End-to-end ecosystem modelling: marine heat waves and endangered Chinook salmon

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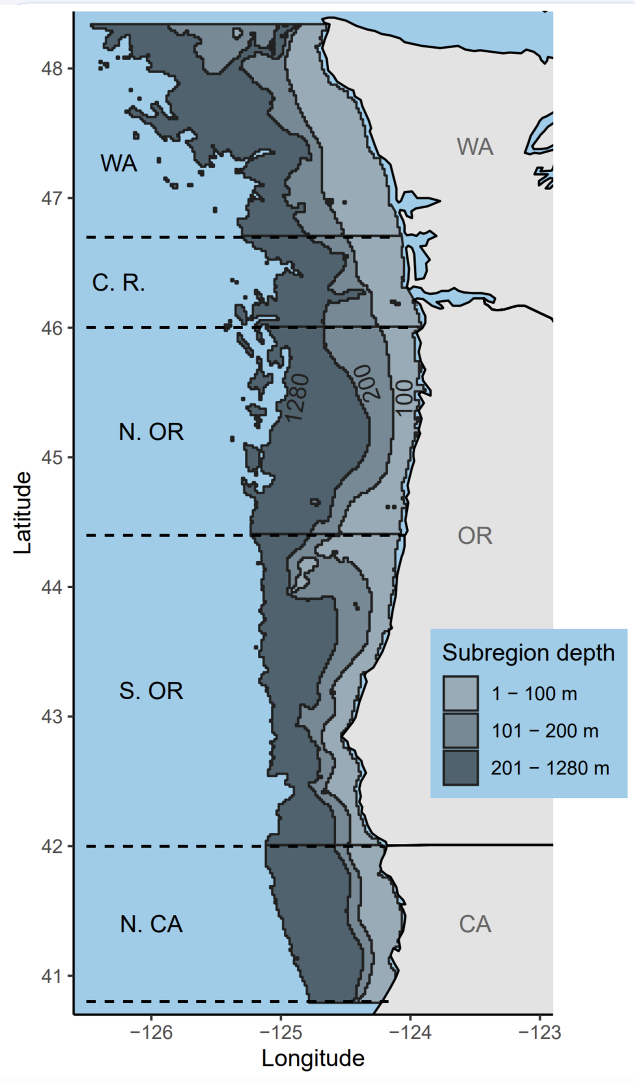
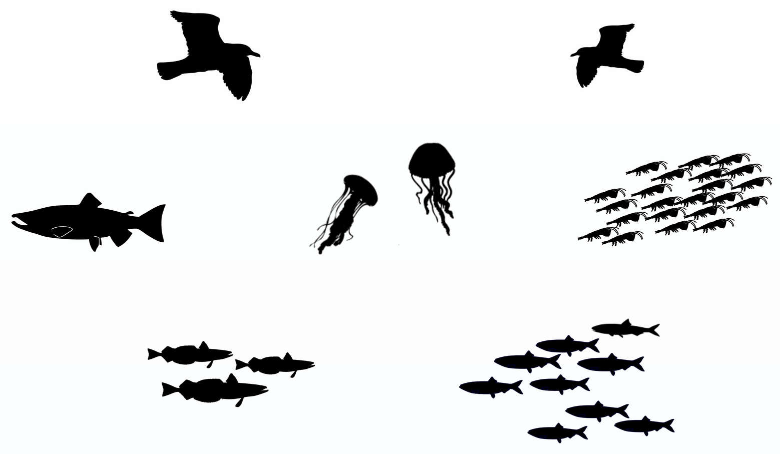


Map of Northern California Current (NCC). Extent of end-to-end ecosystem model in the NCC marine ecosystem. Shaded gray bins indicate the 15 ecosystem model subregions.

