WASHINGTON COASTAL MARINE ADVISORY COUNCIL MEETING

Wednesday, September 23, 2020   9:30 am – 12:30 pm

WEB-EX ONLY Click here to: Join meeting

Meeting number (access code): 133 729 6148

Meeting password: WCMAC2020

JOIN BY PHONE: +1-415-655-0001

AGENDA

Please try to call-in around 9:15 so that everyone can be online and ready to go by 9:30. The meeting will start promptly at 9:30 a.m.

Time	Agenda Item (Action items are marked with "!")	Objective (Information, Discussion, Action?)	Presenter(s)
9:30* *(15 min)*	**Welcome & Introductions, Agenda Review** • Welcome and Introductions • Review agenda ! Adopt summary of June meeting	**Information** *Reference Materials:* • *Agenda* • *Draft Meeting Summary*	Garrett Dalan, WCMAC Chair Susan Gulick, Facilitator
9:45* *(40 min)*	**Updates** • MRC Updates, Agency Updates, General Coastal Updates • MRAC • Coastal Economic Resilience Workshop	**Information**	WCMAC Members Susan Gulick, Facilitator WCMAC Members

10:25* *(20 min)*	**Technical Updates**
	• MSP Data Evaluations
	  ○ Update on survey results and next steps
	• Ecosystem Indicators
	  ○ Status Update
		Information	Teressa Pucylowski, Ecology

10:45*	**15 Minute BREAK**		
11:00* *(15 min)*	**2021-22 WCMAC Workplan and Budget**	**Information, Discussion** *Reference Materials:* • *WCMAC Workplan & Meeting Plan*	Jennifer Hennessy, Gov. Office WCMAC Members Susan Gulick, Facilitator
11:15* *(60 min)*	**Changing Ocean Conditions** • Overview of marine heat waves and regional ocean conditions since 2014 • Major biological responses from a range of organisms • Increase of marine heat waves pose risks for cold water species • Questions/Discussion	**Information, Discussion** *Reference Materials:* • *Recent Ecosystem Disturbance* • *Great Pyrosome Bloom* • NOAA El Nino • Current Marine Heatwave Tracker	Laurie Weitkamp, NOAA
12:15* *(10 min)*	**Public Comment**	**Information**	Public/Observers Susan Gulick, Facilitator

12:20* *(10 min)*	**Other Issues**
	• Reminder of Dates and Times for Future Meetings
	  ○ Agenda Topics for Next Meeting
	  ○ Agenda Topics for Future meetings
	• Other issues or announcements
		Information
		Reference Materials:
		• *WCMAC Workplan & Meeting Plan*
			WCMAC Members
			Susan Gulick, Facilitator

12:30*	**Adjourn**		Garrett Dalan

*** All times are estimates and subject to change.**

Upcoming WCMAC Meetings

- Monday, September 28, 2020 (***Federal Consistency Webinar***)
- Wednesday, December 9, 2020
- *Wednesday, March 17 or 31, 2020*
- *Wednesday, June 16, 2021*

WASHINGTON COASTAL MARINE ADVISORY COUNCIL MEETING

Draft Summary

Wednesday, June 10, 2020   9:30 am – 12:30pm

WEB-EX ONLY

All meeting materials and presentations can be found on the WCMAC website:
http://www.ecy.wa.gov/programs/sea/ocean/advisorycouncil.html

Highlights

- Update on WDFW's next steps for European Green Crab Management
- Presentation on results from Ecology's Marine Spatial Plan survey
- Update on State budget outlook given COVID-19 response

Summary of Decisions

! April Meeting Summary was adopted

Follow-up Items

- None

Upcoming Meetings

- Wednesday, September 23, 2020
- Wednesday, December 9, 2020

*Meetings will be held **virtually** unless otherwise noted.*

Council Members Present	
Alla Weinstein, Energy	Jay Carmony, WA State Parks
Brian Sheldon, Shellfish Aquaculture	Jennifer Hennessey, Governor's Office
Corey Niles, Dept. of Fish and Wildlife	Katrina Lassiter, DNR
Mayor Crystal Dingler, Citizen Rep	Mara Zimmerman, Sust. Salmon Partnership
Dale Beasley, Commercial Fishing	Mike Cassinelli, Recreational Fishing
David Fluharty, Educational Institution	RD Grunbaum, Conservation
Doug Kess, Pacific MRC	Rich Doenges, Dept. of Ecology
Garrett Dalan, Grays Harbor MRC	Rich Osborne, Science
Genevra Harker-Klimes, Coastal Energy	Russell Calendar, Sea Grant
Gus Gates, Recreation	
Council Members Absent	
Joshua Berger, Dept. of Commerce	Todd Souvenir, Wahkiakum MRC
Larry Thevik, Commercial Fishing	VACANT, Economic Development
Randy Lewis, Ports	VACANT, Shipping
Rod Fleck, N. Pacific MRC	
Others Present (as noted in role call)	
Allen Pleus, WDFW	Susan Gulick, Sound Resolutions, Facilitator
Bobbak Talebi, Ecology (WCMAC Staff)	Emily Wright, Cascadia Consulting Group
Teressa Pucylowski, Ecology	Julie Ann Koehlinger, Hoh Tribe
Casey Dennehy, Ecology	~~Kevin~~ Kayla Dunlap, Port of Grays Harbor
Jackson Blalock, ~~TNC~~Washington Sea Grant	Kris Wall, NOAA Office for Coastal Management
Ann Skelton, Pacific County MRC	Kevin Decker, Washington Sea Grant
Tommy Moore, NW Indian Fisheries Commission	

Welcome and Introductions

Garrett Dalan welcomed everyone to the virtual meeting. Technological logistics were discussed. Susan Gulick conducted a role call of attendees and reviewed the agenda.

April Meeting Summary

- Susan asked for edits to the April meeting summary. She received no edits via email prior to the meeting and no edits were raised by members.
- ! The April Meeting Summary was adopted without changes.

Coastal Updates

MRC Updates

- Pacific County MRC has a meeting on June 11th and will decide whether to postpone or change the format of the MRC Summit planned for this summer. They will also discuss the format of the science conference.
- Grays Harbor MRC held its last meeting in March. They are planning to meet virtually to determine their strategy for meetings moving forward.
- North Pacific MRC is holding its meetings virtually. They are currently working with Coast Savers to have an Ocean Week in Washington, D.C. and holding a virtual film festival.
- No updates were provided for Wahkiakum MRC.

Agency Updates

- WA State Parks has been working with emergency management departments to cover gaps in tsunami warning sirens along the coast. Most camping is now open, as Parks is following the Governor's phased opening approach as well as county guidance and restrictions.
- WA Sea Grant's European green crab and Sound Toxics community-based monitoring programs were both declared essential services and are continuing to be implemented. WA Sea Grant submitted a proposal to the national Sea Grant office for a program to work with small producers to ensure their seafood is certified as safe. They also submitted a proposal to NOAA's climate resilience office to assist coastal tribes in hazard resilience planning.
- Ecology's Integrated Pest Management work group continues to meet and has secured funding for several efforts along the coast. Ecology received reports of yellow rope that has washed ashore and will be looking into strategies to reduce the debris. Ecology staffing plans are following the phased approach from the Governor.
    - Bobback Talebi noted that Ecology has heard that Goose Point Oyster Growers are noticing a new source of sediment. Ecology staff are supporting the local conservation district in exploring the source and toxicity of that sediment, and are taking samples for analysis.
- DNR worked closely with State Parks and Mayor Dingler to close and reopen Damon Point State Park. They are following the Governor's phased approach for field staff.
- MRAC will be discussing budgets moving into next year during their meeting today. Garret will send any updates to the WCMAC listserv. He noted that the Olympic Coast National Marine Sanctuary has a number of virtual events occurring and said members could contact the Sanctuary to receive email notifications.
- The Governor's Office is working with agencies to put together a spending plan for funding from NOAA for fisheries and aquaculture industries. WDFW will play a lead role in that plan, but will ensure coordination among all agencies. Jennifer Hennessey noted that WCMAC's work will likely continue virtually into the foreseeable future.

Other Coastal Updates

- Gus Gates announced a new Recreate Responsibly Coalition led by REI and Washington Trails Association with many state agencies as well. The goal is to better coordinate and manage outdoor recreation opportunities while doing so safely during the pandemic. https://www.recreateresponsibly.org/
- Mike Cassenelli said the Sea Resources Fish Hatchery is working with WDFW to acquire fish and they hope by next year to release fish into the Columbia River.
- Dave Fluharty noted that many highly qualified graduates are leaving academic institutions to start working, and he encouraged members to keep them in mind given the difficult job market.
- Rich Osborne shared that harmful algal bloom (HAB) levels are below any threshold of concern. It is a great for shellfish harvesting, but recreational clam harvests are closed due to COVID-19. Razor clam monitoring indicates there will be a bountiful harvest once it can be opened—hopefully in the fall
    - Rich O. also shared that the new position for the Southern Resident Killer Whale Recovery group has been dropped due to budget cuts. The current population estimate for the Southern Residents is 73, but there will be a new official count in July.
    - Rich O. noted that there has been a cold-water band along the outer coast for over a year, and with a neutral El Nino and cold Pacific-Decadal Oscillation, ocean conditions are good. The warm blob is offshore and has not come to the coast.
    - Jay Carmony asked about the Coast Savers organization and opportunities for engaging youth. Rich O. directed him to contact Coast Savers directly or the Olympic Coast National Marine Sanctuary for more information.
- RD Grunbaum noted KBTC TV will be broadcasting the feature film "Chehalis: A Watershed Moment" on June 11th at 8:00 pm.
- Dale Beasley noted that Washington received $50 million from federal COVID-19 response funds for fisheries, but individuals need to show a 35% or greater reduction in income to access those funds; he believes fisheries is the only industry to have a threshold and noted this is problematic.
    - Dale also shared that the Coalition of Coastal Fisheries is discussing how to hold their annual fisheries roundtable, which is supposed to be in October and typically brings people from all over the country.

Next Steps: European Green Crab Management

Susan asked Allen Pleus, Aquatic Invasive Species Manger at WDFW, to provide an update on the European green crab management activities.

- WDFW is primarily working in the Straits Harbor Action Area to develop a memorandum of understanding for local coordination with the Northwest Straits Foundation, Washington Sea Grant, Whatcom County, and cities and other entities in that area. They are developing the 2020 Management Plan for that action area and started trapping on May 26—later than expected due to COVID-19 constraints.
- Budget challenges from COVID-19 have made it difficult to work on the Coastal Region Action Area management plan. However, they are developing the coastal trapping plan for this summer with Washington Sea Grant and are hoping to start that work by July 1st primarily in Willapa Bay and Grays Harbor.
- They are still planning on working with WCMAC members to develop the 2021-2023 Management Plan for the Coastal Region Action Area. Allen will reach out to Susan and Bobbak to start that work later this summer.
- Allen is also writing a comprehensive update on European green crab response and expects to complete it in June.
- Susan shared that when Allen reaches out, WCMAC will form a small work group or technical committee to specifically support the management plan effort.
    - Rich O. noted the Makah Tribe has been doing a lot of monitoring and should be involved in that work group.
    - Bryan Sheldon requested that the WCMAC technical committee—once it is established for the European green crab process—to involve executive directors of the Shellfish Growers Association.

- Bryan also expressed his support for sustaining the efforts at the Willapa Bay Field Station as a best management program. He also asked whether there has been coordination between Washington, Oregon, and California around European green crab management, since he has heard that neither Oregon nor California have trapping programs or other dedicated management efforts compared to Washington.
    - Rich O. noted that Washington could be contributing to the issue due to ballast water from ships from both the U.S. and Canada. Trapping is the only way he is aware of to control them, and he expressed agreement with Bryan's comment that California should have a trapping program.
    - Allen said his team works regionally in California, Oregon, and Canada. He confirmed that California and Oregon do not have dedicated programs to address the issue, and that those areas can be sources of larvae, as can the west coast of Vancouver Island. He expressed that it is a regional issue and the contributions to the problem could be different on the coast compared to in the Salish Sea. He said he will convey these concerns to the management group.
    - Bryan expressed that there should be a sustained management program and questioned why there is not a method to sterilize ballast water before it is released. Allen explained that they manage ballast water across Washington State, including 19 different deep water ports, requiring vessels to do a managed ballast water exchange. They are implementing treatment systems that reduce the number of organisms in the ballast water to minimal levels—this does not completely eliminate the risk, but they have not found evidence of ballast water transferring larvae into Washington State thanks to those management efforts. Rich O. noted that larvae can still come in through ballast that is outside the purview of this management program, which Allen confirmed that there are still possibilities of risk.

Budget Update

- Jennifer shared that the State revenue forecast has a large hole that is growing—as of April, the hole for the next 3 years was estimated to be $7 billion and it is expected to increase in the new revenue forecast in June. However, there is lots of uncertainty around economic recovery. The hole has already triggered response actions from Office of Financial Management, such as:
    - Freeze on hiring and personal services contracts for state agencies.
    - Request for agencies to find cost saving strategies.
    - Planning for 15% budget reductions in state agencies to give range of options for Governor's budget development.
- There may be a special legislative session to address the current budget, which goes through June 2021, and it is likely that the 2021-2023 budget will be affected. There is uncertainty about how much federal support will be available to fill in the budget hole and when that may be available. The State has a "rainy day fund," which will not fill the hole entirely, but it will be a part of the conversation moving forward depending on the degree to which legislators and the Governor propose to tap into it.
- WCMAC may be looking at a different budget scenario than in past years, so members will need to consider options to adapt, such as reducing the frequency of WCMAC meetings and continuing to hold remote meetings into the future. WCMAC will plan to discuss the budget in the September meeting when another budget request is prepared for the next biennium.

Ecosystem Indicators Update

- Bobbak shared a brief update that the State hiring freeze also applied to the budget for the Ecosystem Indicators project, so it is currently on hold in terms of hiring a team of students and researchers for carrying out the project.
- Ecology is currently finding other sources of funding to complete the project; they have a couple of leads, but nothing is confirmed yet.

Economic Resiliency Workshop

- Emily Wright shared an update about the planning for the Economic Resiliency Workshop. She said the planning work group discussed holding the workshop virtually and other options for adapting to the current context.
- The workshop has full funding, thanks to support from Pew Charitable Trusts, but the work group is still waiting to make a decision about whether to move forward with holding the workshop in the fall remotely or to postpone to hold an in-person event in the future.

Coastal Hazards Workshop

- Bobbak shared that the Coastal Hazards workshop was postponed as well until spring 2021, given the value in having in-person conversations among folks was a key purpose of the workshop. They are putting the information-sharing effort by the Coastal Hazards Resilience Network on hold as well.
- By the time of the workshop next spring, they will be further along in the Resilience Action Demonstration project, so they will have more information to inform recommendations for WCMAC.

MSP Data Evaluation

Susan introduced Teressa Pucylowski from Ecology to give a presentation on the results of the marine spatial planning data survey. Presentation materials are available at the WCMAC website (link listed on first page of meeting summary).

Discussion

- Mayor Dingler commented that it would be nice to capture the change in priorities over time (e.g., a 5-year period) and the reason(s) for the change.
- Rich Doenges asked what the next steps are in Teressa's work and when it would make sense for her to give another presentation at WCMAC. Teressa said funding for her work ends at the end of August and she is trying to finish her portion of it by then, including analyzing data and developing next steps and recommendations. She said Casey Dennehy will keep the project going after that time. Bobbak said that WCMAC could hold a special webinar before her contract ends to hear another update, if members are interested in that.

WCMAC Workplan

Susan reviewed the WCMAC Meeting Plan regarding planned topics to be covered in upcoming meetings. She noted that many topics planned for June were rescheduled for September, so that meeting may need to be split into two half-day meetings.

- Casey has connected with Stephanie Moore, a biological oceanographer with expertise harmful algal blooms (HABs), who could talk about the relationship between oceanographic elements, changing ocean conditions, and HABs. He is waiting to confirm with her until he hears back from the steering committee. He asked WCMAC members whether they would like to hear about changing ocean conditions and impacts on fisheries, on HABs, or on both, noting she could bring in her colleagues to offer more information specific to fisheries.
    - Rich O. expressed interest in impacts on fisheries and noted a few people he would suggest from NOAA and University of Washington.
    - Casey mentioned that Stephanie Moore could also provide some information from NOAA about economic impacts of HABS, such as closures of razor clam harvesting. Rich O. noted that he believes Stephanie was referring to a grant impact to look at economic impacts, but he is not sure whether the data is available yet or in preliminary form.
    - Mara Zimmerman expressed support for hearing from Stephanie Moore on those topics. She also suggested Laurie Weitkamp from the Northwest Fisheries Science Center to discuss impacts on fisheries, which Rich O. supported as well.

- On the topic of Federal Consistency, Susan and Bobbak reminded WCMAC members of the email distributed through the listserv with links to resources and information. Members should send Susan or Bobbak details about what they would like to hear about so Ecology can tailor their presentation to their interests.
- Susan summarized that the Steering Committee will move forward with planning the agenda items for September in consideration of the comments made during the discussion. The topics on the meeting list for December will be pursued as well.
- Susan noted Bryan's comment in the chat box to have a future agenda item about ballast water management, including the accepted practices and new technologies being considered to sterilize ballast water before it is released into U.S. waters. He also proposed a discussion of the role of the Invasive Species Council and how it is implementing eradication programs and tracking the results of those programs as aligned with state law.
    - Susan noted that perhaps these topics can be incorporated into the December meeting.
- Jennifer urged consideration to continue shorter meetings to accommodate the virtual format and, if needed, schedule two half-day meetings.
- Susan reminded members that we are assuming that we will be meeting remotely indefinitely.

Public Comment #1

There were no public comments.

Other Issues

- Upcoming meetings are listed at the top of the meeting summary. The September meeting will be held remotely and may be split into two separate meetings. Updated calendar invites will be sent soon. The same approach will likely be taken for the December meeting.

2020-21 WCMAC Meeting Plan

9/15/2020

December 9, 2020	
Topic	**Presenter**
• WCMAC Officer Elections	▪
• Finalize 21-22 Workplan	▪
• Invasive species? ○ Burrowing shrimp ○ Other	▪
• Next Steps on Green Crab Management Plan/WCMAC Role	▪

March 17 or 31, 2021	
Topic	**Presenter**
• Discuss Proposed Recommendations from Coastal Hazards Workshop (if completed)	▪
• Discuss Proposed Recommendations from Economic Workshop (if completed)	▪

June 16, 2021	
Topic	**Presenter**
• Update on N of Falcon	▪ WDFW (Ron Warren)
•	▪
•	▪

Topics to weave into 2020-21 agendas:

- Discussion of data gaps/research needs
- Briefing on status of MSP implementation
- Ecosystem indicators

Economic Workshop: Date TBD	
Topic	**Presenter**
•	▪
•	▪

Coastal Hazards Workshop (Date TBD)	
Topic	**Presenter**
• Flooding and Erosion	▪ Ecology
• Landslides and Tsunamis	▪ DNR
• Sea Level Rise	▪ Sea Grant/OSU (Peter Ruggiero)
• Climate Change Impacts	▪ Climate Impacts Group (Heidi Roop)
•	▪
•	▪

WCMAC Workplan

6/1/20

	Topic	Purpose	Source*	WMCAC Focus	Timeframe	Tasks	Information Needs	Notes/Status Updates
A.	**Coastal Resilience**	Prioritize needs and actions to carry out the recommendations in the Ruckelshaus "Washington State Coast Resilience Assessment Final Report (2017)"	C	Information Sharing; Informal Advice; Formal Recommendations	Ongoing	1. Guide Ecology and Washington Sea Grant in completing the "Washington Coast Resilience Action Demonstration (RAD) Project" 2. Guide and participate in a science-policy workshop on coastal hazards 3. Help shape recommendations to the Governor, the Legislature, and state and local agencies to further support long-term pre-disaster risk reduction for Washington's Pacific coast-wide resilience initiative.		* 18 month NOAA grant was awarded to Ecology's Coastal Program to partner with WCMAC on the "Washington Coast Resilience Action Demonstration (RAD) Project" * Coasal Hazards workship is being planned for 2021
B.	**Ecosystem Indicators**	To provide feedback to the state on refining the list of ecosystem indicators.	C	Informal Advice	thru 6/21	1. Compile existing lists of indicators, summary of methods, and proposed process for refining indicators *(WCMAC staff)* 2. WCMAC briefing and discussion *(WCMAC Meeting)* 3. Staff and other experts participate in OCNMS Ecological Indicator selection process	1. List of current potential indicators 2. Summary of methods used to identify current list 3. Informational briefing on developing scientifically robust indicators 4. Presentation from OCNMS on Conditions Report and Ecological Indicators	*Need to consult with NOAA (NWFSC)
C.	**Economic Resiliency Workshop**	To convene a 1-day workshop on economic resiliency in coastal communities	W	Information Sharing	3/19-6/21	1. Develop scope of work/approach for a 1-day workshop to address economic resiliency in coastal communities (now looking at virtual alternatives in response to Covid-19)	TBD	*Rod has agreed to chair this effort. *The recommendations from the workshop will be by WCMAC for formal recommendation by WCMAC
D.	**Science and Research Agenda**	To provide feedback to the state on the development of a science and research agenda, including data gaps and WCMAC's priorities.	C	Informal Advice	Ongoing	1. Compile Data Gaps *(WCMAC Staff)* 2. WCMAC Discussion on Initial List of Gaps and Priorities *(WCMAC Meeting)* 3. Coordinate with ecosystem indicators work	1. List of data gaps (initial list from MSP) 2. Summary of existing, current science needs documents for WA Coast (e.g. OCNMS, PFMC)	
E.	**Monitor Implementation of MSP**	To keep WCMAC informed of MSP implementation efforts To consider practical applications of the MSP	C	Information Sharing (See also A. above)	Ongoing	1. Summarize status of MSP implementation tasks (WCMAC staff) 2. Federal Consistency: Review Washington's authority in reviewing federal activities	1. Informational Briefing on Status of MSP Implementation	*Include briefing on how the plan gets used, particularly regarding new applications *Review plans that are inconsistent with MSP
F.	**Annual Work Plan**	To develop an annual workplan to guide planning for WCMAC meetings and activities.	B	Operations/Admin	12/20	1. Compile topics and outcomes (*Steering Committee*) 2. Develop draft annual workplan (Steering Committee) 3. Discuss and adopt work plan (*WCMAC Meeting*)	1. Input from WCMAC members and Gov's office on topics and priorities	* Initial draft work plan discussed at September meeting with final work plan addressed at Dec. meeting.
G.	**WCMAC Meeting Agendas and Operations**	To fulfill Steering Committee responsibilities as listed in the by-laws	B	Operations/Admin	Ongoing	1. Set WCMAC Agendas for each meeting 2. Conduct officer elections every 2 years		

Source: C= Governor's Charge; B=Bylaws; W=WCMAC Generated

	Other Topics of Interest/Future Consideration	Notes/Comments
1	Coastal Erosion	Coastal Resiliency Work Group is planning a Science-policy workshop on Coastal Erosion and Sea Level Rise: 2020-21
2	Sea-level rise	
3	Trends in changing ocean conditions	Scheduled for Sept. 2020
4	Shipping overview	
5	Oil terminals	
6	Commercial Net Pen Aquaculture	
7	Offshore Aquaculture	
8	Shellfish Aquaculture Management issues (e.g. invasive species, burrowing shrimp, etc.)	Will provide ongoing updates to WCMAC as appropriate; update on settlement agreement was provided at 12/11/19 meeting
9	Invasive Species and Pest Species Management (other than Green Crab)	Benthic impacts of burrowing shrimp (Kathleen Sayce) (Green Crab presentation provided at 4/1/20 meeting)
10	Changing Fishing Fleets and Alternative Fishing Methods	
11	Coastal Energy	Other coastal groups are considering hosting a workshop
12	Economic Development: How do coastal communities adapt to changing economy?	Workshop planned for 2020-21
13	Building Local Capacity	
14	Watershed Protection	
15	Ecosystem Services Valuation	
16	Federal Consistency	Scheduled for Sept. 2020
17	Ecology's Spill Program	
18	Ecological Indicators in Estuaries	Technical Committee will discuss
19	Regular Financial Updates on WCMAC's budget status	Will be periodically added to WCMAC's agenda
20	Sea Floor Mapping Update	
21	Recreation and tourism issues	
22	Ocean Acidification Sentinel Site	
23	Nanoos Data	Nanoos presentation on new data products/apps for ocean users that help improve understanding of ocean conditions and safety (ideally Jan or Rachel)
24	Renewable Energy and Economics	Presentation by Brian Pologye of UW/PMECC and also a member of the science advisory panel. Could also speak to research happening in OR
25		
26		

Topics Addressed in Previous Meetings	Notes/Comments
Vessel Traffic/Navigational Safety/Transport of hazardous substances	Briefing on Grays Harbor Vessel Traffic Risk Assessment occurred at 3/28/18 meeting.
Ocean Acidification	Presentation by MRAC members at 6/13/18 meeting
Tsunami/Disaster Preparedness	Presentation at 6/13/18 Meeting
Juvenile salmon survey results and ocean conditions	Webinar in 9/18
Briefing from WDFW on recreation and commercial fishing allocation	Presentation at 12/12/18 meeting
Salmon Management	Workshop at 10/2/19 meeting
Potash Terminal in Grays Harbor	Presentation at 12/11/19 meeting
Harmful Algal Blooms (HAB)	Presentation at 4/1/20 meeting

Priorities for 2020 are highlighted in green

Marine Spatial Planning Data Assessment

Follow Up Survey Results

Presentation to WCMAC

Washington Department of Ecology

September 23, 2020





High Priority Data

The following ‘high priority’ components are those that were prioritized 10+ times in the original survey:

PHYSICAL DRIVERS					SEAFLOOR HABITAT	ECOLOGICAL COMPONENTS	
Climate Variability	Low Dissolved O2 Events	Ocean Acidification	Wind-driven Upwelling	Currents, Eddies, & Plumes	Corals / Sponges	Marine Snow / Detritus	Marine Phytoplankton, Zooplankton, Bacteria, Micro/Meiofauna

SPECIES									
Seabirds, Shorebirds, & Waterfowl	Marine Mammals	Forage Fishes	Rockfishes	Groundfish Assemblage	Flatfishes	Salmon	Sea Urchins	Razor Clams	Crabs* & Shrimps

EXISTING HUMAN USES							HISTORIC & CULTURAL RESOURCES		
Recreation	Transportation & Navigation	Shellfish Aquaculture	Tourism	Fisheries - Commercial, Recreational & Tribal	Public Services & Utilities	Scientific Research	Historically/Culturally Significant Sites	Community Culture	Aesthetic Resources

Follow Up Surveys

1. Climate Change & Ocean Acidification
2. Human Wellbeing & Socioeconomic Information
3. Process for Continued Evaluation

- High level overview of key results
- Final report will include full analysis & recommendations

Climate Change & Ocean Acidification

Q: Which components will be influenced directly by climate change <u>and</u> ocean acidification?

