Salmon & jellyfish:
bumping elbows in the Northern California Current

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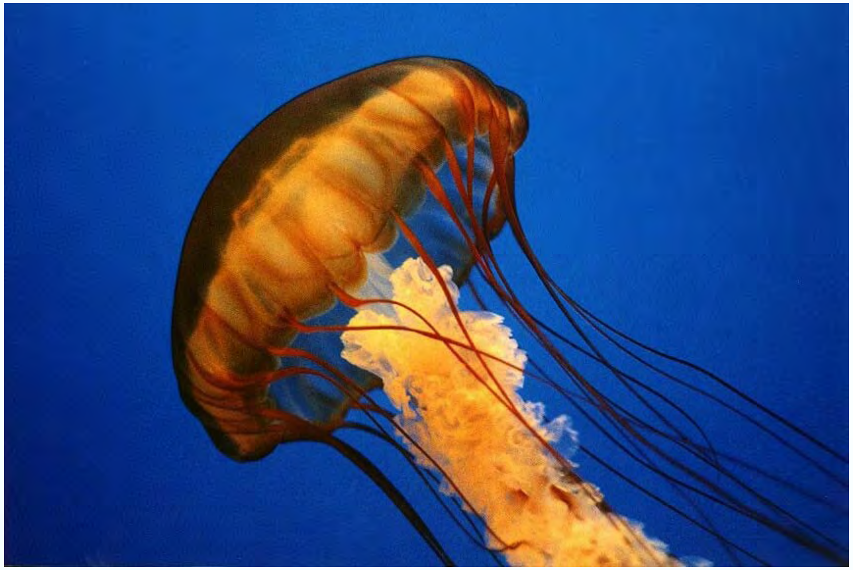
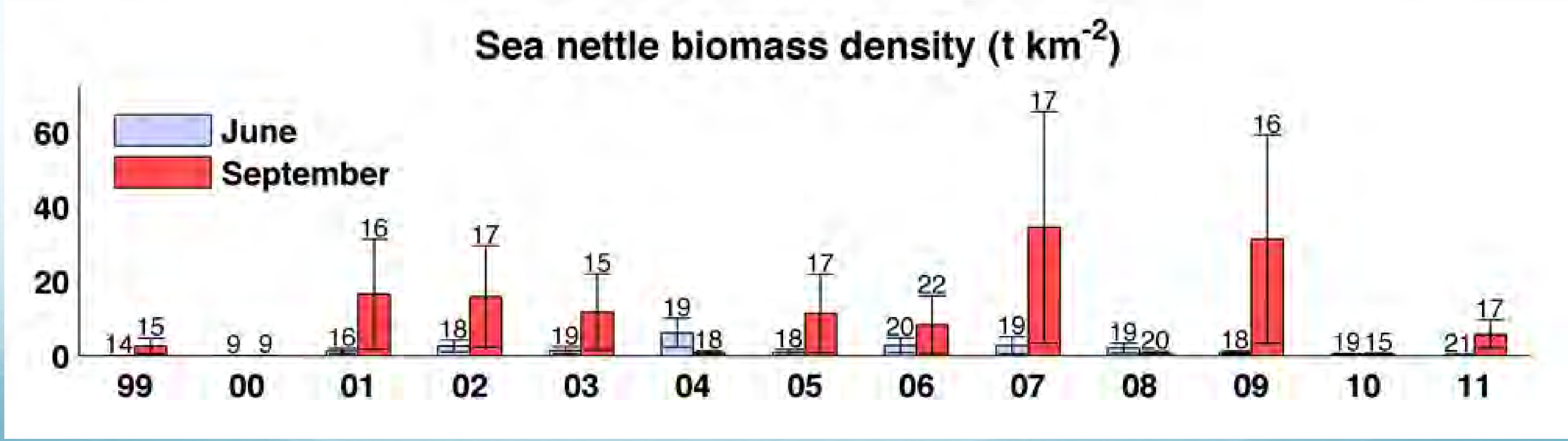
Goals:

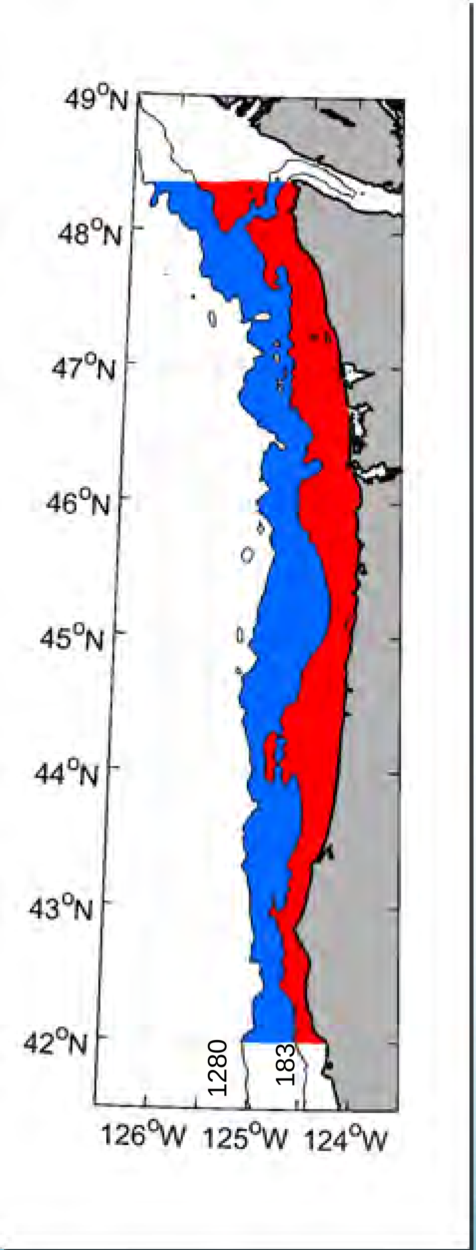
- Explore effects of variable trophic network structure on production of juvenile salmon in Northern California Current (NCC)
- Develop an end-to-end trophic model to quantify net direct and indirect effects of large jellyfish on juvenile salmon
- Examine relation between local juvenile salmon feeding and jellyfish biomass
- Examine relationship between observed Columbia River salmon production and jellyfish abundance



The sea nettle, *Chrysaora fuscescens*



NCC Coastal Upwelling Ecosystem: model domain



Full domain: 42.0 - 48.34°N; 1-183m; 26,000 km^2

Coverage years: 1999-2011…

Seasons: June – September

Platform: ECOTRAN (Steele & Ruzicka, 2011)

Currency: wet weight (jellyfish normalized to forage fish water content)

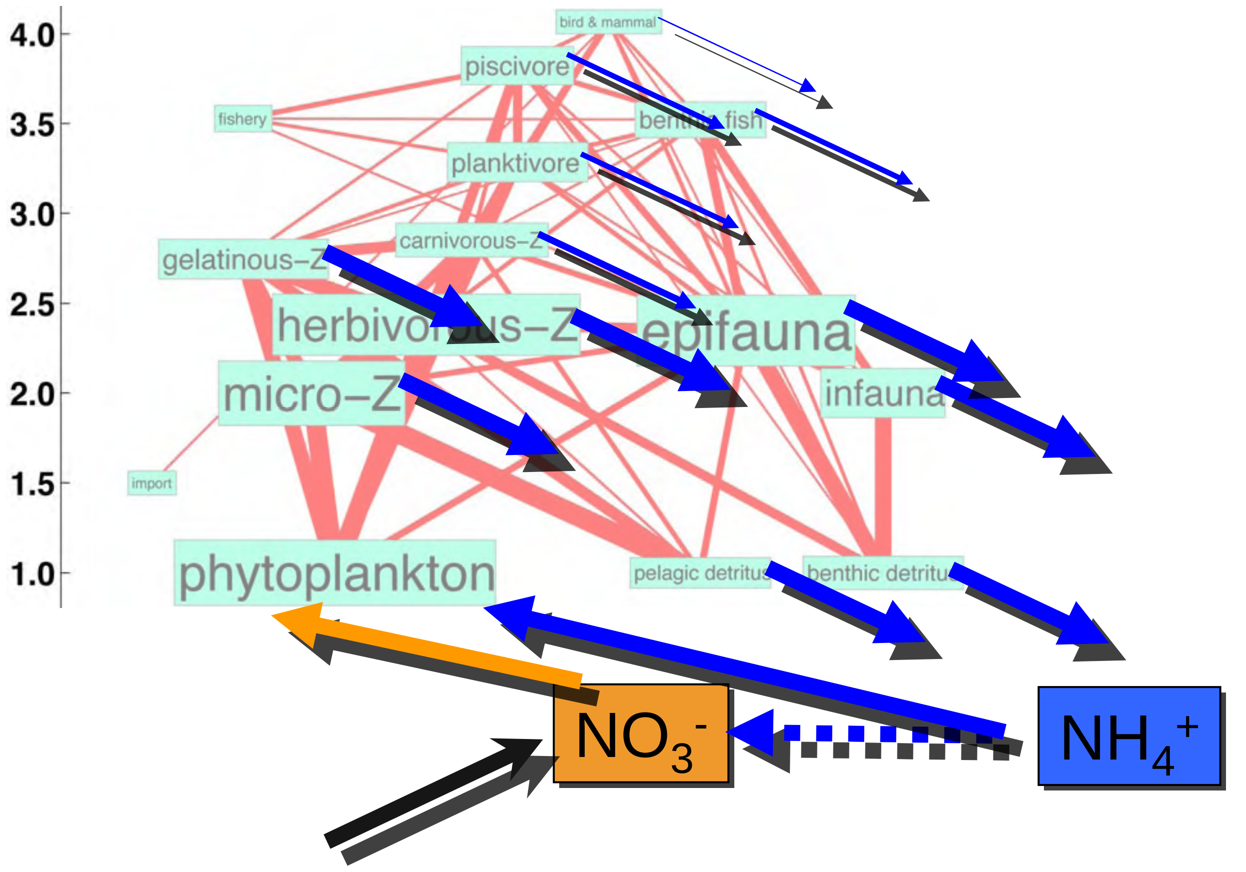
"ECOTRAN"

- maps flow of production UP food web
- account for bioenergetic budgets of each group
- propagation of variability & uncertainty (incl. migration)

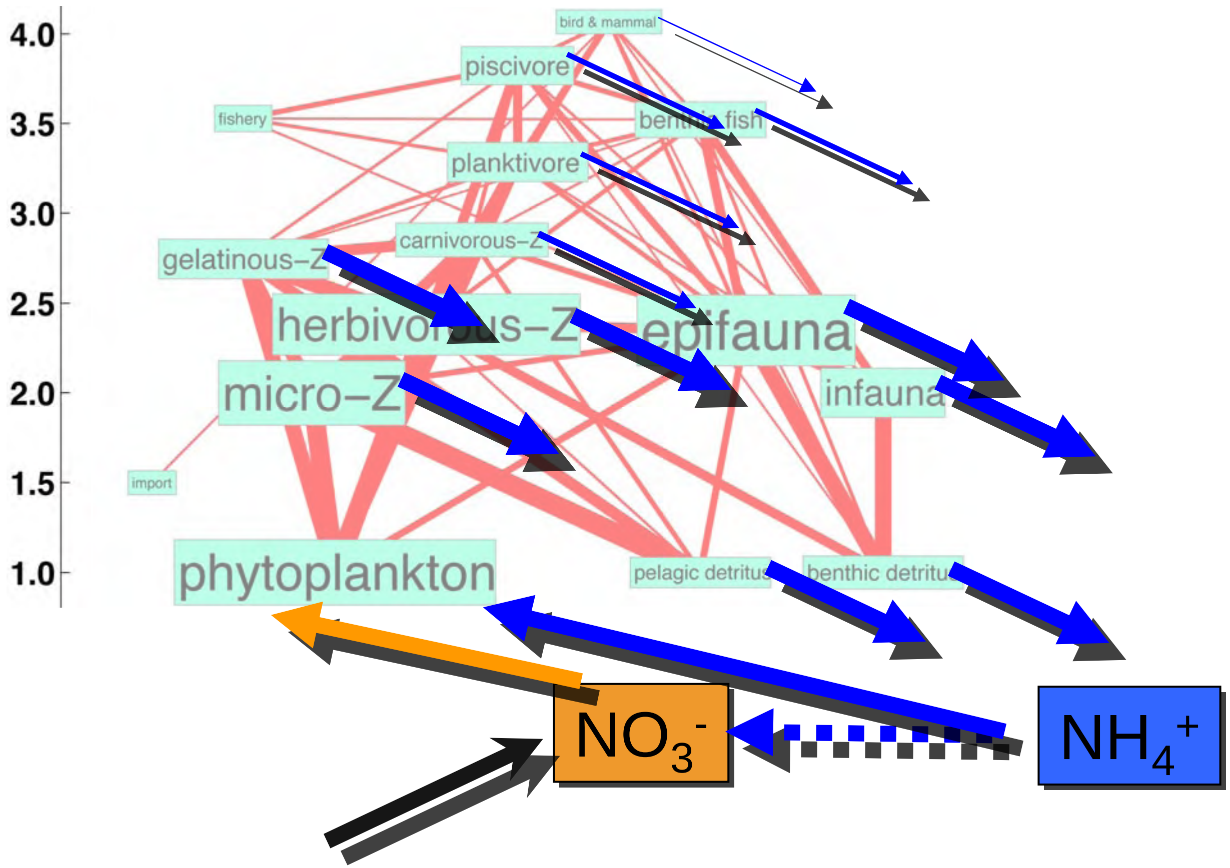
Producers→

CONSUMPTION = **PRODUCTION** +
consumers
fisheries
M0
METABOLISM +
NON-ASSIMILTED

	NO_3	NH_4	P_1	C_1	C_2	F_1
P_1	1	1	0	0	0	0
C_1	0	0	0.5	0	0	0.3
C_2	0	0	0.2	0.5	0.1	0.3
F_1	0	0	0	0	0.1	0
M0	0	0	0.3	0.2	0.4	0
NH_4	0	0	0	0.1	0.2	0
feces	0	0	0	0.2	0.2	0.4