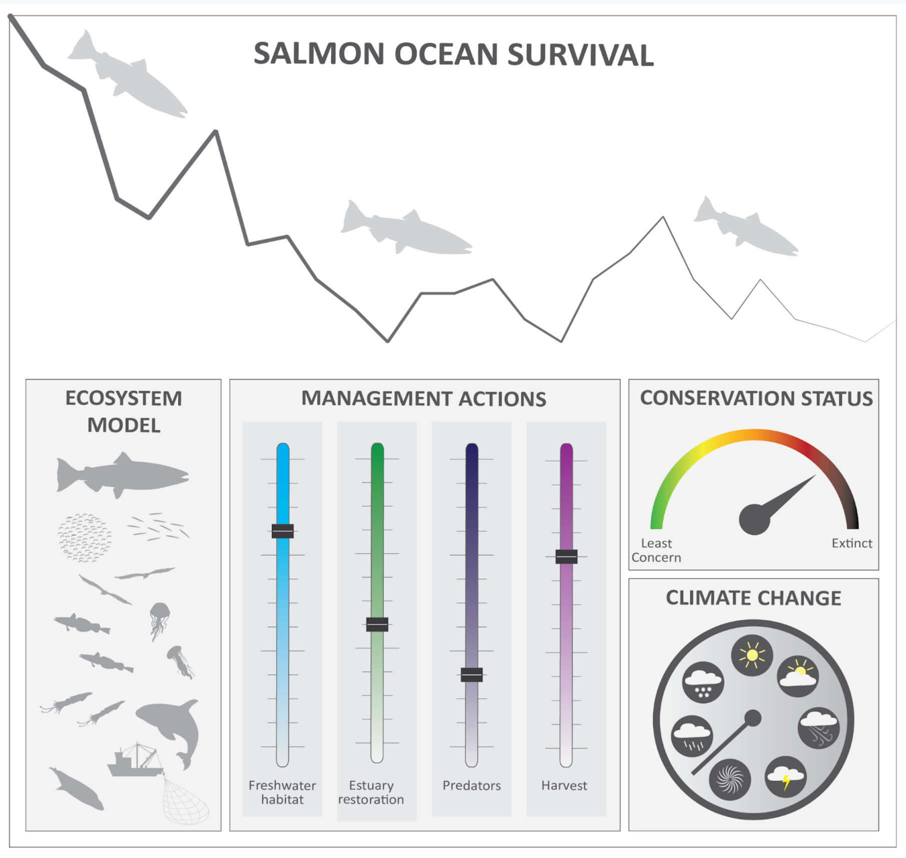
Introduction

- The Northern California Current has experienced multiple marine heatwaves (MHW), starting in 2014 with the "blob"
- The Northern California Current is home to many culturally, economically, and ecologically important species, including populations of endangered Chinook salmon
- MHWs likely impacted these species differently



