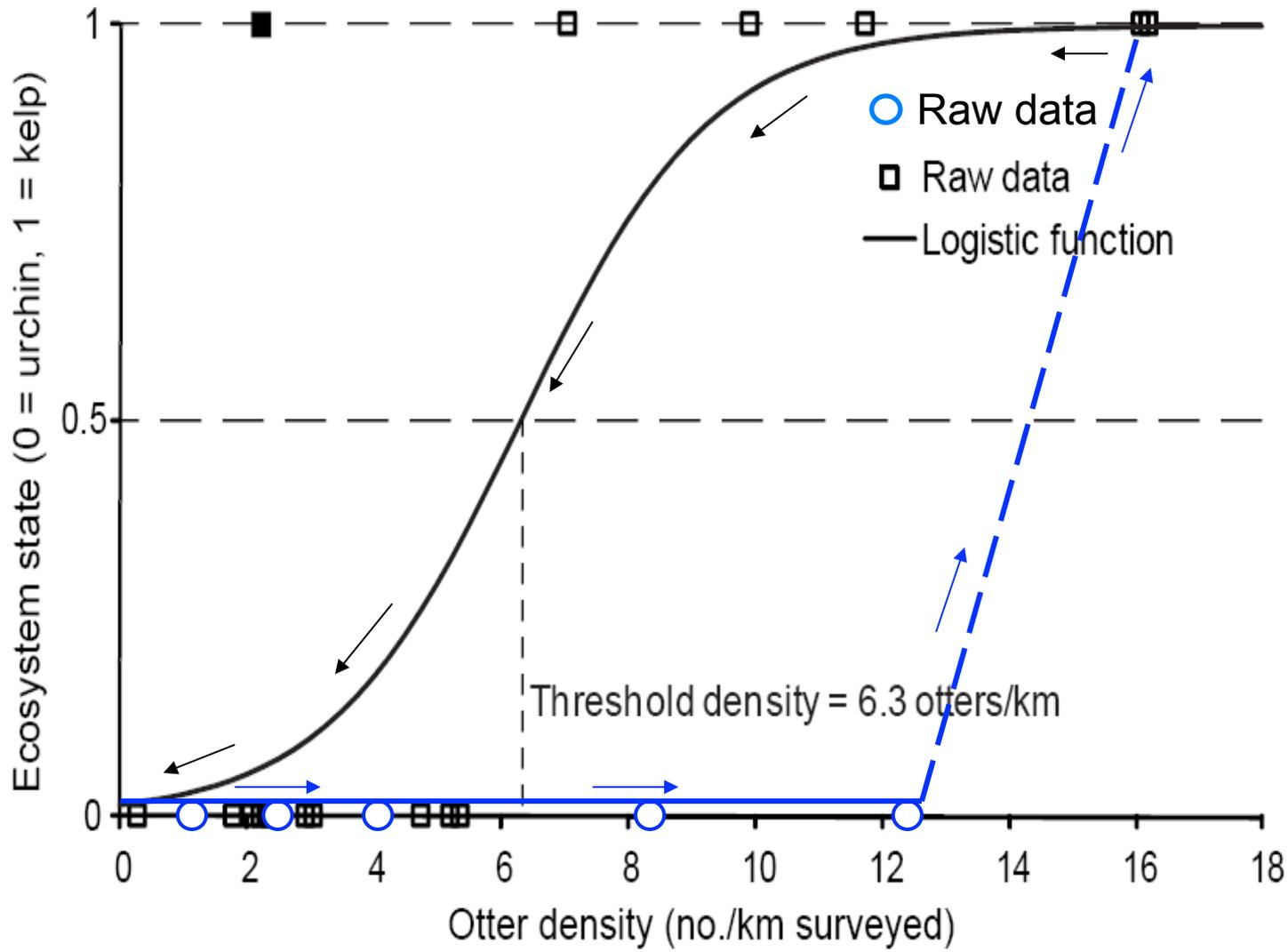
Ecosystem state transitions

U – urchin barrens
K -- kelp forest



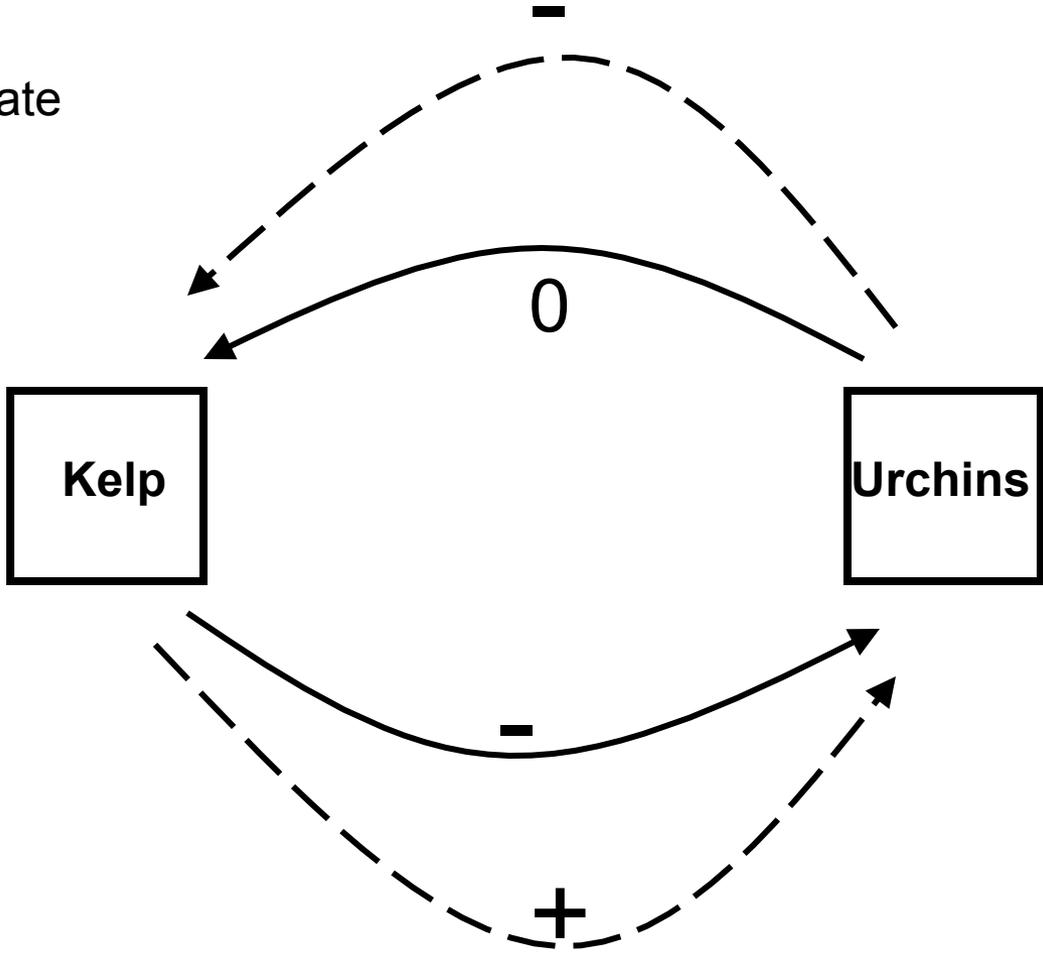
Aleutian Islands





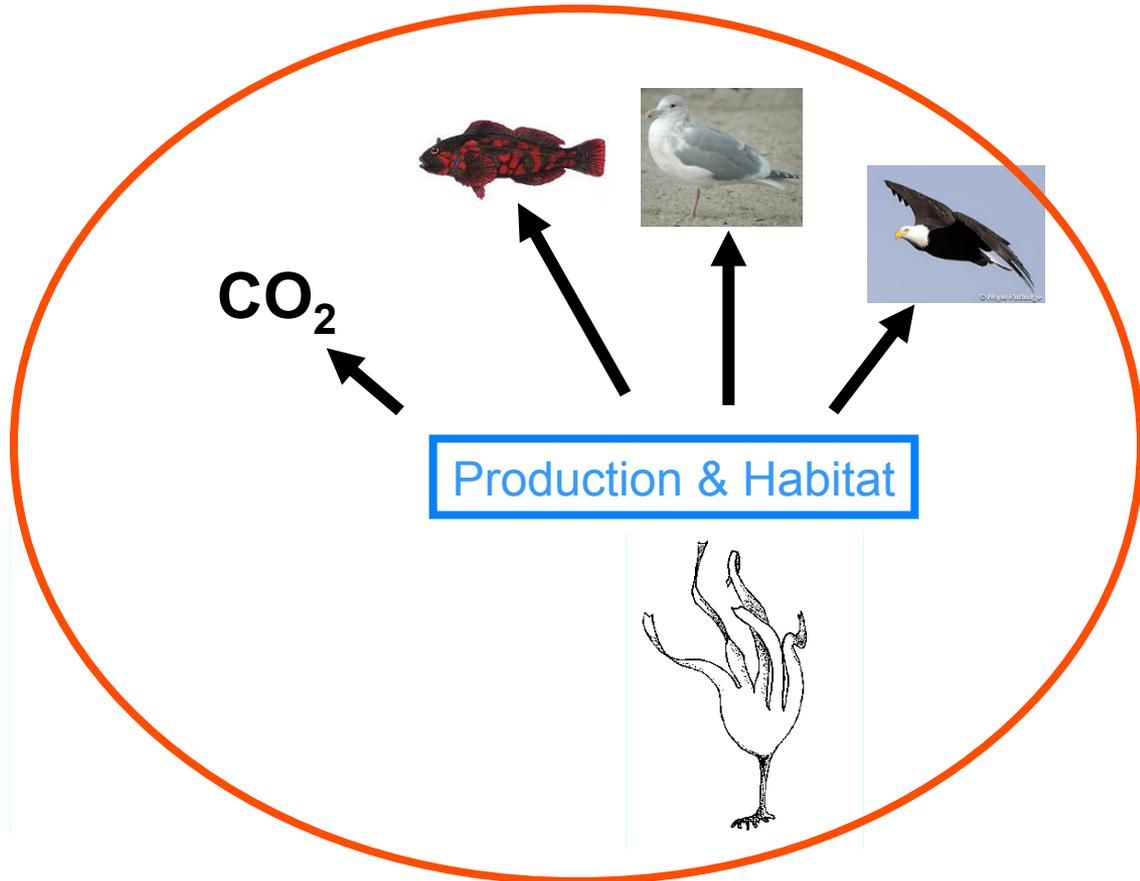
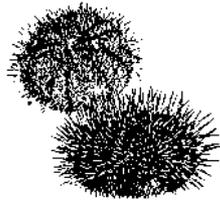
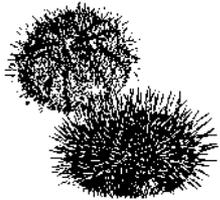
— Kelp state