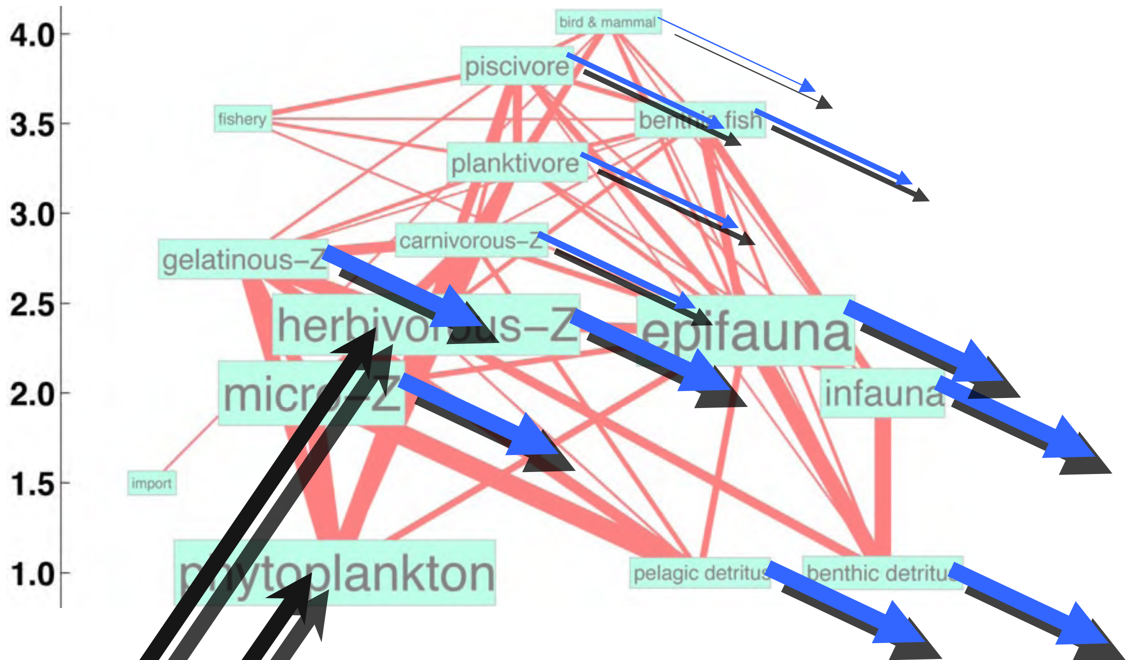


Upwelling driver



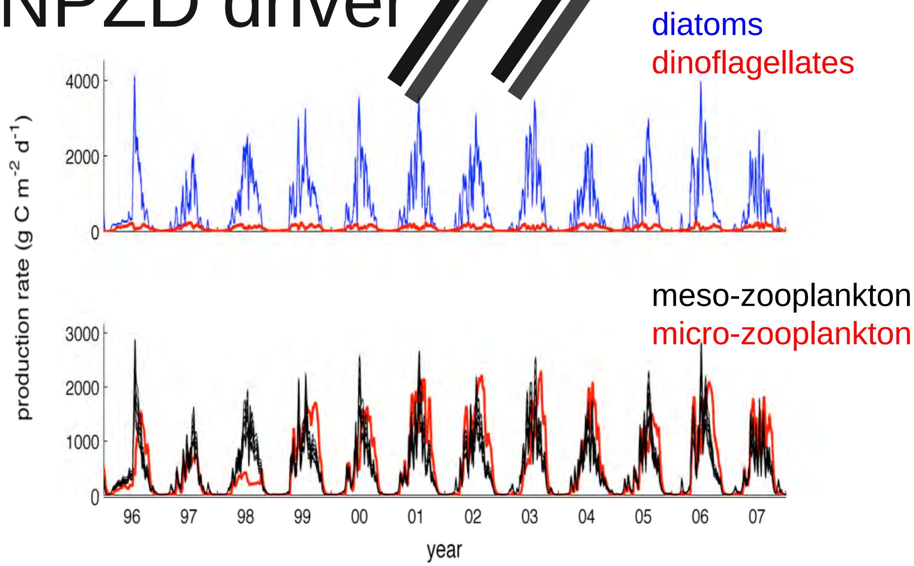
“unit” driver

Sensitivity scenarios
Trophic network efficiency metrics

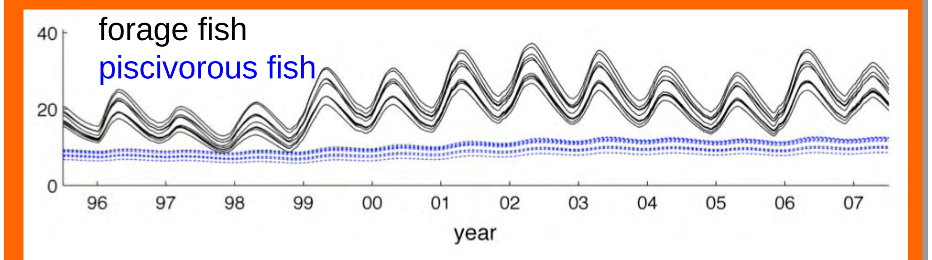


NH_4^+

NPZD driver



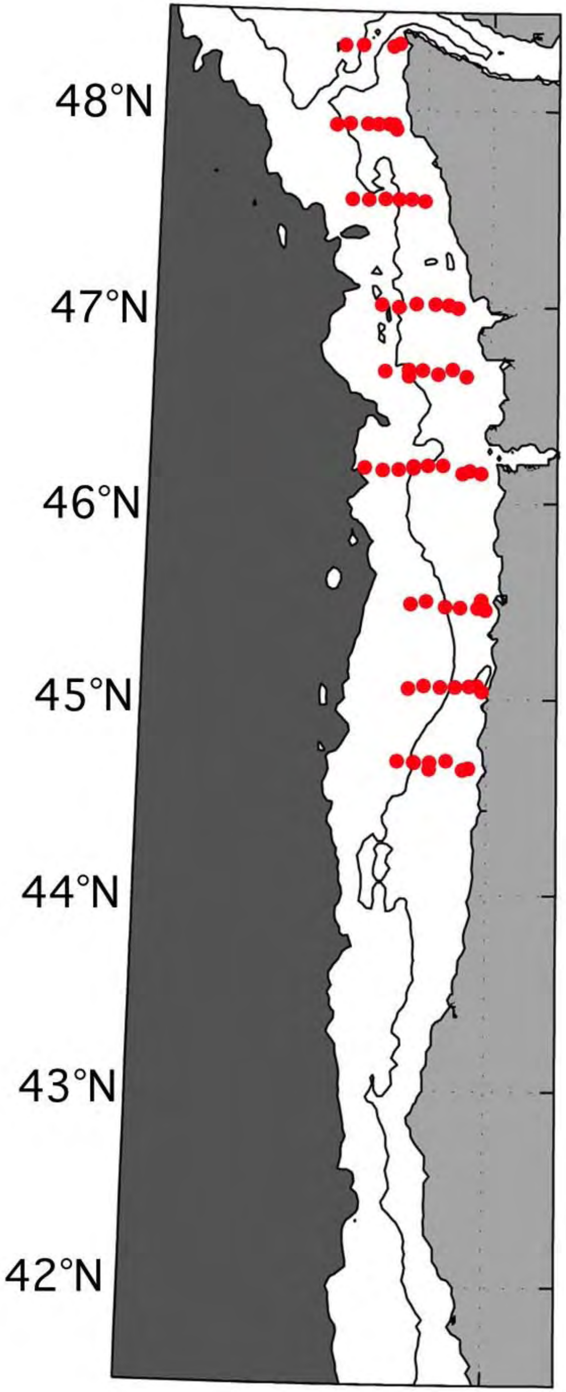
Dynamic time-series scenarios
Foraging relation scenarios



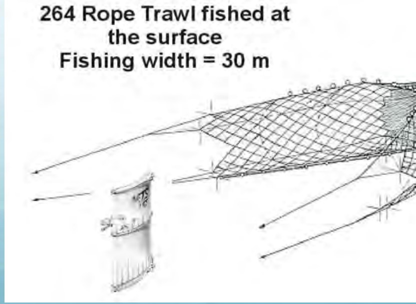
Pelagic survey

zooplankton

birds



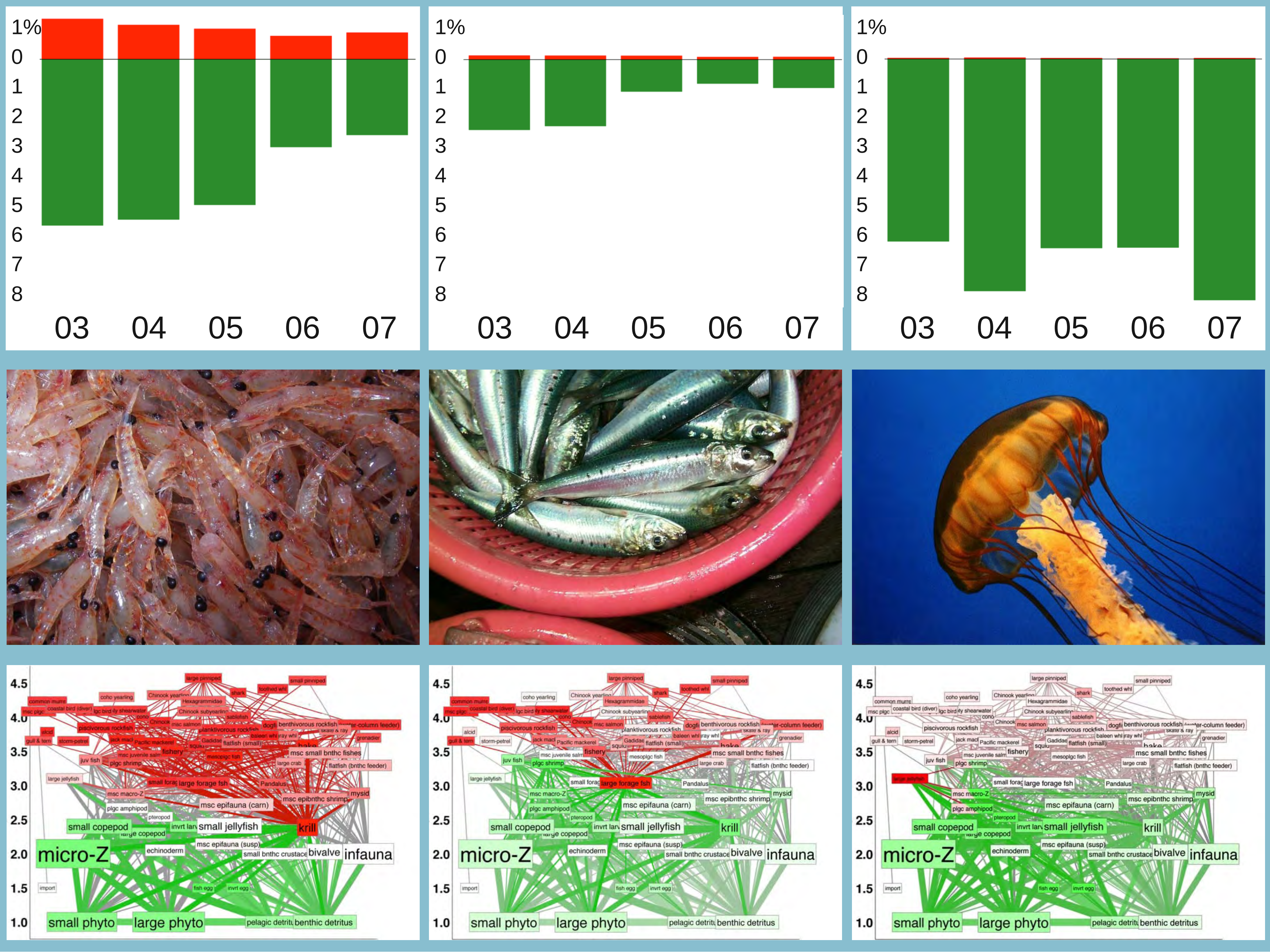
Day sampling (Night off CR)
1998 - 2011
May, June, September



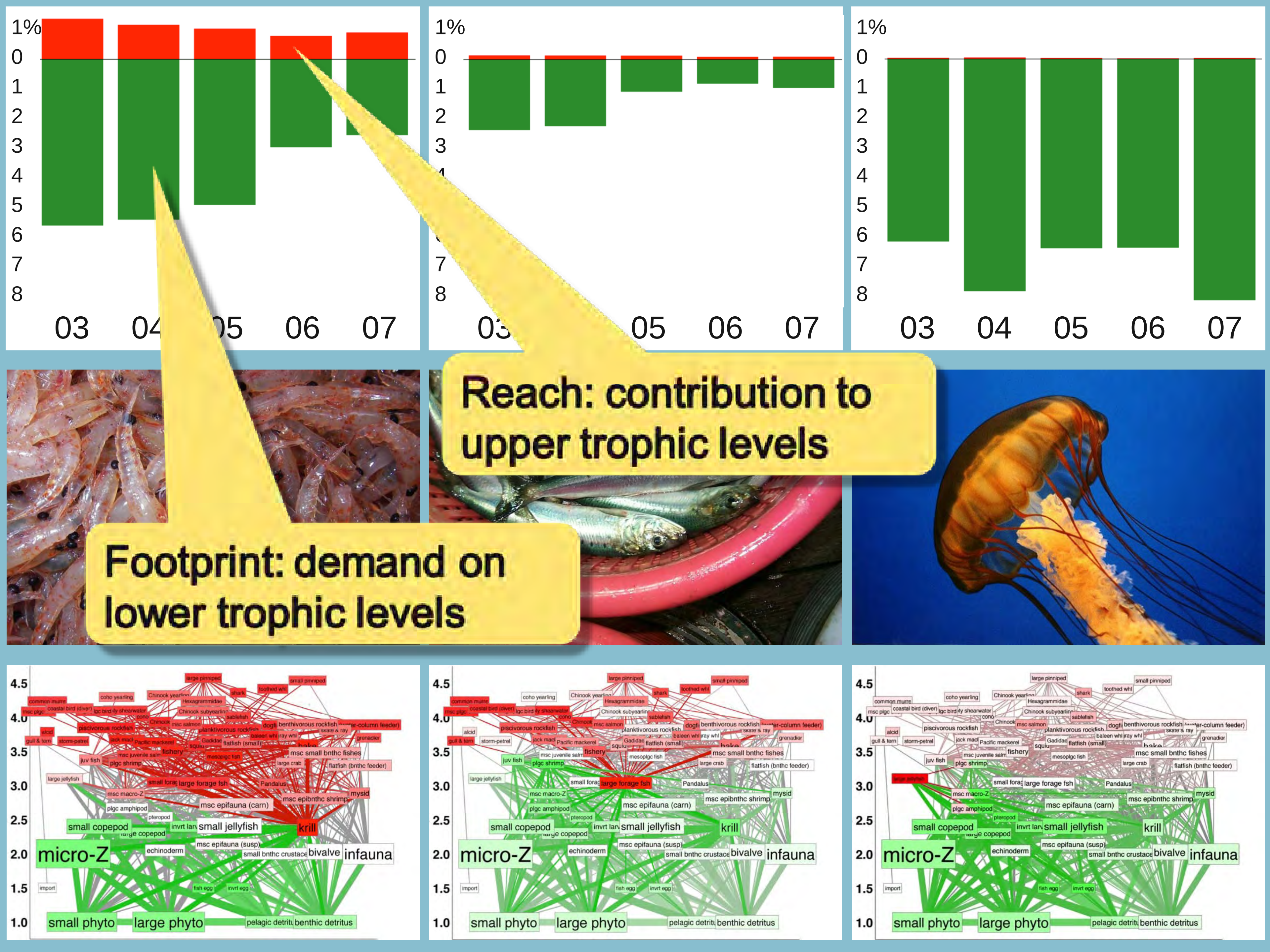
Nordic trawl
30 x 20m

How important are jellyfish?