Objectives

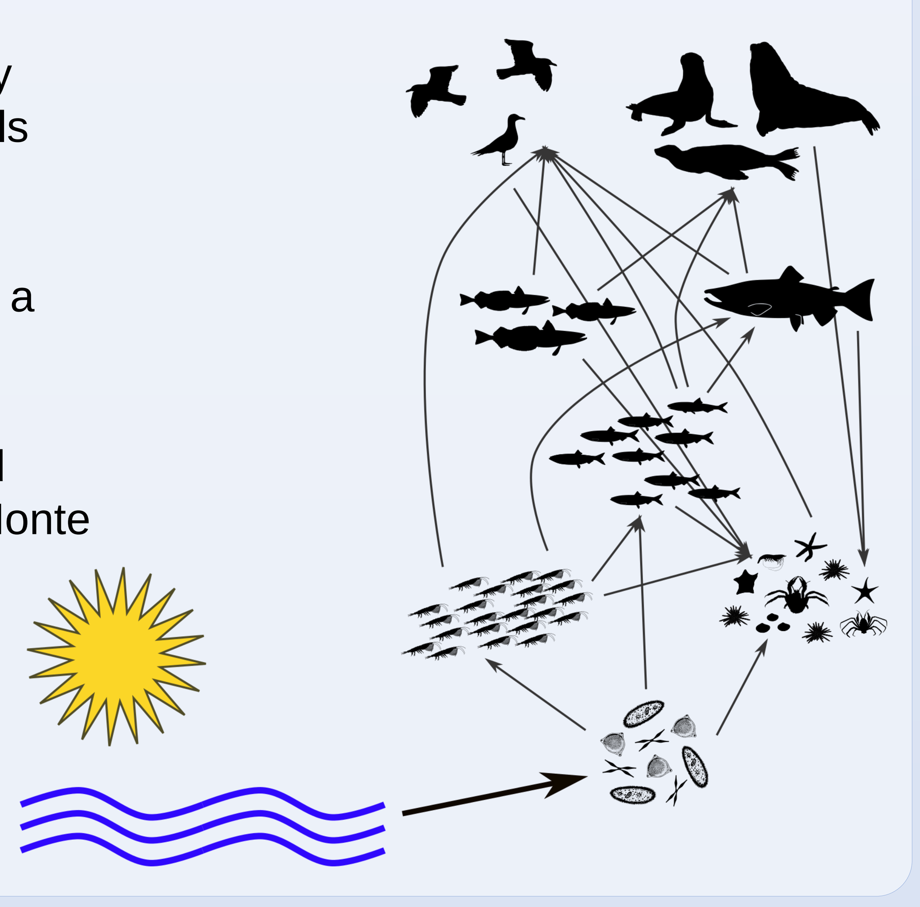
- Update and re-parameterize an end-to-end ecosystem model, reflecting changes in ocean ecosystem (since MHWs).
- Compare ocean ecosystem states between before and after onset of MHWs.
- Understand potential ocean ecosystem mitigation strategies for Chinook salmon in a changing world.