- - Urchin state



Broader Ecosystem Effects

Players and Processes





Aleutian
archipelago

Southeast
Alaska

Vancouver
Island

Approach:

- With vs. without otters
- Before vs. after otters

Production

Sea otters

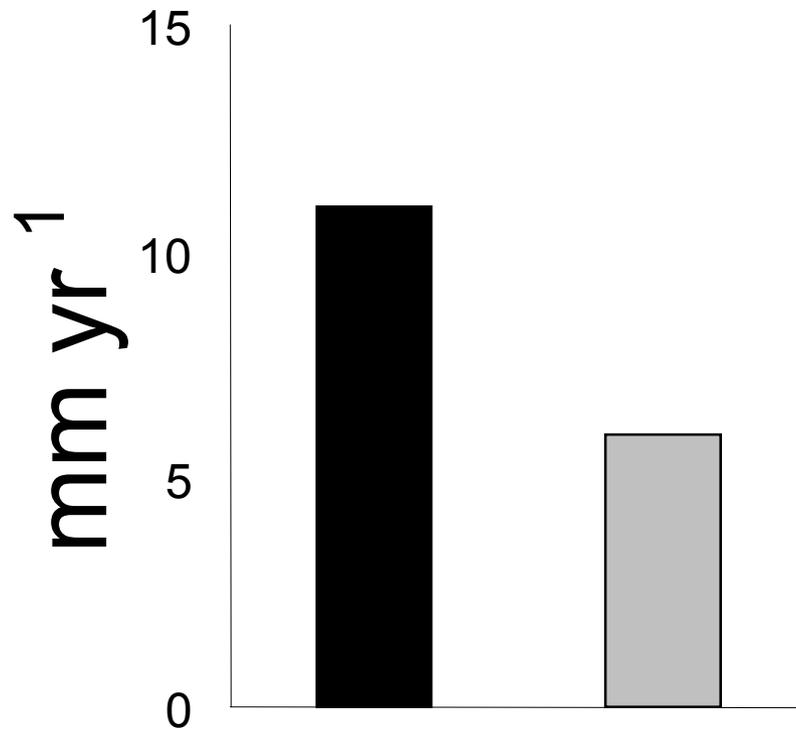


Abundant



Absent

Mussel growth



Kelp forest fish abundance

Sea otters



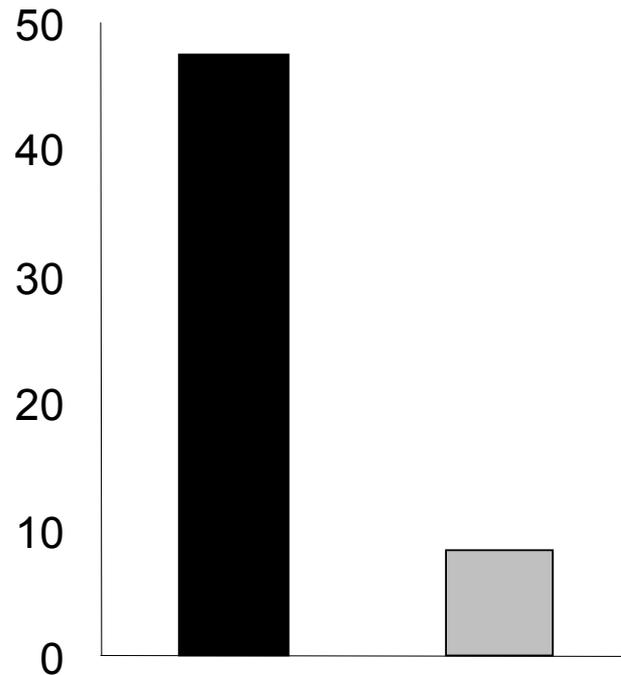
Abundant



Absent



Catch effort



Glaucous winged gull diet

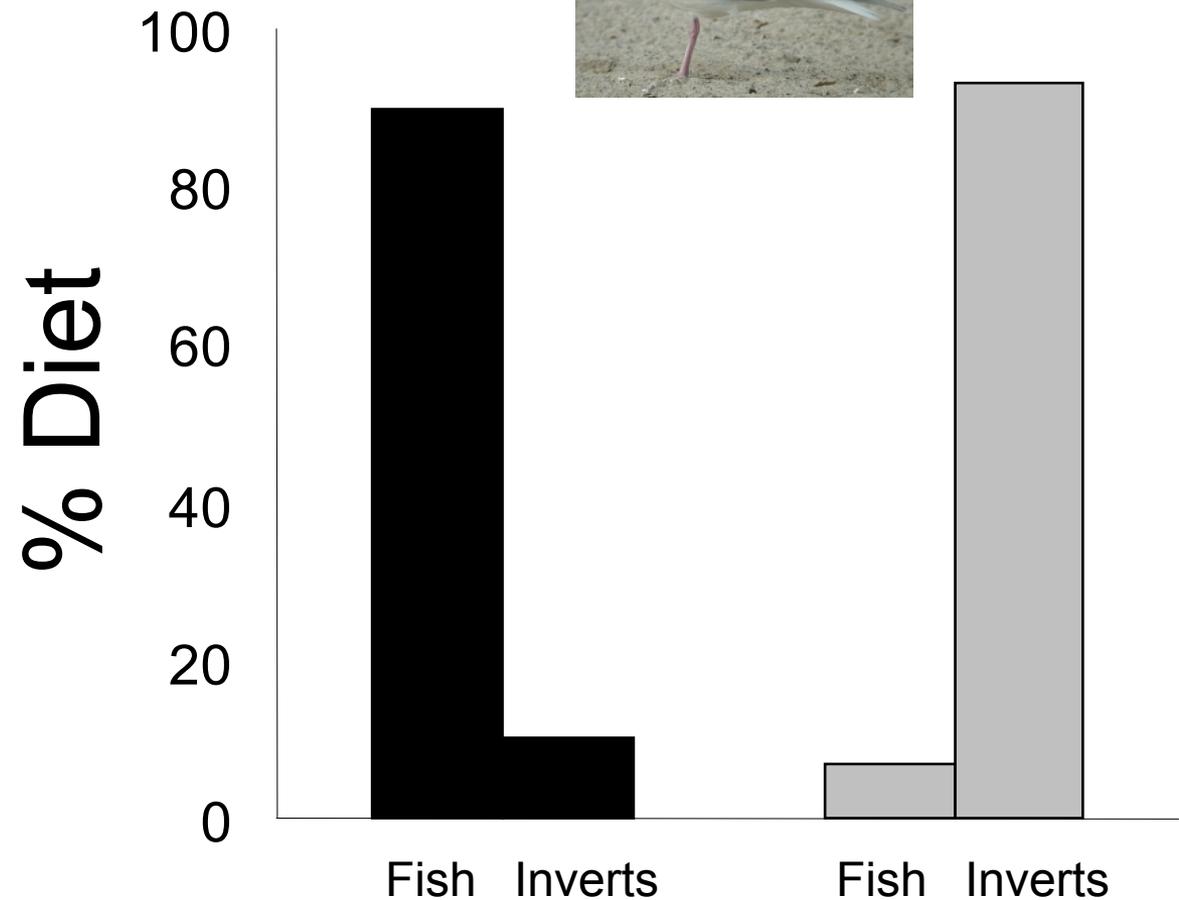
Sea otters



Abundant



Absent



Bald eagle diet

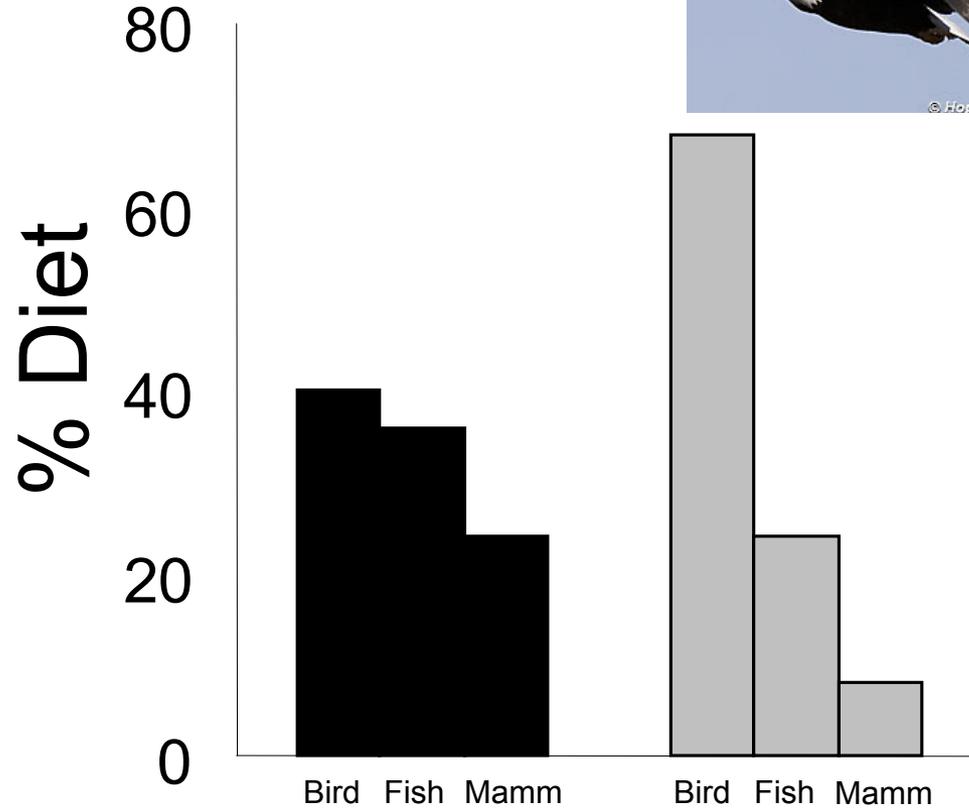
Sea otters



Abundant



Absent