(high consensus, >75%)

- Corals & Sponges
- Marine Phytoplankton, Bacteria, etc.
- Marine Mammals
- Sea Urchins
- Salmon
- Crabs & Shrimps
- *Fisheries

Q: What **data or research is necessary** to better determine how we can understand, detect, or measure effects from CC or OA for each component?

COMPONENT:	Participant # 1	Participant # 2	Participant # 3
Seabirds, Shorebirds, & Waterfowl	Identifying **thresholds** in physical variables that affect the prey conditions of these species that subsequently affect **growth and survival of chicks**	**Shifts in breeding time with prey availability** and if tied to changes in ocean conditions	Monitoring and research into marine **foodweb dynamics** and changes
Forage Fishes	Impacts of warming and changes in upwelling, increased monitoring of population dynamics. Monitoring and research into **spawning and nursery grounds**	Better **understanding of species sensitivity** to changing environmental conditions and better **modeling that goes from environment to species to food web**	How changing ocean conditions will affect **abundance, distribution, and species composition**
Transportation & Navigation	Identify potential changes in shipping routes if **current systems** begin to change	to the extent that **circulation and infrastructure are affected by rising seas and higher rainfall events**, this will be affected. Really think some effort on nailing down circulation changes likely to occur in the future (and even to some extent in the present) relevant at the state level would be helpful for both transpo/navigation AND broader ocean research	Monitoring of **surface currents** and how they might change in the future
Community Culture	**Sense of place** can be altered due to changes in resources or timing	Sustained interactions with tribes and industry to understand observed impacts to field resources is critical going forward in my opinion. Social science in this bellwether region should have a **long-term monitoring component, not just be viewed as a "one and done" exercise**	Better understanding of individual and cultural **adaptive capacity**

Human Wellbeing

Q: What are the indirect impacts from potential new ocean uses to human wellbeing?

(identified 25+ times)

Human Wellbeing Attributes:	Indicators:
Job Quality	Job duration, employment options, living wage, benefits & flexibility, job satisfaction
Subsistence	Subsistence harvests, access to resources and knowledge, ability to meet costs and obtain permits
Research & Technology	Support for and level of research and technology; patents; access to technology and data; ability to produce/contribute new knowledge
Resource Management	Effectiveness of management; perceptions of management; permits & regulations; adequate funding and staff capacity for achieving management objectives; partners and collaboration; voice and participation in management
Resource Abundance & Distribution	Land cover, use & designations; species assemblages & abundances; protected areas, parks, and gardens
Emotional & Mental Health	Happiness, attitude, trust, subjective wellbeing, stress, depression, suicide rates
Food	Agricultural and fisheries harvests; food & drinking water access, abundance, quality, security & sovereignty; nutrition; fertilizers and pesticides
Local & Informal Economies	Farmers' markets; local producers & consumers; gifting, bartering, trading; value, volumes and percentages of reciprocal and in-kind "transactions"
Resource Access & Tenure	Evidence of access to natural resources (e.g. water, minerals, wildlife, fish); constraints to access; land and resource ownership; modes of access; natural resource harvests)
Sense of Place	Activities on the landscape, heritage, social and emotional connections to places
Cultural Values & Practices	Languages spoken; cultural sites; cultural practices; arts; traditional ecological knowledge; environmental ethos; community events

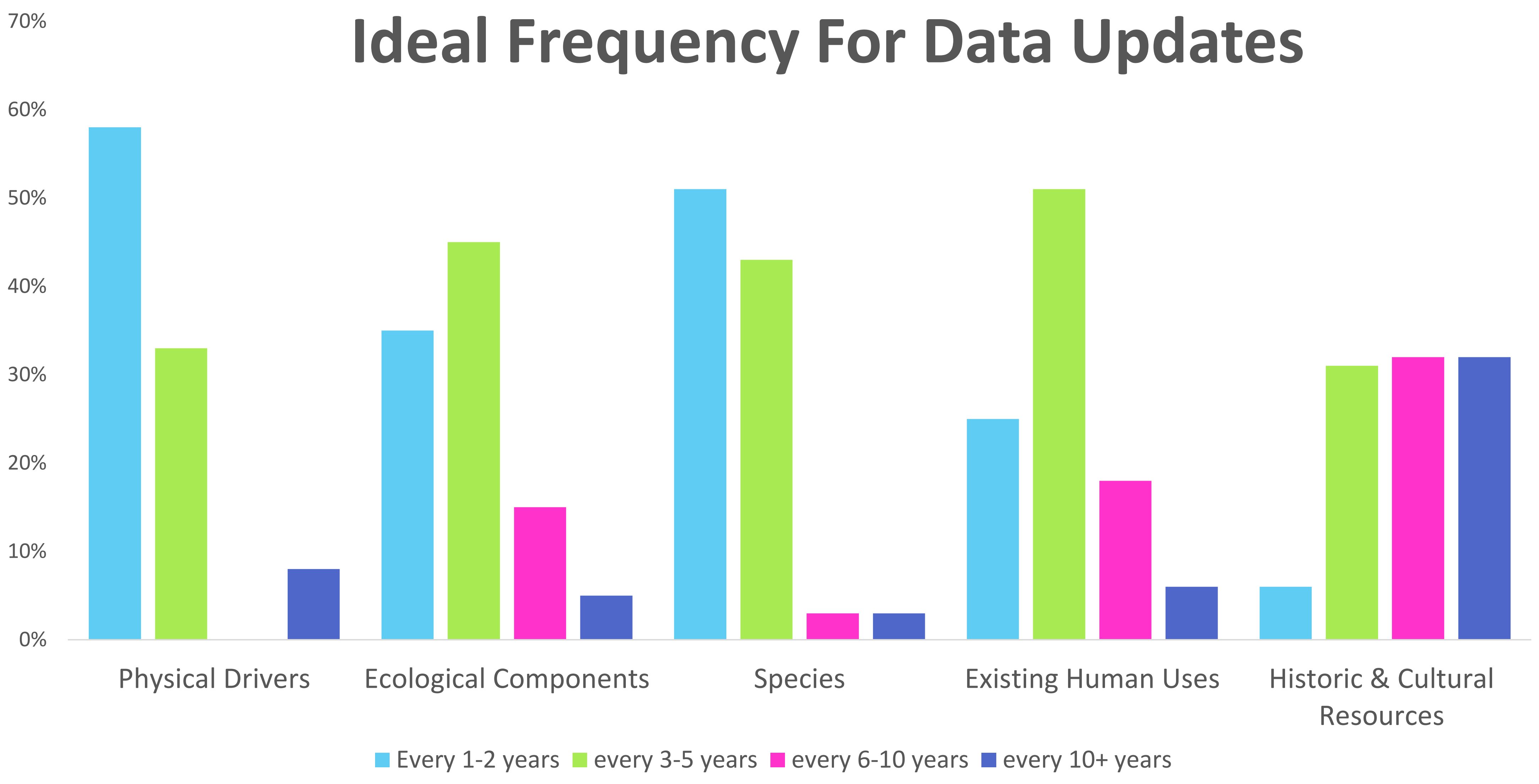
Process for Continued Evaluation

Q: Rank data needs by importance and feasibility.

(at least 25% of participants ranked these as the top 3 most important or most feasible)

Data Updates	
Importance	**Feasibility**
*Forage Fish	Recreation
*Salmon	Tourism
Commercial Fisheries	*Forage Fish
Recreational Fisheries	Transportation & Navigation
	Shellfish Aquaculture
	*Salmon
	Public Services & Utilities
	Historically/Culturally Significant Sites

Data Gaps	
Importance	**Feasibility**
Climate Variability	*Low Dissolved Oxygen Events
Ocean Acidification	Razor Clams
*Low Dissolved Oxygen Events	*Crabs & Shrimps
Marine Phytoplankton, Bacteria	Tribal Fisheries
*Crabs & Shrimps	Aesthetic Resources
Community Culture	



(% of responses for each category of data)

Qualitative Network Models for Washington's Marine Habitats

A Teaser for the Qualitative Network Modeling of Washington Ocean Habitats Workshop

Teressa Pucylowski[1] and Robert Wildermuth[2]

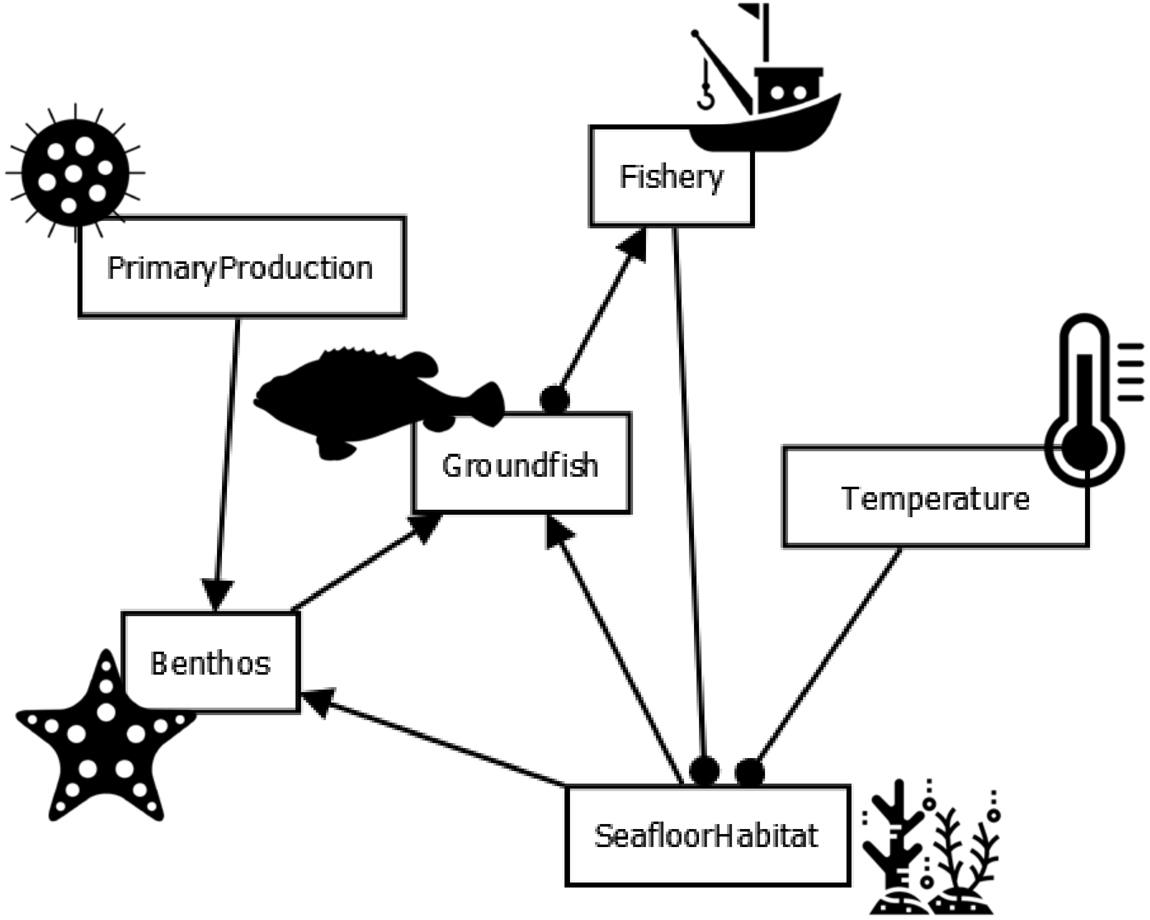
WCMAC Meeting, Sept. 23, 2020

1. Marine Spatial Plan Coordinator, WA Department of Ecology

2. PhD Candidate, School of Marine Science & Technology, University of Massachusetts Dartmouth, @RPWildermuth

What is Qualitative Network Modeling?

- Mathematical approach to simplify dynamics of a system
- Network describes qualitative relationships between system variables
- Assumptions:
  - Only relative linear relationships
  - The system is internally stable



Use in Other Managed Systems

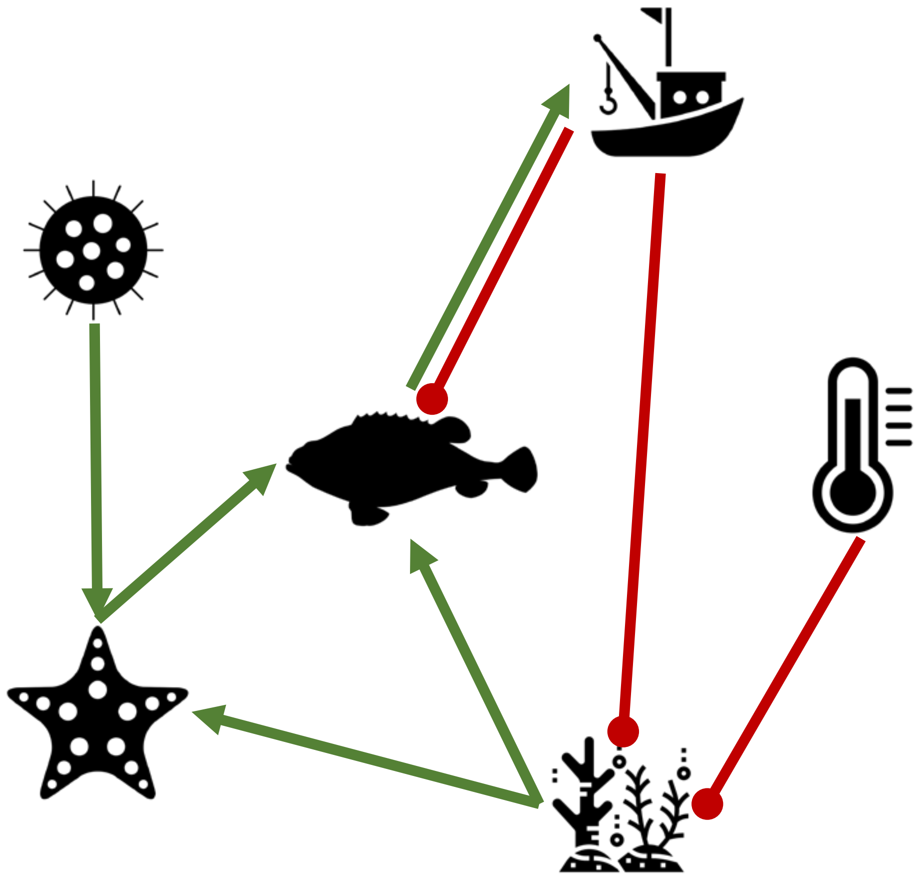
- Helpful for data-limited systems with cumulative human and environmental impacts

Examples:

- NPFMC: Management considerations of Pribilof Island blue king crab populations in the Bering Sea (Reum et al., 2020)
- PSMFC: Risk assessment of Salish Sea Pacific herring (The Salish Sea Pacific Herring Assessment and Management Strategy Team, 2018)
- Guidance of Northeast Fisheries Science Center's Integrated Ecosystem Assessment (ICES, 2017)

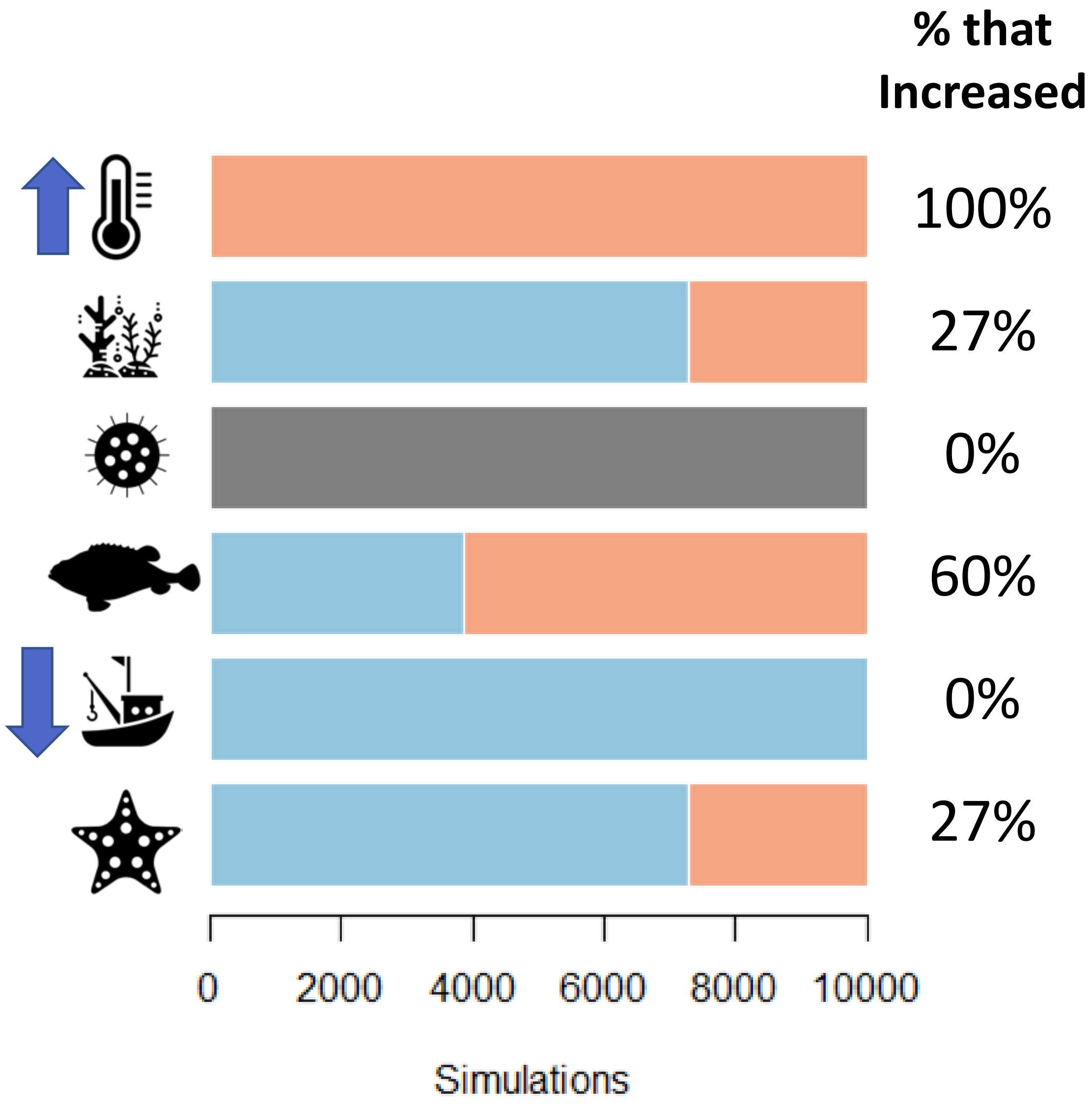
Example Marine Fishery System

- Six interacting variables, including habitat, physical drivers, and human activities
- Interactions only positive or negative
  - No magnitudes
- Evaluate how system responds to a consistent increased temperature and reduced fishing



Interpreting the Output

- Each variable has either increased or decreased **relative to before the change**
- Potential indirect effects
  - Benthos not directly interacting with fishery or temperature
- Uncertainty in outcomes shown by percent of simulated reactions



Purpose & Use of QNMs in WA

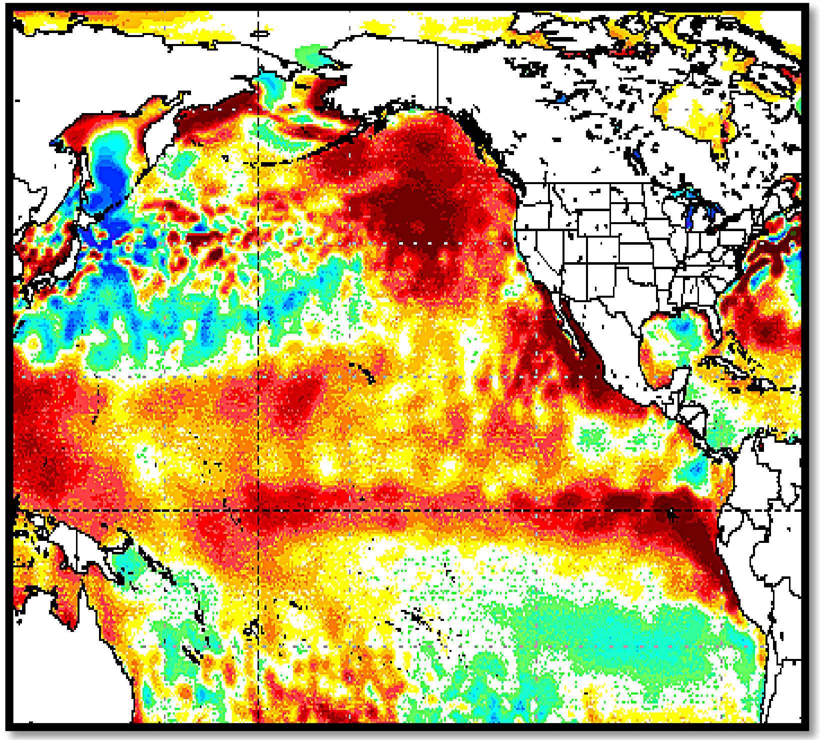
- Creating models of the seafloor & kelp forest habitats
  - Includes climate change and ocean acidification
- We will use the model to run scenarios:
  1. To identify ecosystem indicators that the state should prioritize, track, and report on over time
  2. That relate to current resource management concerns
- Potential for further development of the models
  - Inclusion of socioeconomic/wellbeing indicators
  - Address future concerns as they evolve
  - Update model as new information is gained
- Opportunities for partnerships

Building Habitat Models for WA's Coasts

- What: Qualitative Network Modeling development Workshop
- When: **Oct 1st (9am-12) and Oct 5th (10am-12)**
- Why: To create the foundation of habitat models to assess resource management concerns under WA's Marine Spatial Plan and foster investment in this process
- Who:
  - Experts in Seafloor and Kelp Forest habitat dynamics
  - Users and beneficiaries of ecosystem services from these habitats
  - ***You do NOT have to have modeling expertise!***

Contact: Teressa Pucylowski (tpuc461@ECY.WA.GOV) or Casey Dennehy (cden461@ECY.WA.GOV)

Recent ocean conditions and biological response in the NE Pacific

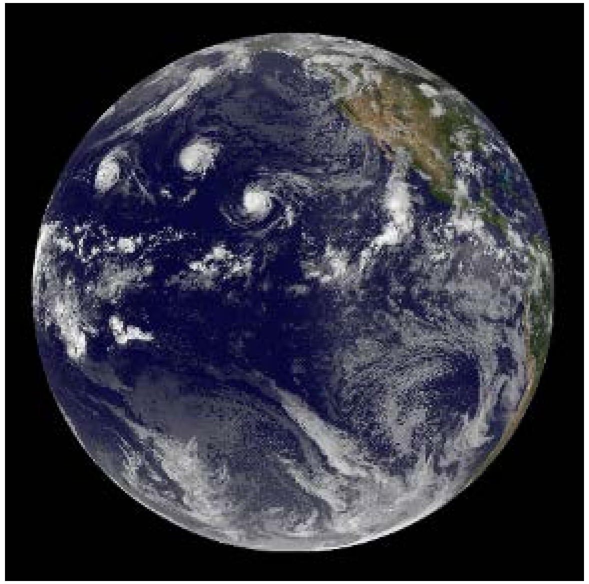


Laurie Weitkamp
Northwest Fisheries Science Center
Newport Research Station
Laurie.weitkamp@noaa.gov