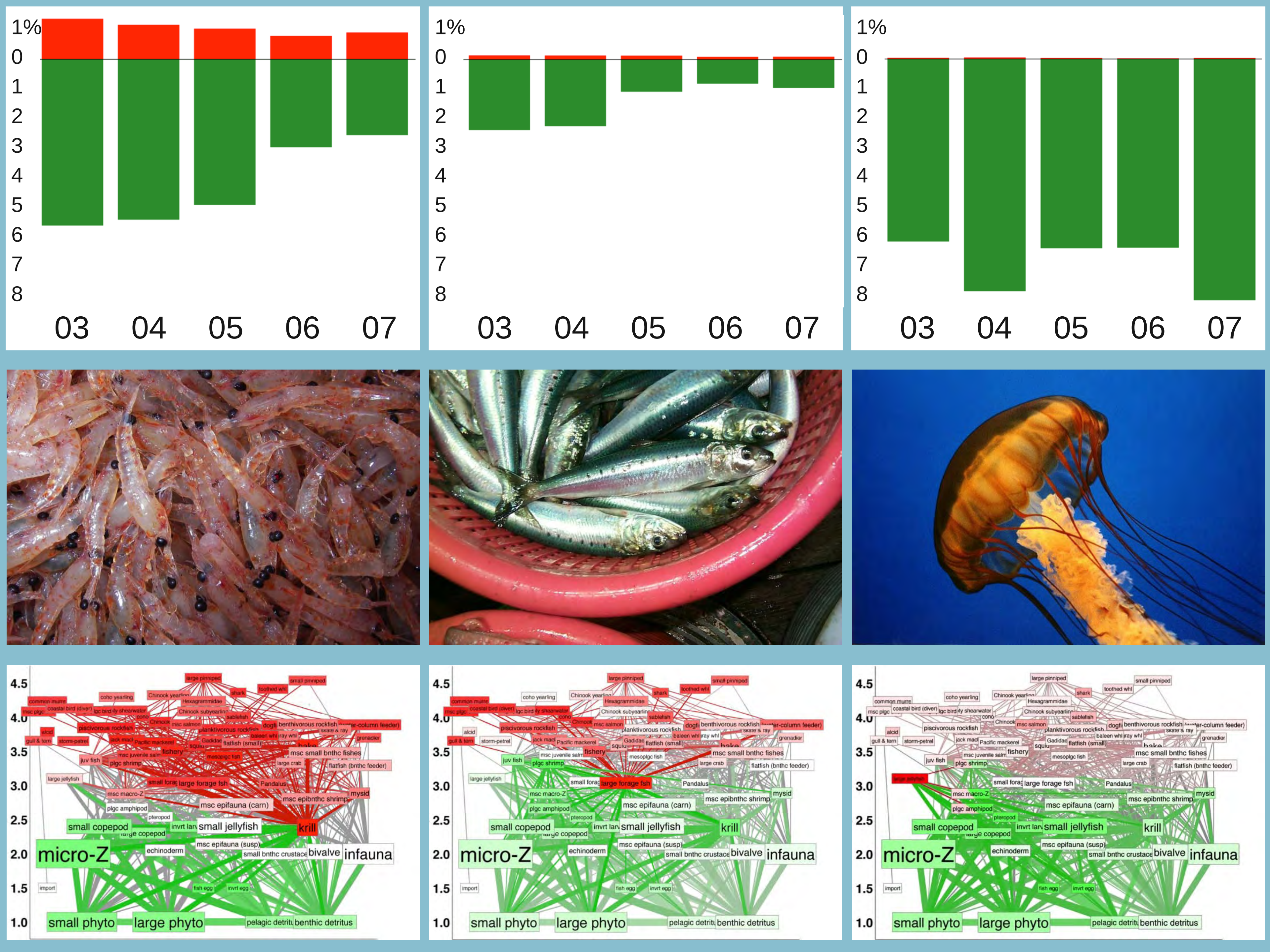
(in terms of energy flow)



1%
0
1
2
3
4
5
6
7
8
03
04
05
06
07
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
large pinniped
small pinniped
toothed whl
shark
common murre
coho yearling
Chinook yearling
Hexagrammidae
Chinook subyearling
sablefish
benthivorous rockfish
piscivorous rockfish
planktivorous rockfish
msc salmon
alcid
gull & tern
storm-petrel
Pacific mackerel
Gadidae
flatfish (small)
fishery
grenadier
msc small bnthc fishes
juv fish
plgc shrimp
mesoplgc fish
large crab
flatfish (bnthc feeder)
large jellyfish
small forag
large forage fsh
Pandalus
msc macro-Z
mysid
msc epibnthc shrimp
plgc amphipod
msc epifauna (carn)
pteropod
small copepod
large copepod
invrt larv
small jellyfish
krill
micro-Z
echinoderm
msc epifauna (susp)
small bnthc crustace
bivalve
infauna
import
fish egg
invrt egg
small phyto
large phyto
pelagic detrit
benthic detritus



Reach: contribution to upper trophic levels
Footprint: demand on lower trophic levels
1%
0
1
2
3
4
5
6
7
8
03
04
05
06
07
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
large pinniped
small pinniped
toothed whl
shark
common murre
coho yearling
Chinook yearling
Hexagrammidae
Chinook subyearling
sablefish
piscivorous rockfish
planktivorous rockfish
benthivorous rockfish
alcid
gull & tern
storm-petrel
Pacific mackerel
flatfish (small)
grenadier
fishery
msc small bnthc fishes
juv fish
plgc shrimp
mesoplgc fish
large crab
flatfish (bnthc feeder)
large jellyfish
large forage fsh
Pandalus
msc macro-Z
msc epibnthc shrimp
mysid
plgc amphipod
msc epifauna (carn)
pteropod
small copepod
small jellyfish
krill
micro-Z
echinoderm
msc epifauna (susp)
bivalve
infauna
import
fish egg
invrt egg
small phyto
large phyto
benthic detritus



1%
0
1
2
3
4
5
6
7
8
03
04
05
06
07
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
large pinniped
small pinniped
toothed whl
shark
common murre
coho yearling
Chinook yearling
Hexagrammidae
Chinook subyearling
sablefish
piscivorous rockfish
planktivorous rockfish
benthivorous rockfish
msc small bnthc fishes
flatfish (bnthc feeder)
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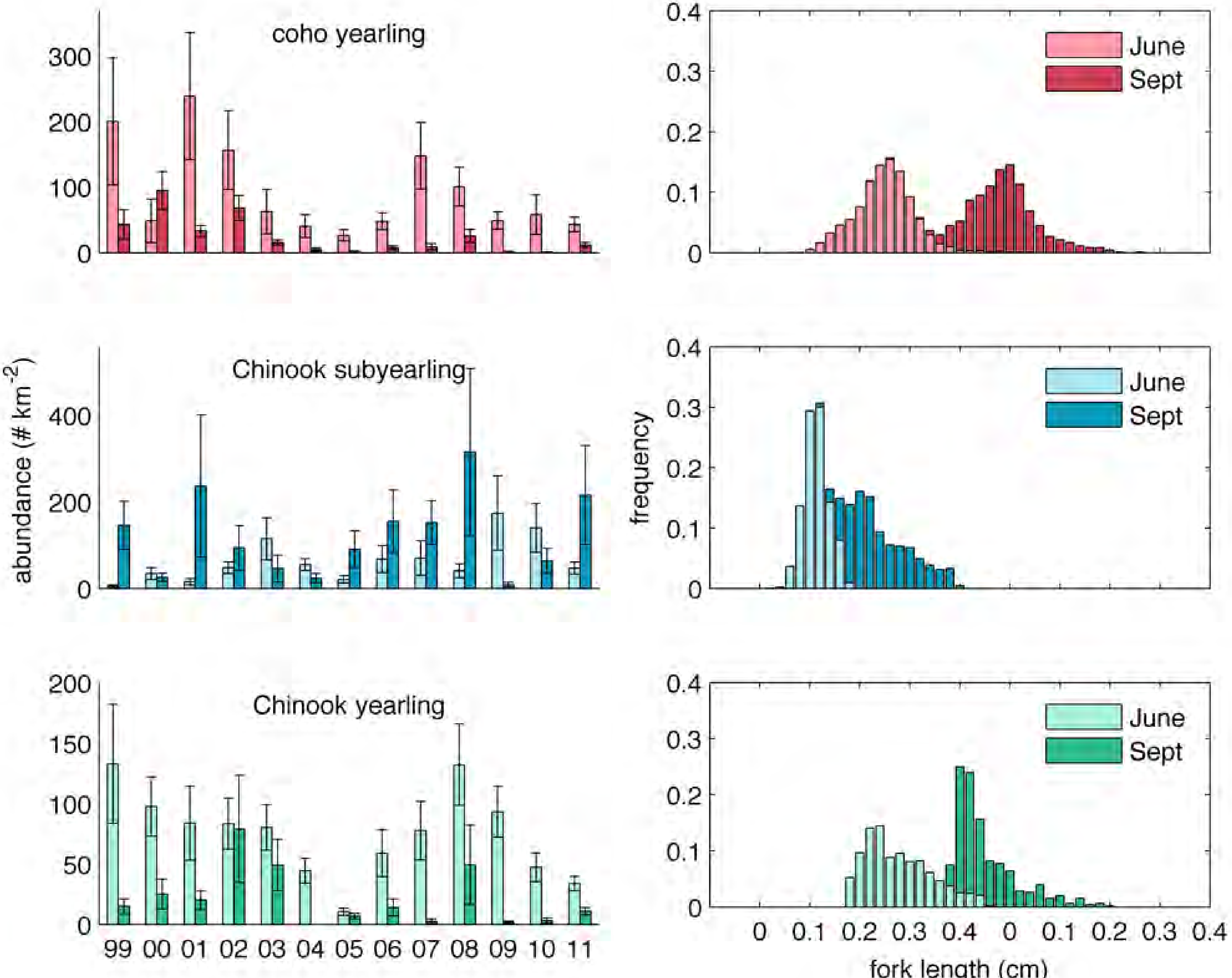
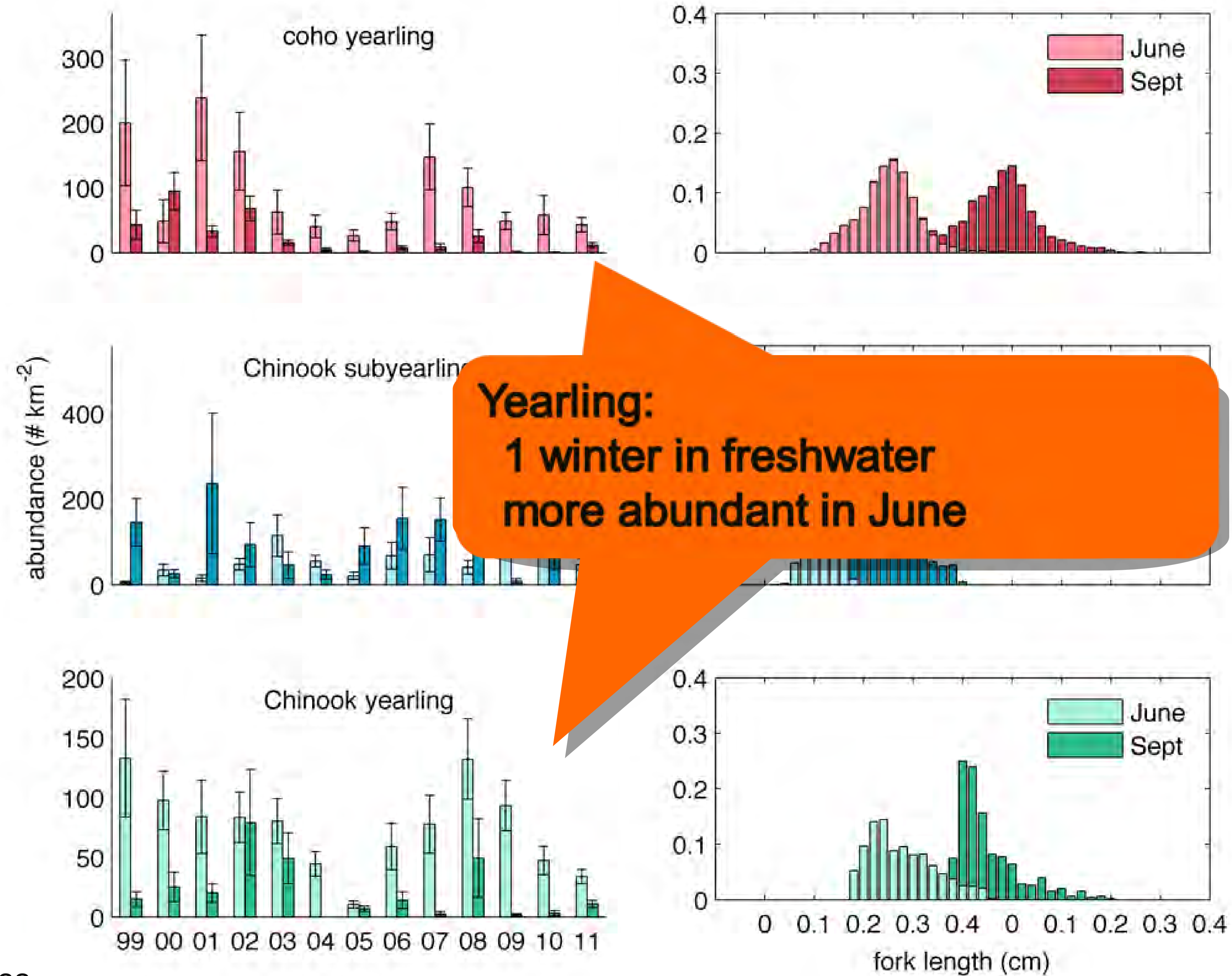
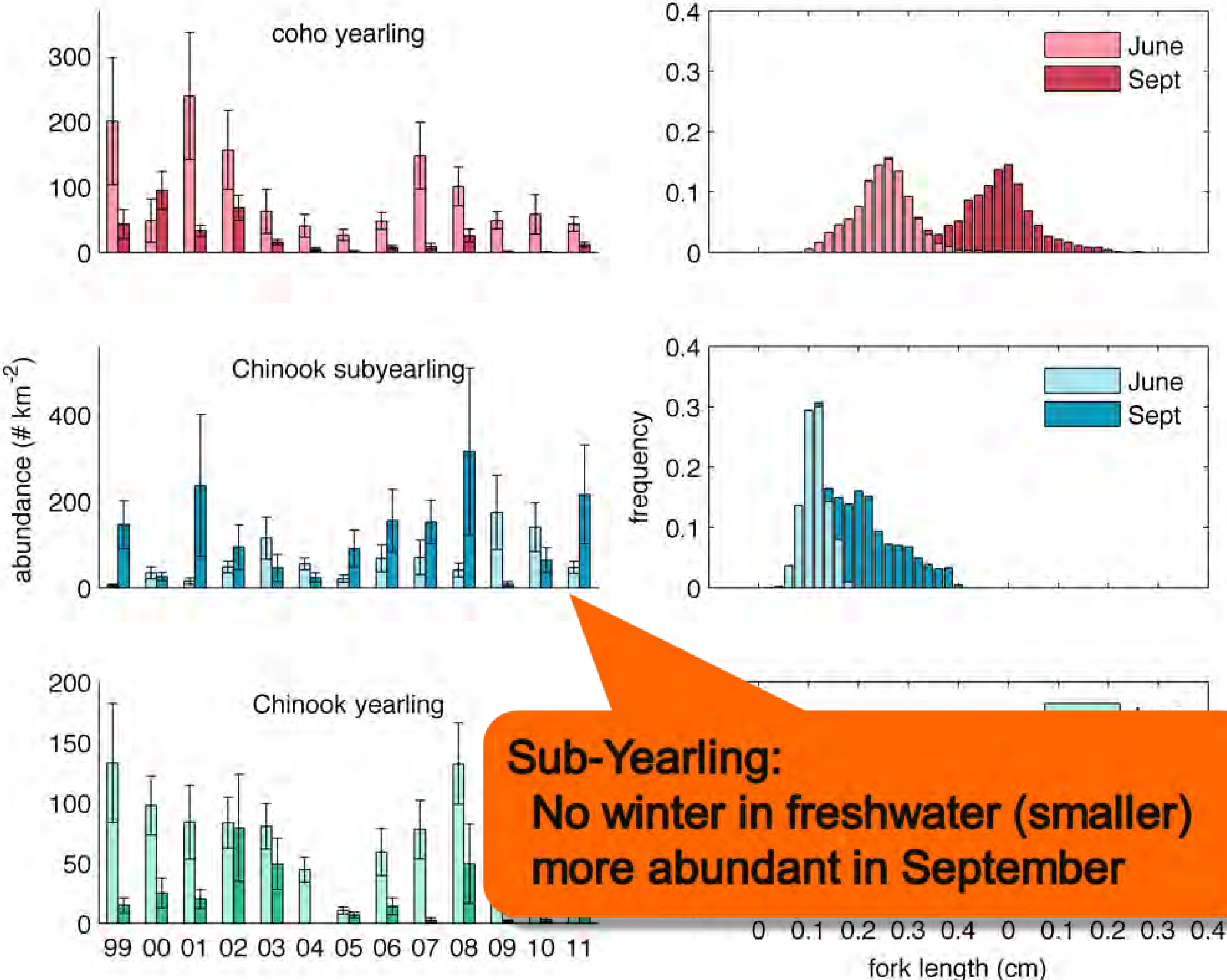
plgc shrimp
juv fish
large jellyfish
small forage fsh
large forage fsh
Pandalus
msc macro-Z
msc epibnthc shrimp
mysid
plgc amphipod
msc epifauna (carn)
small copepod
large copepod
small jellyfish
krill
micro-Z
echinoderm
msc epifauna (susp)
bivalve
infauna
import
fish egg
invrt egg
small phyto
large phyto
benthic detritus

Three juvenile salmon types

(abundance time-series & diets)


coho yearling
Chinook subyearling
Chinook yearling
abundance (# km-2)
99 00 01 02 03 04 05 06 07 08 09 10 11
June
Sept
frequency
fork length (cm)