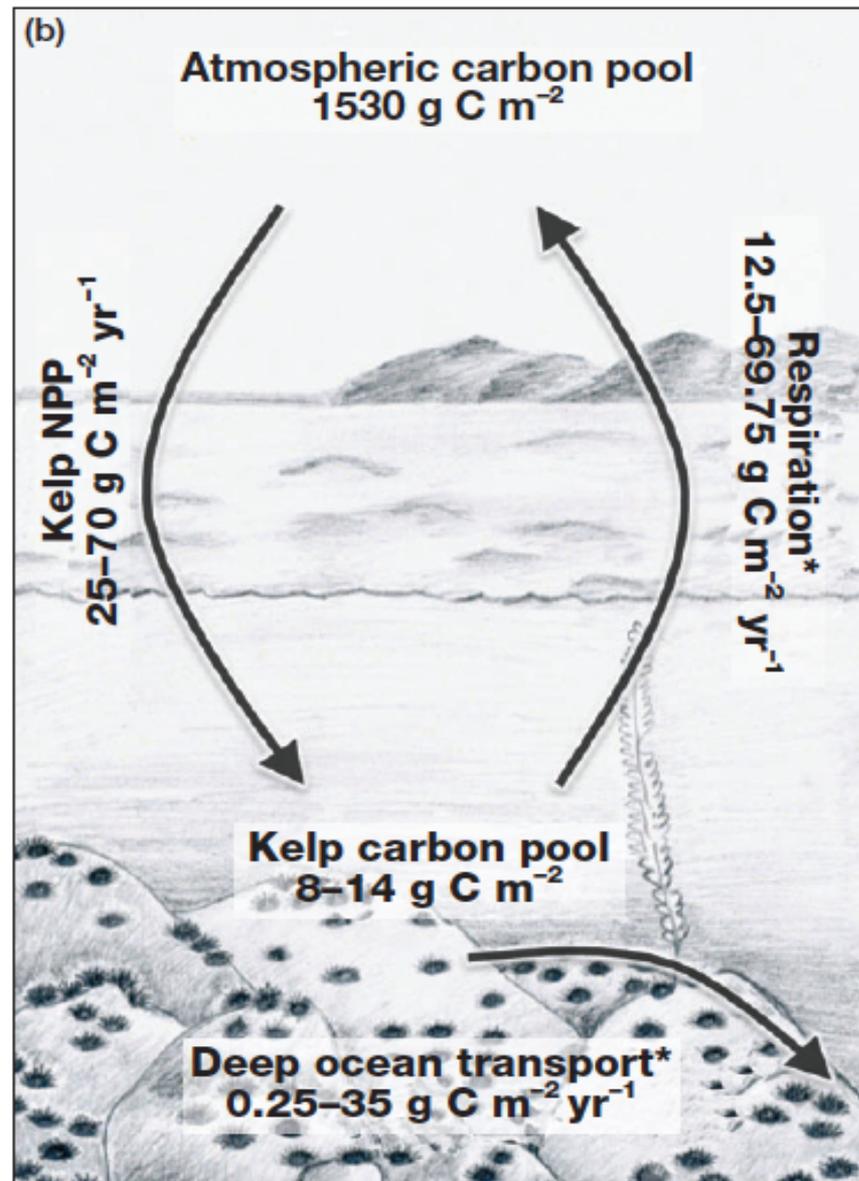
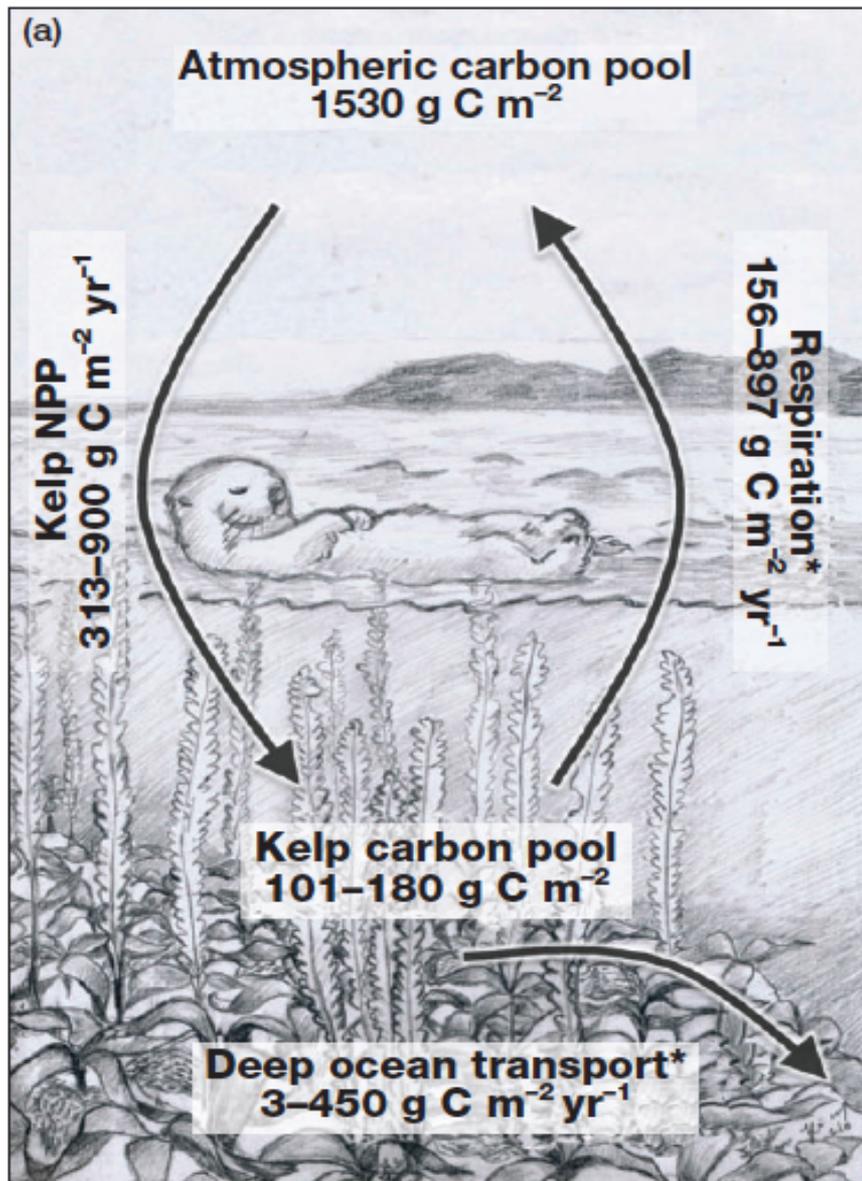


Carbon Storage & Flux

- Sea otters increase kelp abundance
- Kelp photosynthesis transforms inorganic carbon dioxide to organic carbon
- Can sea otters reduce atmospheric carbon dioxide and ocean acidification?

Required information

- ✓ Kelp abundance in areas with and without sea otters
- ✓ Area of habitat
- ✓ Proportion of area that is kelp habitat
- ✓ Carbon content of kelp
- ✓ Net primary production of kelp
- ✓ Amount of carbon dioxide in overlying atmosphere



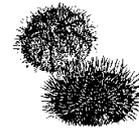
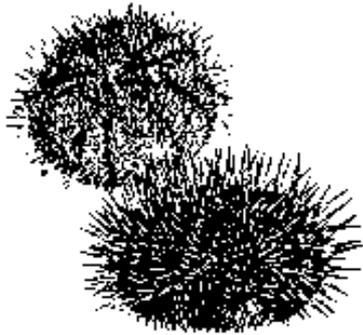
Value?