Today's talk

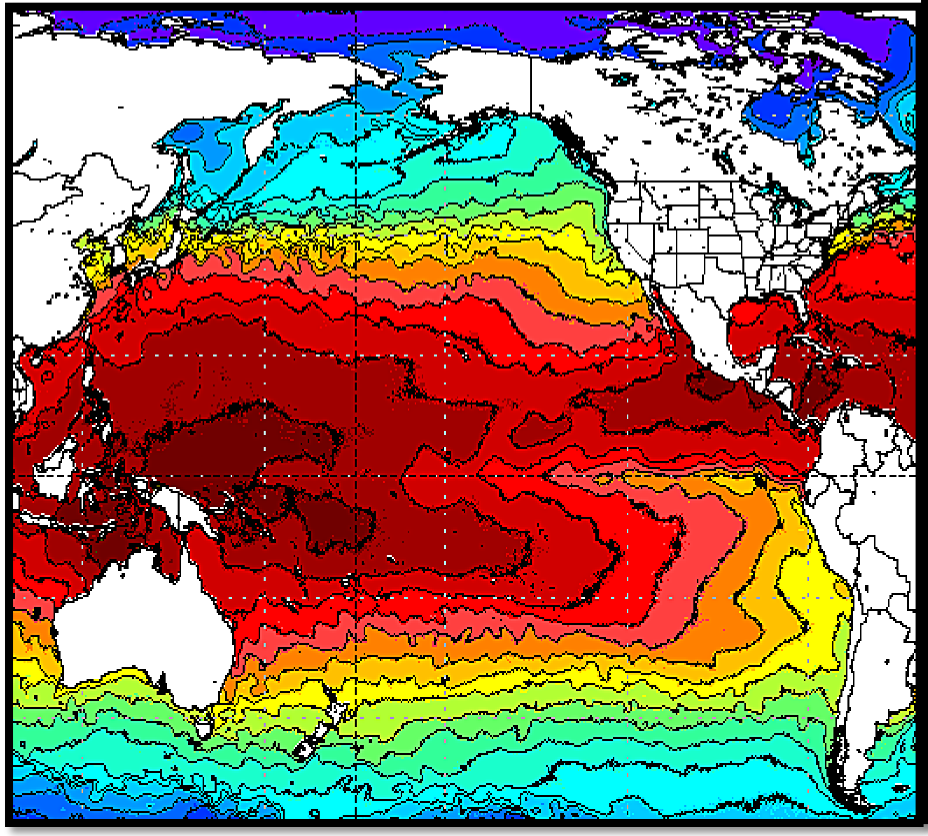
1. Physical conditions across the North Pacific
   - Warming oceans
   - The blob, El Niños, La Niñas,
   - Recent Sea Surface Temperatures (SSTs)
2. Biological response to physical conditions
   - Unusual observations
   - Commercial catches
   - Pacific salmon extremes
3. Predictions
   - El Niños/La Niñas
   - SSTs
4. Summary

Bottom line: ***Marine heat waves off our coast have triggered a huge biological response.***

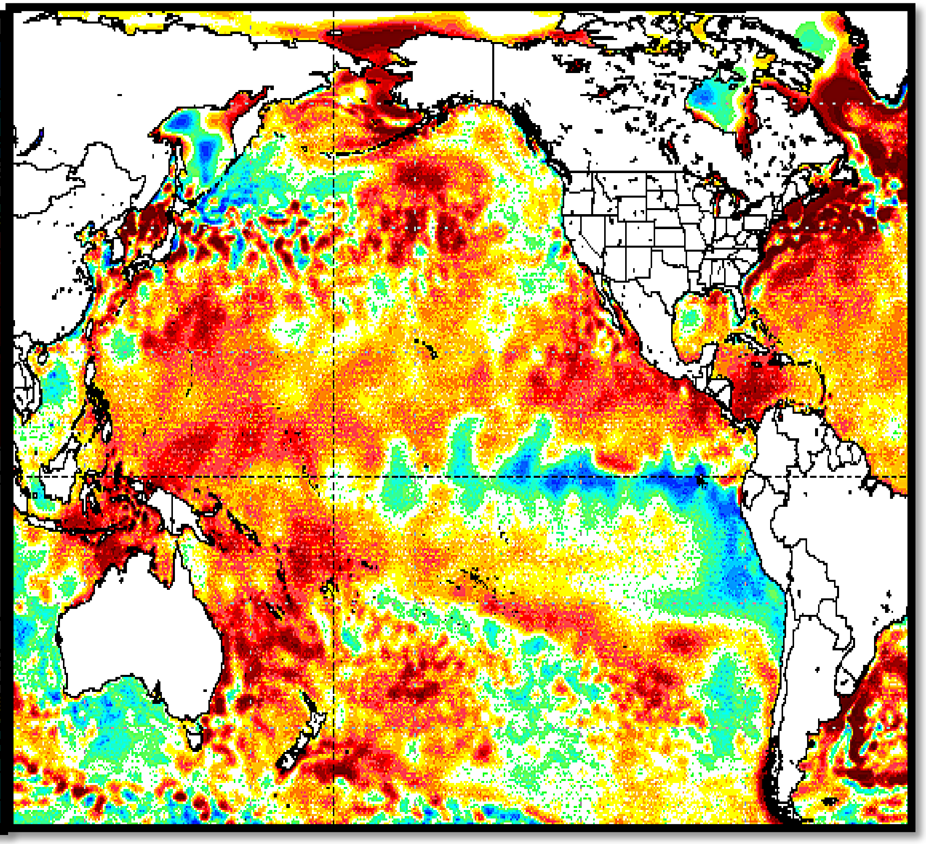


Terminology: Anomaly

Actual sea surface temperature (SST)



SST anomalies



http://polar.ncep.noaa.gov/sst/ophi/

1. Physical conditions across the North Pacific

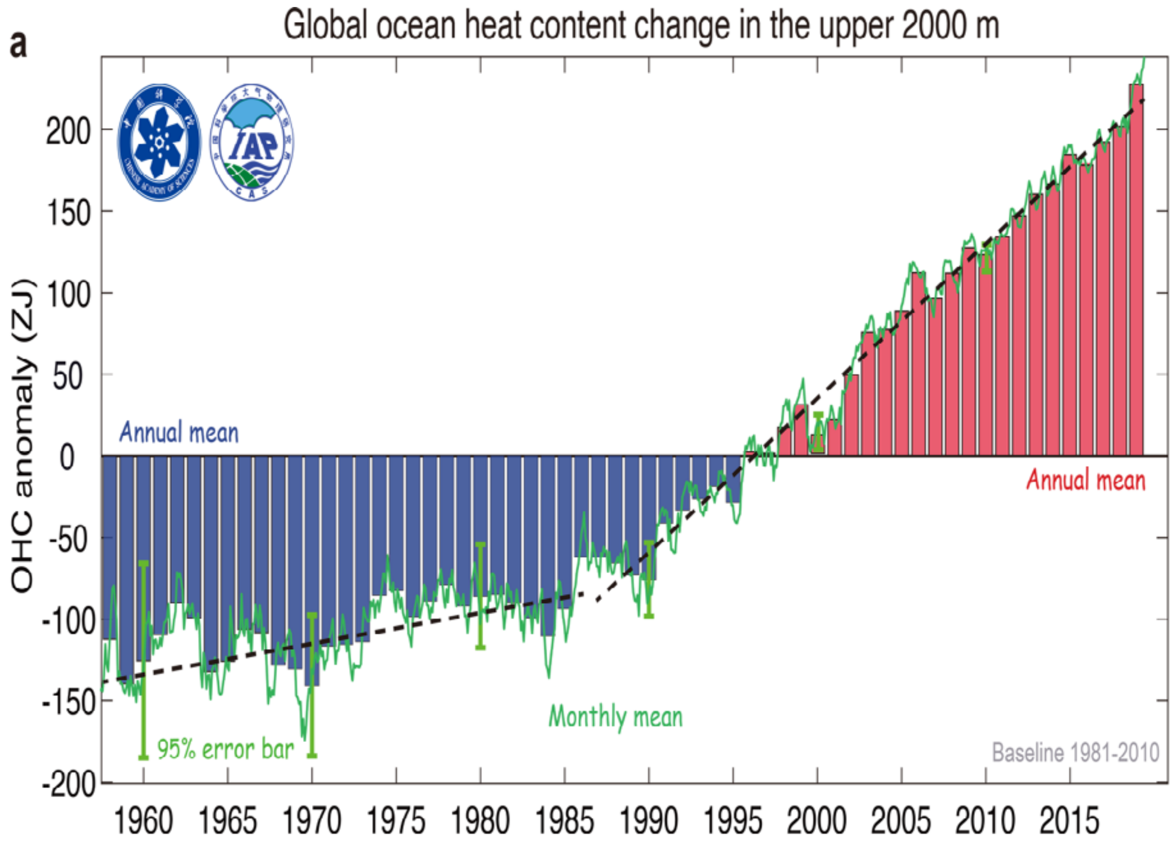
Drivers of physical conditions

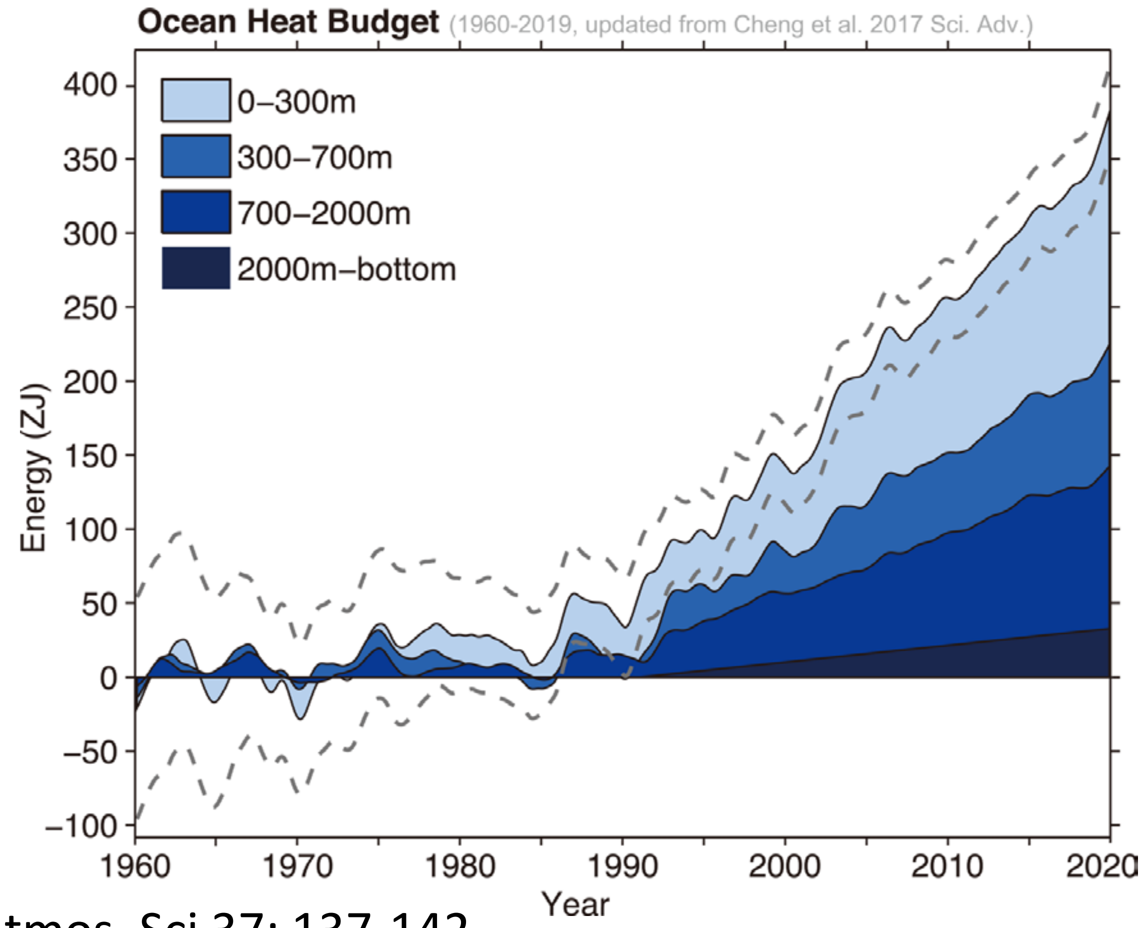
- Warming ocean
- The blob/marine heat waves
- El Niño and La Niñas

Recent sea surface temperature (SST) anomalies

The ocean has absorbed 90% of earth's excess heat

Global warming = ocean warming

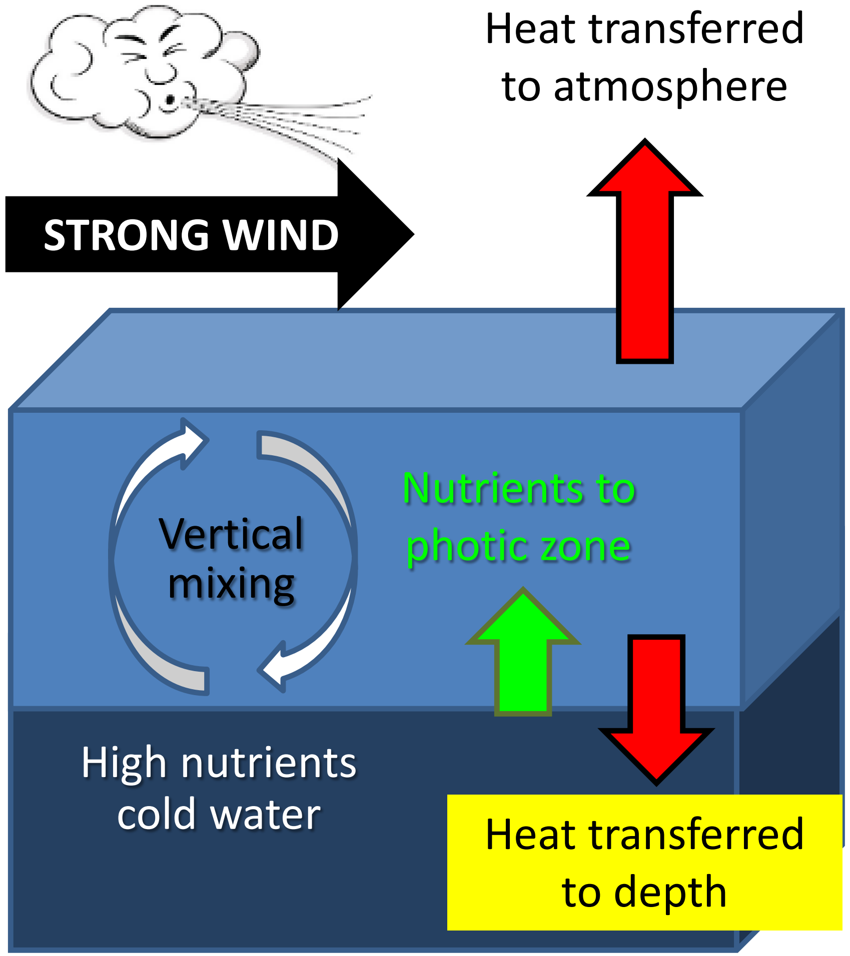




Cheng et al. 2020. Adv. Atmos. Sci 37: 137-142

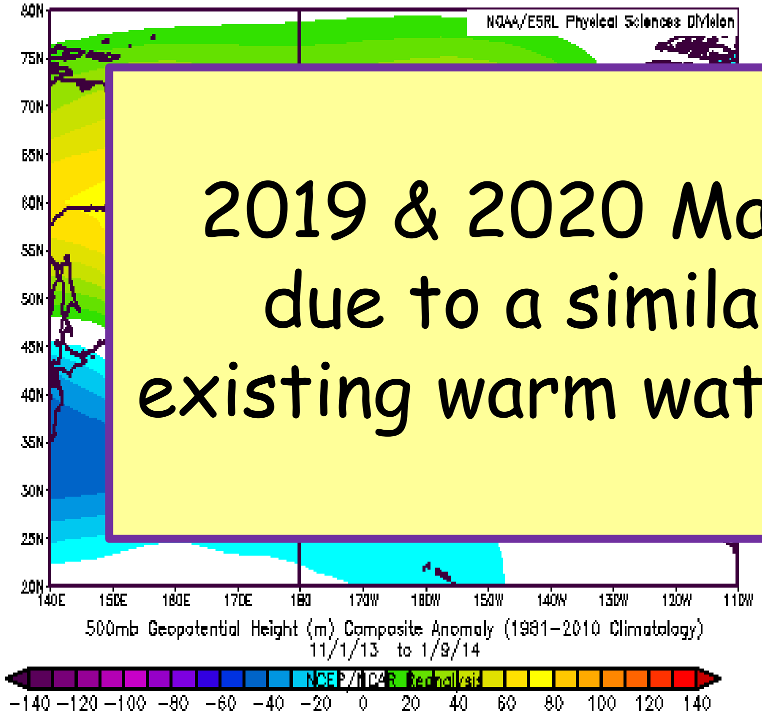
How the blob formed (Winter 2013/14):

Winter storms normally mix and cool the ocean

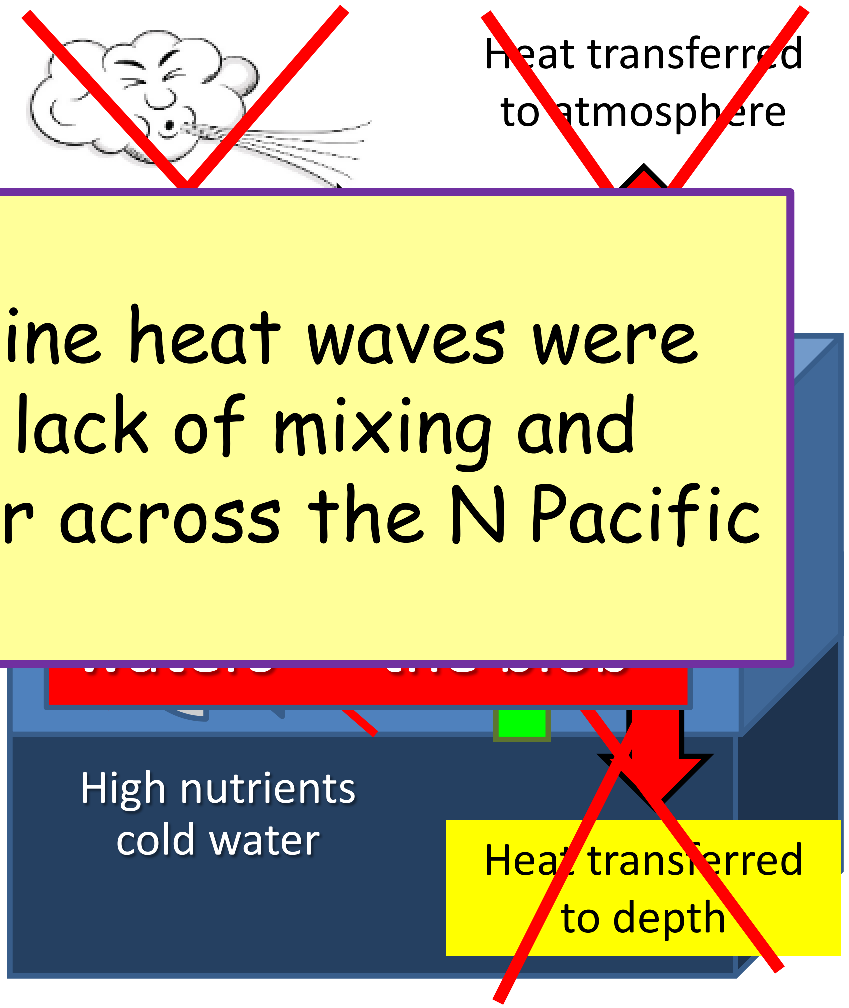


How the blob formed (Winter 2013/14):
Unusual high pressure blocked storms which limited mixing

Ridiculously resilient ridge

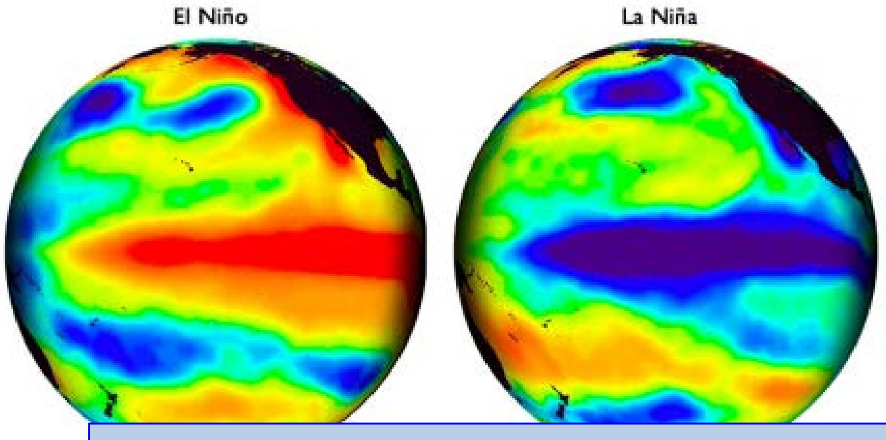


Atmospheric pressure anomalies, Nov 1, 2013-Jan 9, 2014



2019 & 2020 Marine heat waves were due to a similar lack of mixing and existing warm water across the N Pacific

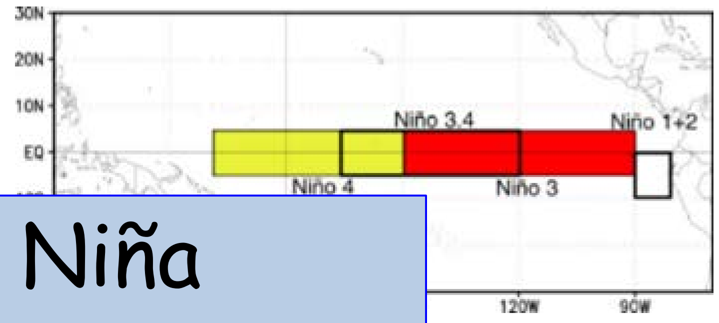
El Niños and La Niñas: Tropical phenomena that impact global weather



Measured as 5 consecutive 3-month SST anomalies in the Niño 3.4 area:

El Niños > +0.5°C

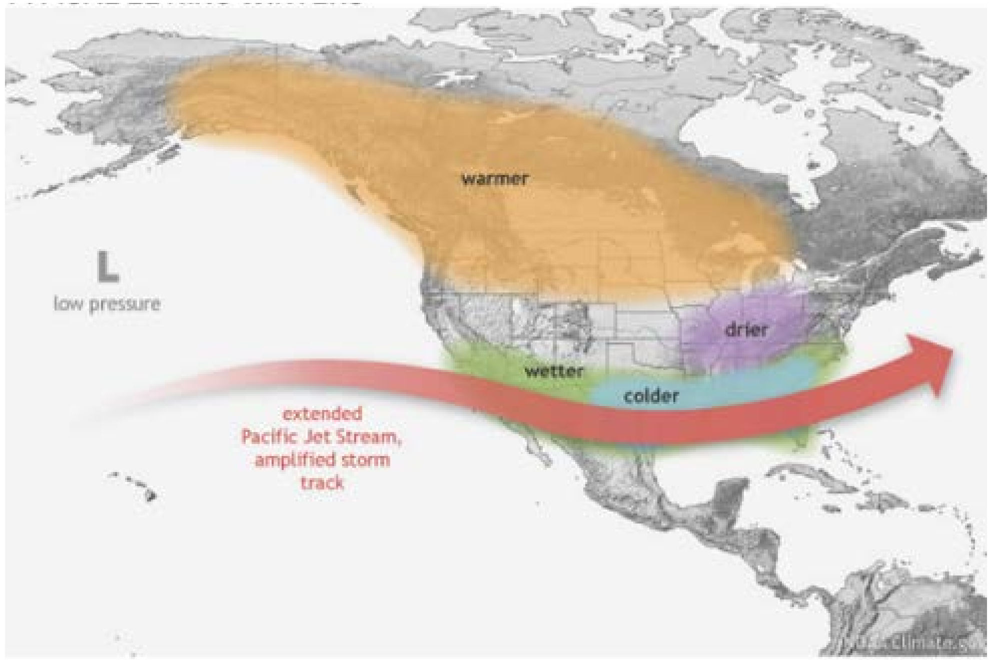
La Niñas < -0.5°C



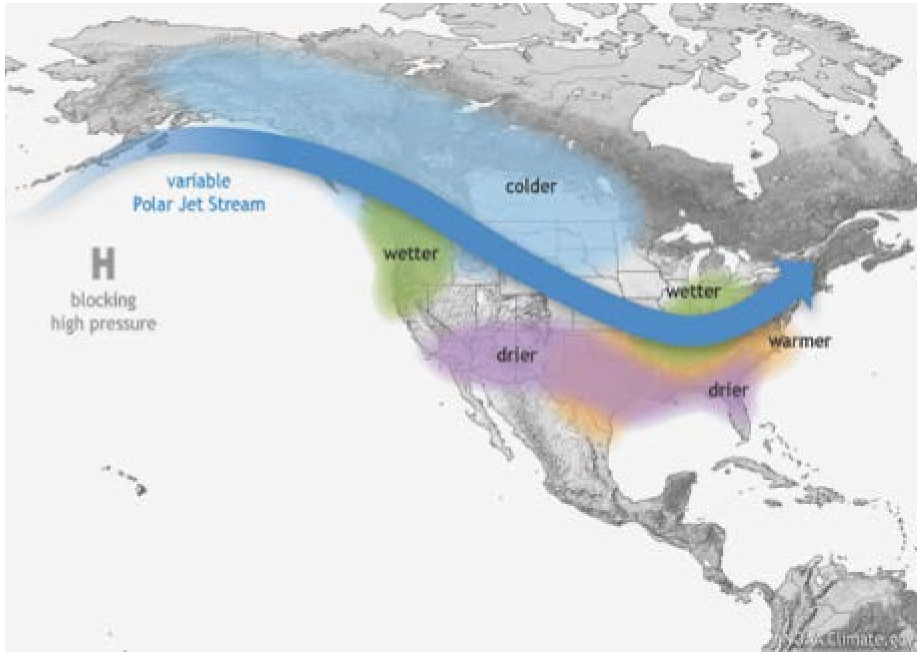
Current conditions: La Niña conditions are present at the equator