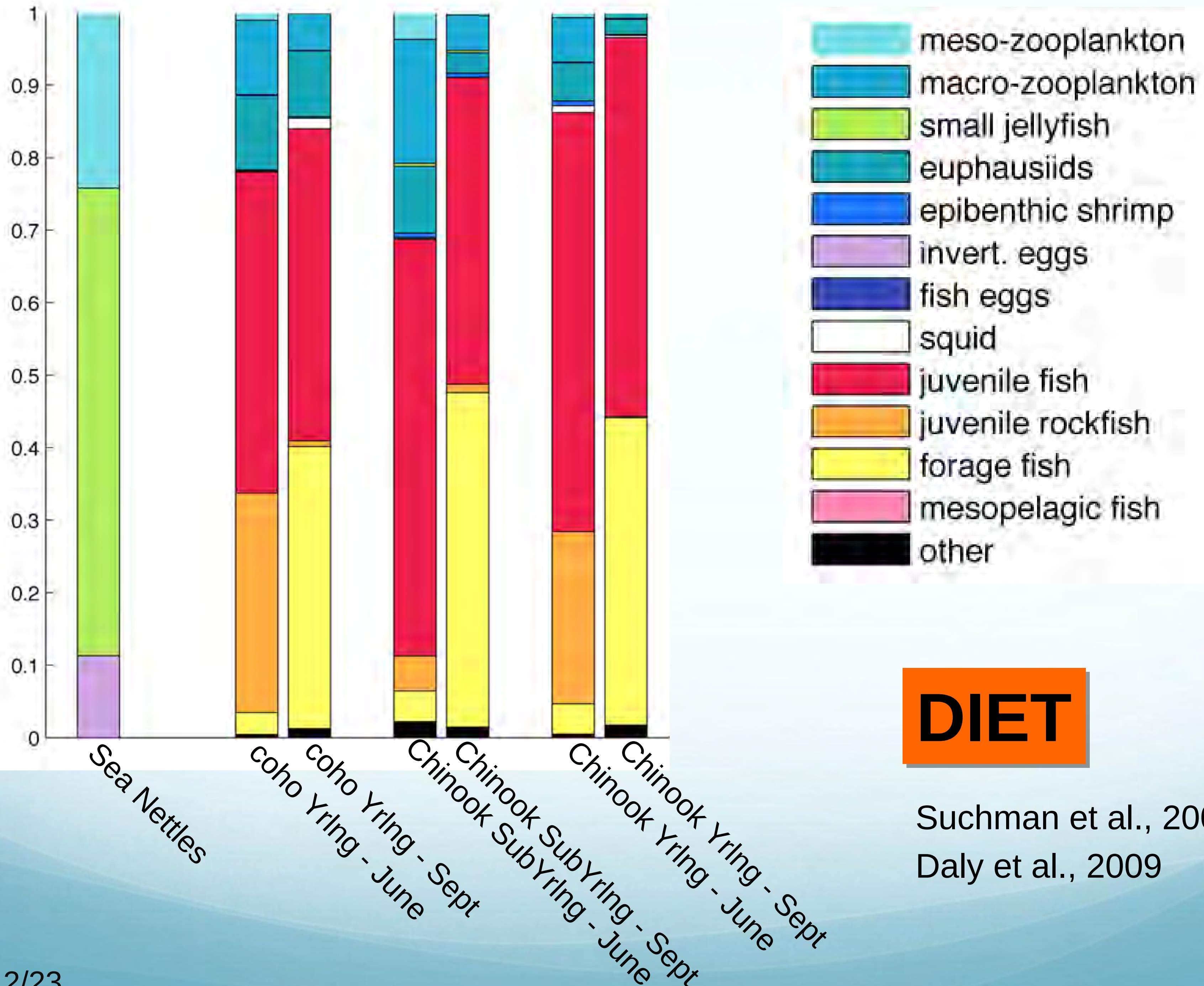

coho yearling
Chinook yearling
June
Sept
abundance (# km-2)
fork length (cm)
99 00 01 02 03 04 05 06 07 08 09 10 11
Yearling:
1 winter in freshwater
more abundant in June



Sub-Yearling:

- **No winter in freshwater (smaller)**
- **more abundant in September**

DIET



Suchman et al., 2008

Daly et al., 2009

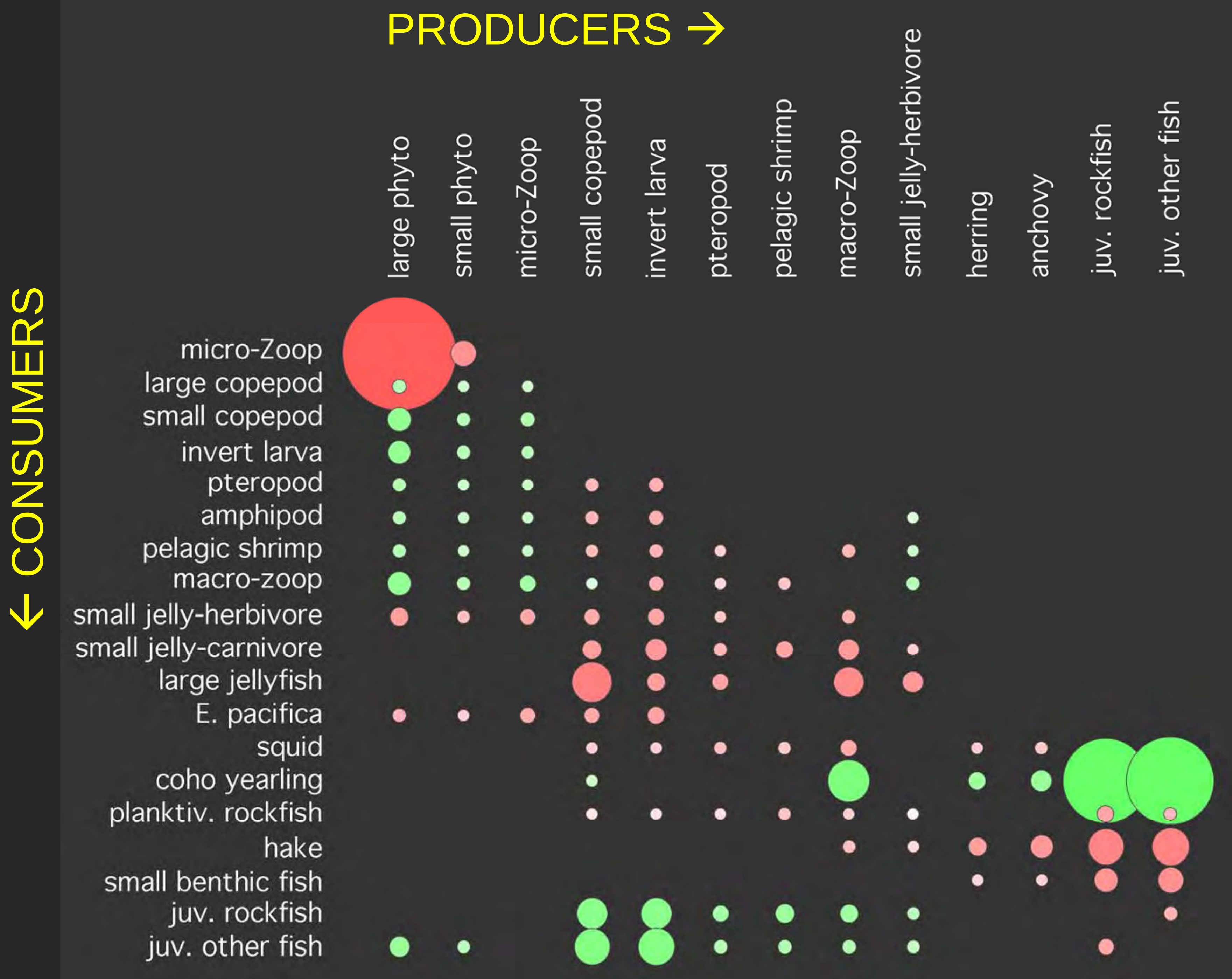
Sensitivity Scenario:

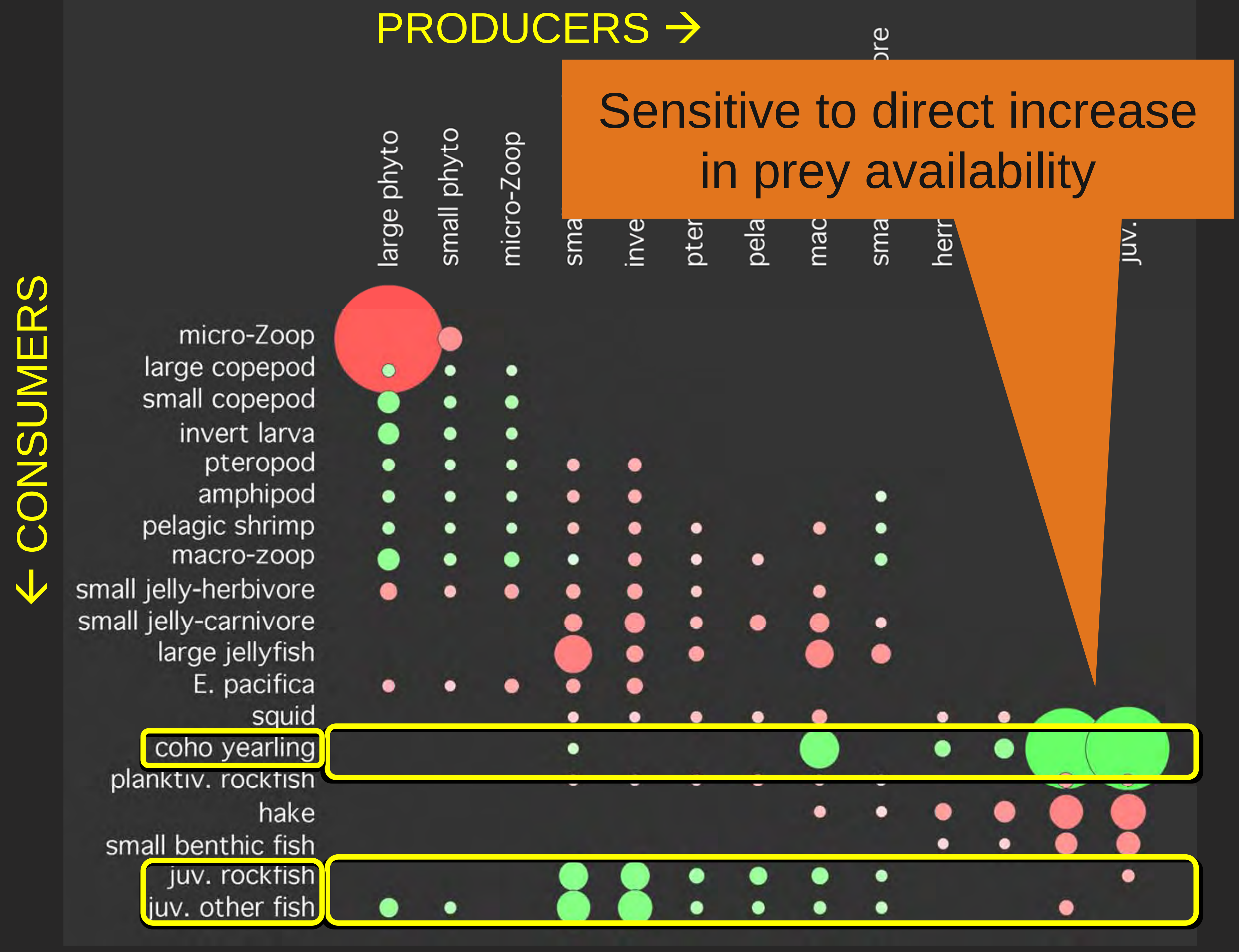
-Which functional groups have the strongest effects on juvenile salmon production?

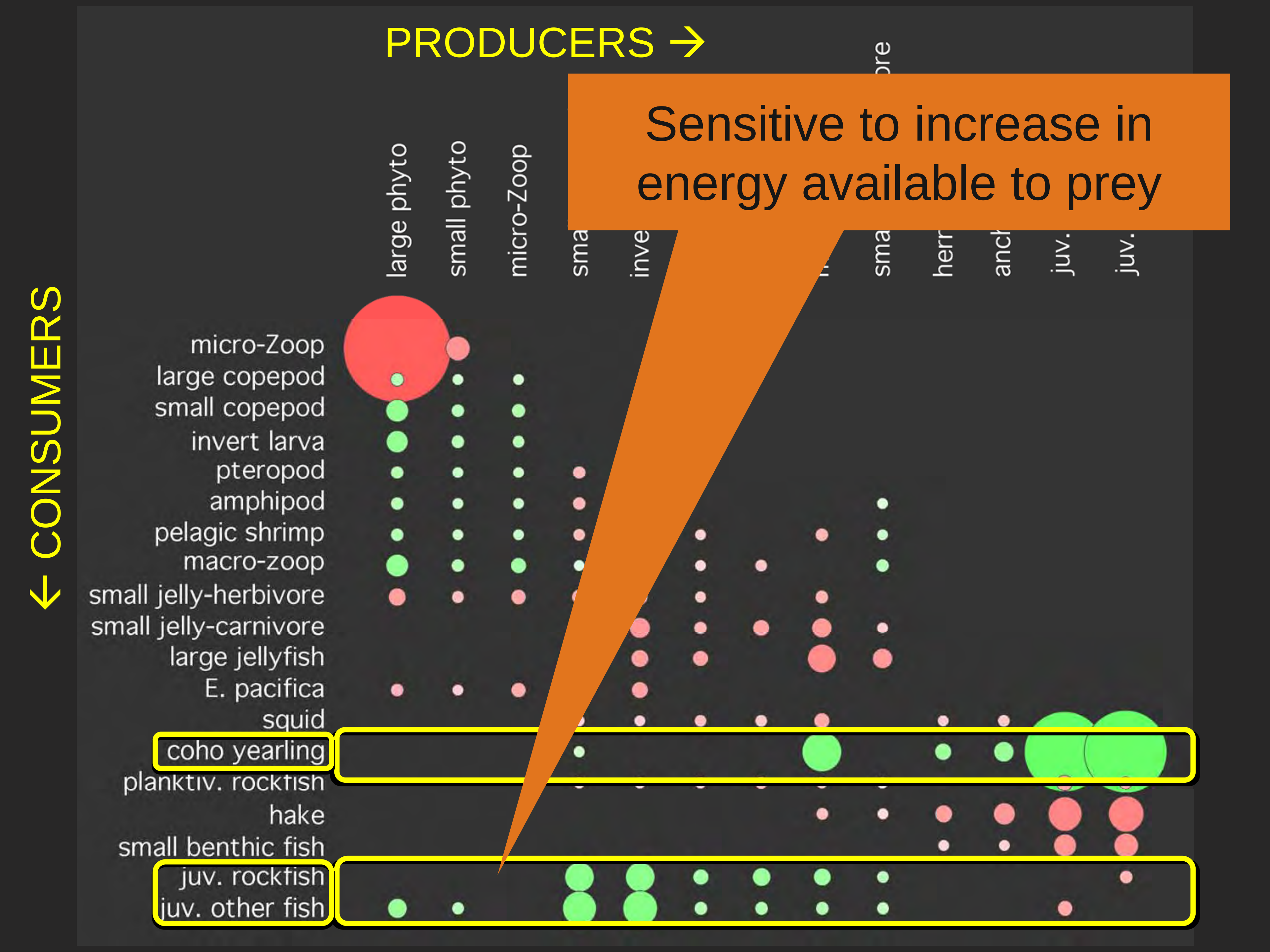
- Estimate juvenile salmon response to a sequential, fixed change across each trophic linkage in the model