Standing biomass - \$205-408 million

Sequestration - \$6 million to 1.06 billion per year

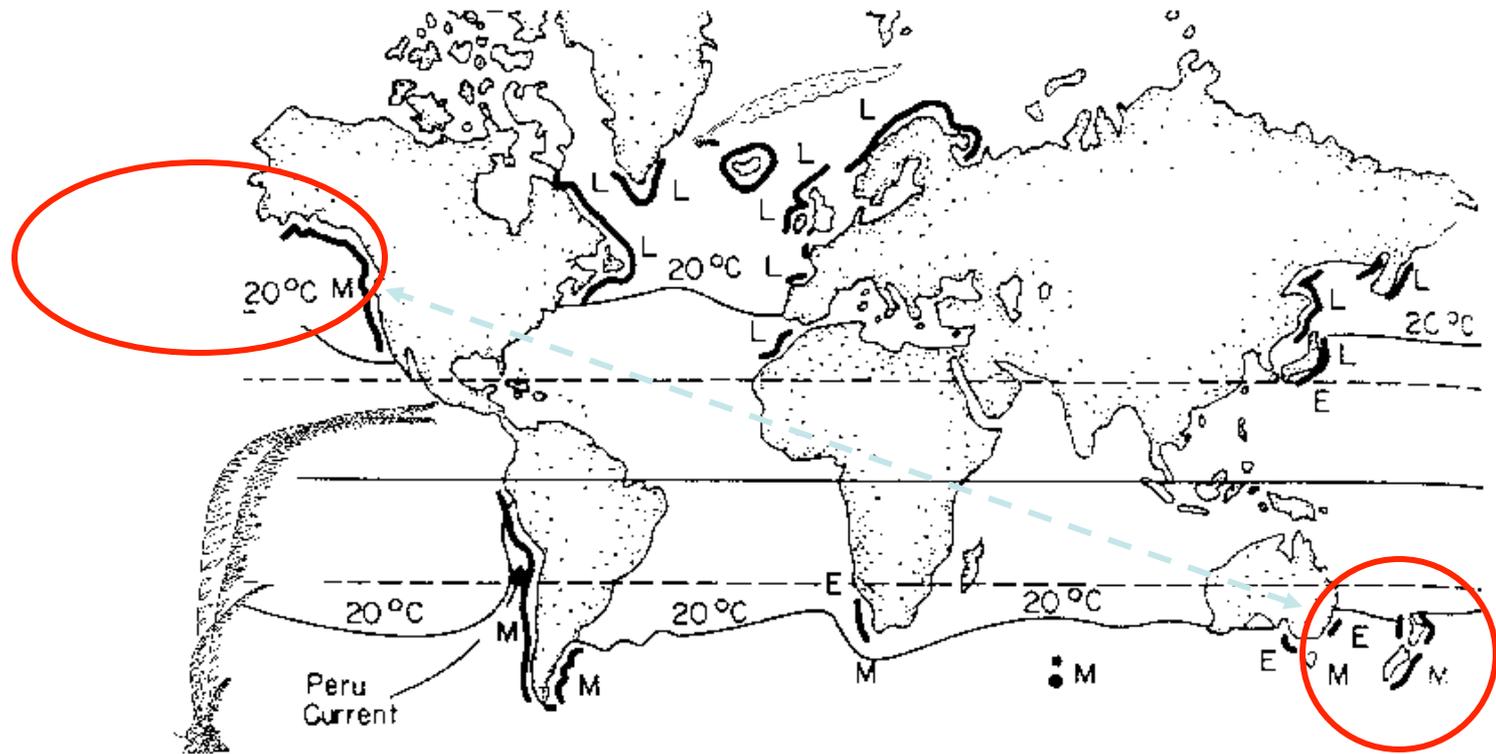
Eco/Evo Reciprocity

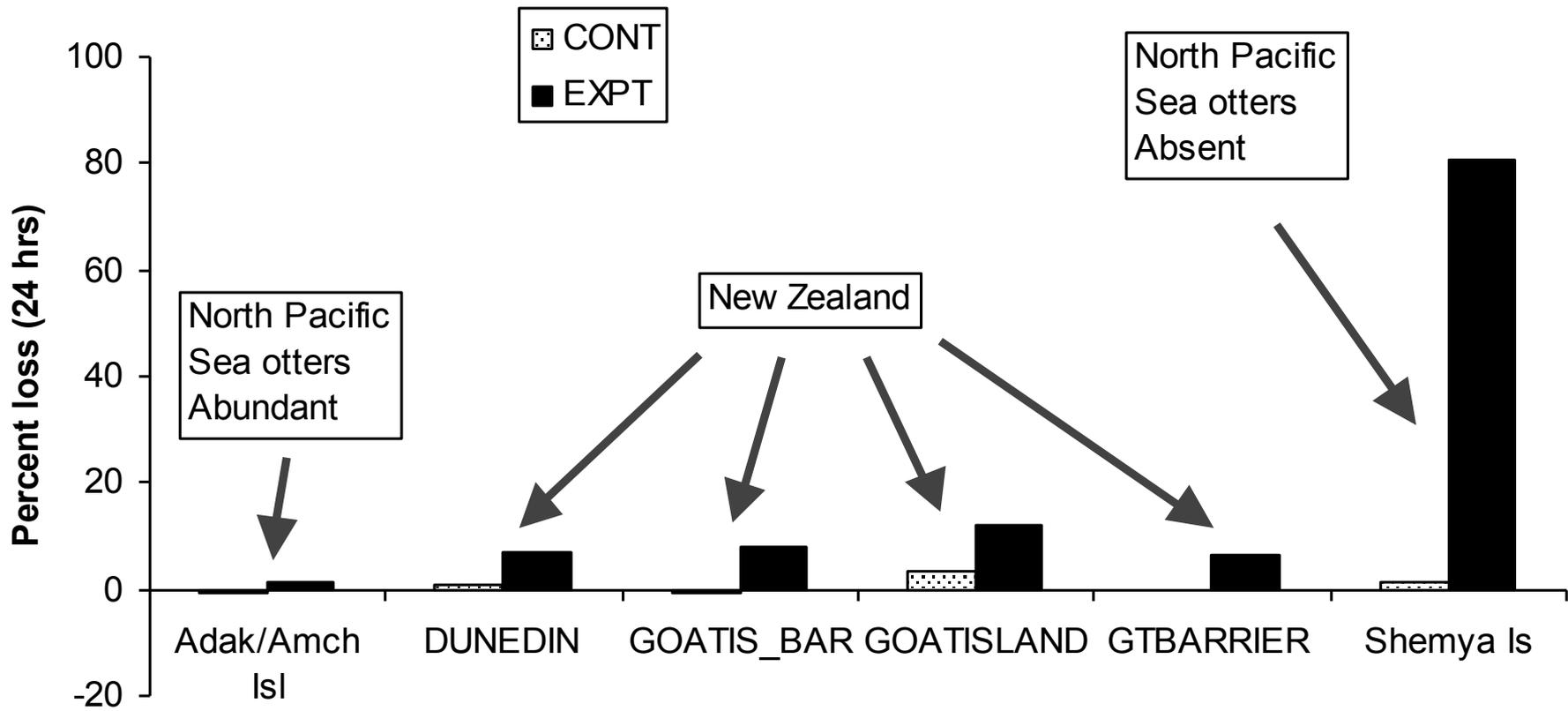
Coevolution?

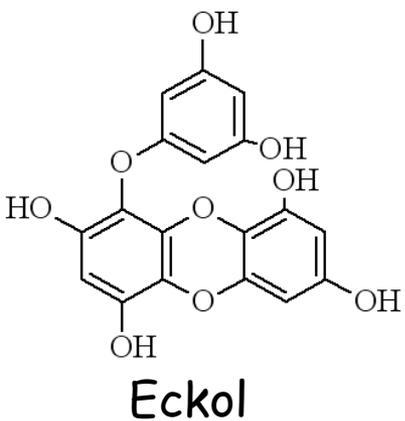


Approach: North Pacific/ Australasian comparison

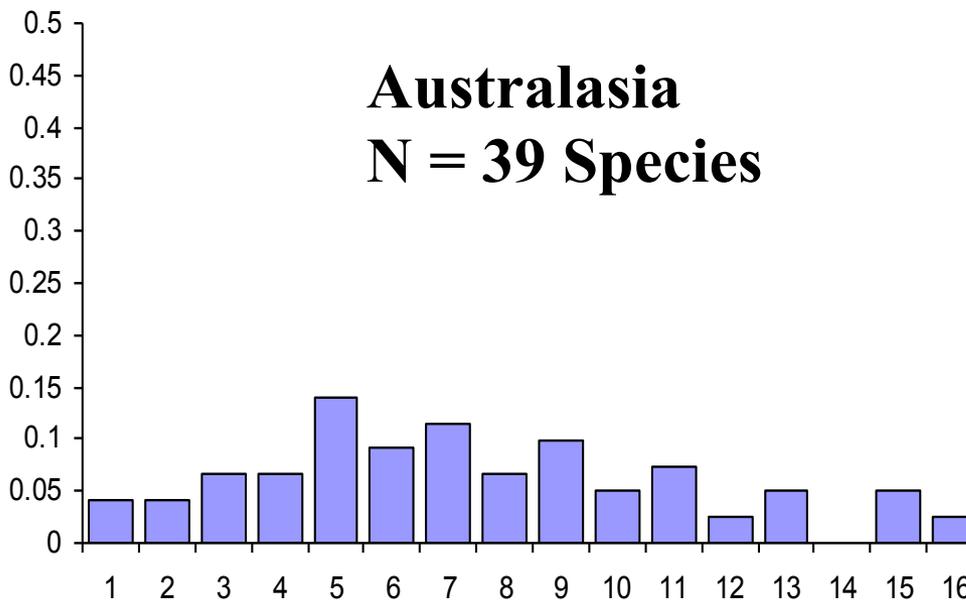
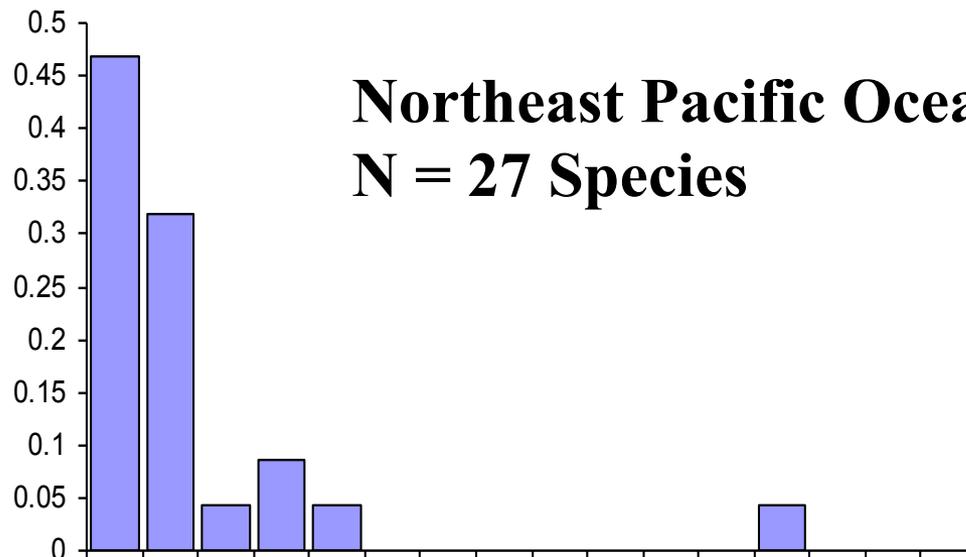
Kelp Forest of the World