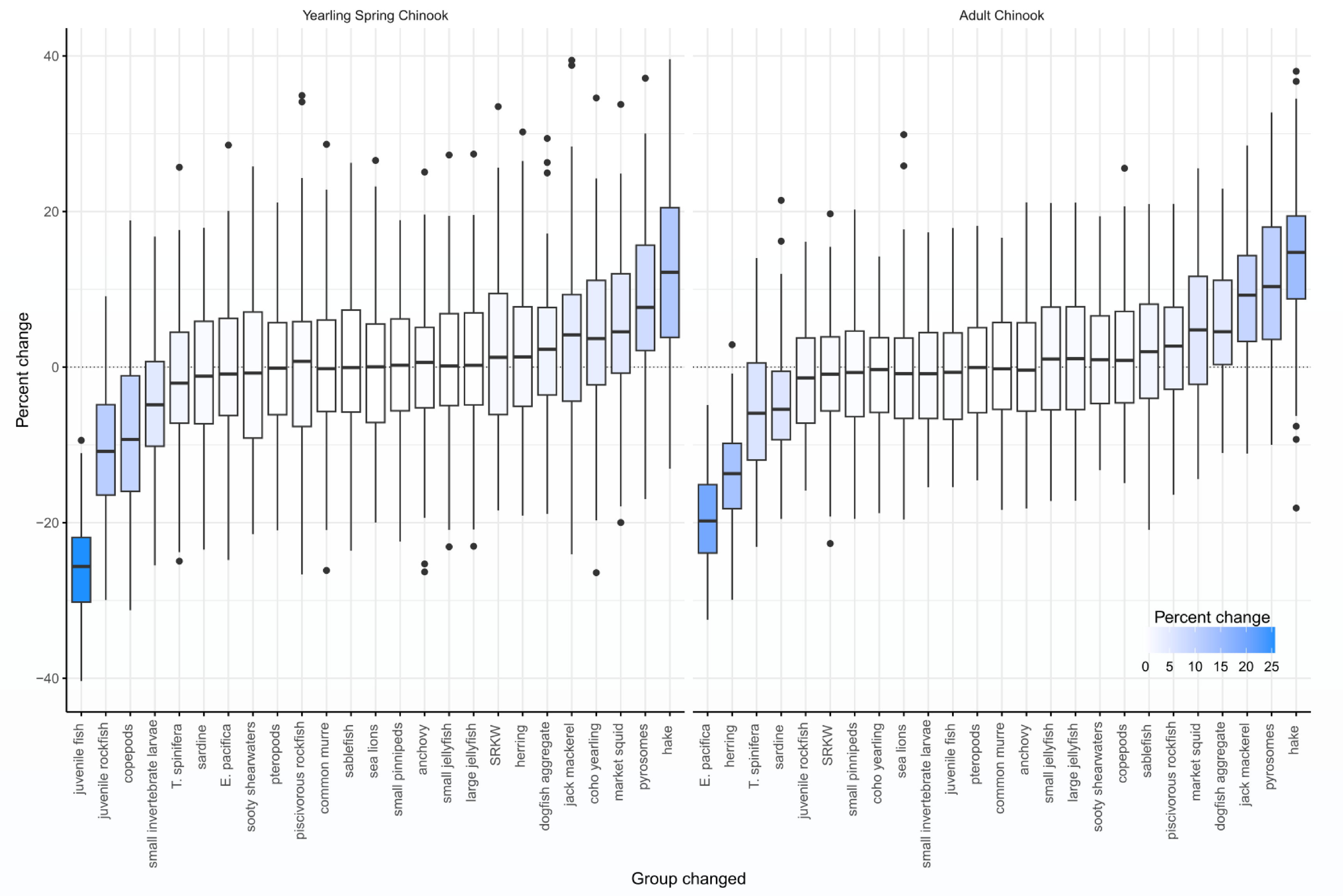
Schematic of salmon declines and management actions. Many salmon populations are threatened or endangered. Ecosystem modelling approaches give us one way to assess the reliability of management actions in the ocean before we carry out such actions. Figure courtesy of Crozier and Kim. See Crozier et al. 2021.