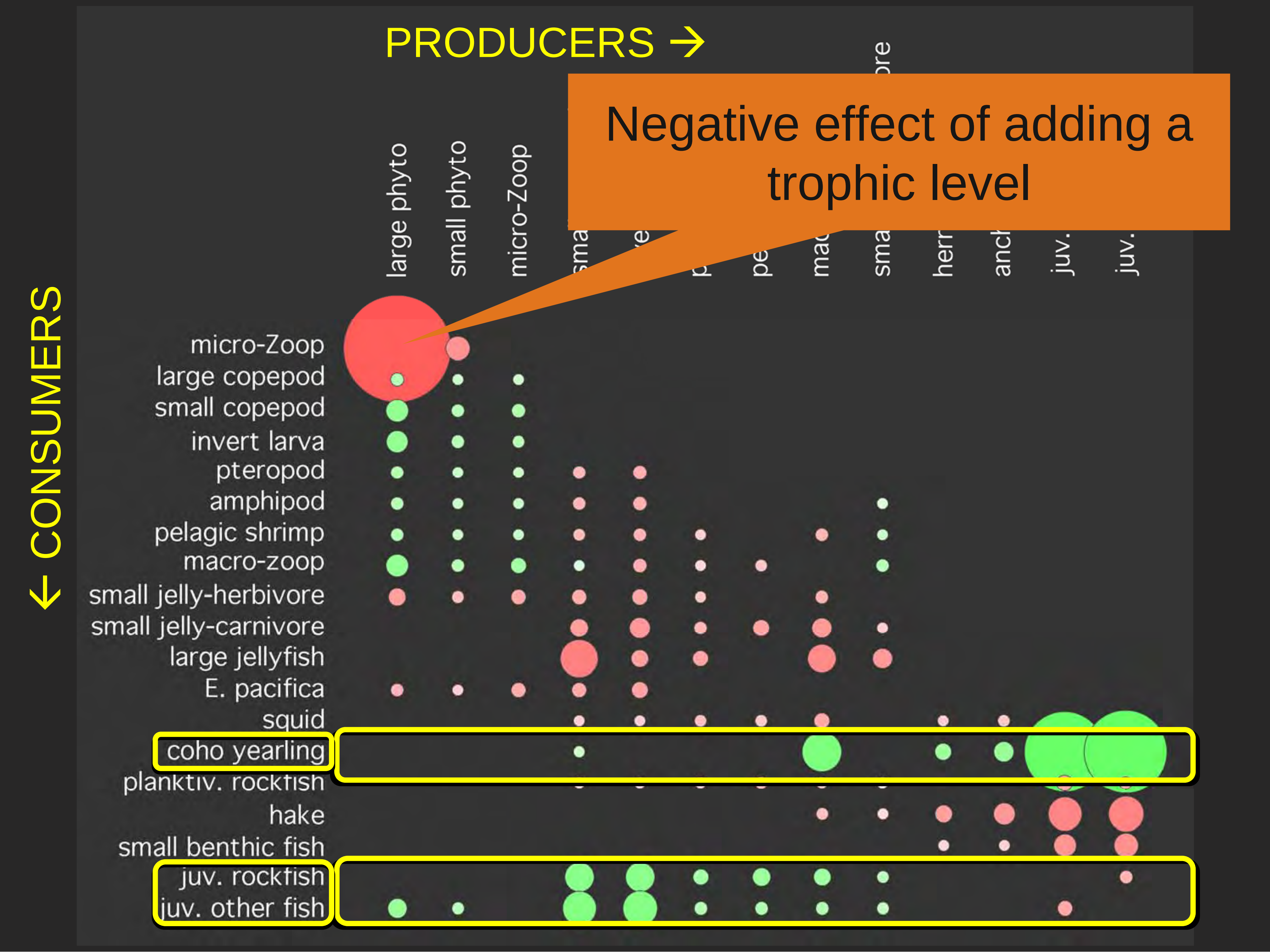
-Estimates effect of high jellyfish biomass across functional groups

- Scenario at 1 STD increase over mean biomass (6.2 + 5.8 t/km^2)

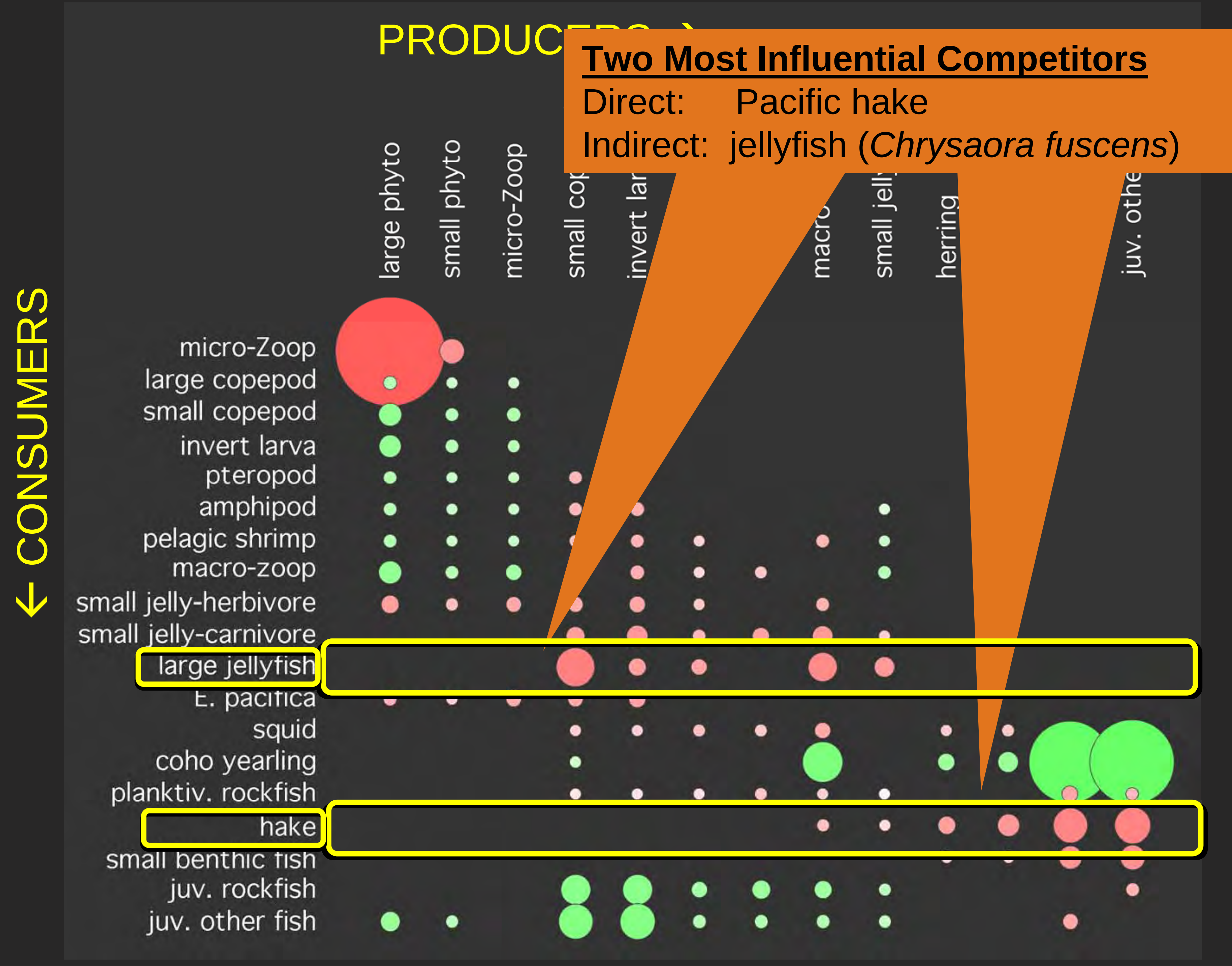

PRODUCERS →
← CONSUMERS
large phyto
small phyto
micro-Zoop
small copepod
invert larva
pteropod
pelagic shrimp
macro-Zoop
small jelly-herbivore
herring
anchovy
juv. rockfish
juv. other fish
micro-Zoop
large copepod
small copepod
invert larva
pteropod
amphipod
pelagic shrimp
macro-zoop
small jelly-herbivore
small jelly-carnivore
large jellyfish
E. pacifica
squid
coho yearling
planktiv. rockfish
hake
small benthic fish
juv. rockfish
juv. other fish

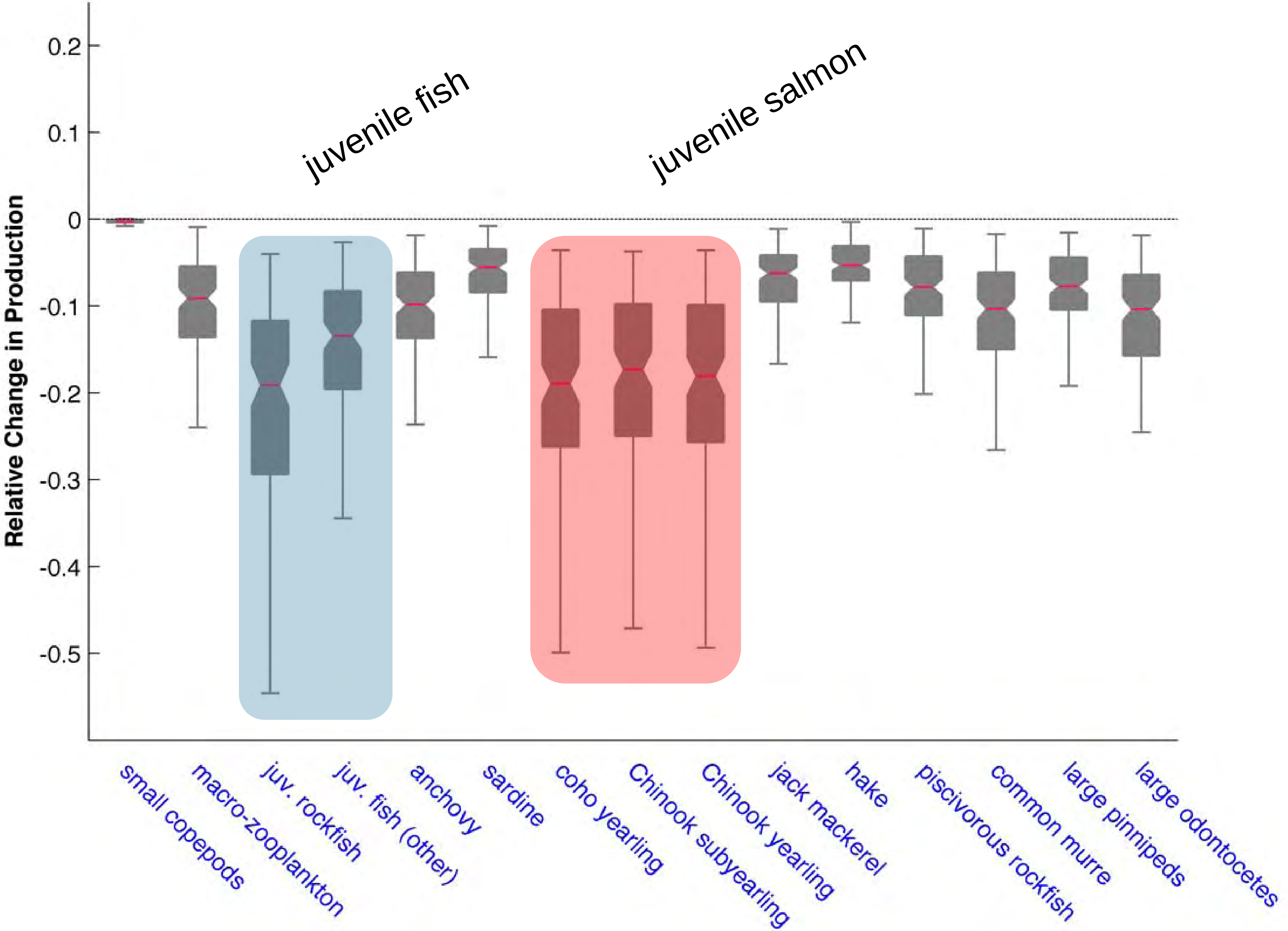

PRODUCERS →
← CONSUMERS
Sensitive to direct increase in prey availability
large phyto
small phyto
micro-Zoop
micro-Zoop
large copepod
small copepod
invert larva
pteropod
amphipod
pelagic shrimp
macro-zoop
small jelly-herbivore
small jelly-carnivore
large jellyfish
E. pacifica
squid
coho yearling
planktiv. rockfish
hake
small benthic fish
juv. rockfish
juv. other fish


PRODUCERS →
← CONSUMERS
Sensitive to increase in energy available to prey
large phyto
small phyto
micro-Zoop
sma
inve
sma
herr
anch
juv.
juv.
micro-Zoop
large copepod
small copepod
invert larva
pteropod
amphipod
pelagic shrimp
macro-zoop
small jelly-herbivore
small jelly-carnivore
large jellyfish
E. pacifica
squid
coho yearling
planktiv. rockfish
hake
small benthic fish
juv. rockfish
juv. other fish

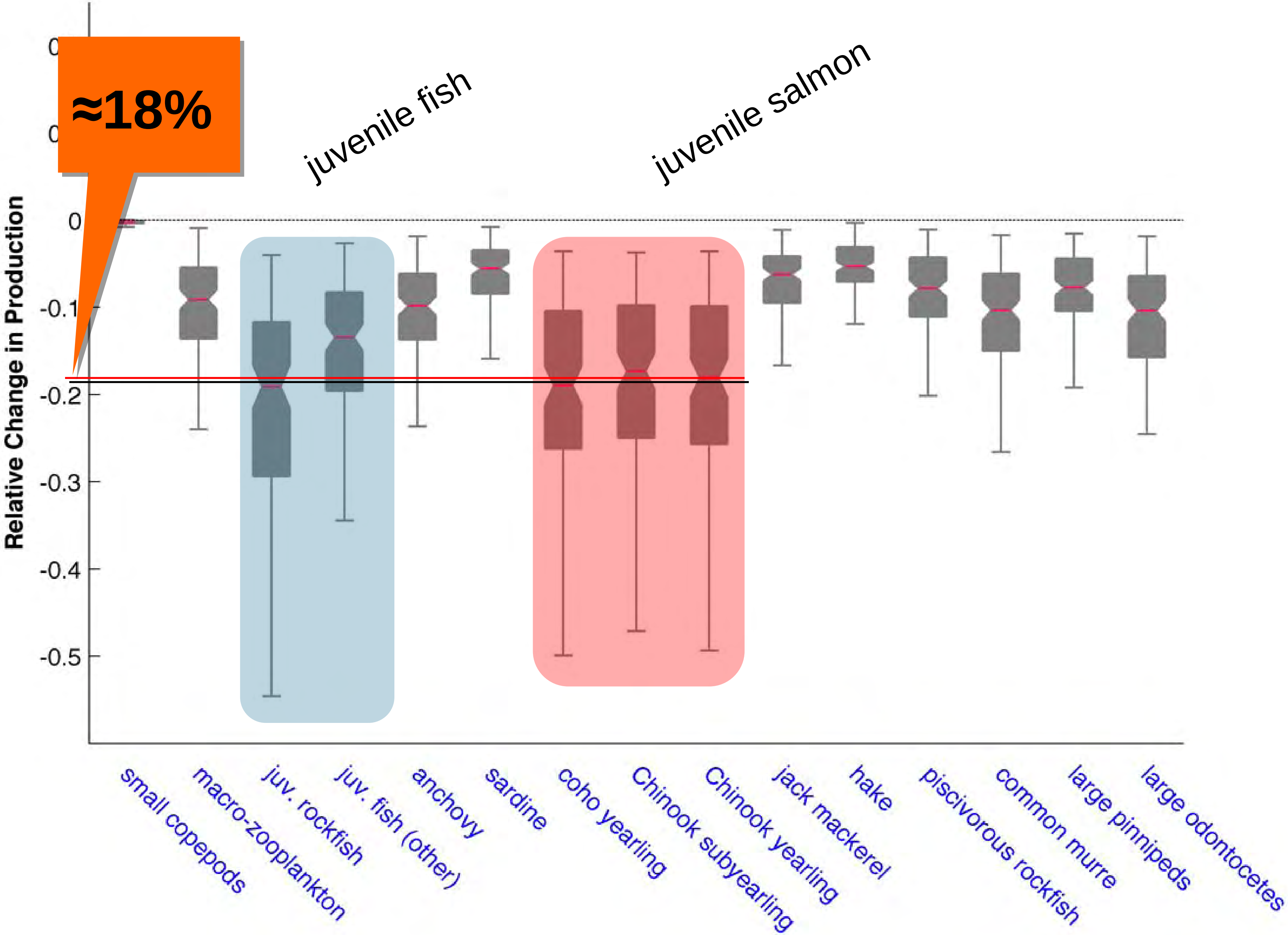


PRODUCERS →
← CONSUMERS
Negative effect of adding a trophic level
large phyto
small phyto
micro-Zoop
micro-Zoop
large copepod
small copepod
invert larva
pteropod
amphipod
pelagic shrimp
macro-zoop
small jelly-herbivore
small jelly-carnivore
large jellyfish
E. pacifica
squid
coho yearling
planktiv. rockfish
hake
small benthic fish
juv. rockfish
juv. other fish