Proportion of Species

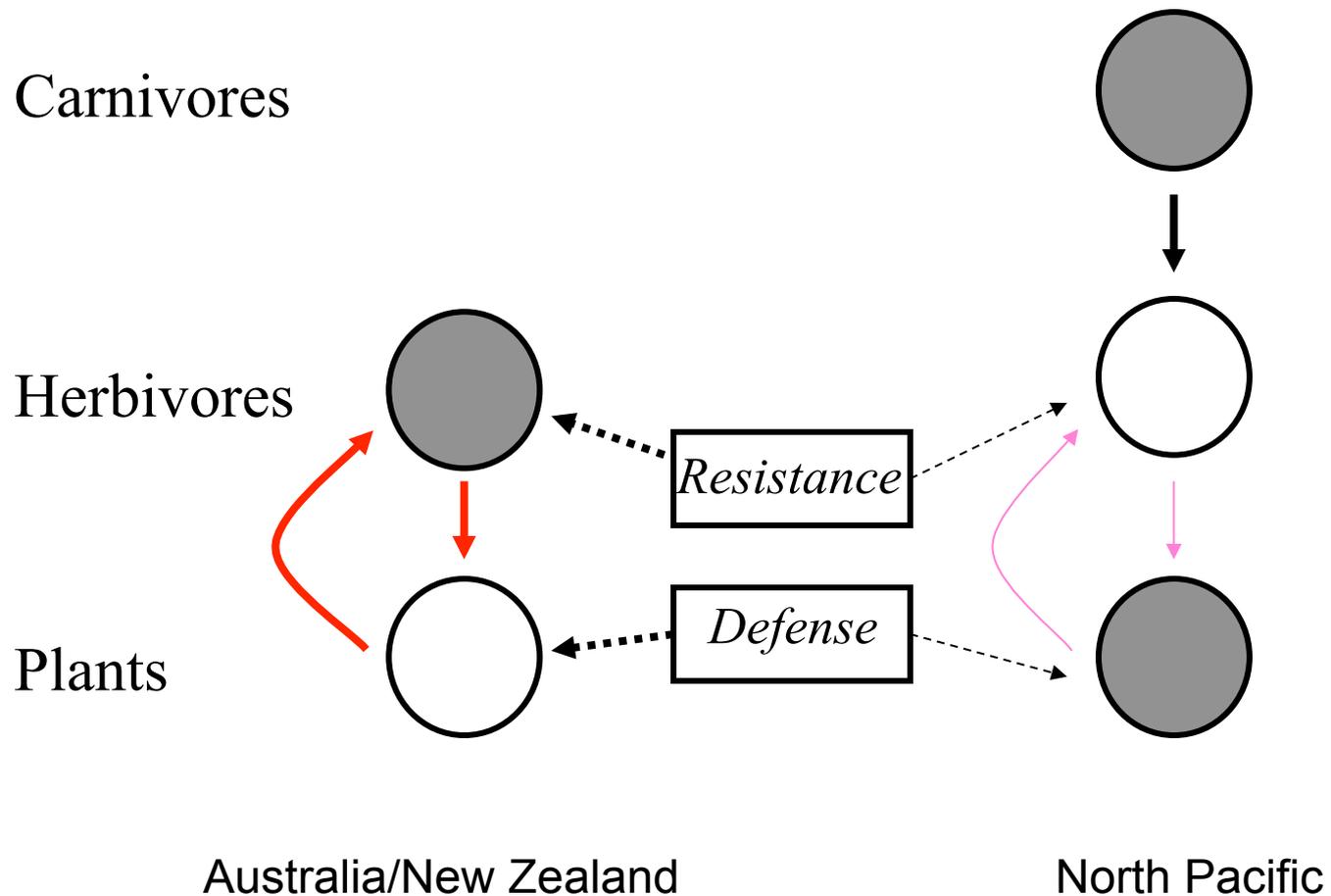


% Total Phlorotannins

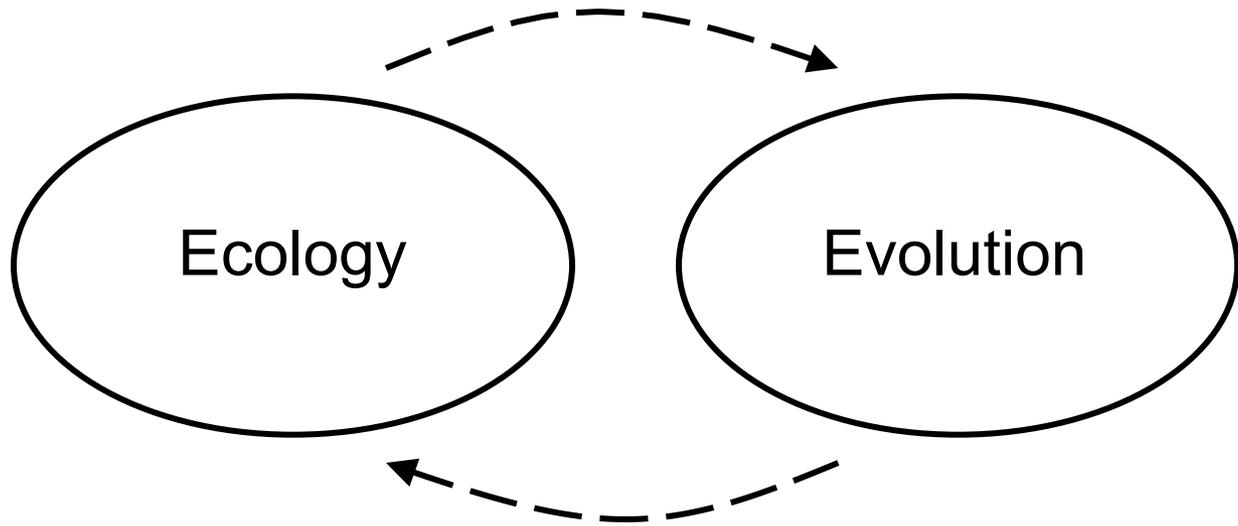


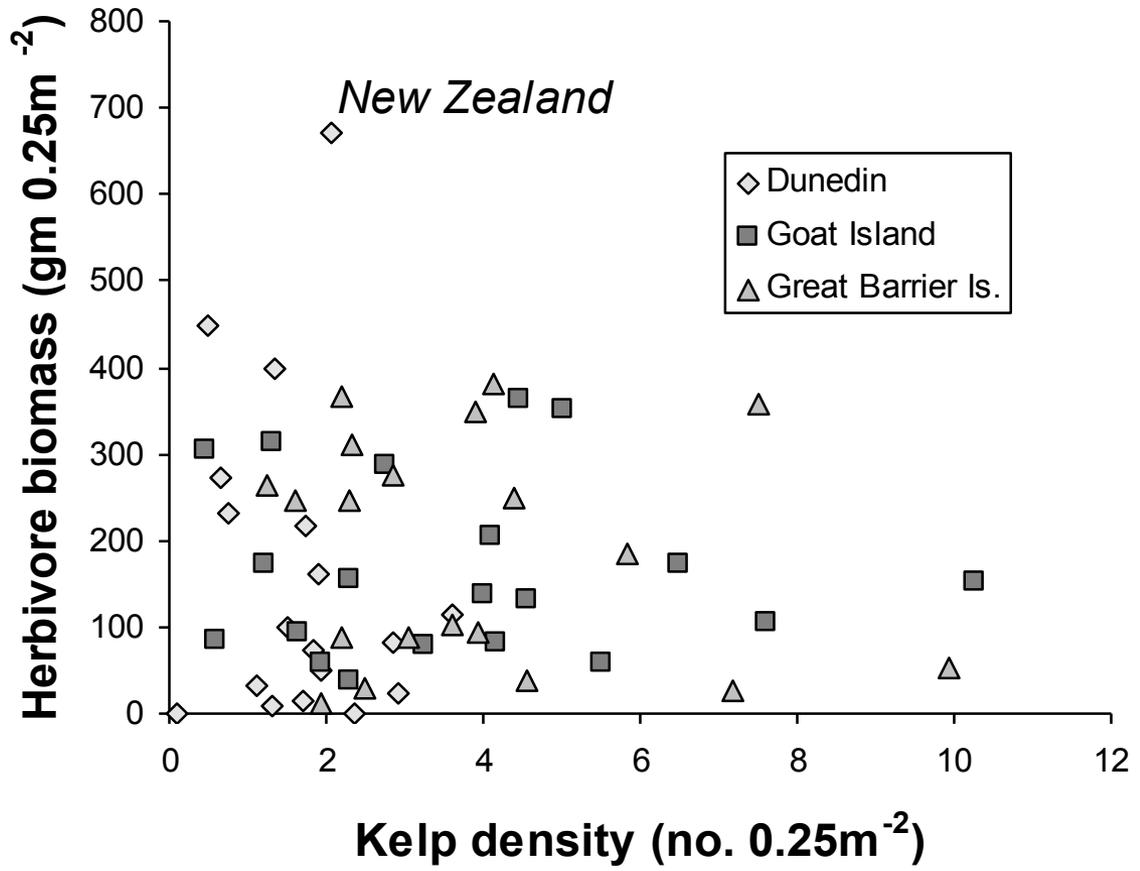
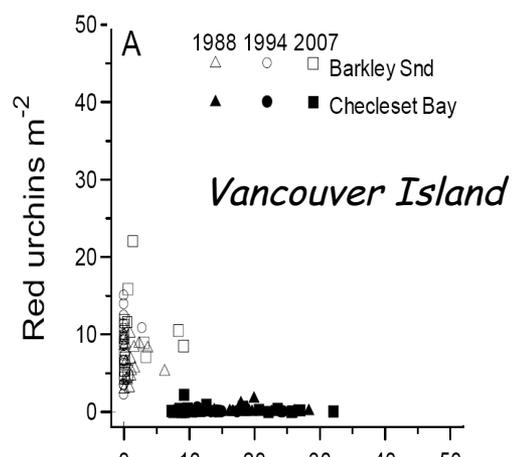
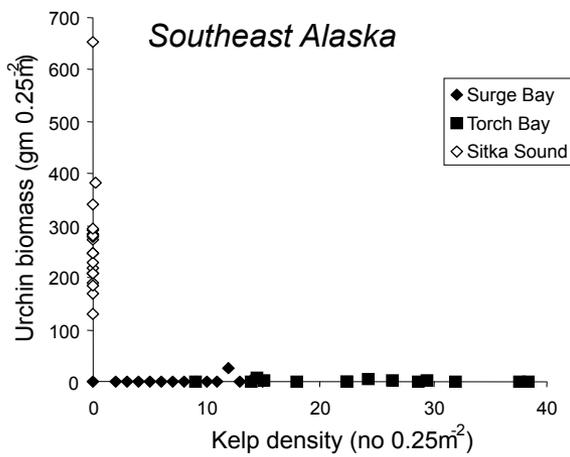
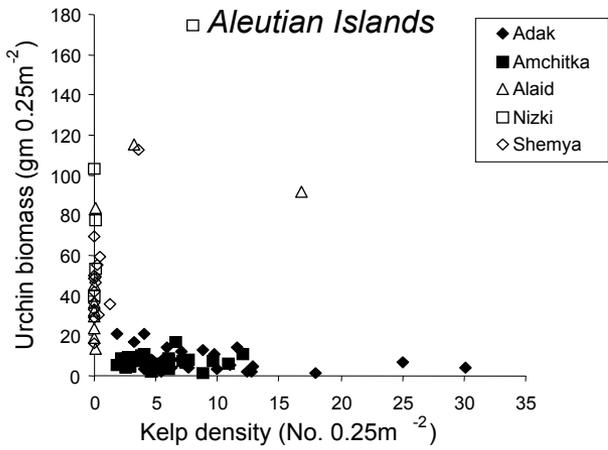
		California Herbivores			New Zealand Herbivores			
		<i>Tegula funebris</i>	<i>Tegula brunnea</i>	<i>S. purpuratus</i>	<i>Evechinus chloroticus</i>	<i>Centrostephanus rodgersii</i>	<i>Cookia sulcata</i>	<i>Turbo smaragdus</i>
Phlorotannins from % Dry Wt.								
<u>New Zealand Algae</u>								
<i>Ecklonia radiata</i>	5	*	*	*	NS	NS	***	NS
	13.4	**	**	*	*	NS	***	*
<i>Carpophyllum</i>	5	*	NS	NS	NS	NS	NS	NS
<i>maschalocarpum</i>	13.4	NS	**	*	NS	NS	NS	*
<u>North American Algae</u>								
<i>Agarum cribrosum</i>	5	0.073	**	*	NS	NS	NS	<i>nd</i>
	13.4	*	NS	NS	NS	NS	NS	<i>nd</i>
<i>Dictyoneurum</i>	5	*	*	0.057	NS	NS	NS	NS
<i>californicum</i>	13.4	**	**	*	*	NS	NS	*