Influence of El Niño and La Niña events on North American winter weather

El Niño winters

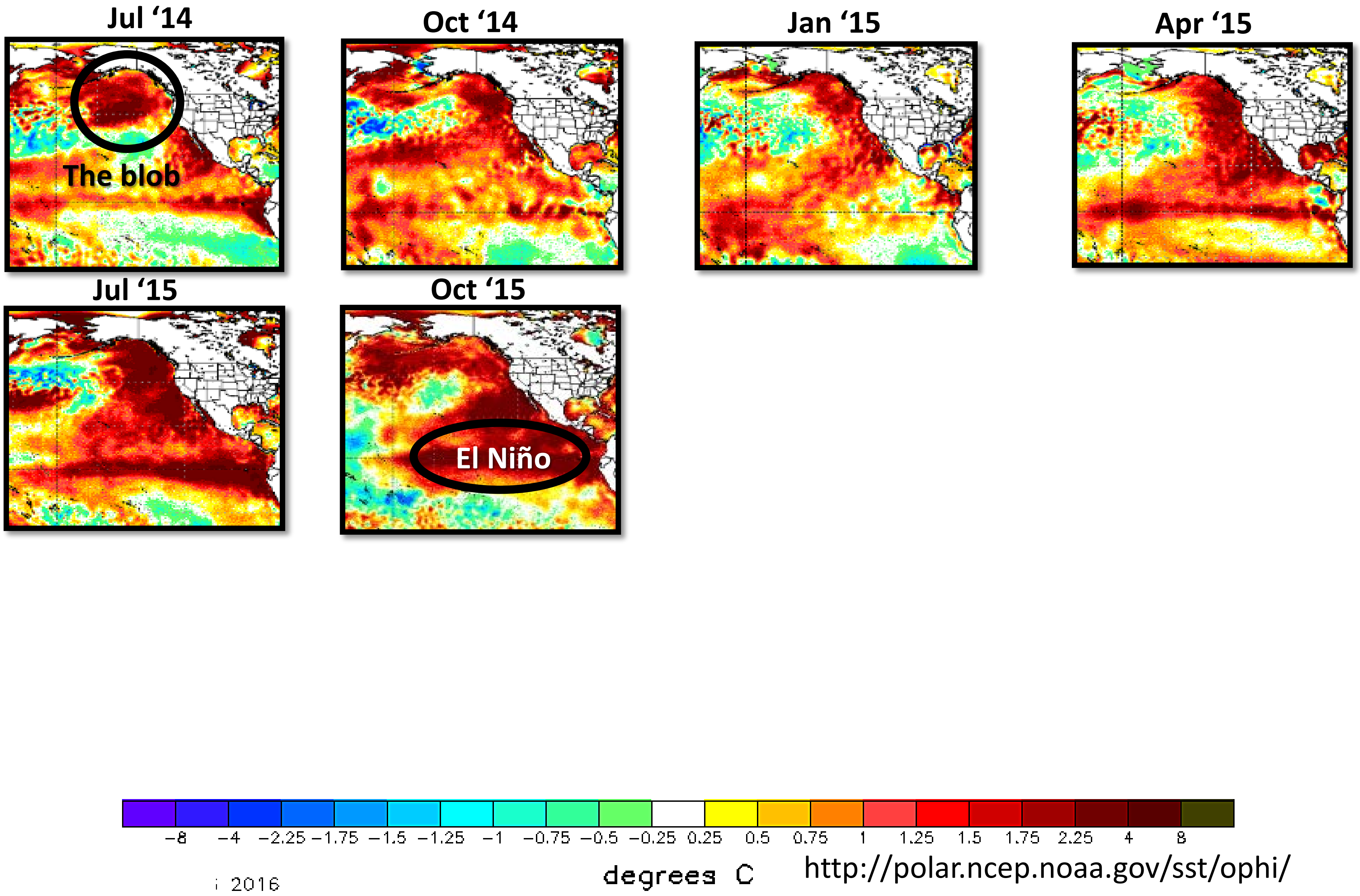


La Niña winters

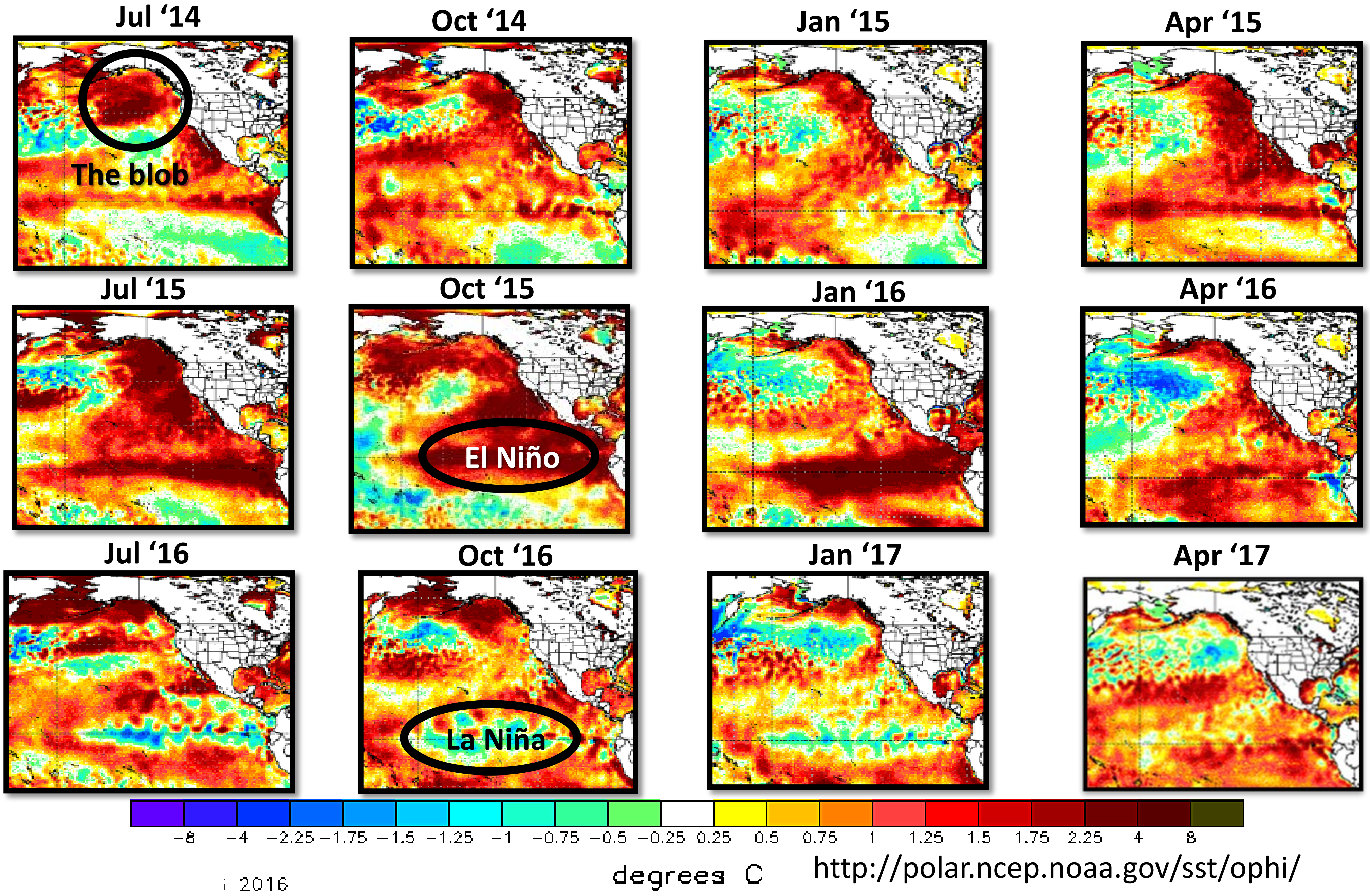


https://www.pmel.noaa.gov/elnino/what-is-el-nino

North Pacific surface temperature anomalies

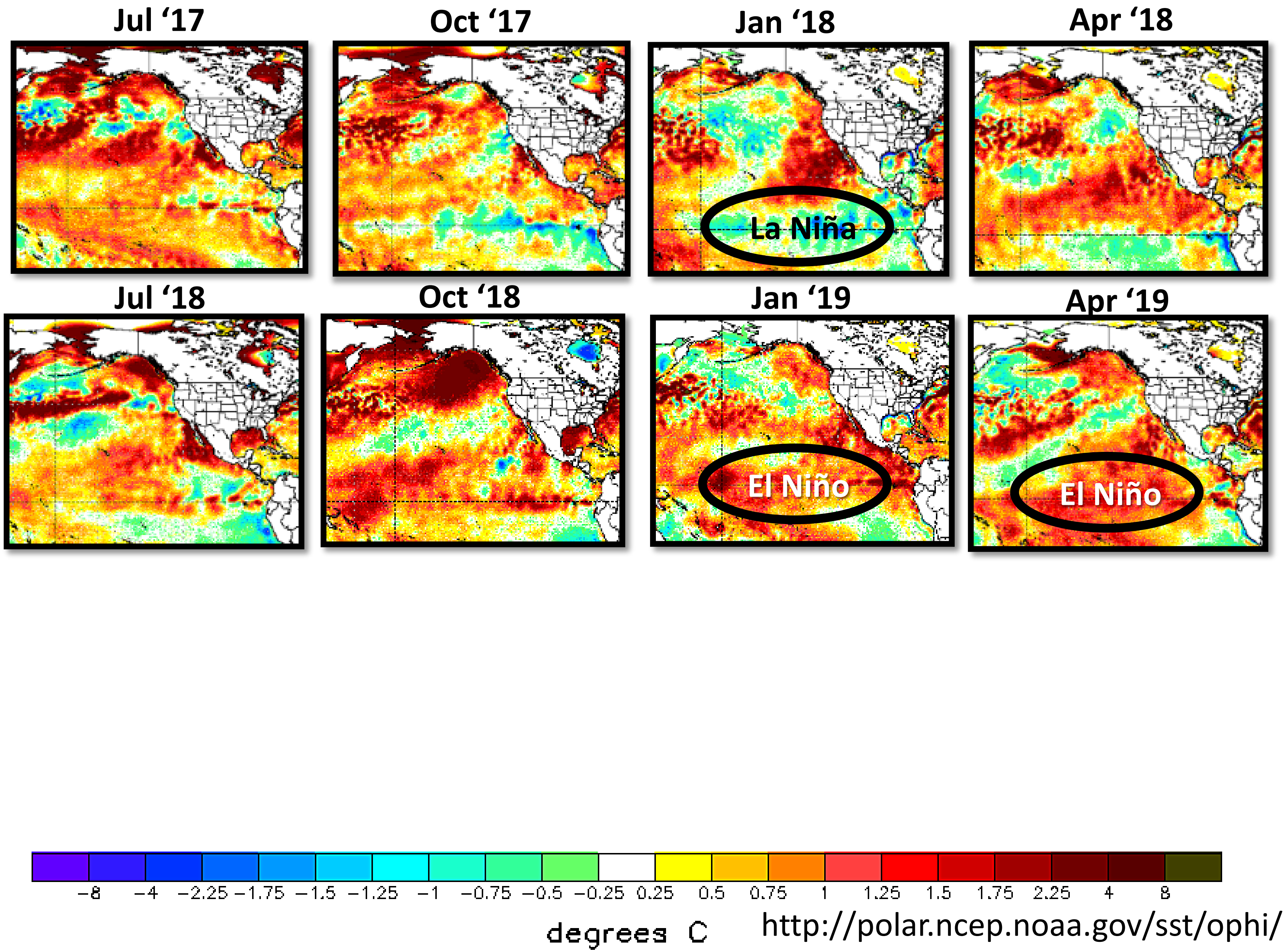


North Pacific surface temperature anomalies



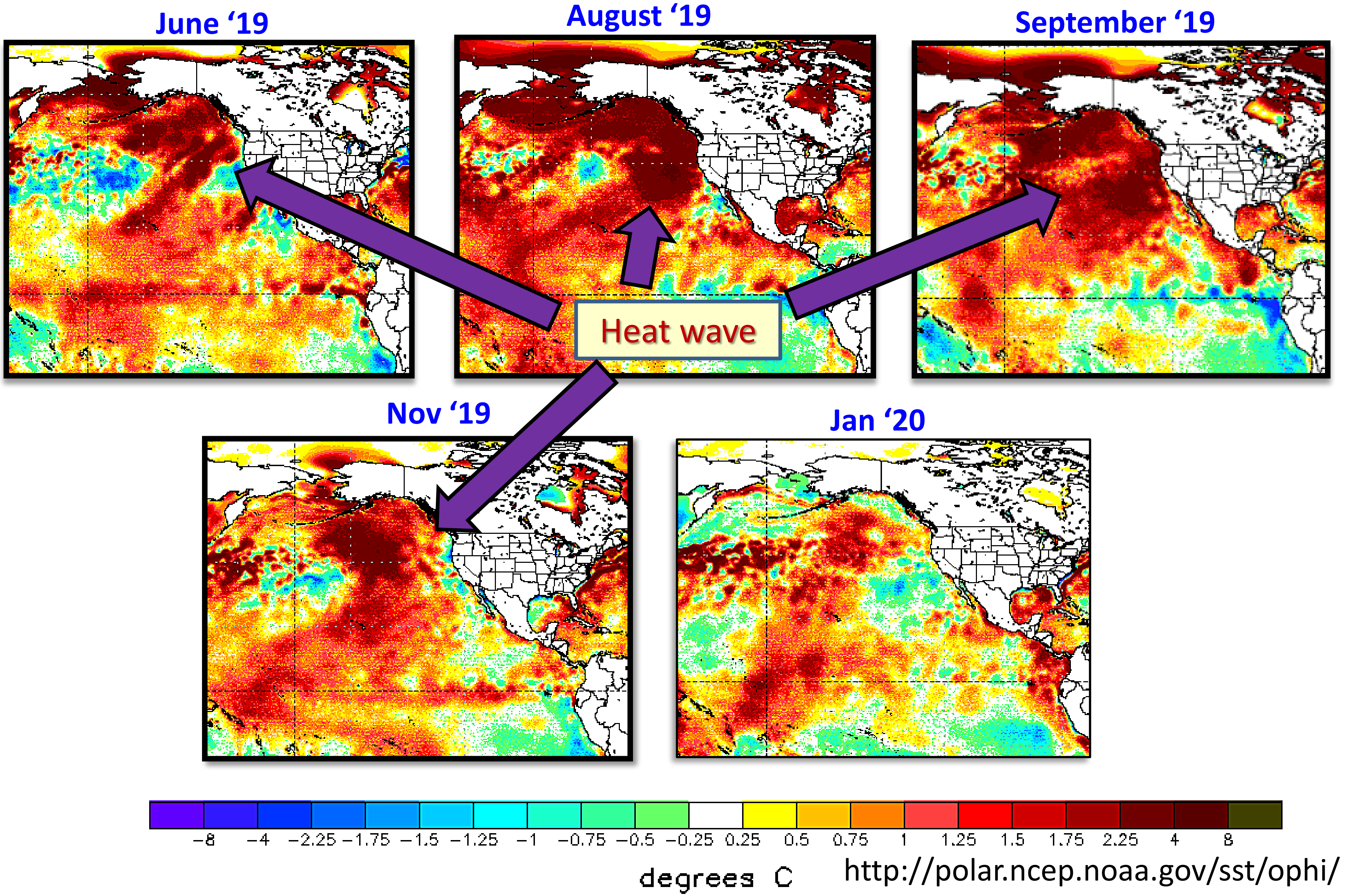
http://polar.ncep.noaa.gov/sst/ophi/

North Pacific surface temperature anomalies



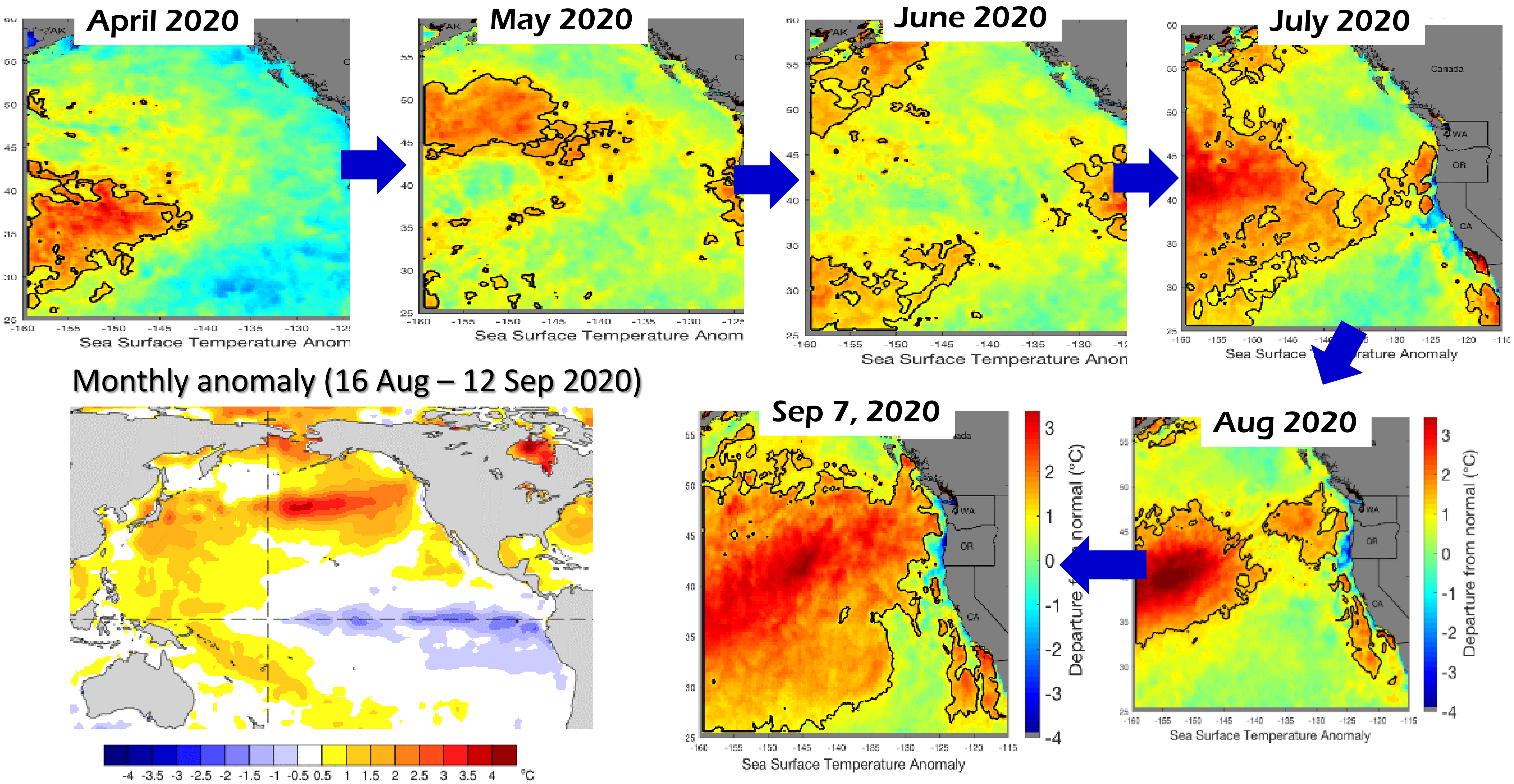
http://polar.ncep.noaa.gov/sst/ophi/

Recent ocean conditions: North Pacific surface temperature anomalies



http://polar.ncep.noaa.gov/sst/ophi/

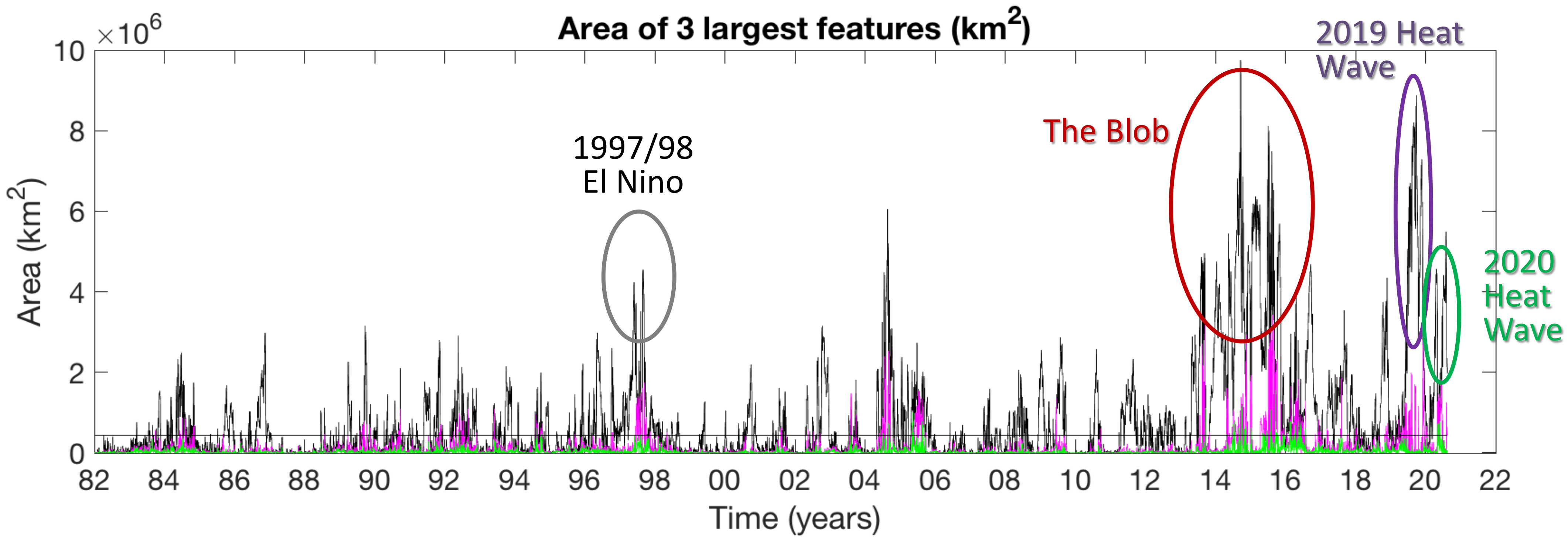
The 2020 marine heat wave: sea surface temperature anomalies



https://www.integratedecosystemassessment.noaa.gov/regions/california-current/cc-projects-blobtracker

California Current IEA Marine Heat Wave Tracker

https://www.integratedecosystemassessment.noaa.gov/regions/california-current/cc-projects-blobtracker



2. Biological response to physical conditions

Barracuda caught in Alberni Inlet, BC, summer 2020
THE CANADIAN PRESS/HO-Tyler Vogrig

<u>Highlights</u>

A. Extremes across the N Pacific
B. Commercial landings
C. Adult salmon returns, AK to CA

<u>Bottom line</u>

- Huge response to physical conditions at all trophic levels across NE Pacific.
- **Biological lags** mean response will continue for several more years.

Biological lags

Early life stages (egg, larvae, juveniles) most susceptible to environmental variation. Don't see results until animals reach commercially important ages.

A. Extreme biological response to warm oceans

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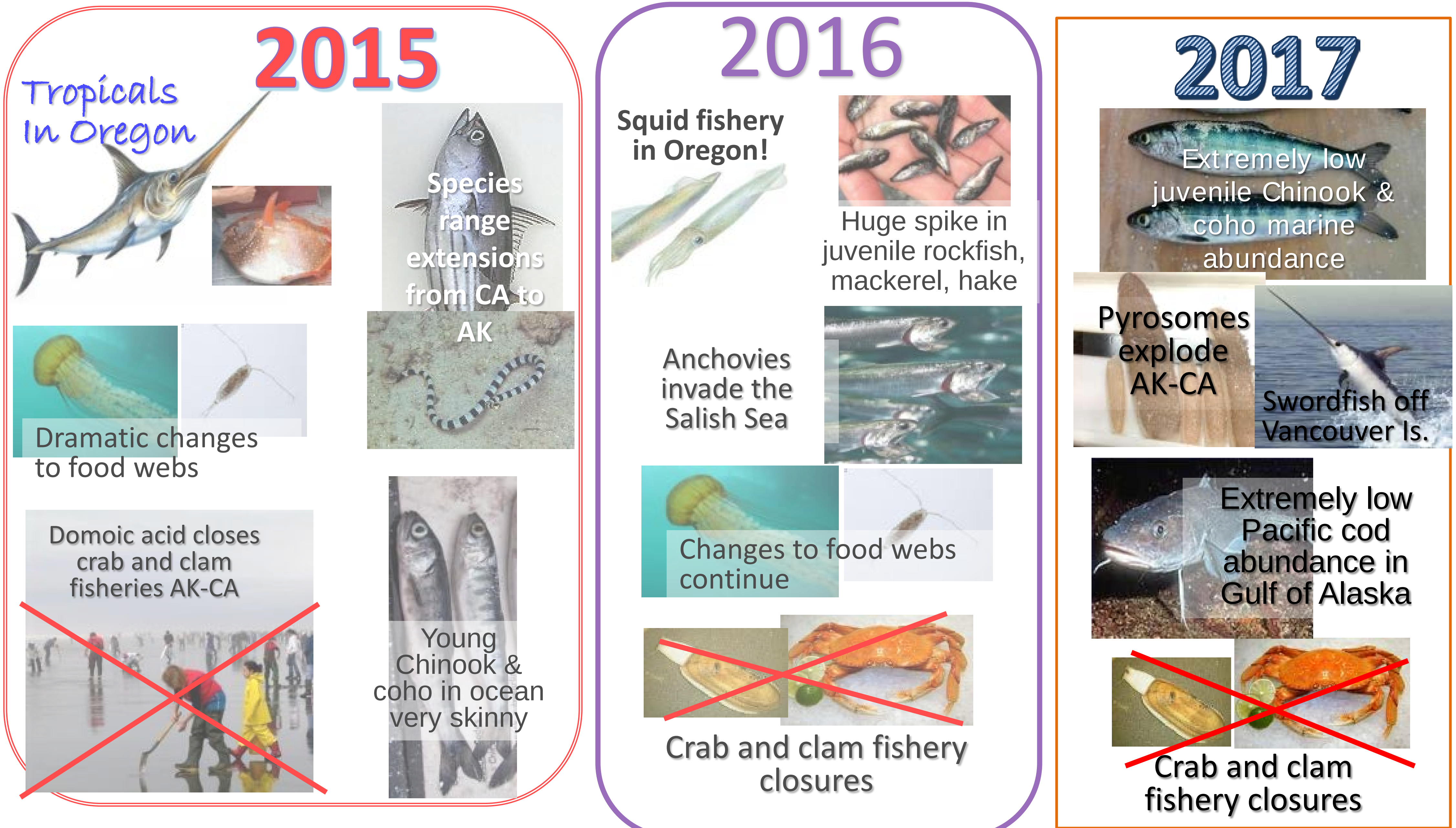

A. Extreme biological response to warm oceans

2018

Big hypoxia event caused crab die-offs

Huge squid fishery in Oregon!