PRODUC
Two Most Influential Competitors
Direct: Pacific hake
Indirect: jellyfish (*Chrysaora fuscens*)
large phyto
small phyto
micro-Zoop
herring
← CONSUMERS
micro-Zoop
large copepod
small copepod
invert larva
pteropod
amphipod
pelagic shrimp
macro-zoop
small jelly-herbivore
small jelly-carnivore
large jellyfish
E. pacifica
squid
coho yearling
planktiv. rockfish
hake
small benthic fish
juv. rockfish
juv. other fish

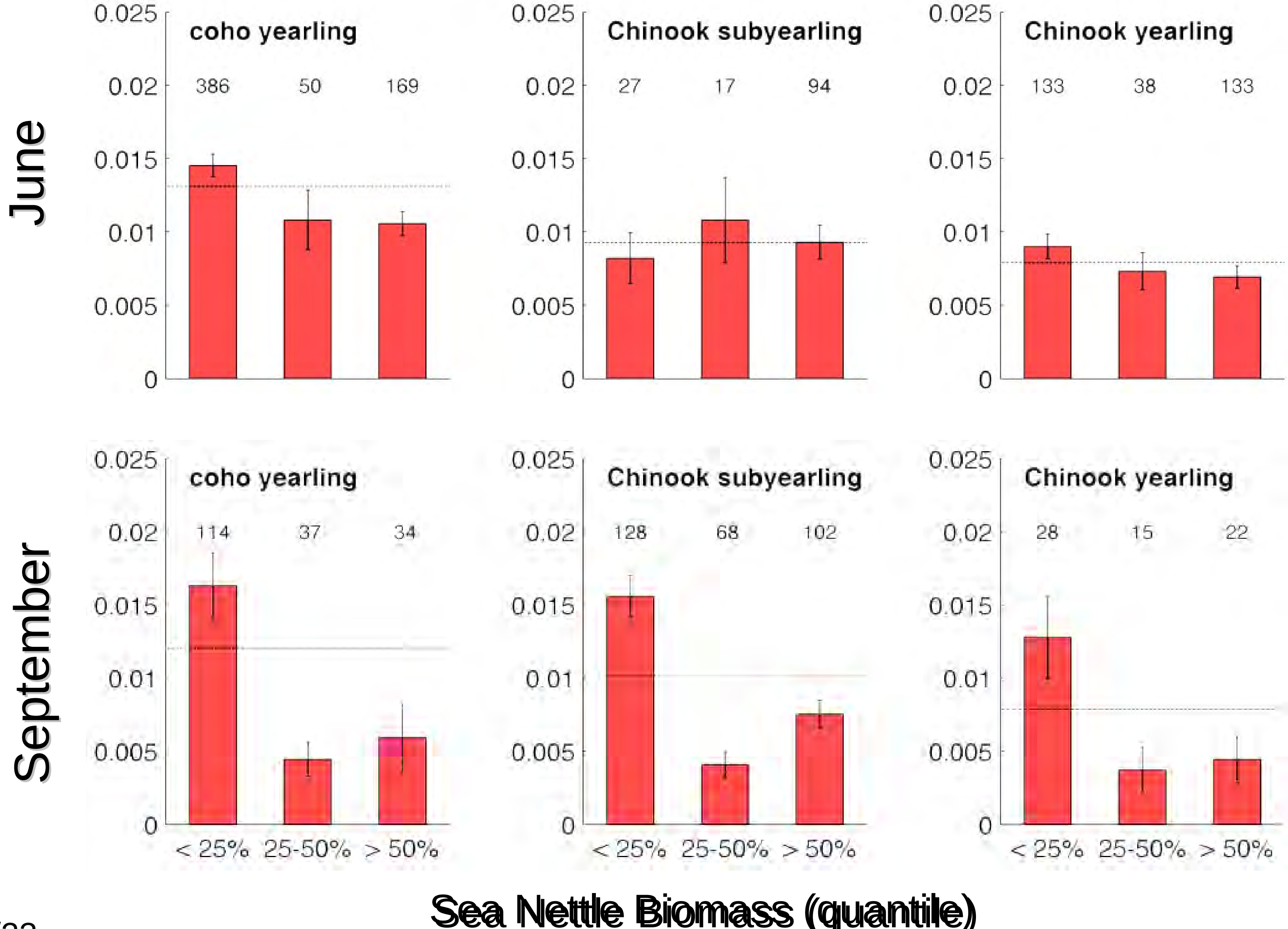


juvenile fish
juvenile salmon
Relative Change in Production
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
small copepods
macro-zooplankton
juv. rockfish
juv. fish (other)
anchovy
sardine
coho yearling
Chinook subyearling
Chinook yearling
jack mackerel
hake
piscivorous rockfish
common murre
large pinnipeds
large odontocetes


≈18%
juvenile fish
juvenile salmon
Relative Change in Production
0
-0.1
-0.2
-0.3
-0.4
-0.5
small copepods
macro-zooplankton
juv. rockfish
juv. fish (other)
anchovy
sardine
coho yearling
Chinook subyearling
Chinook yearling
jack mackerel
hake
piscivorous rockfish
common murre
large pinnipeds
large odontocetes

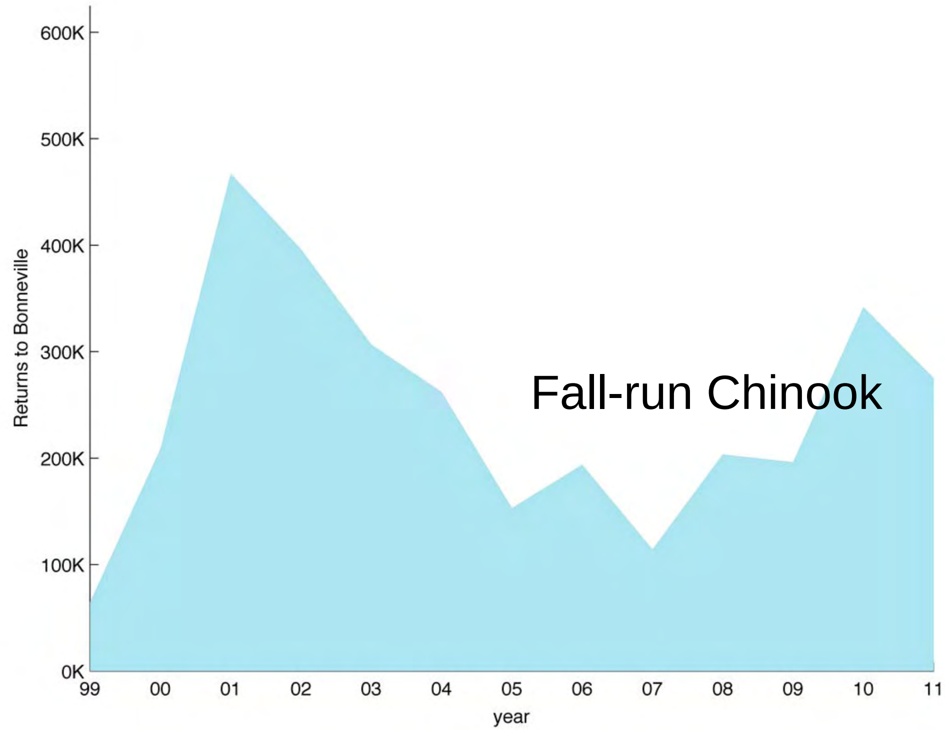
Is there a relation between local feeding success and jellyfish biomass?

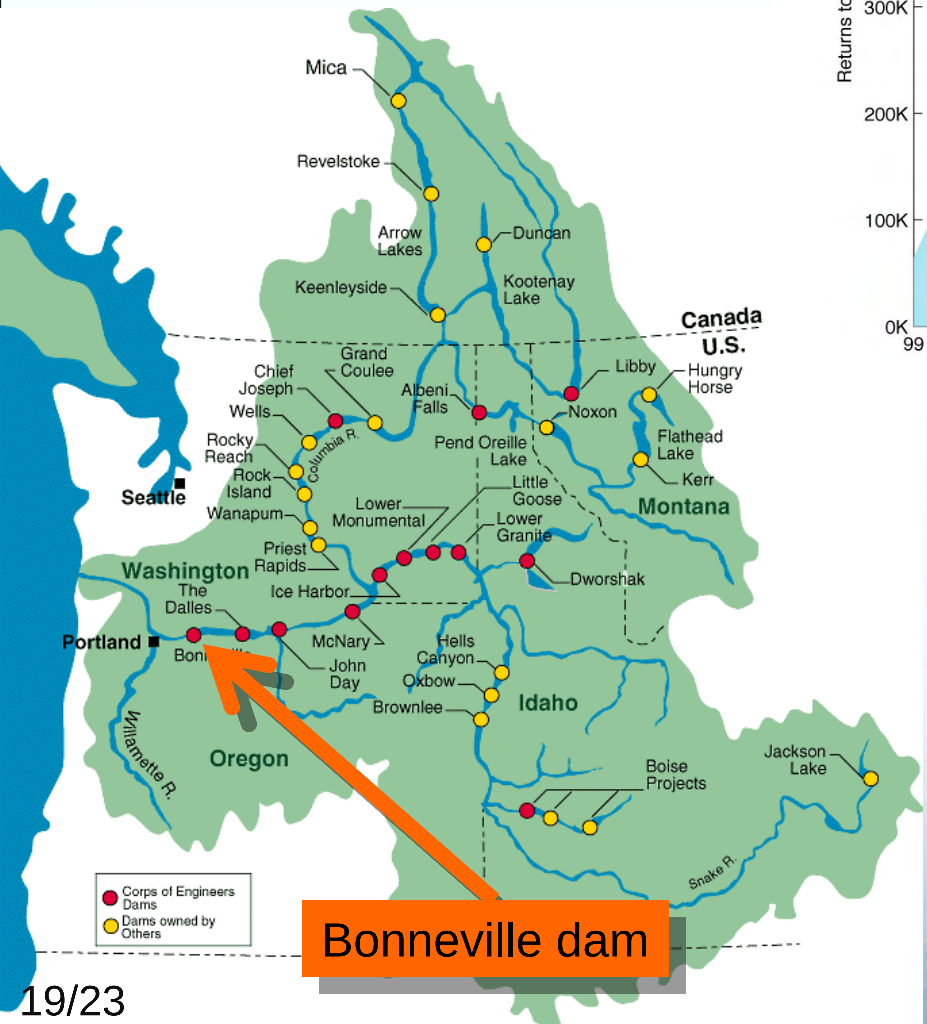
Index of Feeding Intensity



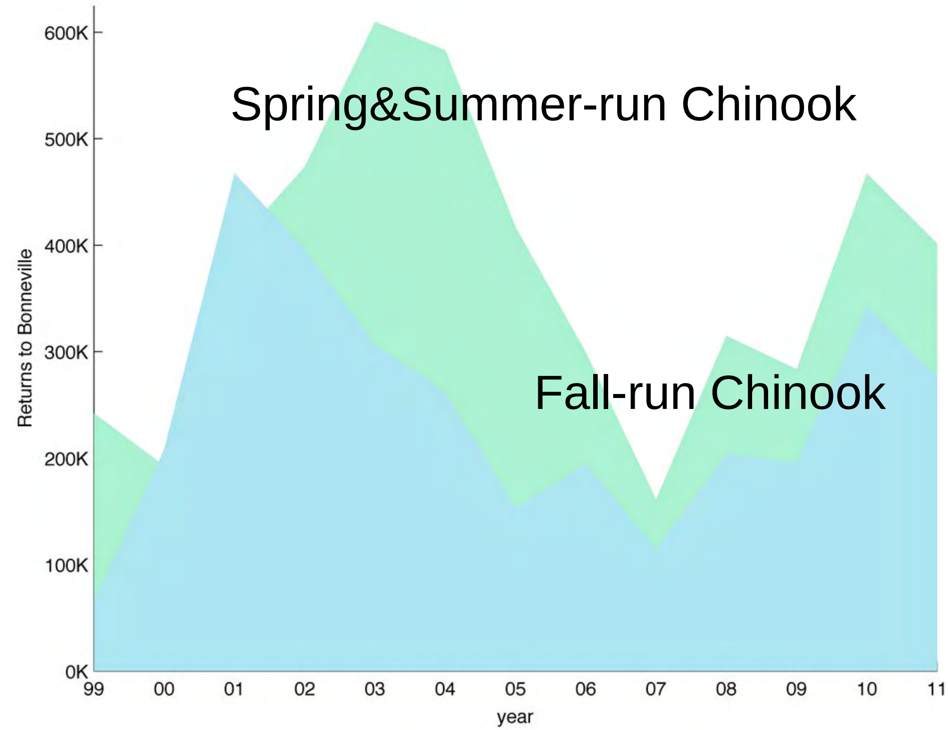
Is there a relationship between observed Columbia River salmon production and jellyfish abundance?