Plant/herbivore coevolution?

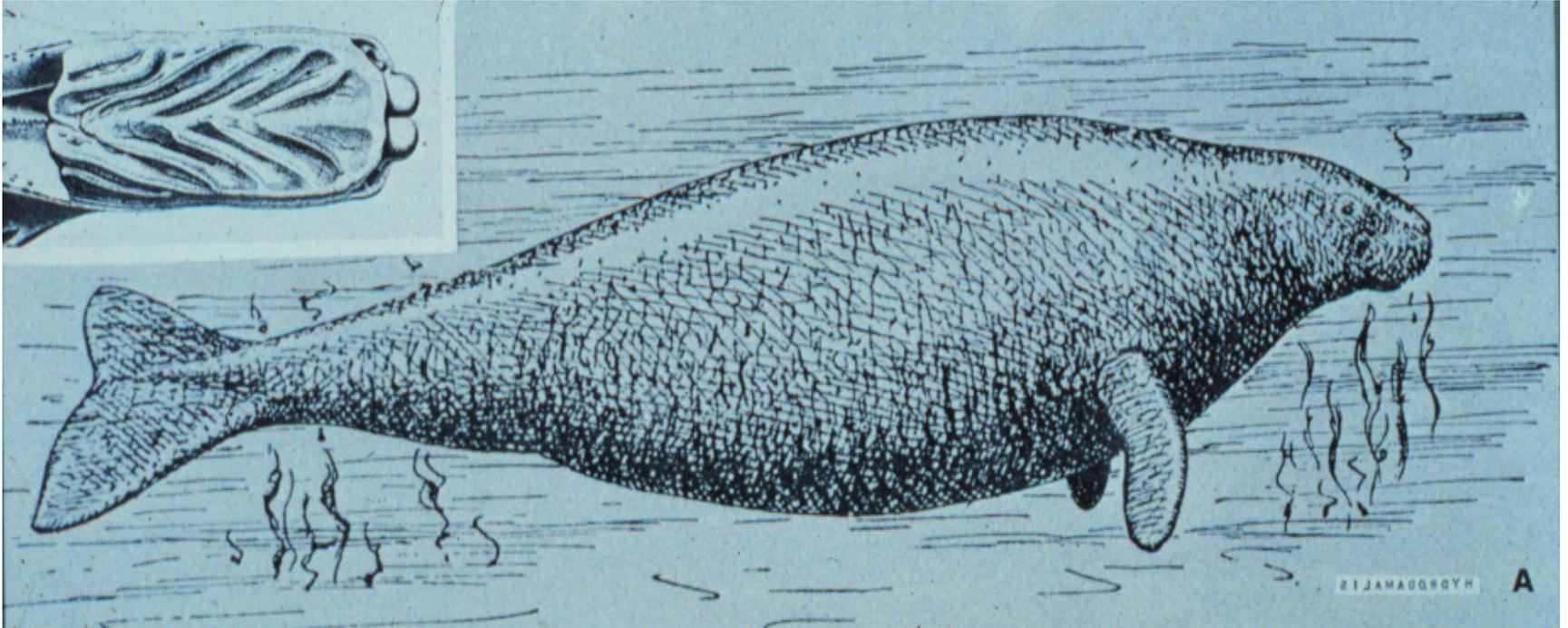


Eco/evo reciprocity





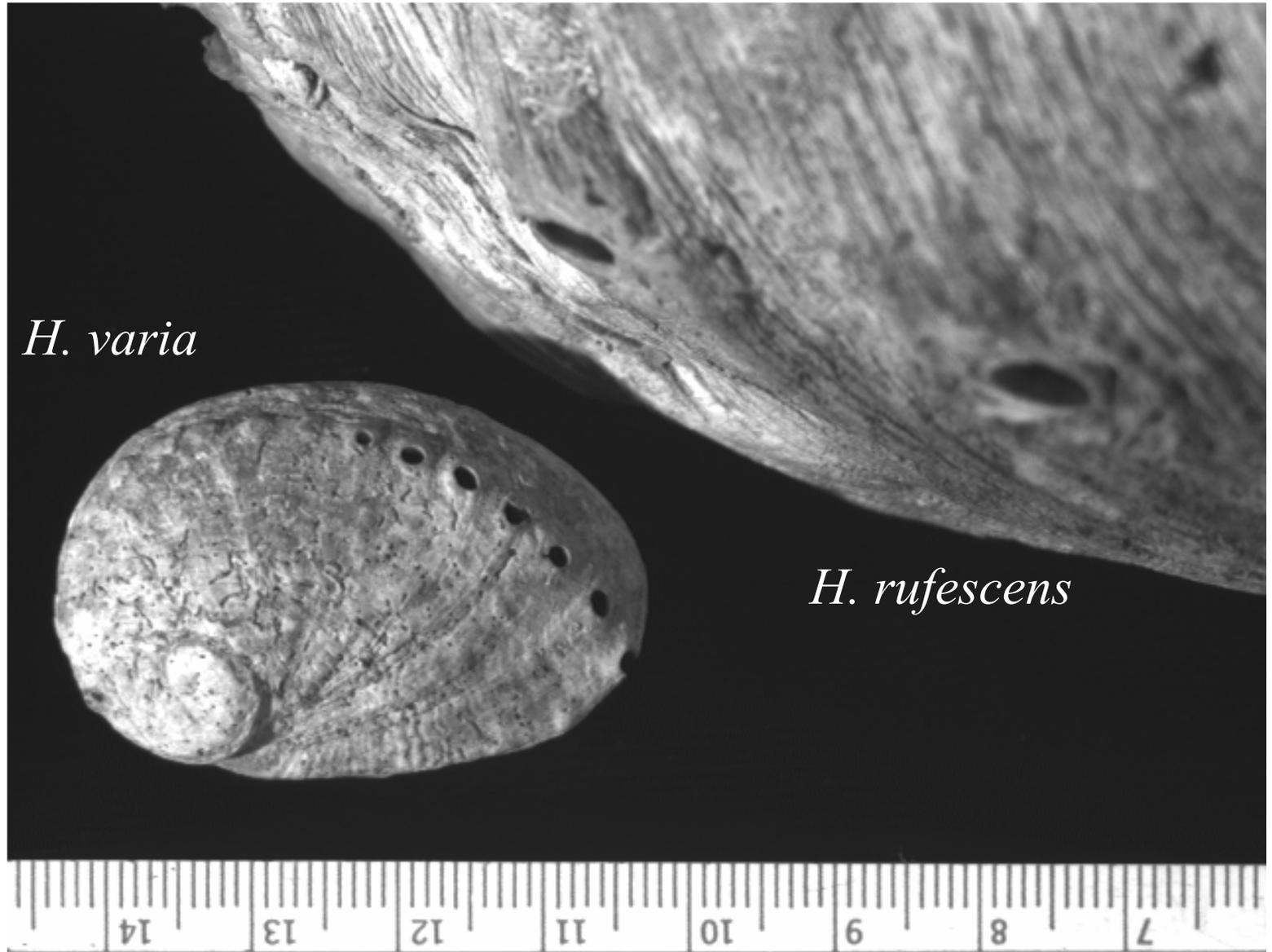
Evolution and extinction of hydrodamaline sirenians