Some warm water fish still around

Pyrosomes thick in spring, gone by fall

Zooplankton returning to “normal”

Continuing crab and/or razor clam fisheries closures due to domoic acid

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2019

Squid boats in Newport, big squid fishery

They're back! Invasion of subtropical fishes on West Coast

Striped marlin

Yellowtail Jack

Zooplankton "normal"

Domoic acid still present in Oregon & N California

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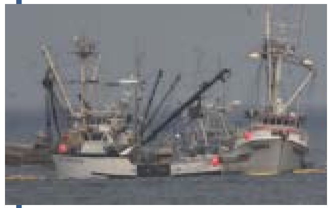
2020



Squid boats in OR/WA, **HUGE** squid fishery

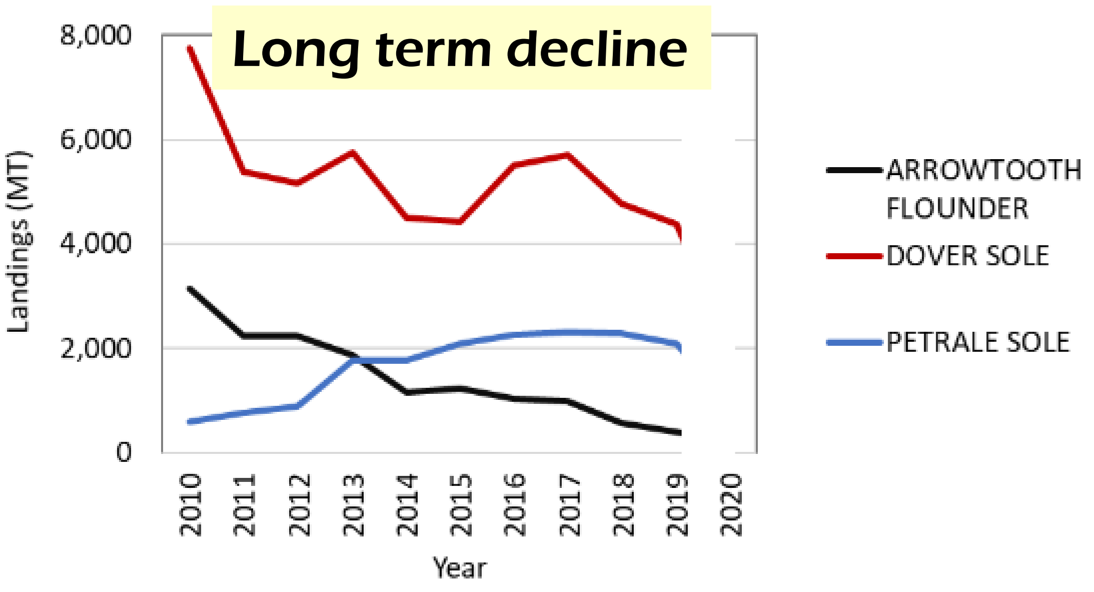
Subtropical fish on West Coast

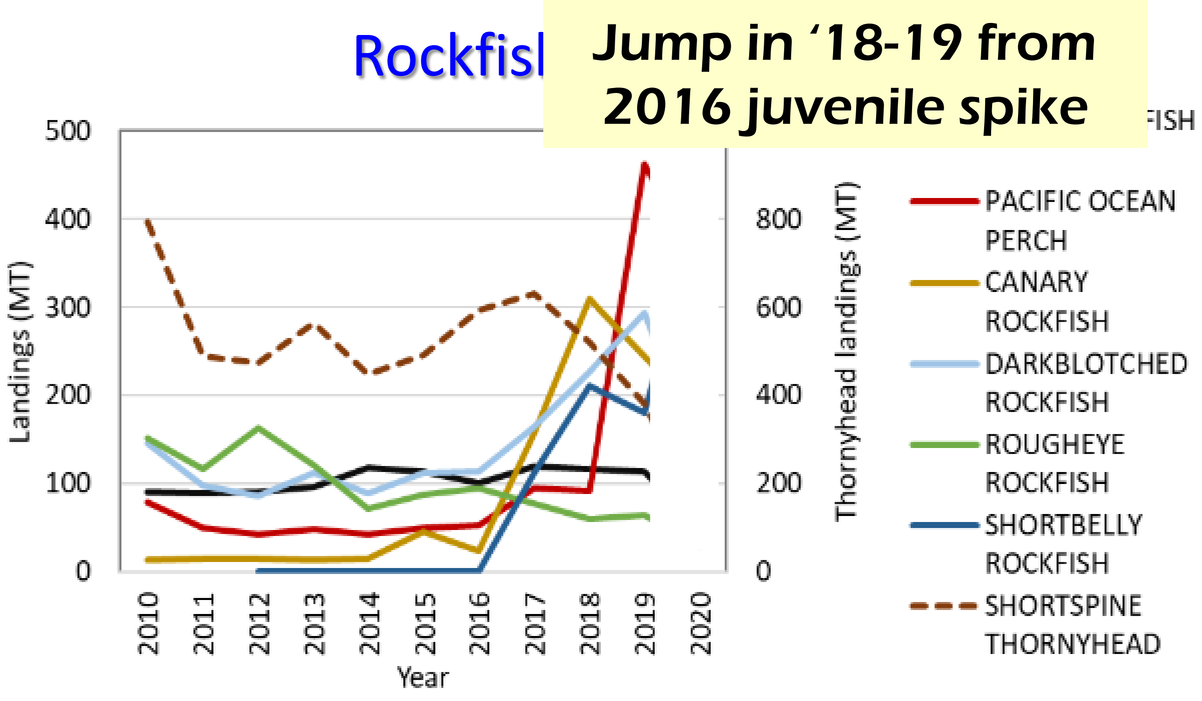
Zooplankton “normal”

Domoic acid still present in S Oregon & N California

B. Commercial landings from WA & OR

Flatfishes



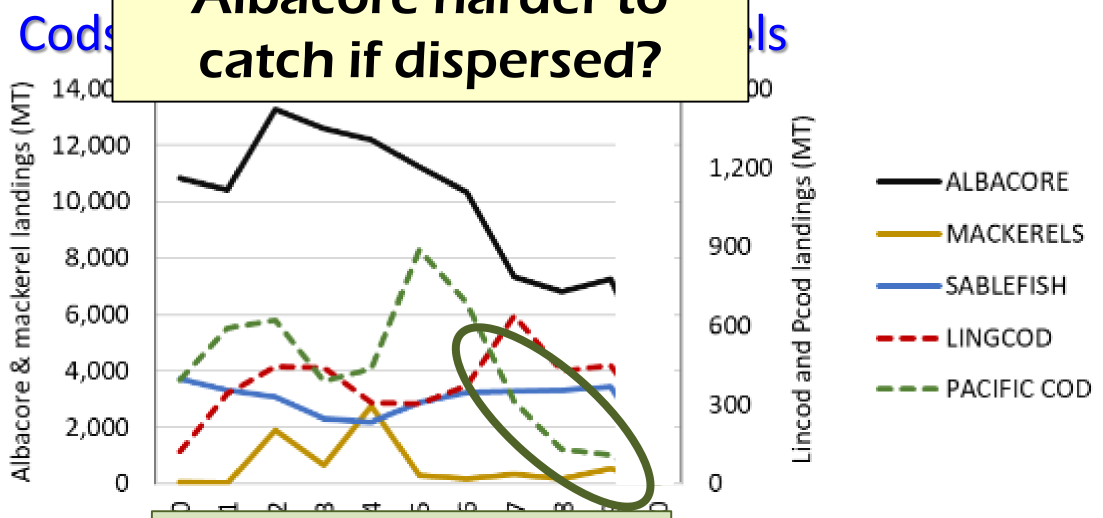


Dashed line = right axis

Data from PacFIN (http://pacfin.psmfc.org/)

B. Commercial landings from WA & OR

Albacore harder to catch if dispersed?



Pacific cod decline

Dashed line = right axis

Data from PacFIN (http://pacfin.psmfc.org/)

C. Unusual adult salmon returns, AK to CA

- Some populations doing extremely well, others not so much
- Due largely to differences ocean distributions and therefore favorable or harsh conditions they encounter.

First summer in the ocean:
3 patterns for Columbia River salmon

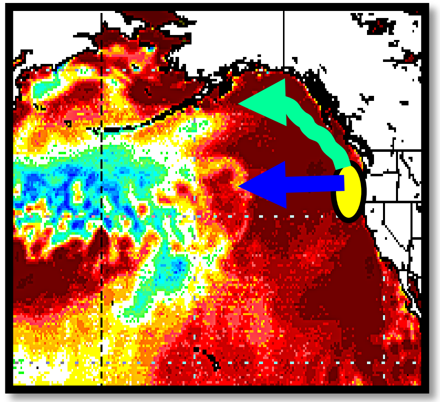
Pattern 1: Rapid north-wards movement on shelf to Gulf of Alaska
Which: Spring Chinook, chum, sockeye, some coho

This is when most marine mortality is thought to occur

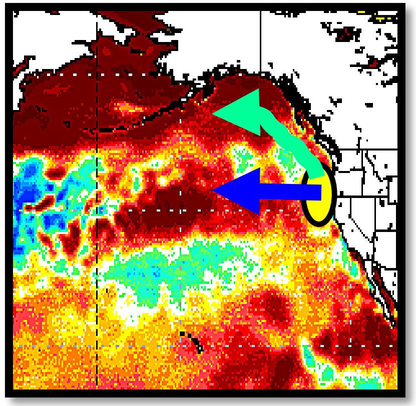
Initial ocean migrations of Columbia River salmon in recent Julys

(shading = sea surface temperature anomalies)

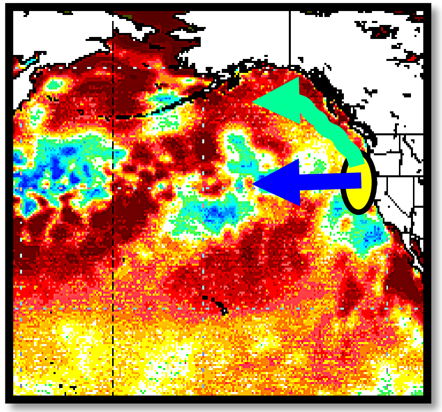
July 2015



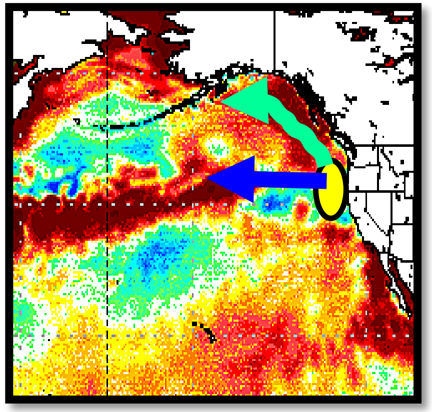
July 2016



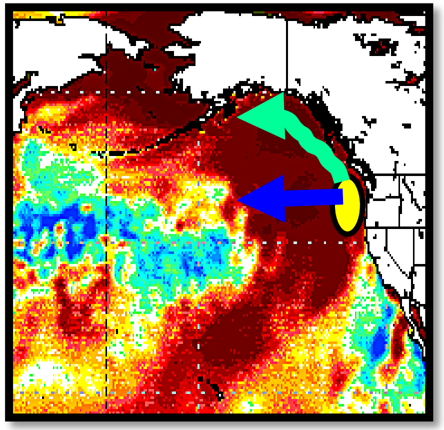
July 2017



July 2018



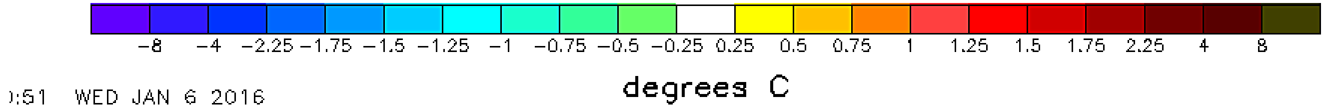
July 2019



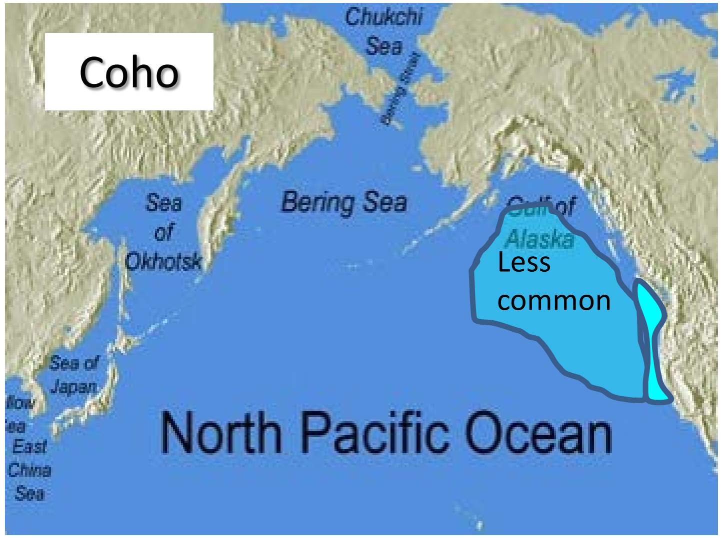
Spring Chinook, sockeye

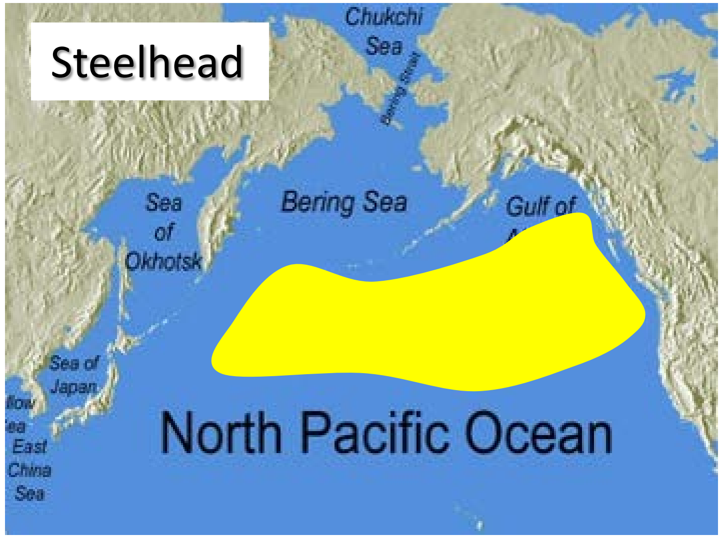
Steelhead

Fall Chinook, coho



Columbia River high seas distributions (least known period)





Adults returning to the Columbia:
3 general migration patterns

Pattern 1: Southwards movement along shelf

Which: Fall Chinook, Chum (?), sockeye (?)

Pattern 2: Northwards along California & Oregon Coasts

Which: Coho

Pattern 3: Move rapidly onshore (or unknown)

Which: Steelhead, Spring Chinook

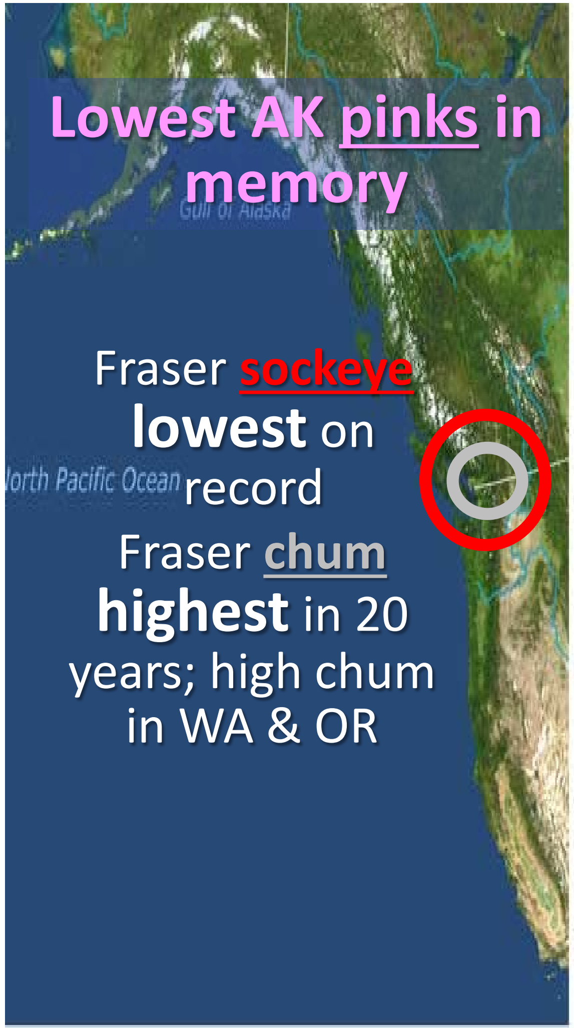
C. Unusual adult salmon observations

2015

C. Unusual adult salmon observations

2015

2016



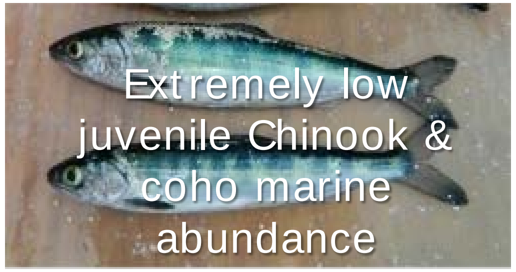
2017

C. Unusual adult salmon observations

2019

4th largest Bristol Bay sockeye return ever (56 mill)

2017



Salmon kills in Alaska due to hot river temps

Offspring of fish killed in 2015 due to high river temps

S. BC closed to Chinook fishing to protect expected extremely low Fraser returns.
Lowest Fraser River sockeye return **ever**

Even higher **shad** count across Bonneville Dam (7.5 million)
Extremely low steelhead return to Columbia

C. Unusual adult salmon observations

2020 (so far)

Modest returns of salmon to AK (all species)

Extremely low sockeye return to Fraser (300K); ~1/3 of expected

Big sockeye return to Columbia (341K)

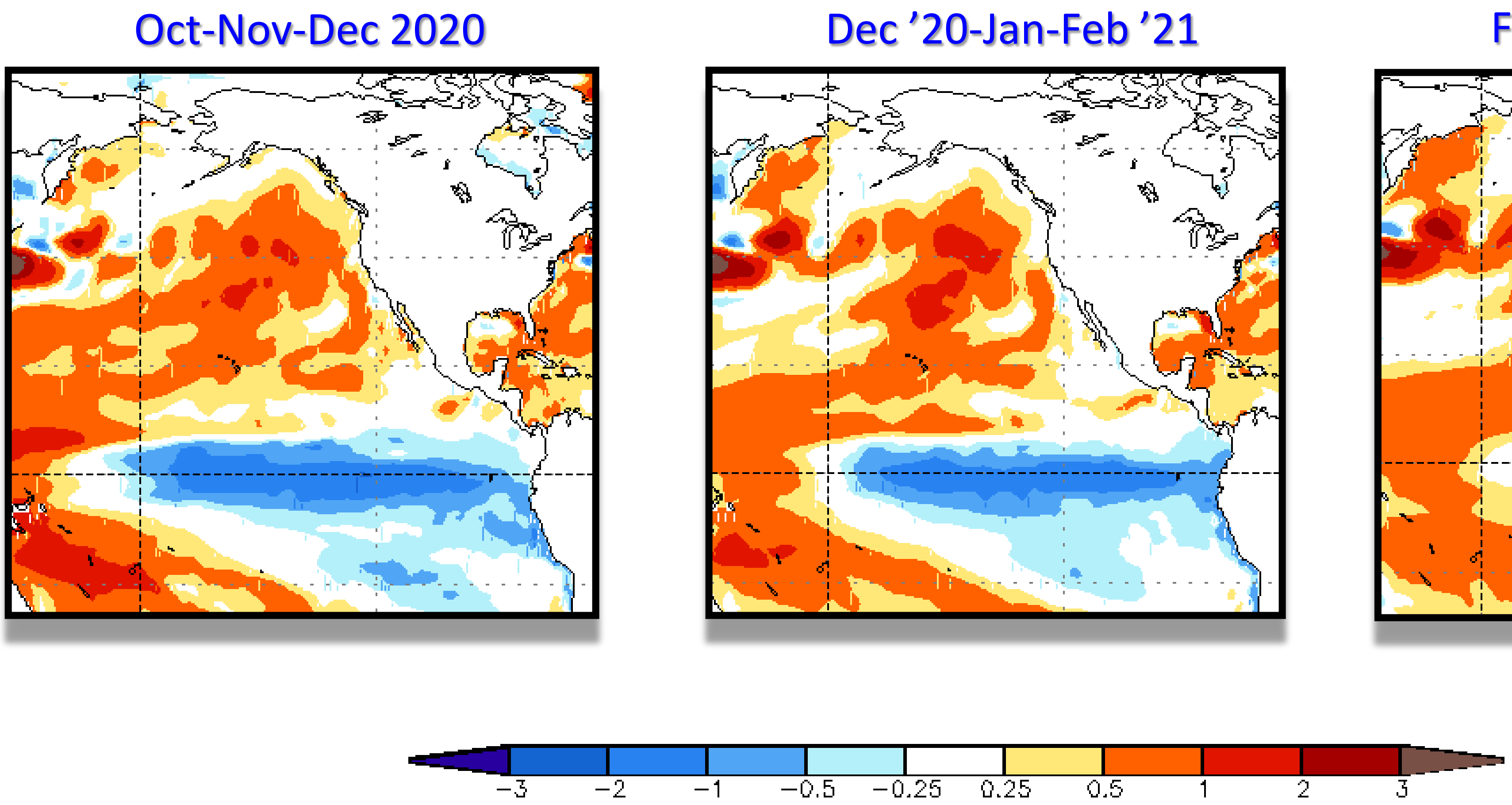
Big **shad** count across Bonneville Dam (5.8 million)

3. Forecasts

- El Nino/La Nina
- SST anomalies

Forecast SST anomalies

NOAA Climate prediction Center coupled forecast model 2

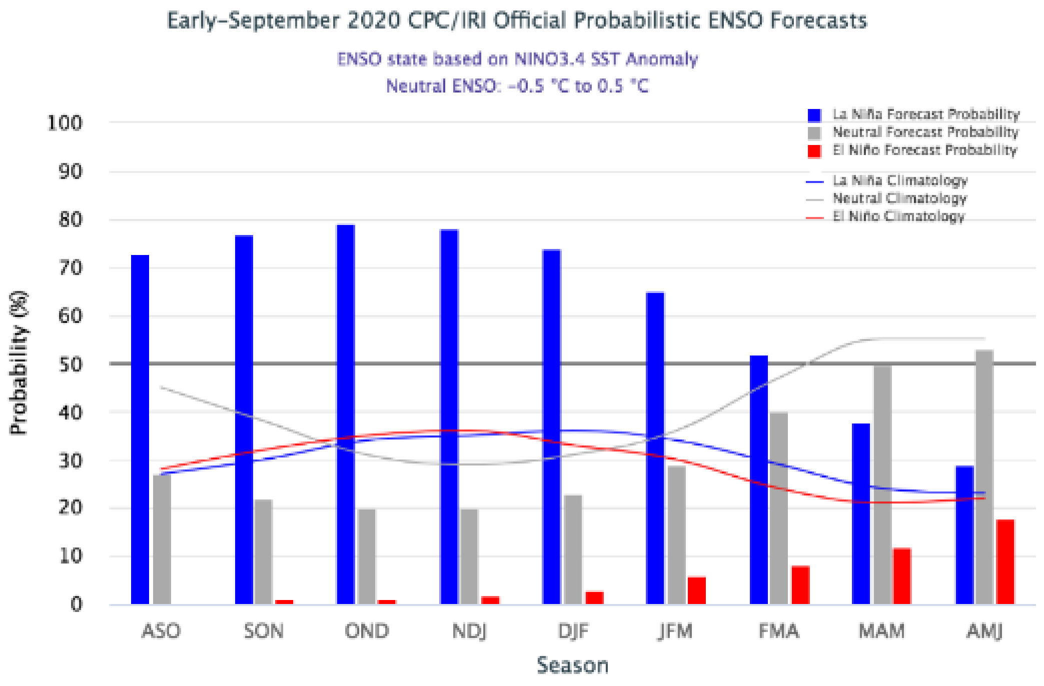


http://www.cpc.ncep.noaa.gov/products/CFSv2/CFSv2seasonal.shtml

ENSO Outlook

Updated: 21 September 2020

ENSO Alert System Status: La Niña Advisory
La Niña conditions are present at the equator and are likely to continue through the Northern Hemisphere winter (~75% chance).