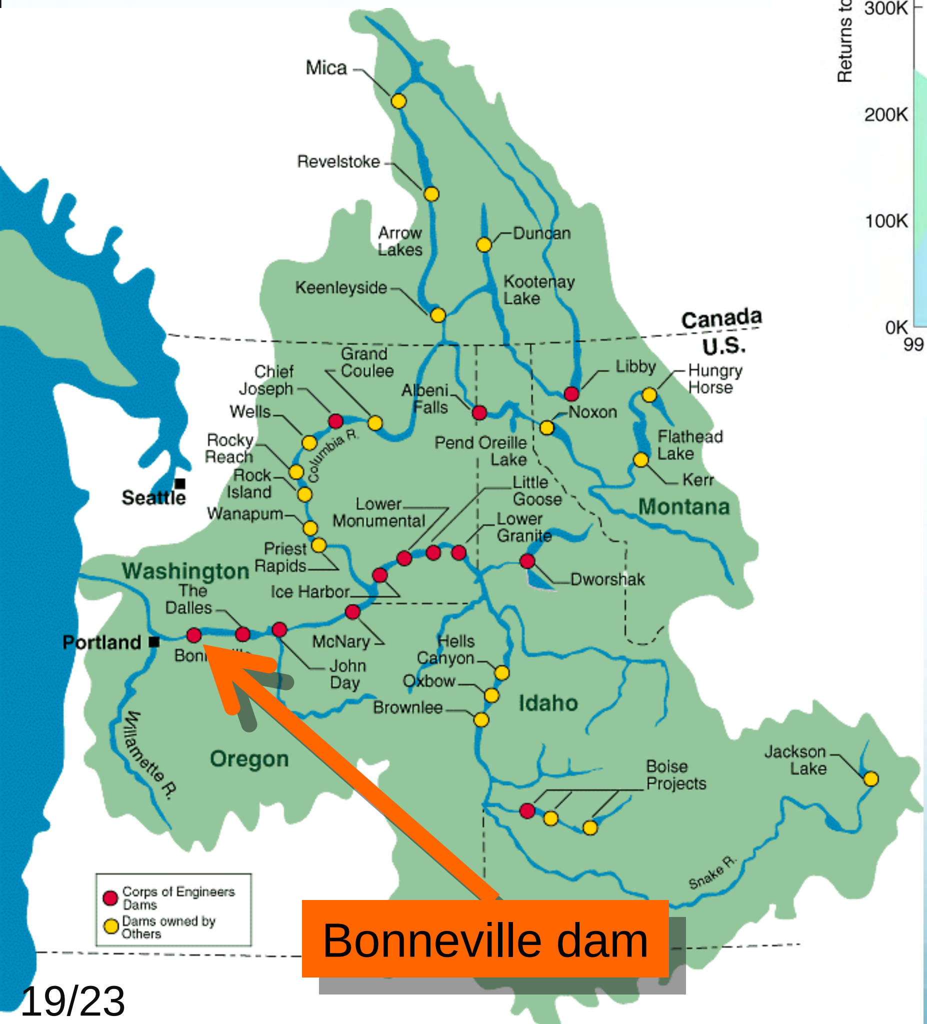
SALMON RETURNS



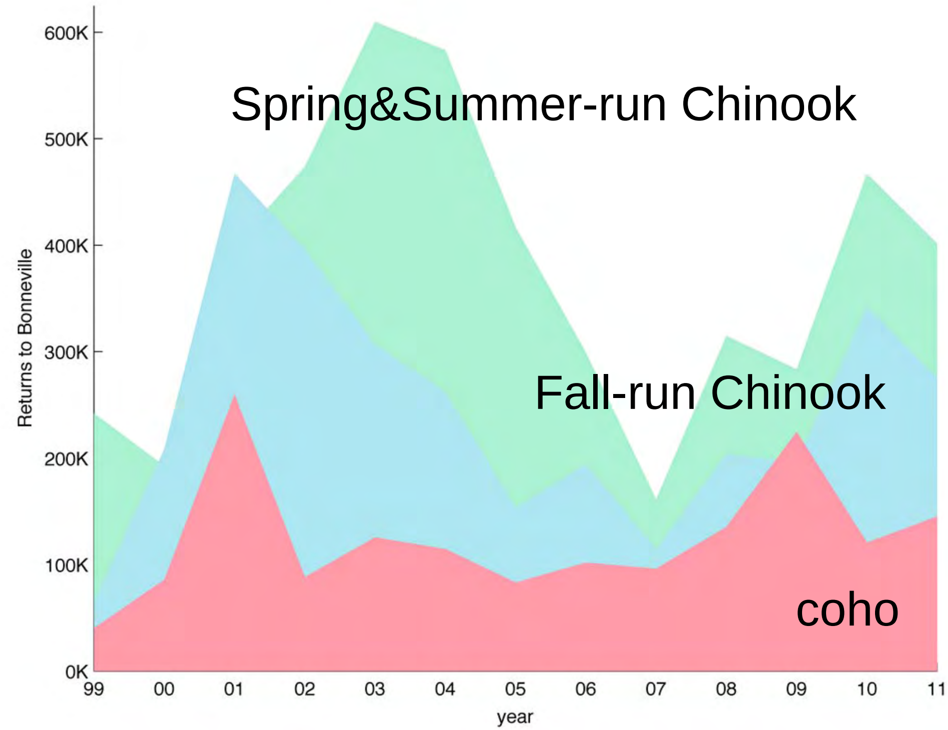


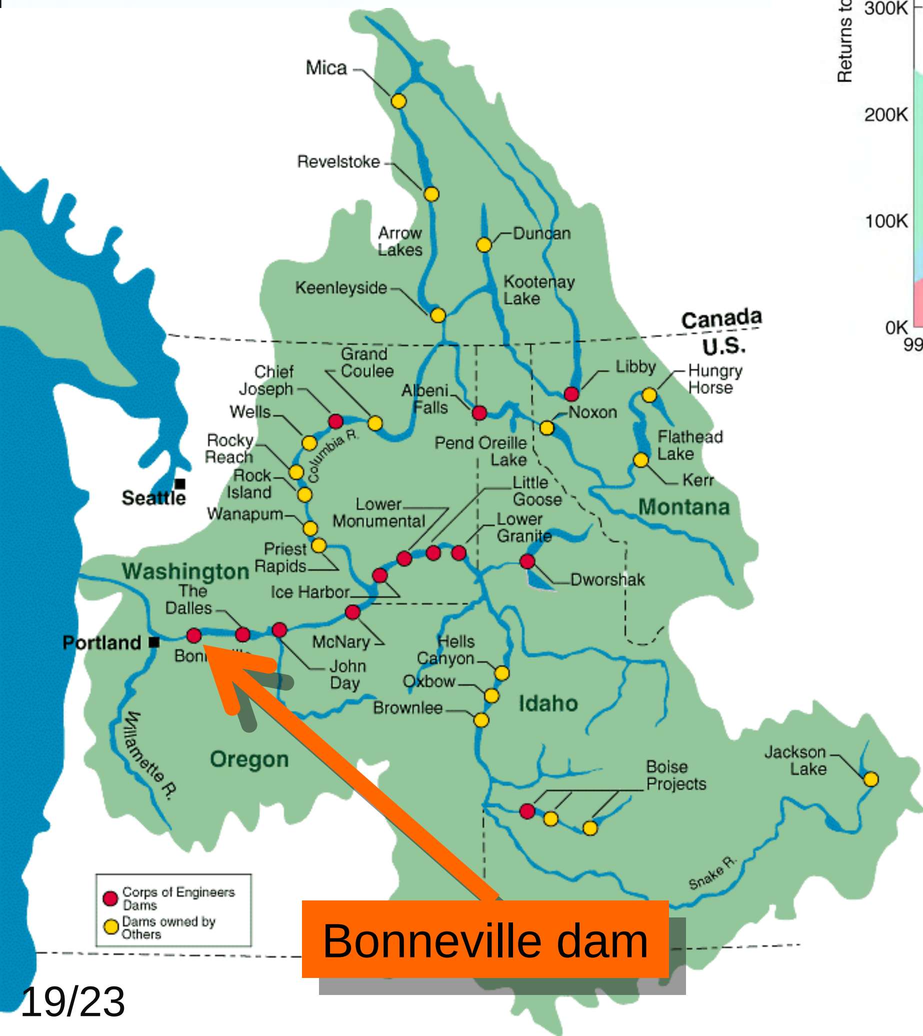
SALMON RETURNS



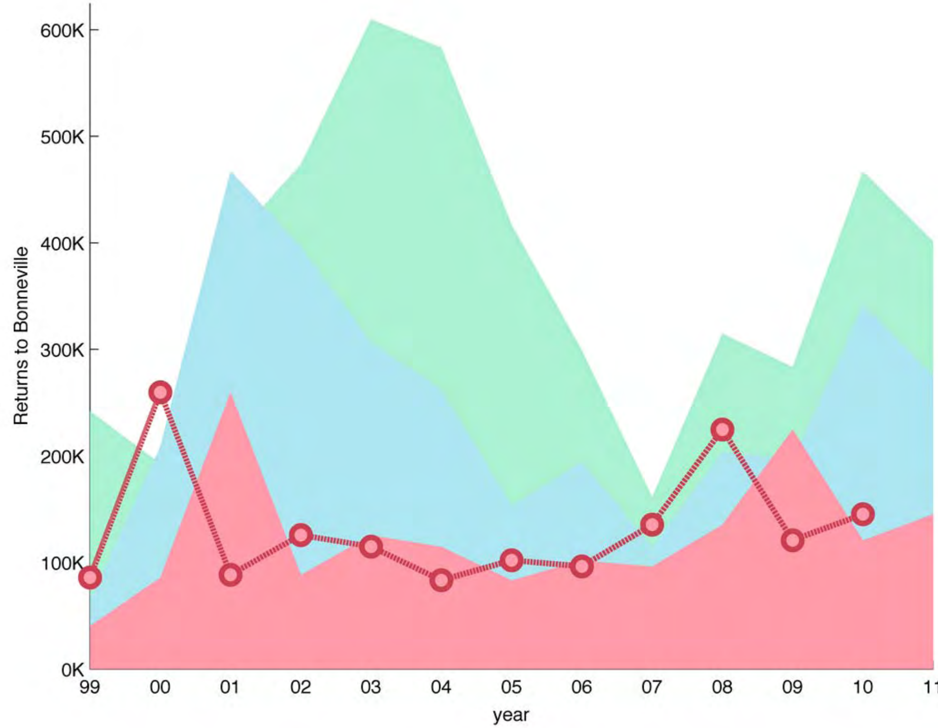


SALMON RETURNS



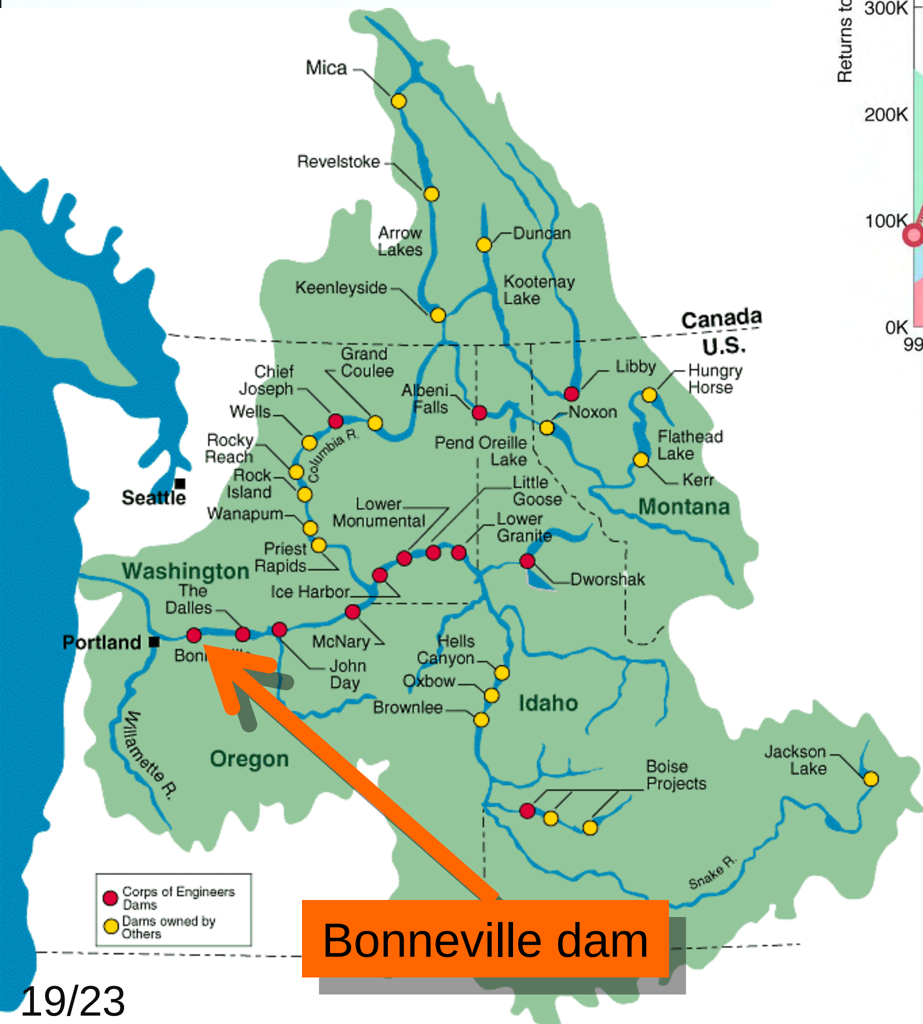


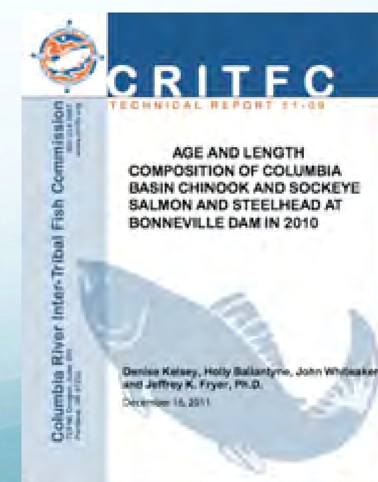
SALMON RETURNS



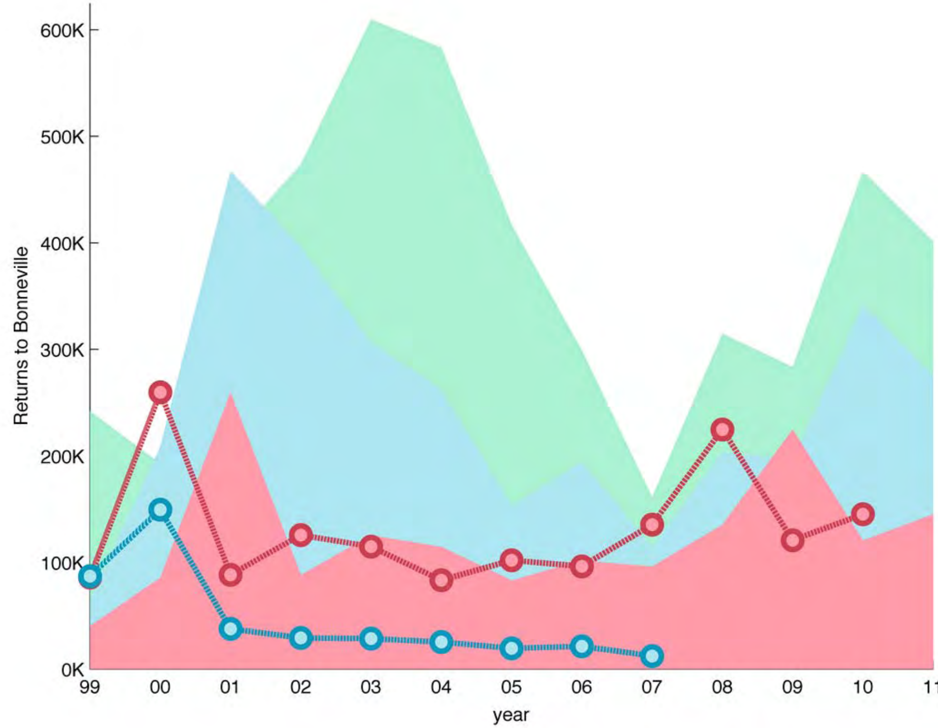
Returns by smolt-entry year & life-history