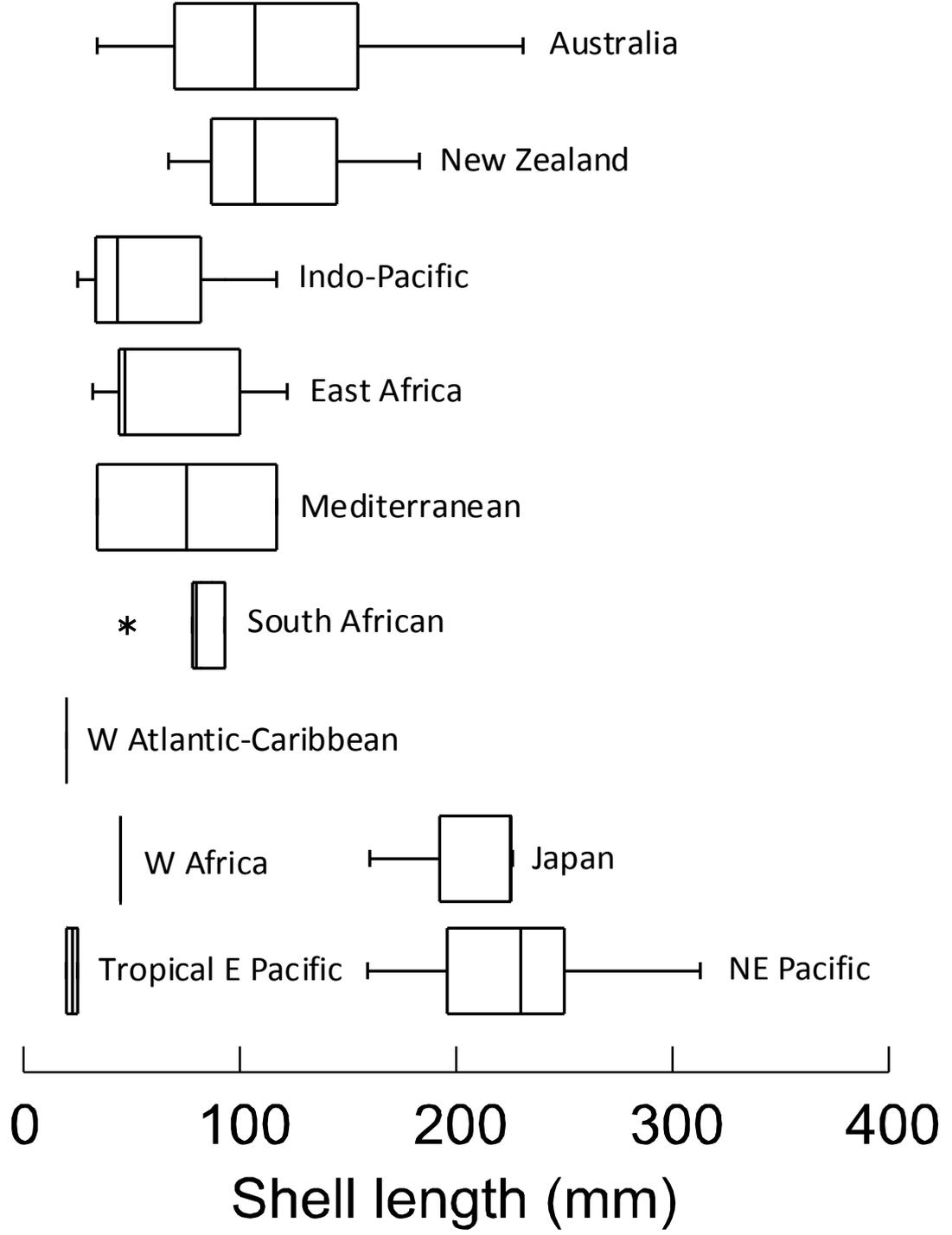


Hydrodamalis gigas

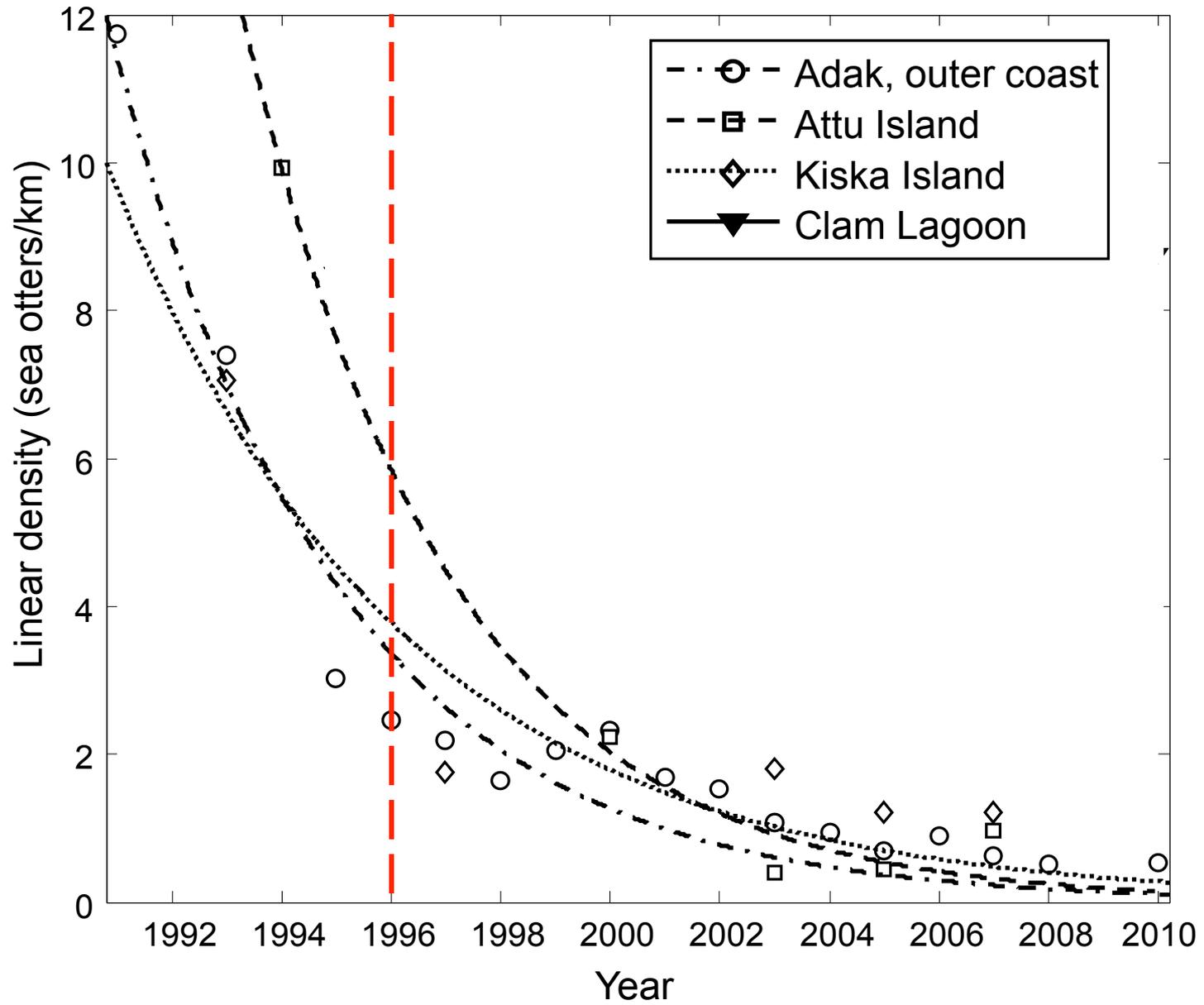
Steller sea cow

Evolution of body size in abalones





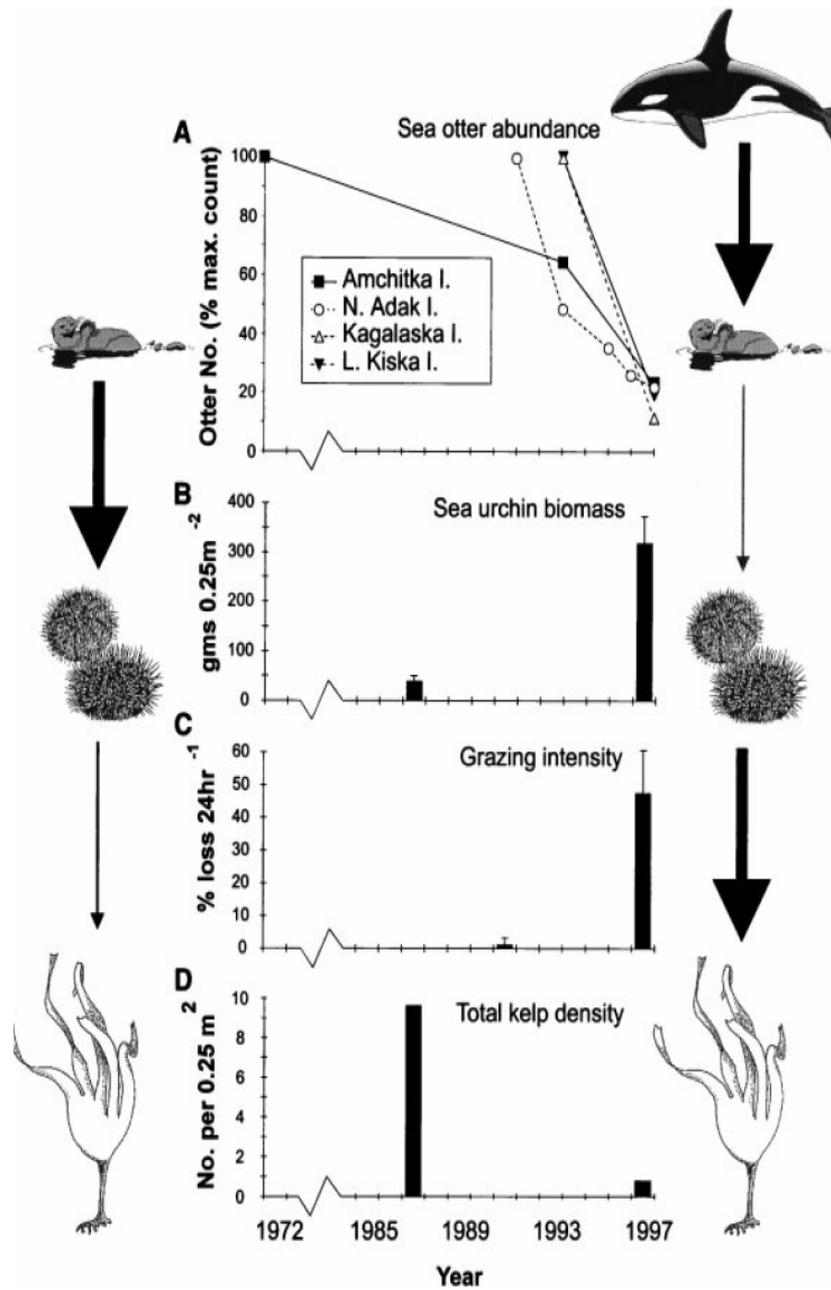
Inter-system connectivity





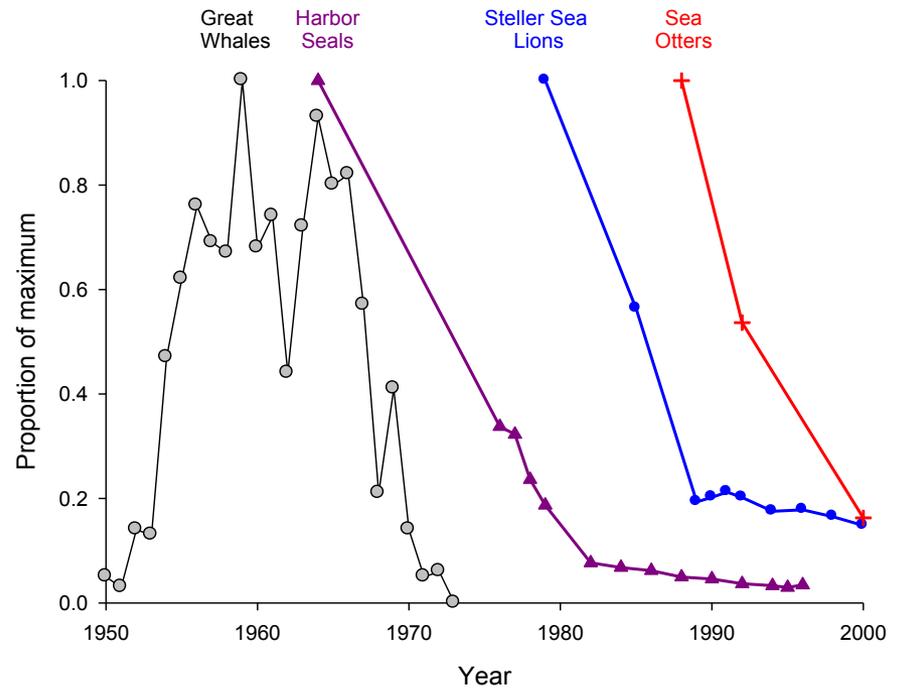
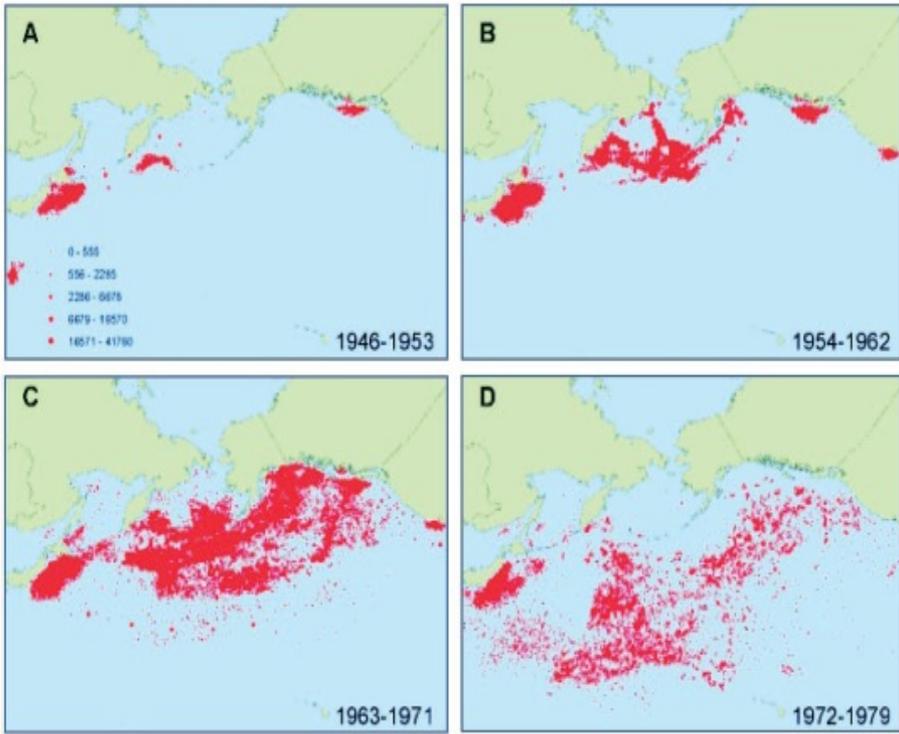
Evidence:

1. Increased KW sightings