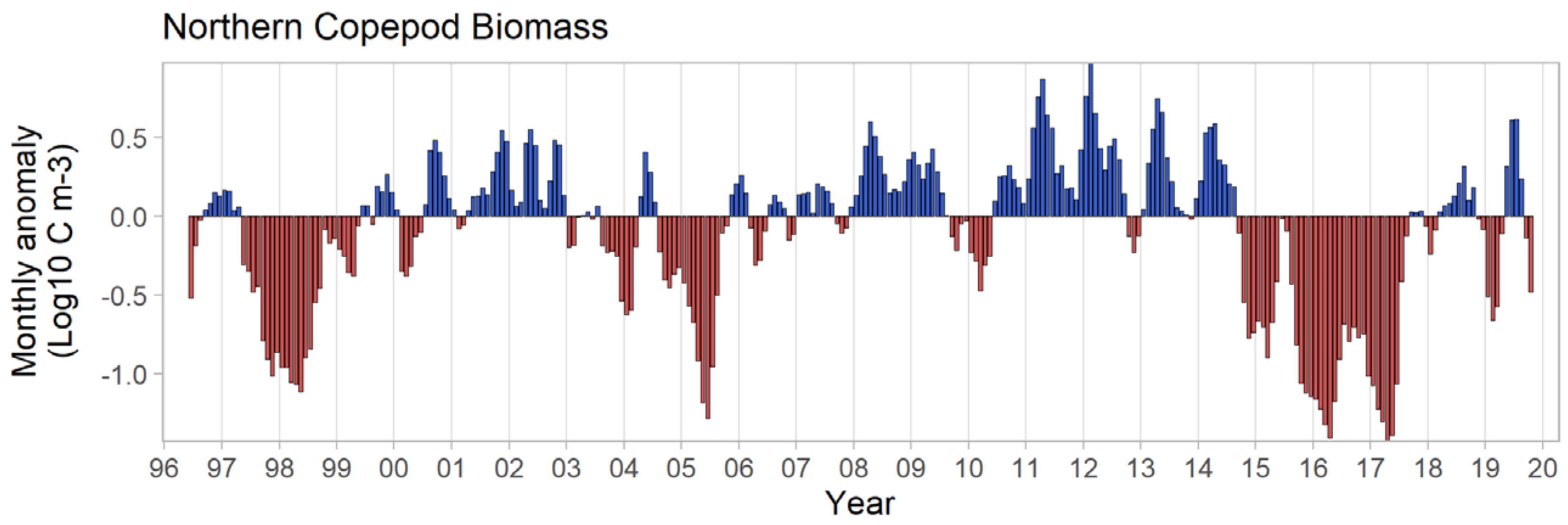


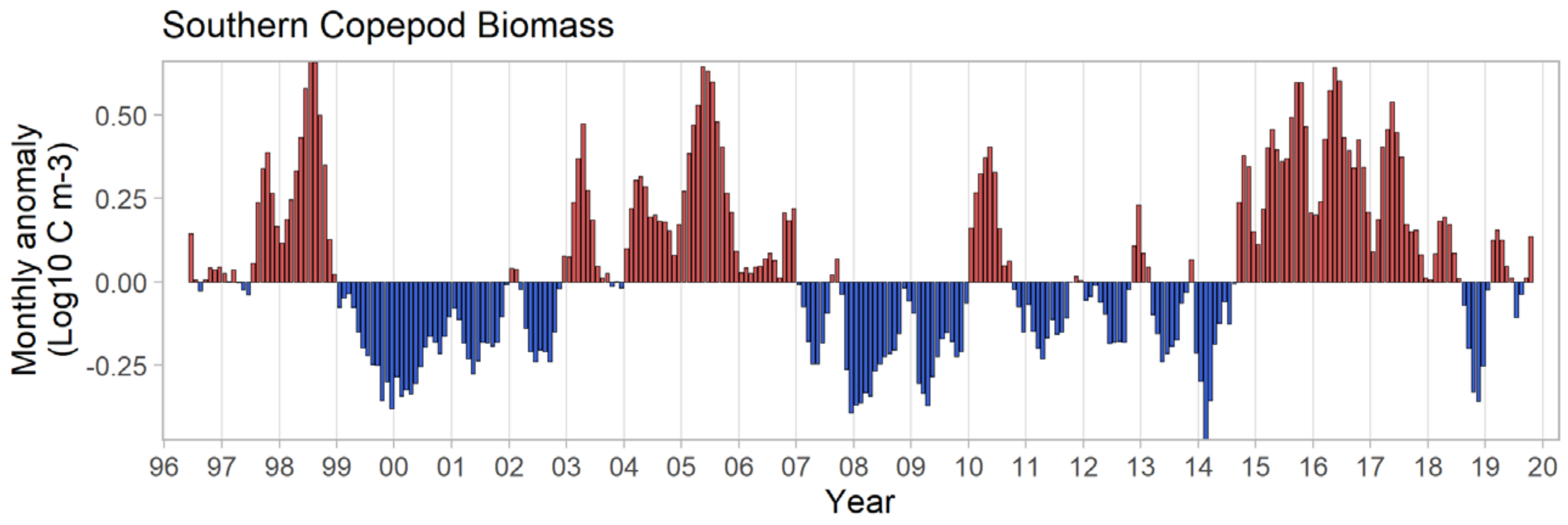
Summary

- Warm ocean waters present since 2014 still continue across large parts of the North Pacific Ocean
- Biological response to warm ocean has been huge
  - Effects observed at all levels of marine ecosystem
  - Expect biological effects of warm ocean conditions will continue for several years (e.g., salmon returns, hake increase)
- A La Niña this winter should cause high snowpack (good river flow next spring)
- Continuing marine heat waves are unlikely to be favorable for cold water species (e.g., salmon, crab).
- **What's next?!**


Questions?
Laurie.weitkamp@noaa.gov

Newport line copepods





Changing behavior? Humpback whales entering large coastal estuaries for anchovy?

2015

Humpback whales in Columbia estuary

2016

Humpback whales in the Columbia estuary & San Francisco Bay

2017

Humpback whales in San Francisco Bay & Columbia River again!

2018

Humpback whales in San Francisco Bay again!

Increased entanglements in crab gear, ship strikes

And **2019**

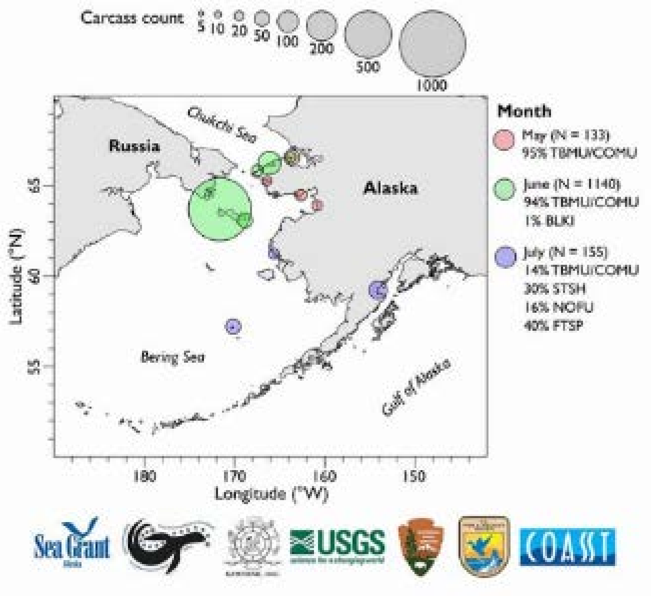
Sea bird die-offs

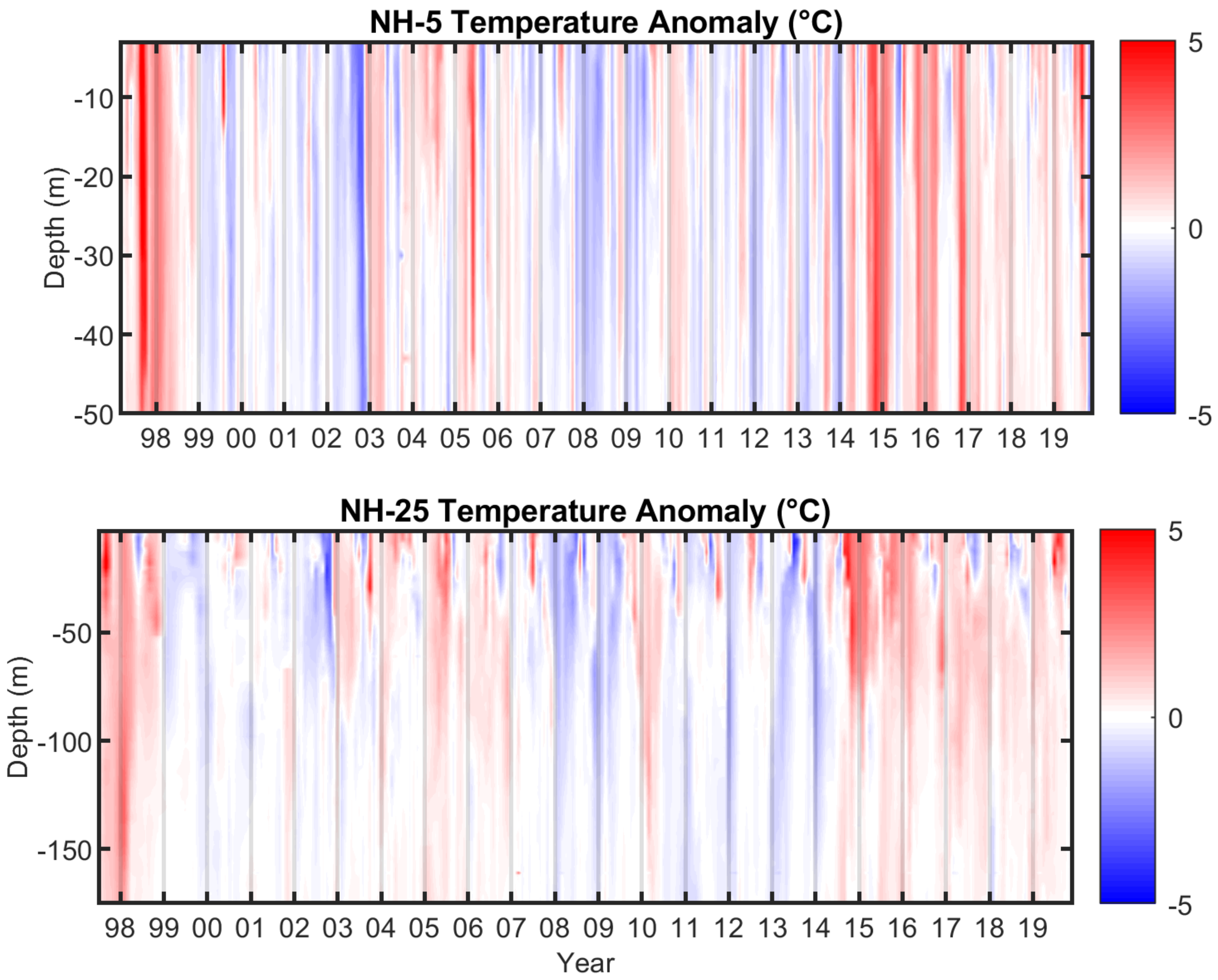
Cassin's Auklets off WA/OR coasts, Winter 2014

Common murres, N. California to Alaska, summer 2015

Fulmars and shearwaters, Bering Sea, summer 2017

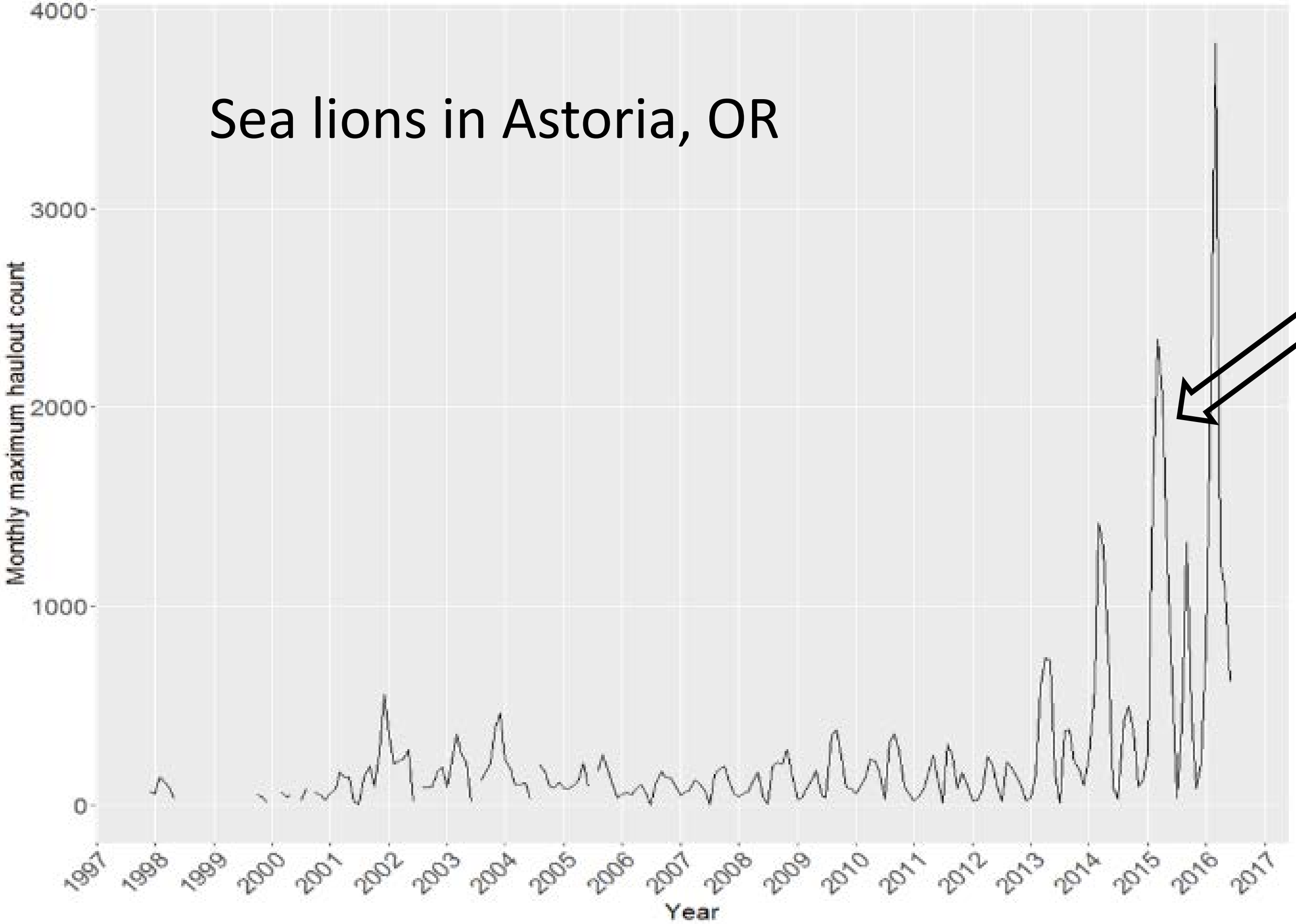
Many species, Bering Sea, summer 2018




NH-5 Temperature Anomaly (°C)
Depth (m)
-10
-20
-30
-40
-50
98 99 00 01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19
5
0
-5
NH-25 Temperature Anomaly (°C)
Depth (m)
-50
-100
-150
98 99 00 01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19
Year
5
0
-5

Bad conditions elsewhere can affect our area: California sea lions left S. California for the Columbia

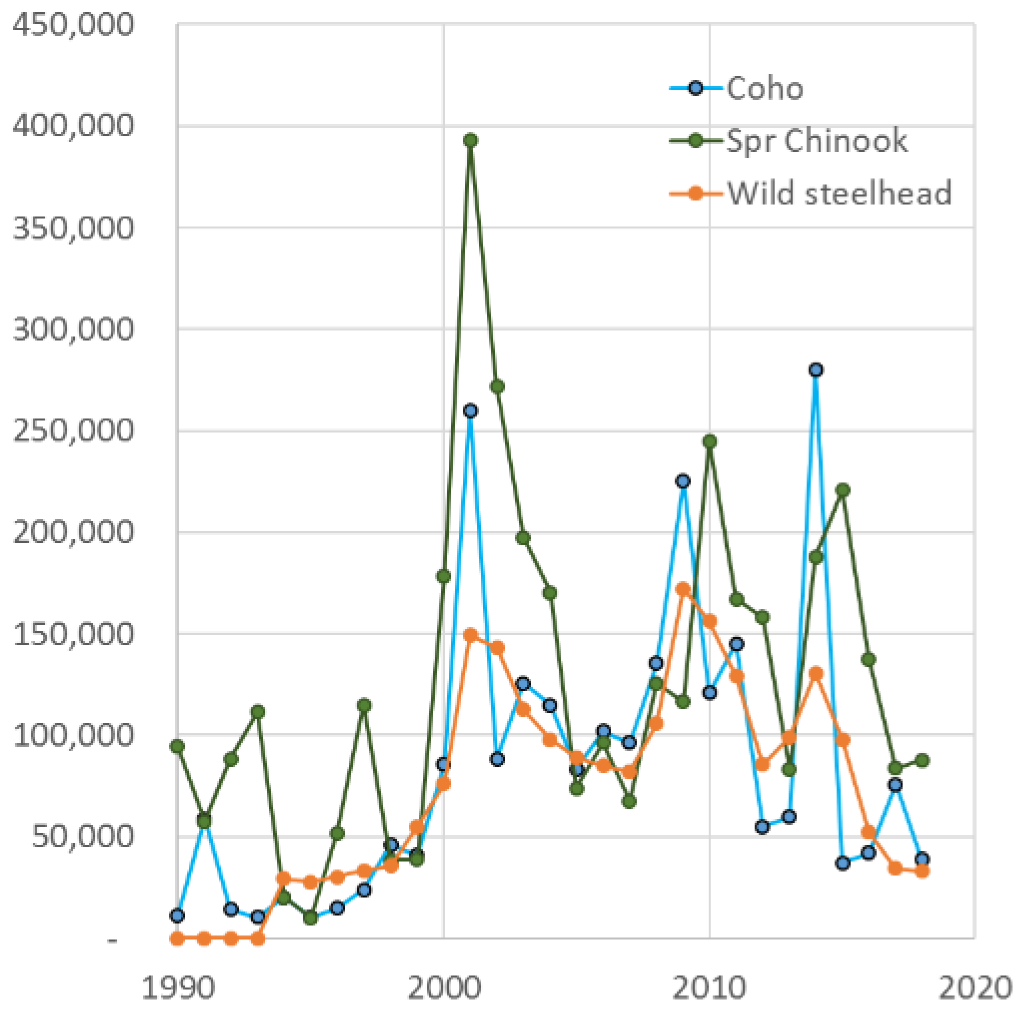
Sea lions on the docks in Astoria

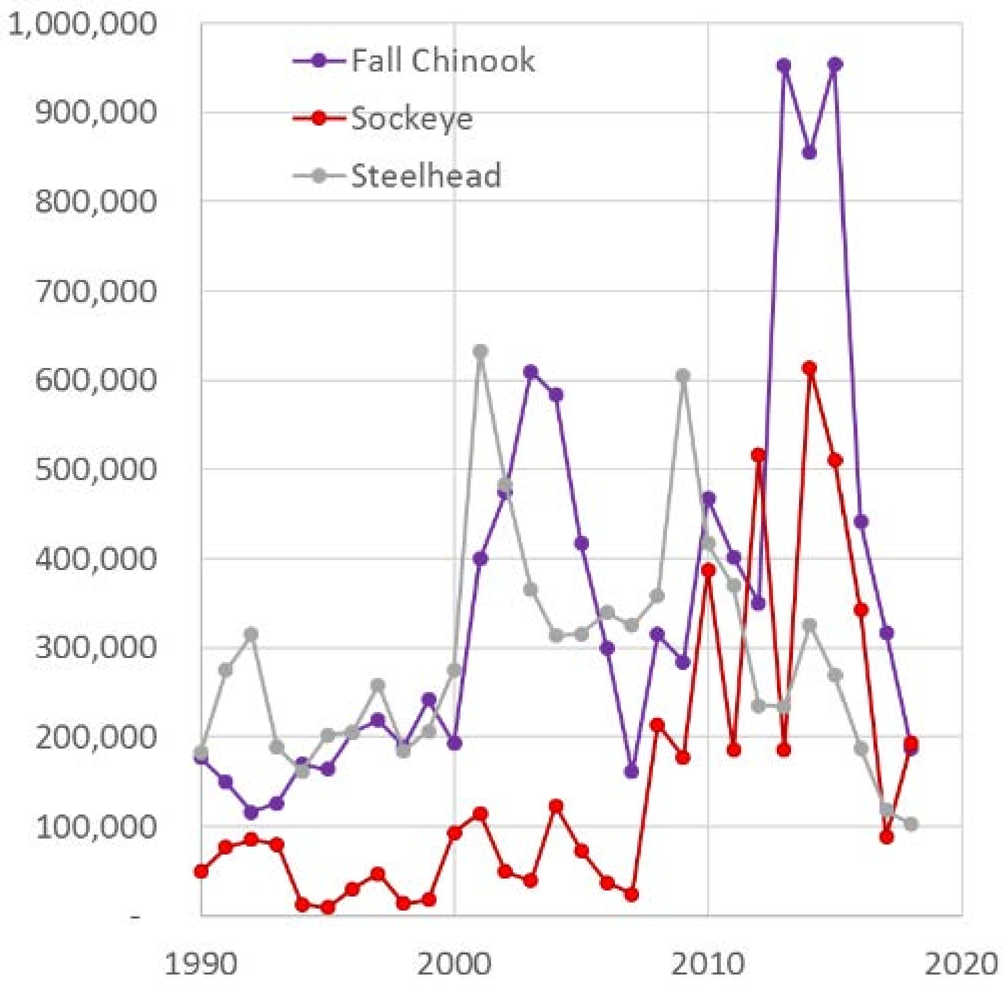


2015: starving sea lion pups in California

Source: Bryan Wright, ODFW

Bonneville Dam Counts



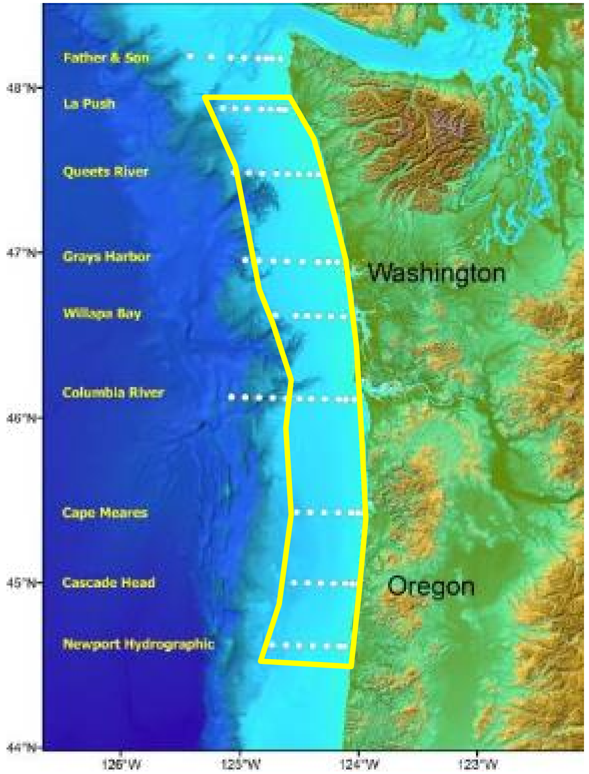


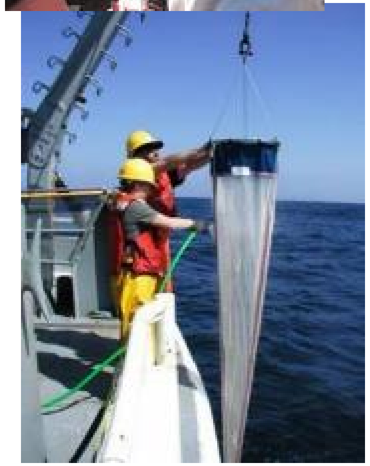
II. Juvenile Salmon Surveys

- Document distribution and condition of juvenile salmon off OR/WA coasts
- 1998 – present (also 1981 – 85)
- Sampling fish community, hydrography, plankton
- Funded by BPA