Methods

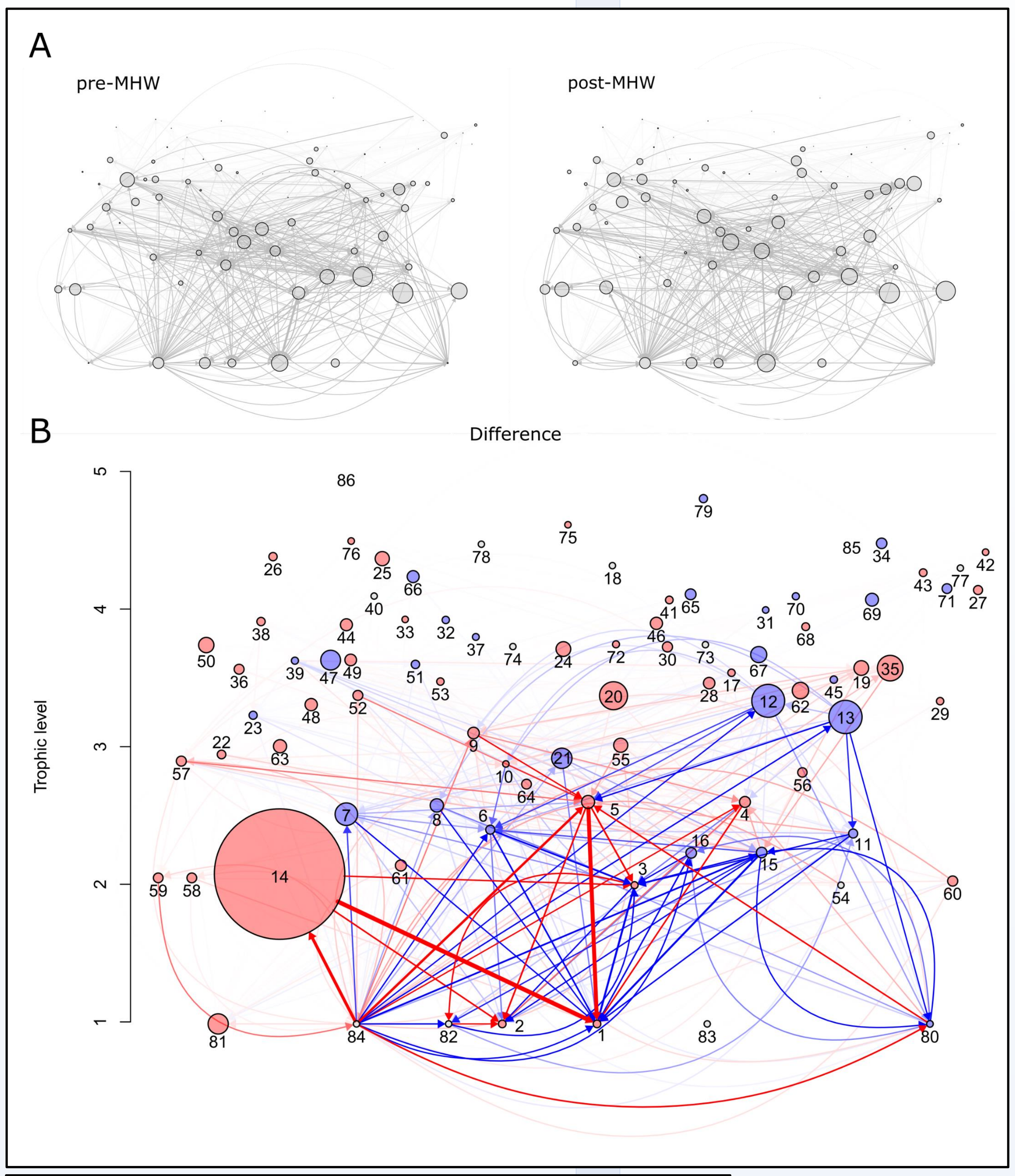
- Re-parameterized and expanded an earlier ECOTRAN ecosystem model (Ruzicka et al. 2012) with new biomass estimates for 77 functional groups, integrated landings information of 8 fisheries fleets, and updated diet information for 26 groups (Gomes et al. 2022).
- Compared and contrasted static energy flow between the two ecosystem models (pre- and post- onset of MHWs).
- 2-D Time-dynamic model is driven by Coastal Upwelling Transport Index and a nutrient timeseries from the NH line.
- Assessed the effects of experimentally decreasing competitors, predators, and prey in 75-year simulations, with 100 Monte Carlo models per scenario.



Schematic of Ecosystem model. The model is physically driven by upwelling and nutrient timeseries. Nitrogen is then transferred up the food web in a bottom-up, or donor-driven, fashion.



75-year Time-dynamic ocean simulations. Functional groups on the x-axis were forced to have 50% of original total consumption. The effects of these forced scenarios, through all direct and indirect pathways, are visualized for one juvenile (left) and one adult (right) salmon groups. Boxplots represent uncertainty via 100 Monte Carlo ocean food web models (median; box = Q1 & Q3; whiskers = 1.5 x IQR).