2. Increased SO attacks
3. Refuge habitat
4. Observation vs expectation

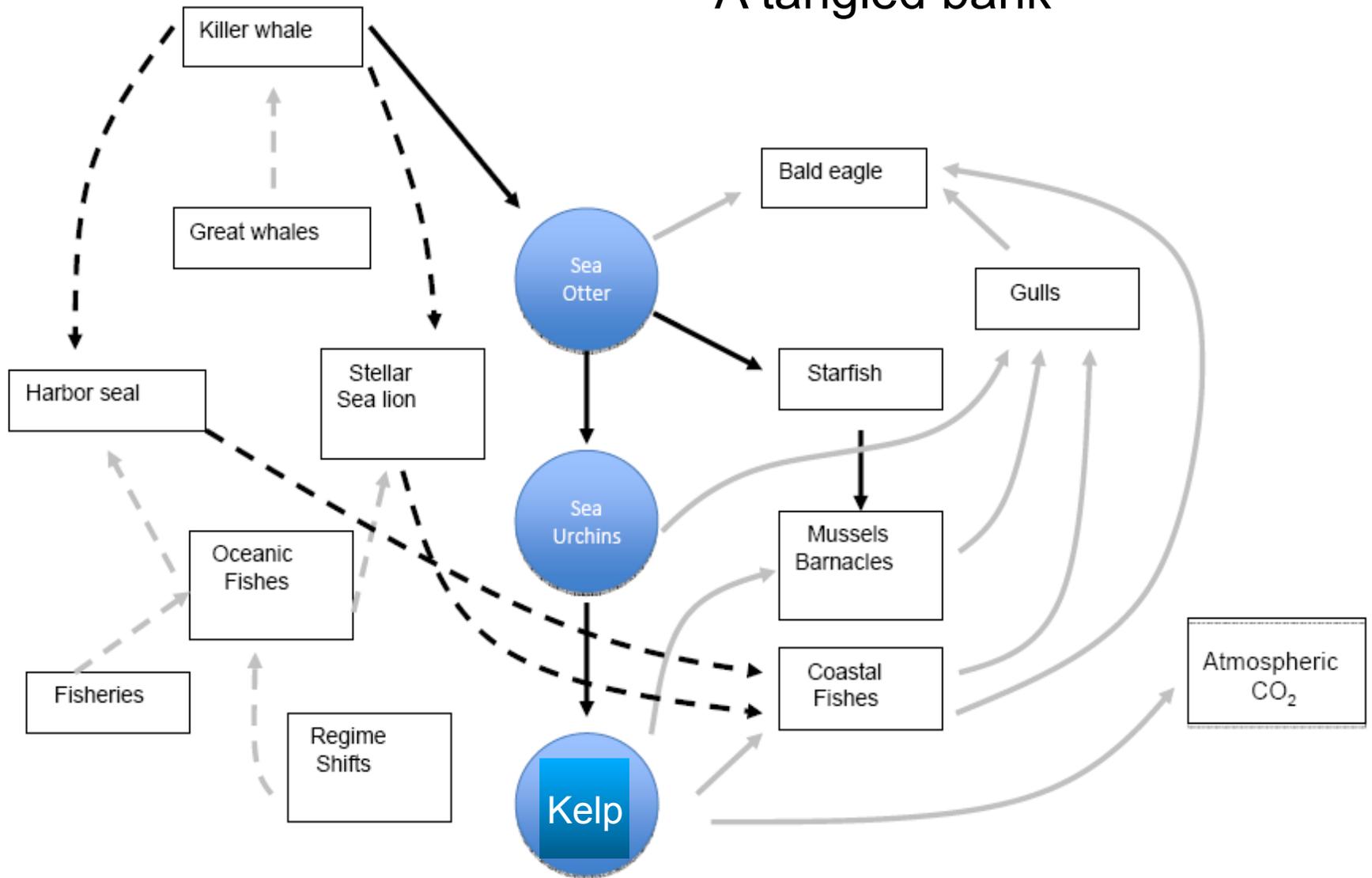


What happened?





Darwin's simile "A tangled bank"



Retrospection

- I. Sea otters and kelp
- II. Generality
- III. Food web effects
- IV. Evolution and adaptation
- V. Linkage and connectivity
- VI. The future