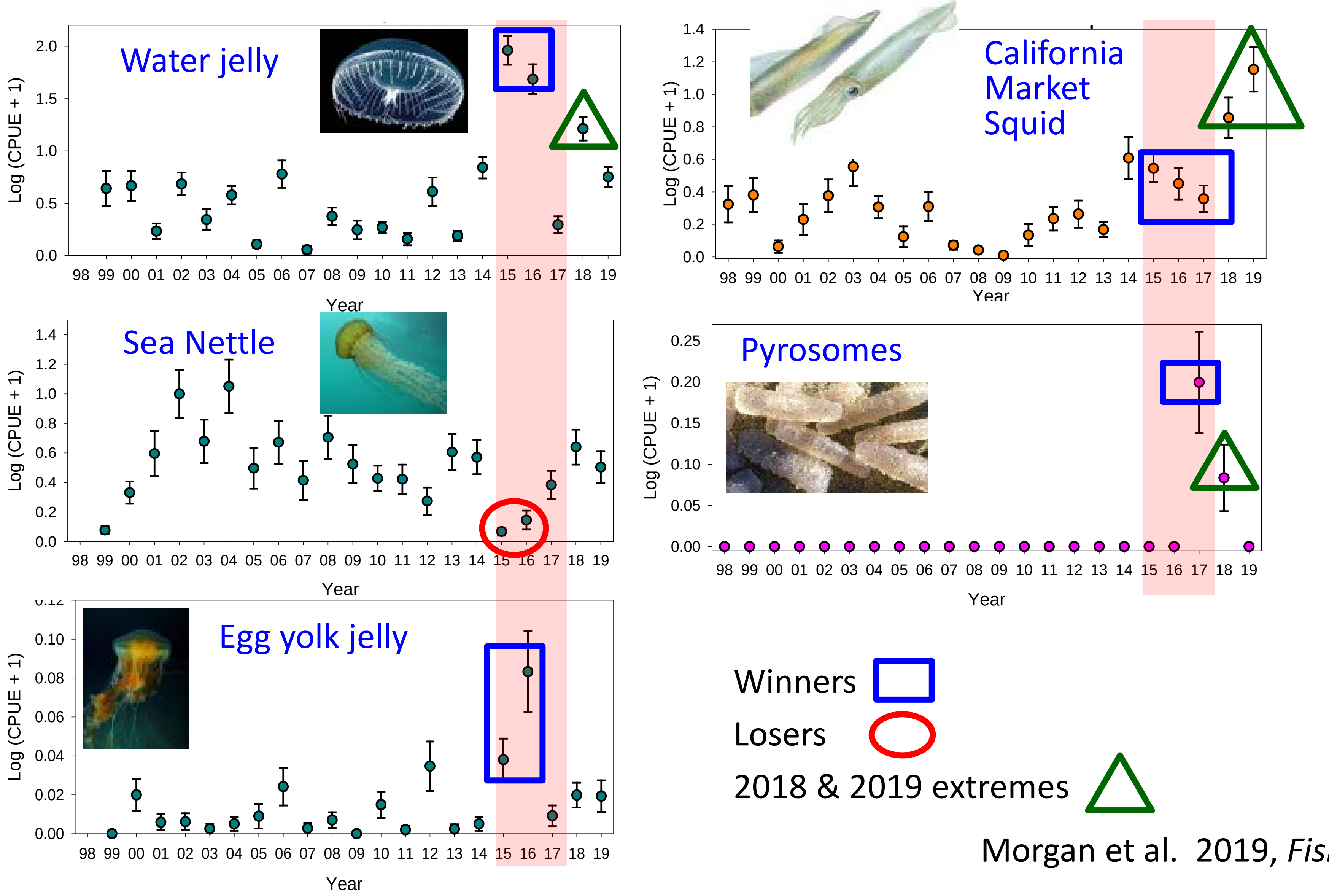
Pearcy

Emmett



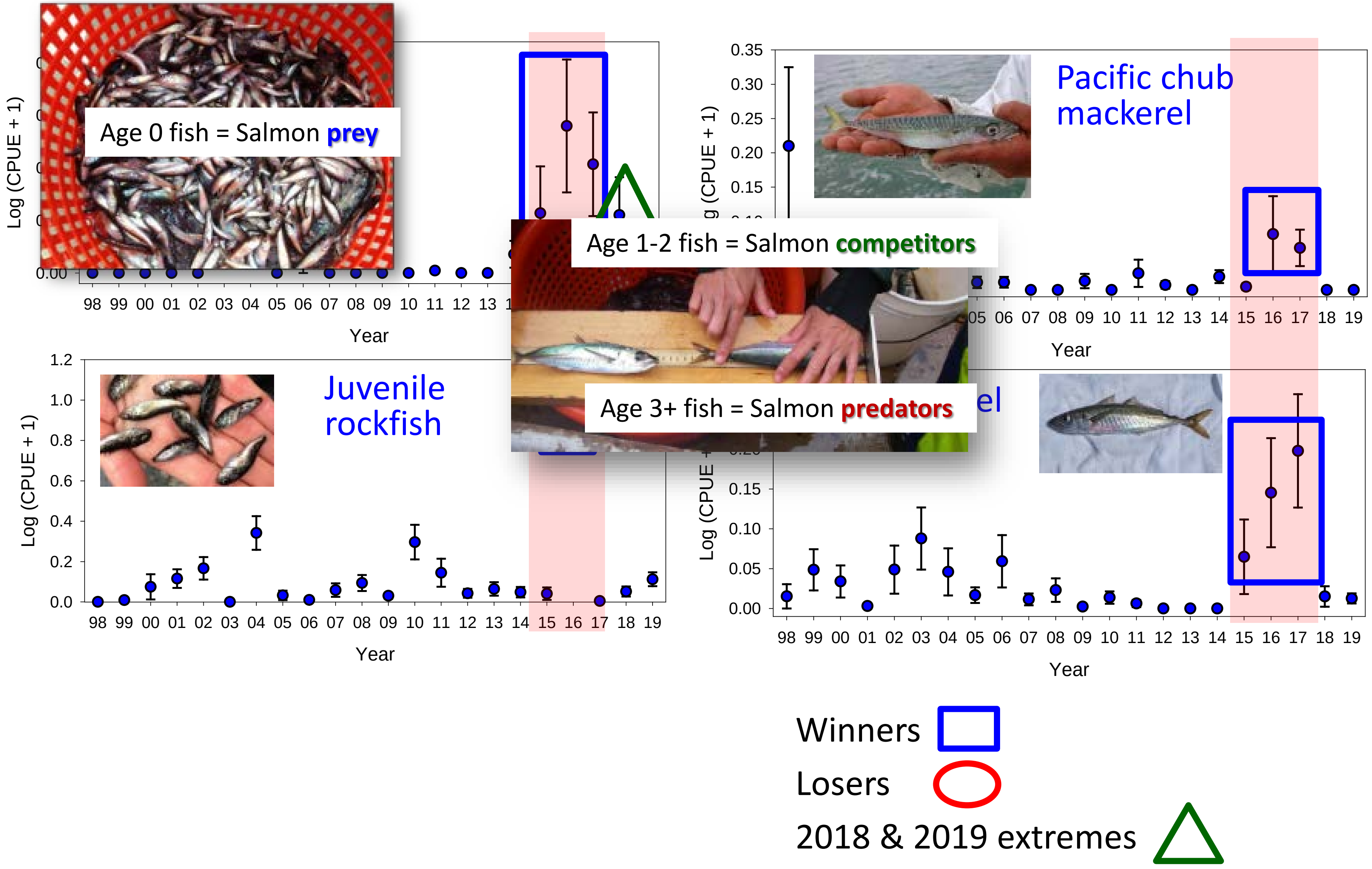


Unusual abundances of **invertebrates** in Juvenile salmon surveys, 1998-2019

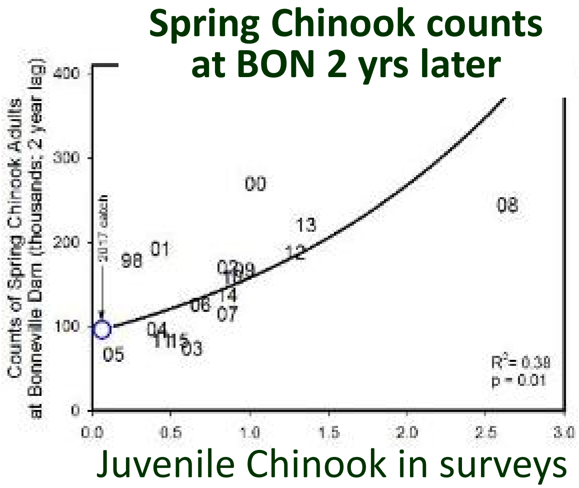


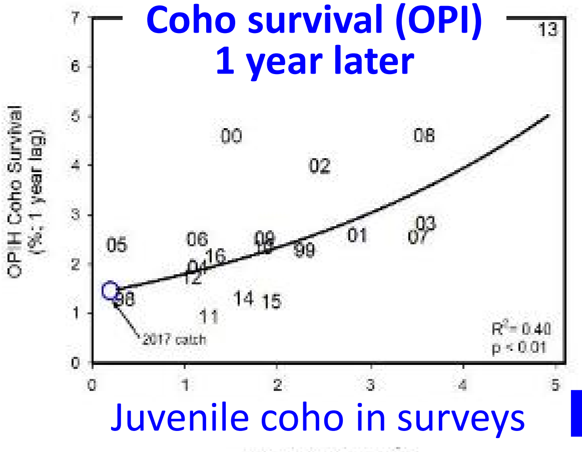
Morgan et al. 2019, *Fisheries*

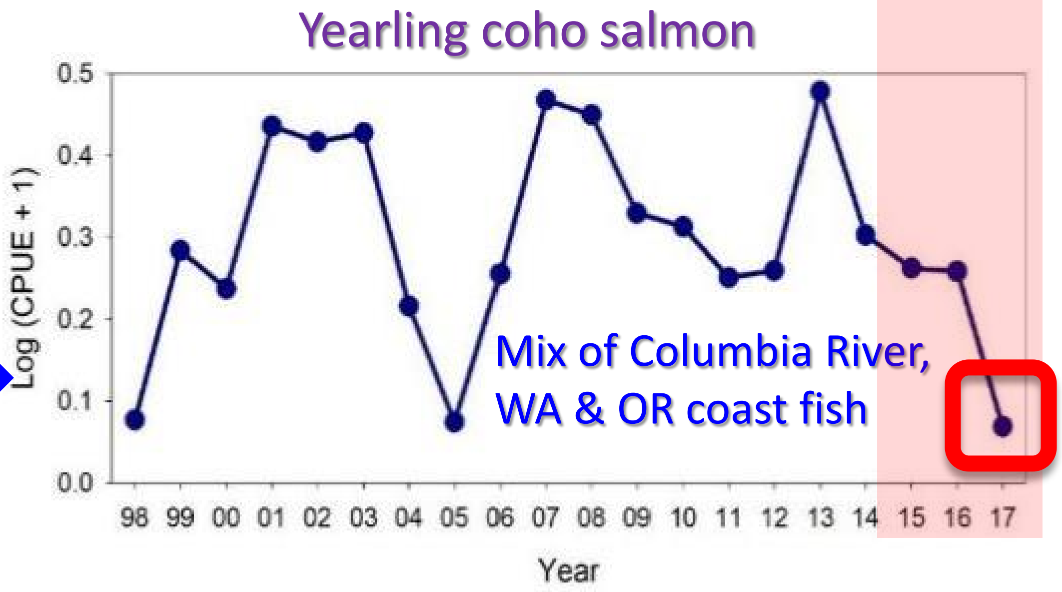
Unusual abundances of fish in Juvenile salmon surveys, 1998-2018



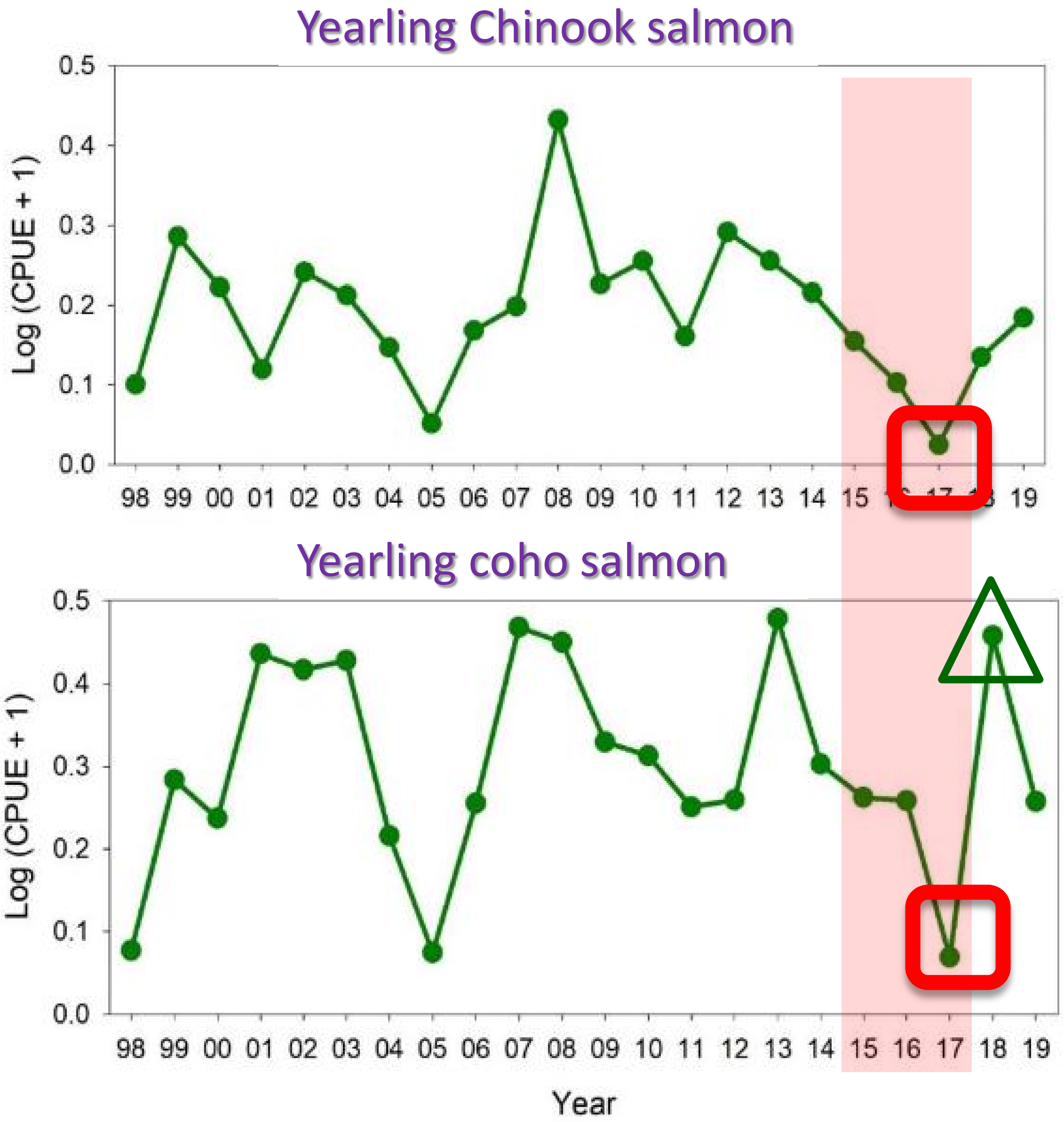
Extremely low juvenile salmon abundances in 2017 resulted in poor coho returns in 2018 & poor spring Chinook in 2019







Juvenile salmon catches in 2018 and 2019 suggested a large coho return in 2019, “normal” in 2020 for both



An unusual gelatinous plankton event in the NE Pacific: The Great Pyrosome Bloom of 2017

by Richard Brodeur, Ian Perry, Jennifer Boldt, Linnea Flostrand, Moira Galbraith, Jacquelynne King, James Murphy, Keith Sakuma and Andrew Thompson

In the winter of 2016, and continuing into summer 2017, people exploring the open ocean beaches of northwestern North America were surprised and puzzled to find strange gelatinous creatures littering the shoreline. These creatures turned out to be colonies of the pelagic tunicate *Pyrosoma atlanticum* (Fig. 1). This species is common in warm open ocean waters throughout the tropics, but along the west coast of North America it has been common only as far north as southern California, and is rarely seen north of the state. However, in the past year these tropical tunicates were highly abundant in the waters from Oregon to British Columbia, and occurred in scientific samples as far north as the Gulf of Alaska. In this report, we examine the magnitude and extent of this anomalous event in the NE Pacific, suggest possible causes, and describe some potential ecosystem implications of this bloom.

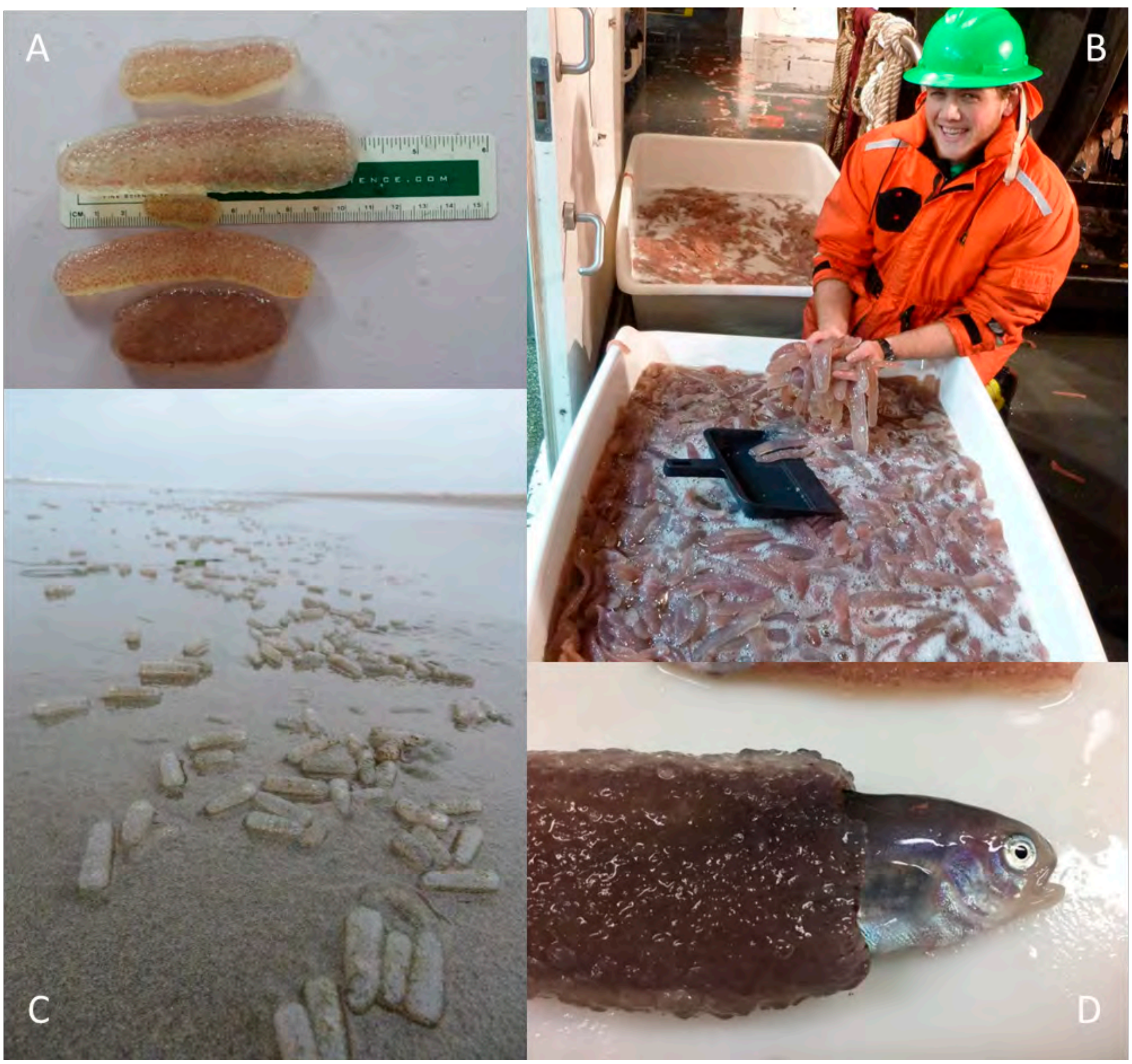


*Fig. 1 A) Close-up of pyrosomes caught in the Gulf of Alaska; B) a large catch of pyrosomes from a pelagic survey off Oregon, C) pyrosomes on a beach off Oregon in November 2017, and D) medusafish (*Icichthys lockingtoni,*) found in the body cavity of a pyrosome caught in pelagic surveys off California.*

What are pyrosomes?

Pyrosomes (Greek for “fire bodies” because of their bioluminescence) are a small group of pelagic tunicates, of which eight species in three genera have been described worldwide. They are colonial, with each colony comprising thousands of individual clones encased in a rigid gelatinous ‘tunic’ that is open at one end (Hirose *et al*., 2001). Individuals draw water from the outside surface and release water into the hollow core of the colony. This provides the colony with a type of hydrostatic ‘skeleton’ and the means for jet propulsion. Although individual pyrosomes are small (mm in size), their colonies can reach lengths of several meters; the species of this NE Pacific event is known to reach over 80 cm in length. Colonies undertake diel vertical migrations, sometimes over 700 m depth (Anderson and Sardou, 1994), and have among the highest phytoplankton clearance rates of any zooplankton grazer (Perissinotto *et al*., 2007). It has been suggested that internal lipid accumulation by pyrosomes is limited, with colonies instead using their food intake to drive high biomass turnover (Perissinotto *et al*., 2007).

The 2017 Pyrosome event in the NE Pacific

Over the past three decades, *P. atlanticum* had occurred regularly in offshore midwater trawl surveys off southern California, but in 2012 there was a notable increase in their numbers coincident with large abundances of salps (another pelagic tunicate) (Wells *et al*., 2017). While their numbers in 2013 were much reduced, pyrosome abundance dramatically increased in 2014 and 2015 resulting in them being the dominant organism collected off the shelf break of California (Sakuma *et al*., 2016). Starting in June 2014, they occurred in pelagic trawl surveys in offshore waters of southern Oregon, moving progressively northward in the summer of 2015 and 2016, but still in waters off the shelf break. Collections were made using near-surface or midwater trawls from research surveys conducted by the National Marine Fisheries Service (NMFS), NOAA and Fisheries and Oceans Canada (DFO) from May through September of 2017 from southern California to the northern Gulf of Alaska (Fig. 2). *Pyrosoma atlanticum* was found at most sampled stations in these surveys, including high catches on the continental shelf and close to shore. Densities in some trawls were extraordinary, exceeding 60,000 kg/km^3 at locations off Oregon, over 200,000 kg/km^3 off Vancouver Island, and over 150 kg/km^3 off SE Alaska (Fig. 2). Catches were often so high that research nets were ripped open due to the high biomass, and some stations easily sampled in previous years had to be aborted in 2017. The varying catch rates demonstrate that the distributions of pyrosomes were not continuous along the continental shelf, but that they tended to occur in clusters, possibly associated with specific oceanographic conditions (currently under investigation).

Routine plankton surveys along the continental shelf of Vancouver Island began to collect pyrosome individuals (less than 5 mm in length) and small colonies (greater than 4 cm in length) in spring and summer 2016. By February 2017, plankton surveys were catching pyrosome colonies up to 15 cm in length from the continental shelf along the west coast from Oregon to Vancouver Island. By late spring and summer 2017, the pyrosome event was in full bloom, with very high abundances and large colonies occurring from California to Alaska and into the central NE Pacific, including over open ocean seamounts.

Potential implications of this pyrosome event

The causes of this extraordinary event are unknown. Individuals may have been advected into the NE Pacific during the marine heat wave of 2014–2015 and the strong El Niño in early 2016. They may have found an environment in transition between these very warm conditions and a return to normal conditions in 2017, which provided sufficiently warm temperatures and ample food for their growth and reproduction to accelerate. The causes of this event remain under investigation but recent (November 2017) observations of small pyrosomes washing up on west coast beaches similar to those seen in the winter of 2016/2017 suggest that conditions may be favorable for another bloom in the summer of 2018 (Fig. 1).

Pyrosome colonies were visible at the surface, and coated oceanographic sampling gear and clogged fishing nets and hooks throughout this region. Substantial negative impacts have been reported on many different commercial and sport fishing operations from Oregon to SE Alaska, including salmon troll, shrimp and fish bottom trawl gear (Fig. 3A). Estimates of the economic impact of this bloom on lost or spoiled fisheries are not available but anecdotal reports suggest that they may have a substantial negative impact to coastal fisheries of the NE Pacific.