1	large phytoplankton	29	mesopelagic fish aggregate	58	echinoderms
2	small phytoplankton	30	planktivorous rockfish	59	benthic amphipods isopods and cumaceans
3	micro-zooplankton	31	adult coho	60	bivalves
4	copepods (large >= 0.025mg C)	32	adult Chinook	61	misc. epifauna (suspension feeders)
5	copepods (small < 0.025mg C)	33	other salmon aggregate	62	Dungeness crab
6	small invertebrate larvae	34	shark aggregate	63	Tanner crab
7	**pteropods**	**35**	**jack mackerel**	64	misc. epifauna (carnivorous)
8	pelagic amphipods	36	Pacific mackerel	65	sooty shearwaters
9	pelagic shrimp	37	piscivorous rockfish	66	common murre
10	other macro-zooplankton	38	dogfish aggregate	67	gulls & terns
11	small jellyfish (net-feeders)	39	hake	68	alcids
12	**small jellyfish (carnivores)**	40	tuna aggregate	69	large pelagic seabirds
13	**large jellyfish**	41	sablefish	70	other pelagic seabirds
14	**pyrosomes**	42	hexagrammidae	71	coastal seabirds (divers)
15	E. pacifica (adult & juveniles)	43	flatfish (water-column feeders)	72	storm-petrels
16	T. spinifera (adult & juveniles)	44	skates & rays	73	gray whales
17	small cephalopod aggregate	45	misc. small benthic fishes	74	baleen whales
18	cephalopod humboldt	46	benthivorous rockfish	75	small pinnipeds
19	smelt aggregate	47	Gadidae (cod haddock pollock)	76	large pinnipeds
20	**shad**	48	flatfish (benthic feeders)	77	small toothed whales
21	**sardine**	49	flatfish (small)	78	large toothed whales
22	herring	50	grenadier	79	killer whales
23	anchovy	51	juvenile rockfish	80	invertebrate eggs
24	saury	52	juvenile fish (other)	81	fish eggs
25	coho yearling	53	juvenile fish (chondrichthys)	82	pelagic detritus
26	Chinook yearling	54	infauna	83	fishery offal
27	Chinook subyearling	55	Pandalus spp.	84	benthic detritus
28	other juvenile salmon	56	other epibenthic shrimp	85	commercial fishery
		57	mysids	86	recreational fishery

Network Diagrams. A) Pre-MHW and post-MHW network diagrams show the food web consumption matrix. Weighted ties demonstrate the consumption between groups. The size of circles represent the absolute biomass densities (on the log scale). B) A "difference" network was calculated between the pre- and post- MHW models for both the edge weights and node biomasses. Sizes and colors are dependent on the magnitude and direction of change, respectively. Red indicates an increase, while blue colors indicate a decrease. Node locations are identical in all three networks.

Results

- The largest changes to the ecosystem during MHWs were in gelatinous taxa, especially in the arrival of pyrosomes, but also in the decrease in jellies.
- Lower trophic levels experienced larger changes than upper trophic levels.
- For **juvenile** Chinook salmon in the ocean ecosystem model:
  - Copepods and juvenile fishes were the most important **prey** (or prey of prey).
  - Market squid and pyrosomes were the most important **competitors**.
  - Hake and jack mackerel were the most important **predators**.
- For **adult** Chinook salmon in the ocean ecosystem model:
  - *Euphausia pacifica* and herring were the most important **prey** (or prey of prey).
  - Hake, jack mackerel, and pyrosomes were the most important **competitors**.
  - Reducing **predators** did not have large effects on adult salmon in the model.

Assumptions and caveats

- Consumption reduction scenarios assume that prey that are unconsumed by one predator are available to other predators.
- Reduction scenarios affect all direct and indirect pathways. E.g., while hake do consume juvenile salmon, they also compete with them, so their role in reducing salmon works via both pathways.
- This ecosystem model is strictly an ocean model and does not suggest anything about what salmon experience in freshwater systems or in estuaries, where other interactions are important.
- This ecosystem model does not include behavioral interactions in time and space, but instead represents a snapshot of consumption based on available data.

Conclusions

- Marine heatwaves have dramatically altered the availability of gelatinous groups and food web connections between many lower trophic levels.
- Fisheries management of piscine salmon predators such as hake and jack mackerel could have a beneficial effect on salmon populations.
- Protecting and restoring habitat where larval fish are generated might benefit juvenile Chinook salmon during the early-ocean life stage.

References

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