coho yearling

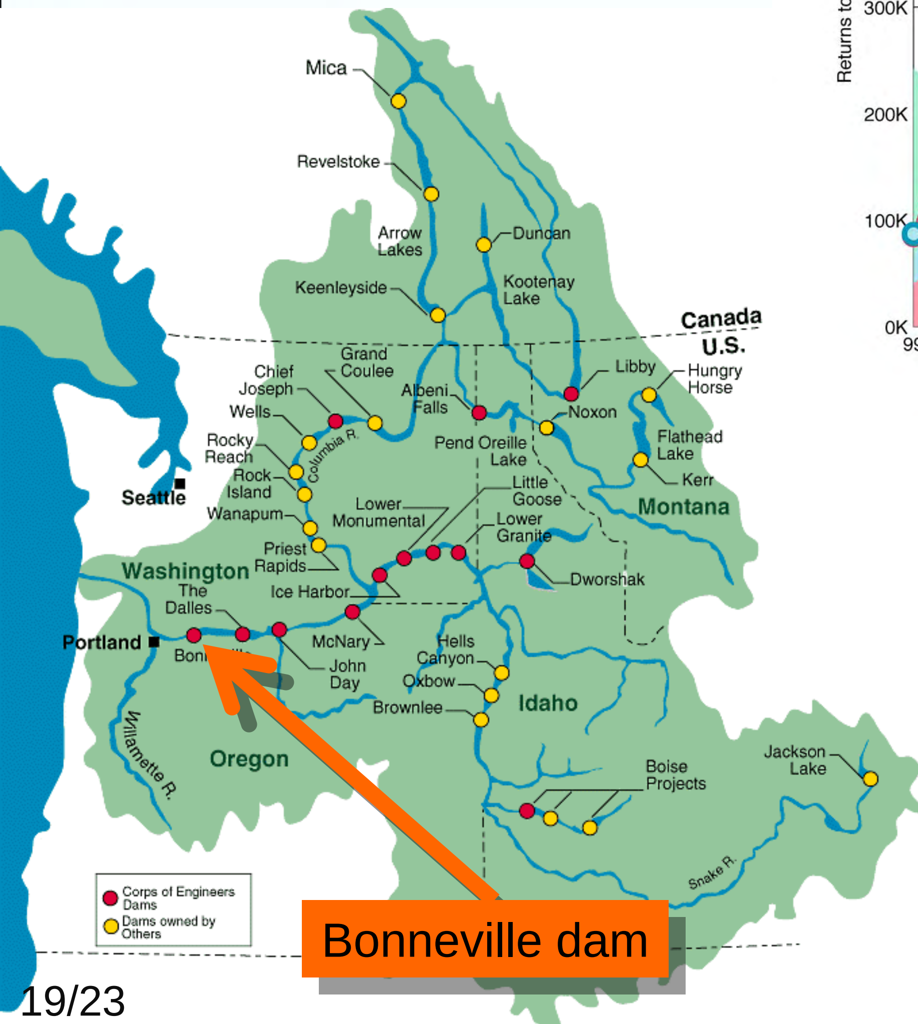




SALMON RETURNS

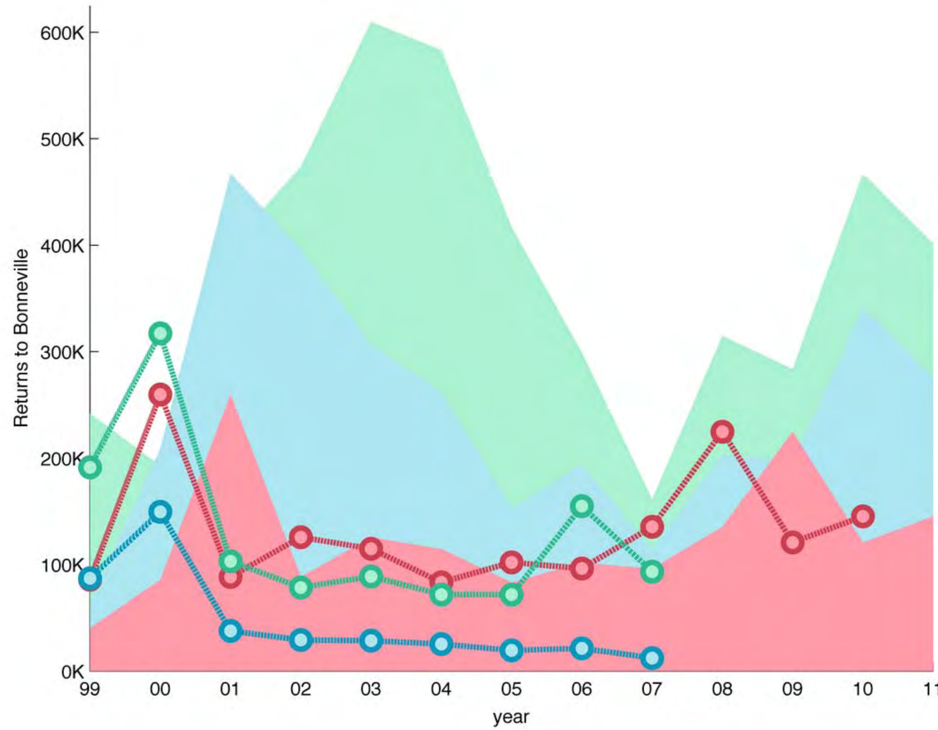


Returns by smolt-entry year & life-history

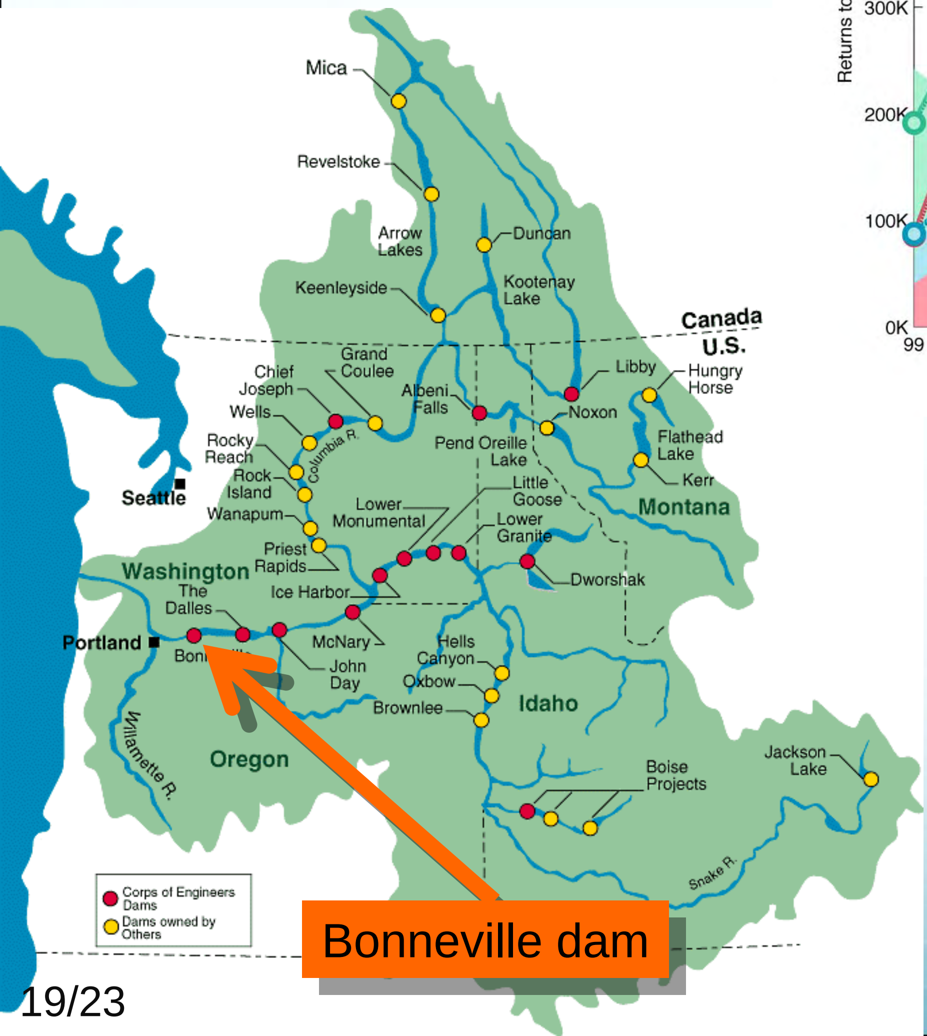


Fall sub-yearling

SALMON RETURNS

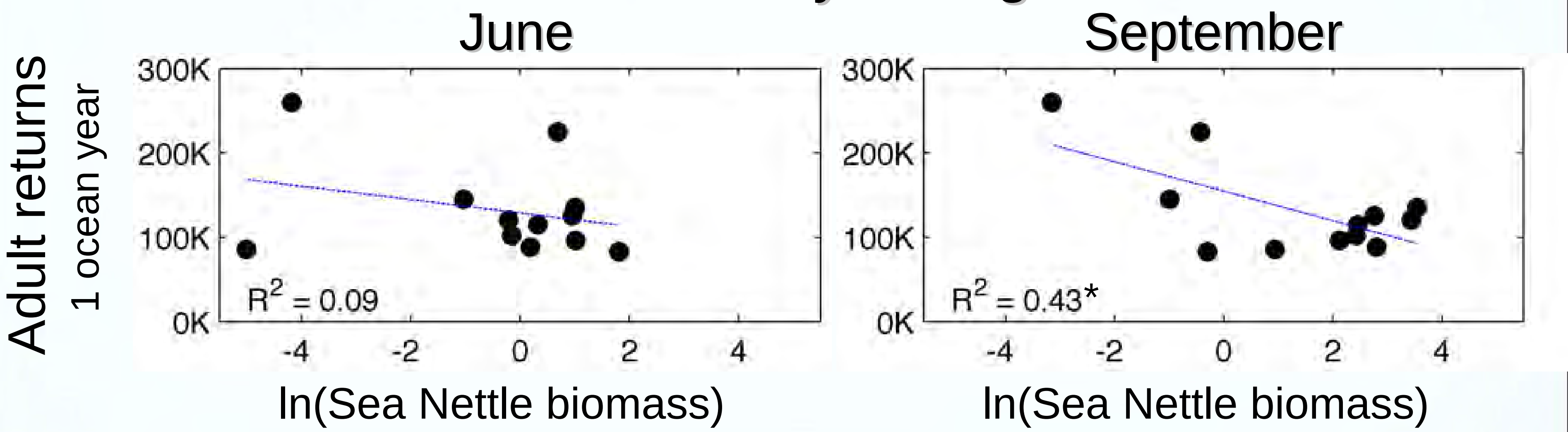


Returns by smolt-entry year & life-history



Sprng&Smmr yearling

Coho yearling



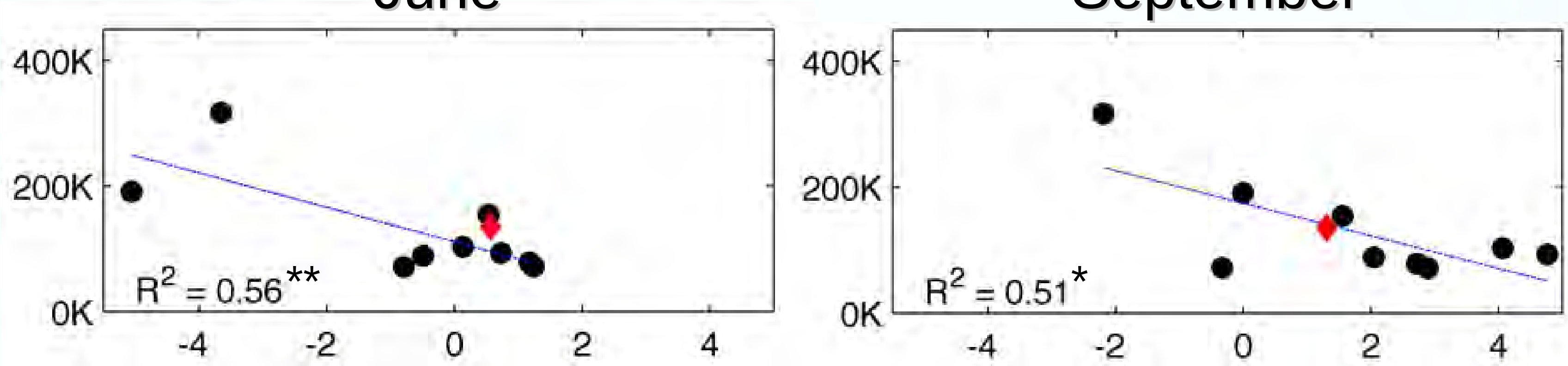
Fall Chinook subyearling

June

September

Adult returns

3 ocean years



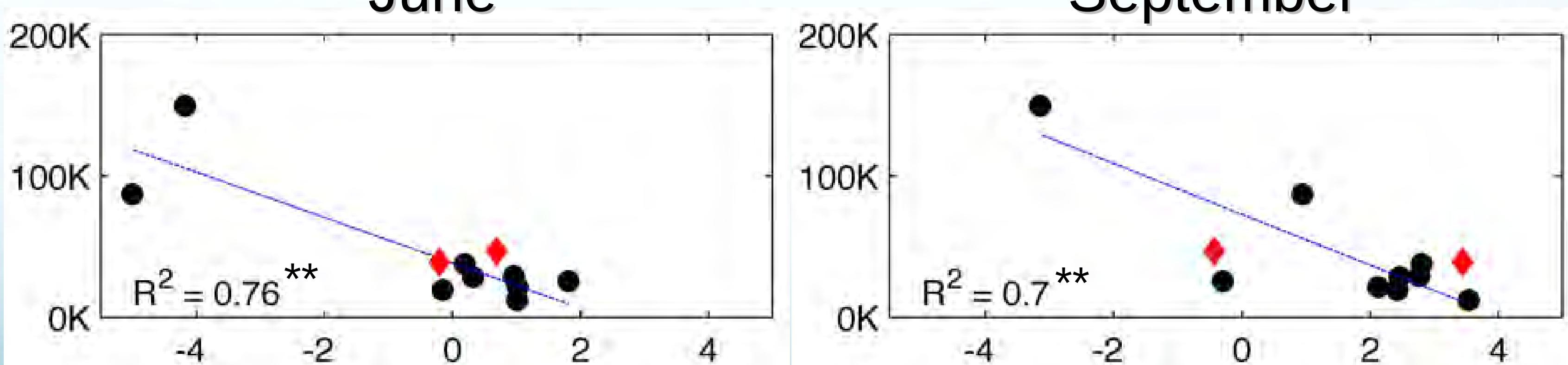
Spring/Summer Chinook yearling

June

September

Adult returns

3 ocean years



ln(Sea Nettle biomass)

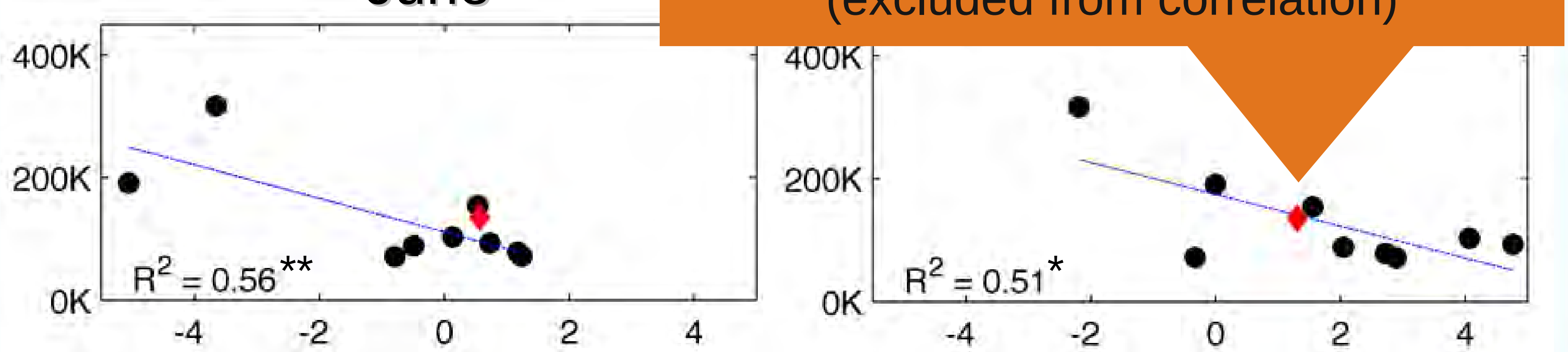
ln(Sea Nettle biomass)

Fall Chinc

Annual age structure not yet available extrapolated from 99-10 mean (excluded from correlation)

June

Adult returns
3 ocean years

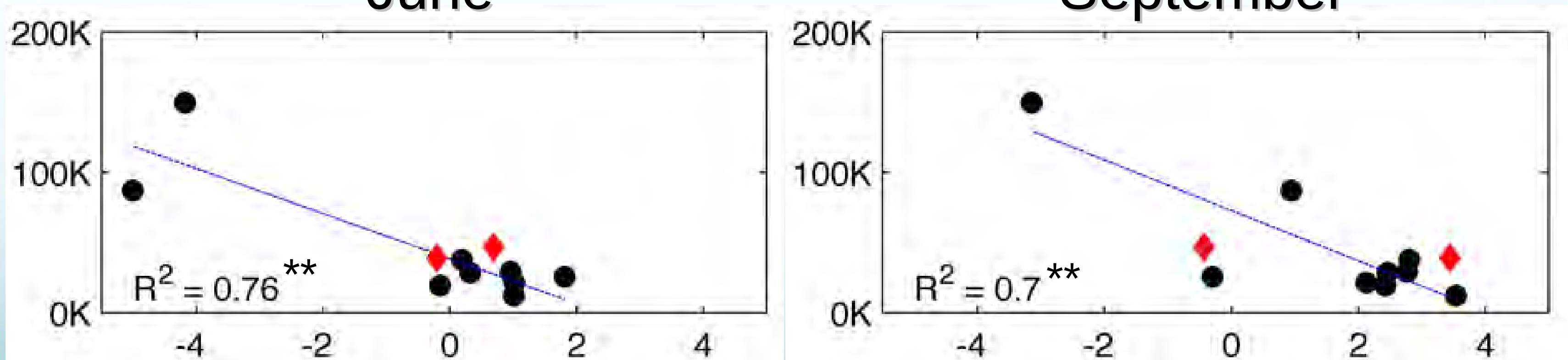


Spring/Summer Chinook yearling

June

September

Adult returns
3 ocean years



ln(Sea Nettle biomass)

ln(Sea Nettle biomass)

Conclusions:

- Juvenile salmon are sensitive to indirect competition from *Chrysaora fuscescens*
  - Otherwise insensitive to indirect trophic pathways
- Interannual correlation between adult salmon returns and *C. fuscescens* biomass during year when smolts enter the ocean
  - True for all three life-history stages examined
  - Relation to June jellyfish biomass is not robust
- Inverse relation between local jellyfish abundance and feeding incidence of juvenile salmon in September
  - (using <100 m isobath restriction)
- 1 STD *C. fuscescens* scenario estimates 18% reduction in salmon production

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