The impacts of this event to the marine ecosystems of the NE Pacific are also being studied. Such a high biomass of easily captured prey has obvious potential for marine predators and integration into the food webs of high trophic levels. However, the low accumulation of lipid stores in pyrosomes (Perissinotto *et al*., 2007) suggests that they may be a sub-optimal prey item. Studies of pyrosomes in their normal tropical habitats show that numerous fishes, seabirds, and marine mammals can consume pyrosomes (Harbison, 1998). Fishers along the west coast of North America during the peak of this event reported finding pyrosomes in the stomachs of Pacific halibut, rockfishes, sablefish, and other demersal fish species, and in juvenile and adult Pacific salmon and other pelagic forage fishes (Brodeur *et al*., in press). A beached fin whale in Washington State had numerous pyrosomes in its stomach (Fig. 3C). Pyrosomes have also been observed in the NE

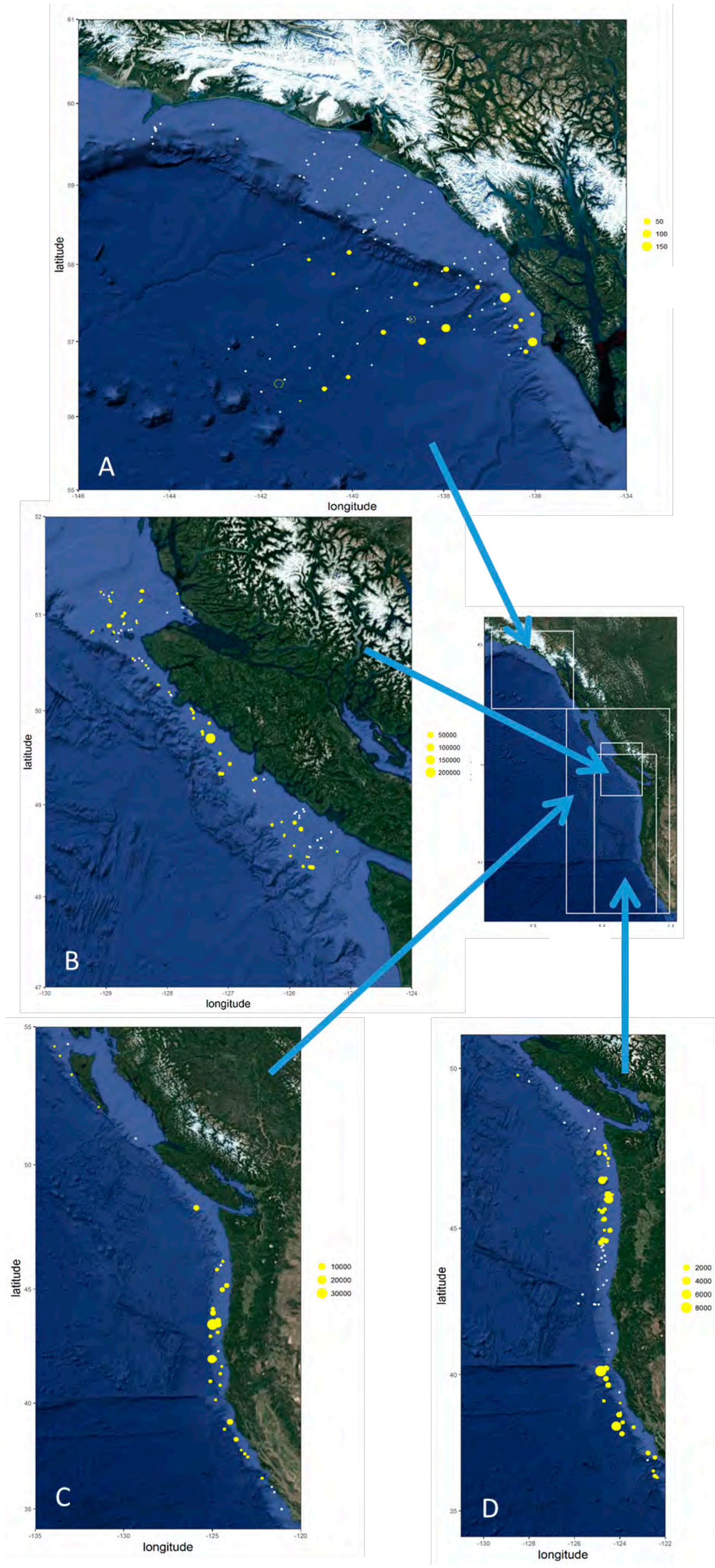


Fig. 2 *Distribution and density (kg km*$^{-3}$*) of pyrosomes from A) NMFS Gulf of Alaska surveys during summer of 2017 (July 4–August 16, 2017). B) DFO integrated pelagic ecosystem survey (July 19–August 2, 2017), C) NMFS coastal pelagic fish survey (June 25–August 9), and D) NMFS coastwide Pacific hake survey (June 26–September 6, 2017; data courtesy of NWFSC FEAT group). Inset shows relative locations of the panels in the Northeast Pacific Ocean. White dots depict samples without pyrosomes and yellow circles are scaled by pyrosome density (note that the scale differs in each plot). In panel A, solid circles are from surface trawls and open circles from midwater trawls.*

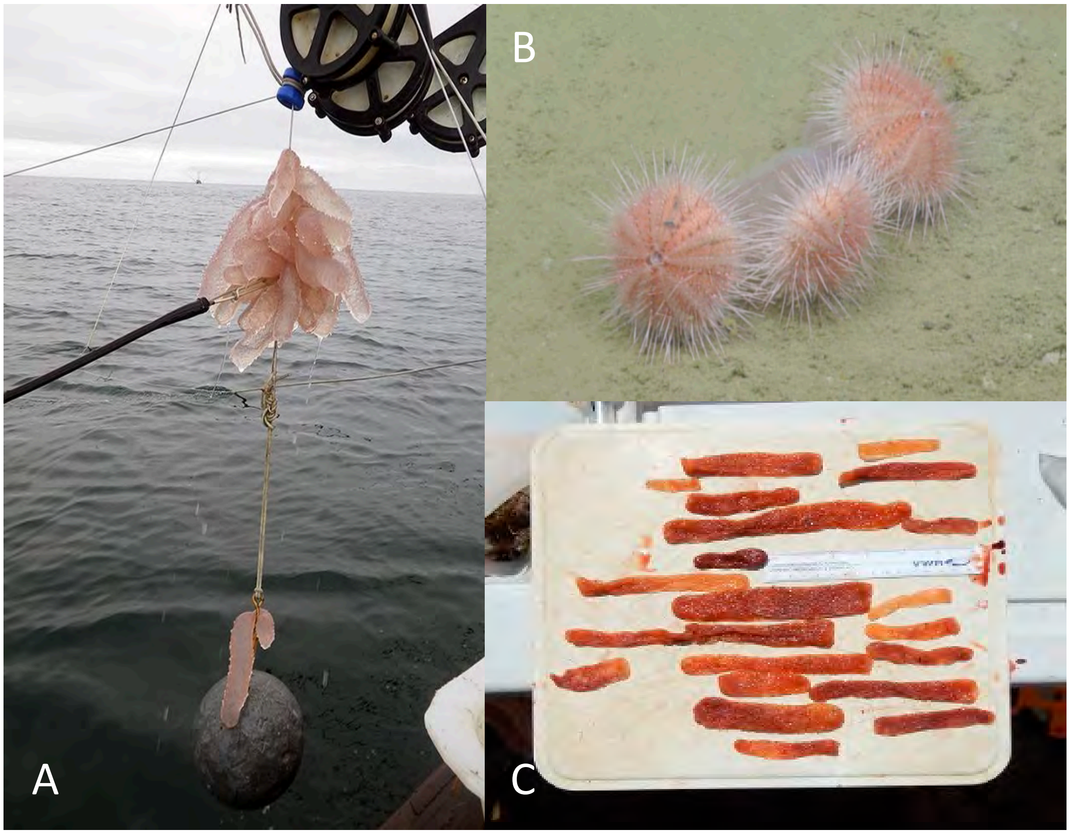


Fig. 3 A) Pyrosomes caught on salmon fishing gear off British Columbia, B) pyrosomes being consumed by sea urchins (photo taken by ROV Hercules in Quinault Canyon, off Washington State, courtesy of Ocean Exploration Trust), and C) pyrosomes taken from stomach of fin whale (courtesy Jessie Huggins, Cascadia Research, Olympia, WA).

Pacific being eaten by benthic animals such as sea anemones, crabs, sea urchins and sea stars (Archer *et al*., in Press), even at bottom depths of several hundred meters (Fig. 3B). The impacts of these very high biomasses of pyrosomes that die and sink to the bottom, drawing down oxygen concentrations as they decompose, is unknown, but the die-off of these blooms has the potential to provide a substantial input of carbon to the benthic food web (Lebrato and Jones, 2009). An additional positive effect has been the observation that some pelagic fishes (medusafish and juvenile rockfish) have been seen living inside the tubes of pyrosomes and potentially consuming part of the pyrosomes in coastal waters (Fig. 1D), thus providing a possible pelagic refugium from predation and source of food for these fishes (Janssen and Harbison, 1981).

Previous work on the feeding of *P. atlanticum* in tropical waters has found a preference for phytoplankton cells greater than 10 µm in diameter (*Perissinotto et al*., 2007). The diet composition of this species in the more productive coastal waters of the NE Pacific is unknown but several studies are underway to examine this. The very high filtration rates may also reduce phytoplankton biomass locally when abundances of pyrosomes are very high (Drits *et al*., 1992), although how extensive this grazing pressure may have been in 2017, and its implications for coastal productivity during the NE Pacific event, are presently unknown, but warrant further investigation.

Conclusions

In the past few years, anomalous ocean conditions in the NE Pacific, including the marine heat wave (Bond *et al*., 2015; Di Lorenzo and Mantua, 2016), have been accompanied by unusual occurrences of species (Perry *et al*., 2017). Some of these occurrences were isolated events (*e.g*., first ever record of a Pacific angel shark in British Columbia waters in 2016; Perry *et al*., 2017); whereas, others are broad both spatially and temporally, such as the extended toxic algae blooms and consequent marine mammal deaths in 2015 (McCabe *et al*., 2016). The 2016-2017 bloom of pyrosomes was also a large-scale event and is expected to last into 2018. Both positive and negative impacts of the pyrosomes are expected to occur, however, the cumulative impacts of this event are not known but are presently being investigated in different laboratories along the west coast of North America. There is more to learn about how ocean conditions are linked to these events and the implications of these blooms on the trophodynamics of the Northeast Pacific marine ecosystems. Projected climate change in the coming decades may lead to anomalous events such as the pyrosome bloom becoming more common in the future, requiring continuing monitoring to assess its impacts.

References

Andersen, V., Sardou, J. (1994) *Pyrosoma atlanticum* (Tunicata, Thaliacea): diel migration and vertical distribution as a function of colony size. J. Plankton Res. 16: 337–349.

Archer, S.K., Kahn, A.S., Leys, S.P., Norgard, T., Girard, F., Du Preez, C., Dunham, A. (In press) Pyrosome consumption by benthic organisms during blooms in the NE Pacific and Gulf of Mexico. Ecology.

Bond, N.A., Cronin, M.F., Freeland, H., Mantua N. (2015) Causes and impacts of the 2014 warm anomaly in the NE Pacific, Geophys. Res. Lett. 42: 3414–3420, doi:10.1002/2015GL063306.

Brodeur, R.D., Hunsicker, M.E., Hann, A., Miller, T.W. (In press) Effects of warming ocean conditions on feeding ecology of small pelagic fishes in a coastal upwelling ecosystem: a shift to gelatinous food sources. Mar. Ecol. Prog. Ser.

Di Lorenzo, E., Mantua, N. (2016) Multi-year persistence of the 2014/15 North Pacific marine heatwave. Nature Climate Change, published online: 11 July 2016 DOI:10.1038/nclimate3082.

Drits, A.V., Arashkevich, E.G., Semenova, T.N. (1992) *Pyrosoma atlanticum* (Tunicata, Thaliacea): grazing impact on phytoplankton standing stock and role in organic carbon flux. J. Plankton Res. 14: 799–809.

Harbison, G.R. (1998) The parasites and predators of Thaliacea. In: Bone Q. (Ed.) The biology of pelagic tunicates. Oxford University Press, Oxford, pp. 187–214

Hirose, E., Ohshima, C., Nishikawa, J. (2001) Tunic cells in pyrosomes (Thaliacea, Urochordata): cell morphology, distribution, and motility. Invert. Biol. 120: 386–393.

Janssen, J., Harbison, G.R. (1981). Fish in salps: the association of squaretails (*Tetragonurus* spp.) with pelagic tunicates. J. Mar. Biol. Assoc. U.K. 61: 917–927.

Lebrato, M., Jones, D.O.B. (2009) Mass deposition event of *Pyrosoma atlanticum* carcasses off Ivory Coast (West Africa). Limnol. Oceanogr. 45: 1197–1209.

McCabe, R.M., Hickey, B.M., Kudela, R.M., Lefebvre, K.A., Adams, N.G., Bill, B.D. Gulland, F.M.D., Thomson, R.E., Cochlan, W.P., Trainer, V.L. (2016) An unprecedented coastwide toxic algal bloom linked to anomalous ocean conditions, Geophys. Res. Let. 43: 10,366–10,376, doi:10.1002/2016GL070023.

Perissinotto, R., Mayzaud, P., Nichols, P.D., Labat, J.P. (2007) Grazing by *Pyrosoma atlanticum* (Tunicata Thaliacea) in the south Indian Ocean. Mar. Ecol. Progr. Ser. 330: 1–11.

Perry, R.I., King, S., Boldt, J., Chandler, P. (2017) Unusual events in Canada's Pacific marine waters in 2016. In Chandler, P., King, S., and Boldt, J. (Eds.) State of the physical, biological and selected fishery resources of Pacific Canadian marine ecosystems in 2016. Can. Tech. Rep. Fish. Aquat. Sci. 3225: 243 + vi pp.

Sakuma, K.M., Field, J.C., Mantua, N.J., Ralston, S., Marinovic, B.B., Carrion, C.N. (2016) Anomalous epipelagic micronekton assemblage patterns in the neritic waters of the California Current in Spring 2015 during a period of extreme ocean conditions. Calif. Coop. Ocean. Fish. Invest. Rep. 57: 163–183.

Wells, B.K., Schroeder, I.D., Bograd, S.J., Hazen, E.L., Jacox, M.G., Leising, A., Mantua, N., Santora, J.A., Fisher, J., Peterson, B., Bjorkstedt, E., Robertson, R.R., Chavez, F.P., Goericke, R., Kudela, R., Anderson, C., Lavaniegos, B.E., Gomez-Valdes, J., Brodeur, R.D., Daly, E.A., Morgan, C.A., Auth, T.D., Field, J., Sakuma, K., Mcclatchie, S., Thompson, A.R., Weber, E.D., Watson, W., Suryan, R.M., Parrish, J., Dolliver, J., Loredo, S., Porquez, J.M., Zamon, J.E., Schneider, S.R., Golightly, R.T., Warzybok, P., Bradley, R., Jahncke, J., Sydeman, W., Melin, S.R., Hildebrand, J., Debich, A.J., Thayre, B. (2017) State Of The California Current 2016–17: Still anything but "normal" in the North. CALCOFI Rep, 58: 1–55.

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Dr. Andrew Thompson (andrew.thompson@noaa.gov) is a Research Fisheries Biologist at NOAA's Southwest Fisheries Science Center in La Jolla, CA. At present, his research primarily focuses on using larval fish and oceanographic data collected by the California Cooperative Oceanic Fisheries Investigations (CalCOFI) program to elucidate causes of dynamics of fish distributions and population sizes in the California Current Ecosystem. He also supervises 3 postdoctoral researchers who are using CalCOFI data to 1) develop Next Generation Sequencing methods to rapidly identify fish species that are present in plankton samples; 2) assess feeding condition of larval anchovy and sardine using bulk and compound-specific stable isotopes and 3) understand if larval condition quantified through otolith characteristics impact rockfish recruitment success. Previously he used field studies, mathematical modelling and genetics to better understand processes affecting the ecology and evolution of mutualistic gobies and shrimps on coral reefs, stream fish in the Appalachian Mountains and southern California, and lizards in the Coachella Valley, California.

FEATURE

Recent Ecosystem Disturbance in the Northern California Current

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An extended marine heat wave occurred across the North Pacific during 2014–2016, including the formation of the warm "Blob" followed by a strong El Niño in 2016. Coincident with this marine heat wave, we documented unprecedented biological changes in plankton and nekton in the Northern California Current (NCC) within pelagic surveys conducted over 20 years (1998–2017). The recent warm period was dominated by warmwater gelatinous invertebrates and fishes, some of which were previously either extremely rare or absent. Mixing of organisms originating from more southern or western regions with those previously present in the NCC may have resulted in novel and unpredictable trophic interactions that produced some of the observed changes in relative abundance. Continued long-term monitoring is needed to determine whether this is a temporary ecosystem disturbance or a fundamental change in the very productive NCC upwelling region.

The Northern California Current (NCC) ecosystem (from the Canadian border to Cape Blanco, Oregon) has undergone a great deal of oceanic variability over the past 20 years, including a strong El Niño in 1998, a strong La Niña in 1999, a Pacific Decadal Oscillation (PDO) regime shift during 1998–2002 (Peterson and Schwing 2003), and a much-delayed spring/summer upwelling period in 2005 (Lindley et al. 2009). These oscillations between warm and cool periods have resulted in shifts in abundance of many commercially important species, including squid, hake, rockfish, and juvenile salmonids.

In fall 2014, an extreme warming of coastal waters occurred as a large parcel of anomalously warm water—the so-called "blob"—moved eastward and caused a sudden increase in coastal temperatures (Bond et al. 2015). The warm Blob formed in the Gulf of Alaska during the winter of 2013–2014 and generally persisted in the Northeast Pacific through 2016, although brief periods of cooling occurred during May–June 2015 following strong equatorward winds and upwelling (Peterson et al. 2015, 2017). The blob was immediately followed by a strong El Niño event in 2015–2016 (Jacox et al. 2016). These oceanographic phenomena resulted in a prolonged marine heat wave throughout the NCC during 2014–2016 (Di Lorenzo and Mantua 2016; Gentemann et al. 2017). This heat wave resulted in shifts in the occurrence and abundance of a broad range of taxa, including copepods (Peterson et al. 2017), ichthyoplankton (Auth et al. 2017; Daly et al. 2017), squid (Sakuma et al. 2016), gelatinous invertebrates, krill and shrimp (Sakuma et al. 2016; Peterson et al. 2017; Brodeur et al., 2019), and fishes (Leising et al. 2015; Sakuma et al. 2016). Trophic shifts were also evident in juvenile salmon diets (Daly et al. 2017).

We collected physical and biological data, including plankton and pelagic nekton, on the same coastal grid from central Oregon to the Washington–British Columbia border over a 20-year period from 1998 to 2017. This allowed us to develop an oceanographic and biological baseline for the pelagic ecosystem of the NCC. We documented unique abundance variations within our 20-year time series, with effects at all trophic levels. Unlike other recent publications, our data indicate that biological disturbances continued through 2017, after cessation of surface manifestations of the blob. This report describes effects of the recent marine heat wave on the NCC pelagic ecosystem and the status of the post-Blob NCC ecosystem. Because of impacts on larval and juvenile fishes, we expect marine heat wave effects to continue for several more years.

METHODS

We obtained information from surveys conducted over the continental shelf, 1.9–56.0 km (1–30 nautical mi) offshore of Washington and Oregon, USA, in late June 1998–2017. During each survey, we sampled five to seven fixed stations along each of five to eight transect lines perpendicular to the shore between the northern tip of Washington (48°13.7'N) and Newport, Oregon (44°40.0'N; Figure 1). In this paper, we summarize sampling and analysis methods used for these surveys, but more detailed descriptions of these methods are provided by Brodeur et al. (2005), Morgan et al. (2005), and Peterson et al. (2010).

At each station, we sampled temperature, chlorophyll-*a* concentration, zooplankton, and nekton. Temperature was measured with a conductivity–temperature–depth instrument to within 5 m of the bottom or a depth of 200 m, and chlorophyll-*a* samples were collected at a depth of 3 m using a Niskin bottle. Temperatures for each station were averaged over the top 20 m of the water column that the trawl sampled. Zooplankton collections were made with either a 1.0-m-diameter ring net (1999–2000) or a 0.6-m-diameter bongo net (2001–2016), both of which were fitted with 335-μm mesh and a General Oceanics flowmeter to estimate the water volume filtered. Plankton nets were fished by letting out 60 m of cable and immediately retrieved at 30 m/min while being towed at 3.704 km/h (2 knots). The maximum depth

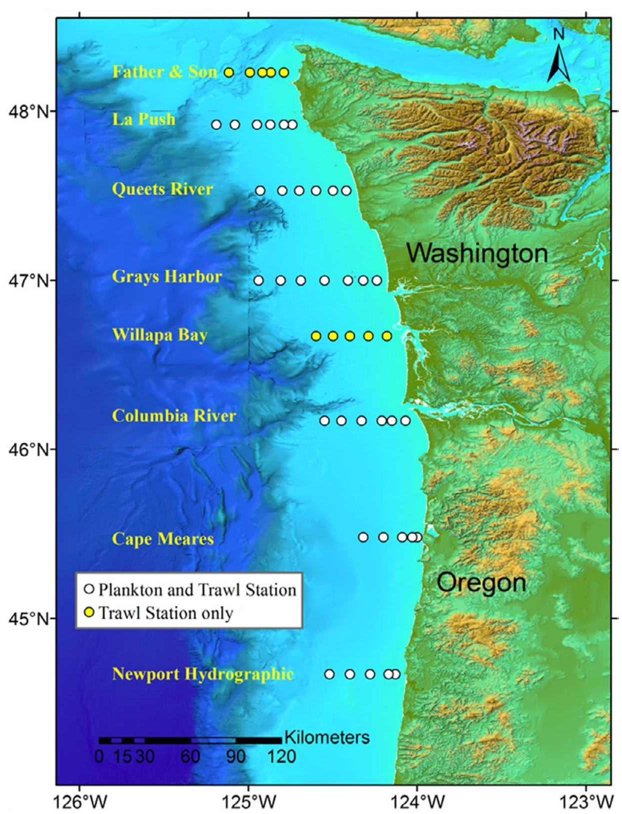

Figure 1. Locations of Oregon–Washington coastal stations included in the analysis for plankton (white) and pelagic nekton (white and yellow).

fished was 20–30 m. We did not include plankton samples from 1998 and 2017 in our results, as samples were taken at only a few stations in 1998 and those from 2017 have not yet been analyzed.

Fish and invertebrate nekton were sampled using a Nordic 264 rope trawl (Nor'Eastern Trawl Systems, Bainbridge Island, Washington) towed to sample the upper 20 m of the water column for 15–30 min at approximately 6.5 km/h. Only stations that were sampled during the day, over the continental shelf (≤200-m water depth), and in at least 10 of the study years were included in our analyses. We did not include jellyfish data from 1998, since jellyfish occurrence was not reliably recorded. We report only on species that exhibited significant changes during the blob period compared to previous years.

Our report consists of simple estimates of abundance for the biological organisms of interest. Our evaluation of interannual variation in abundance is also simple. We started by generating an overall mean abundance (grand mean [GM]) and variance (SD [grand]) based on the average of 20 individual annual means (AMs; 1998–2017; see below). For each year of sampling, we then determined the number of SDs (grand) between the AM and the GM. All calculations were performed using Statgraphics Centurion version 17.1 (StatPoint Technologies, Inc., Warrenton, Virginia). We evaluated the abundance of organisms found in each year in reference to the number of SDs between the GM and the AM, and we designated these yearly abundance estimates as follows: typical (AM < 1 SD from the GM), notable (AM > 1 SD to 2 SDs from the GM), exceptional (AM > 2 SDs to 3 SDs from the GM), or extreme (AM > 3 SDs from the GM).

Abundance was calculated differently for zooplankton and nekton. Total abundance of each zooplankton species caught in each haul was calculated using counts and water volume filtered, converting to biomass by using length-to-mass regressions and literature values (Morgan et al. 2005), and then standardizing to units of milligrams of carbon per cubic meter (mg C/m^3). Total abundance of each nekton species caught in each haul was either (1) determined directly from a total count of individuals or (2) estimated from the total weight caught, based on the number of individuals in a weighed subsample of that haul. Trawl catches of each species at each station were standardized to linear density by dividing station catch by the distance of the tow, as determined by a Global Positioning System receiver. After standardizing for distance, densities were $\log_{10}(x + 1)$ transformed ($\log_{10}$[number/km + 1]) to make the data easier to visualize, interpret, and compare.

We used large-scale indices of ocean conditions, including the PDO and the Oceanic Niño Index (ONI), to place local-scale phenomena within a larger-scale mechanistic picture and to provide a framework in which to examine physical phenomena and lagged biological responses (Mantua et al. 1997; Fisher et al. 2015; Peterson et al. 2017). Positive PDO values were associated with relatively warm ocean conditions in our region. Similarly, positive ONI values—indicative of El Niño events on the equator—were also often associated with warming of the NCC. For our study, the PDO was reported as an average of May and June values for each year (data available from the Joint Institute for the Study of the Atmosphere and Ocean, University of Washington: http://jisao.washington.edu/pdo/PDO.latest.txt), and the ONI was reported as an average of November–January and December–February values for each year (data available from the National Weather Service's Climate Prediction Center: origin.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ONI_v5.php).

RESULTS AND DISCUSSION

Physical Conditions in the Northern California Current

Temperatures in the NCC have been unusually warm since 2014 (Bond et al. 2015; Peterson et al. 2015). This was reflected by the strongly positive PDO during 2014–2016, which was the longest period of positive PDO in our time series (48 months; January 2014–December 2017; Figure 2), and by the highly positive 2016 ONI value, which reflected the extremely strong El Niño at the equator (data from the National Weather Service's Climate Prediction Center: http://origin.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ONI_v5.php). Despite overall warmer temperatures documented in the NCC due to the warm Blob (Bond et al. 2015; Peterson et al. 2015), the upper 20-m temperatures in June during our 2014–2016 surveys were not unusually high; this was due to short periods of upwelling prior to the surveys (data available from the National Marine Fisheries Service's Pacific Fisheries Environmental Laboratory: https://www.pfeg.noaa.gov/products/PFEL/modeled/indices/upwelling/NA/upwell_menu_NA.html; Figure 2). However, the complete monthly time series in this region from 2014 to 2016 did show that temperatures in the upper water column were elevated (Leising et al. 2015; McClatchie et al. 2016; Peterson et al. 2017). Finally, while physical oceanographic indicators suggested a return to neutral ocean conditions in summer 2017 (PDO; Peterson et al. 2017), temperatures in our survey area were still high.

Biological Patterns of Change

In 2014, we observed biological changes coinciding with development of the offshore blob and a positive PDO (Figure 2). For example, in June 2014, the chlorophyll-*a* concentration was rated as exceptional and was one of the three highest values in the time series. Similarly, Peterson et al. (2017) also observed high chlorophyll-*a* concentrations in June 2014 during more frequent sampling off Newport, Oregon. Among the animals sampled, both California market squid *Doryteuthis opalescens* and furcilia-stage larval North Pacific krill *Euphausia pacifica* had notable deviations in abundance and were more numerous than in the previous 15 years (Figure 2).

In 2015, the abundances of more species deviated markedly from their 20-year mean values (Figure 2; Table 1). The deviation in biomass abundance of North Pacific krill furcilia-stage larvae was exceptional, and for Pacific sand crab *Emerita analoga* zoeal-stage larvae, the deviation was notable. Both species were much more abundant than they had previously been in the time series. Abundances of all three common jellyfish species changed markedly but differed in their direction of change. The deviation in abundance of the normally scarce water jellyfish *Aequorea* spp. was exceptional, and it became the most abundant jellyfish in our catches. In contrast, the generally most common jellyfish, the Pacific sea nettle *Chrysaora fuscescens*, had notably lower abundances and was nearly absent from our samples. The deviation in abundance of egg-yolk jellyfish *Phacellophora camtschatica* was notably high, and this species became more abundant than in previous years. Finally, the abundances of three nektonic species increased. Although only the California market squid was characterized by a notable deviation in abundance, Pacific Pompano *Peprilus simillimus* and Jack Mackerel *Trachurus symmetricus* abundances were higher than in any of the 8 previous years.

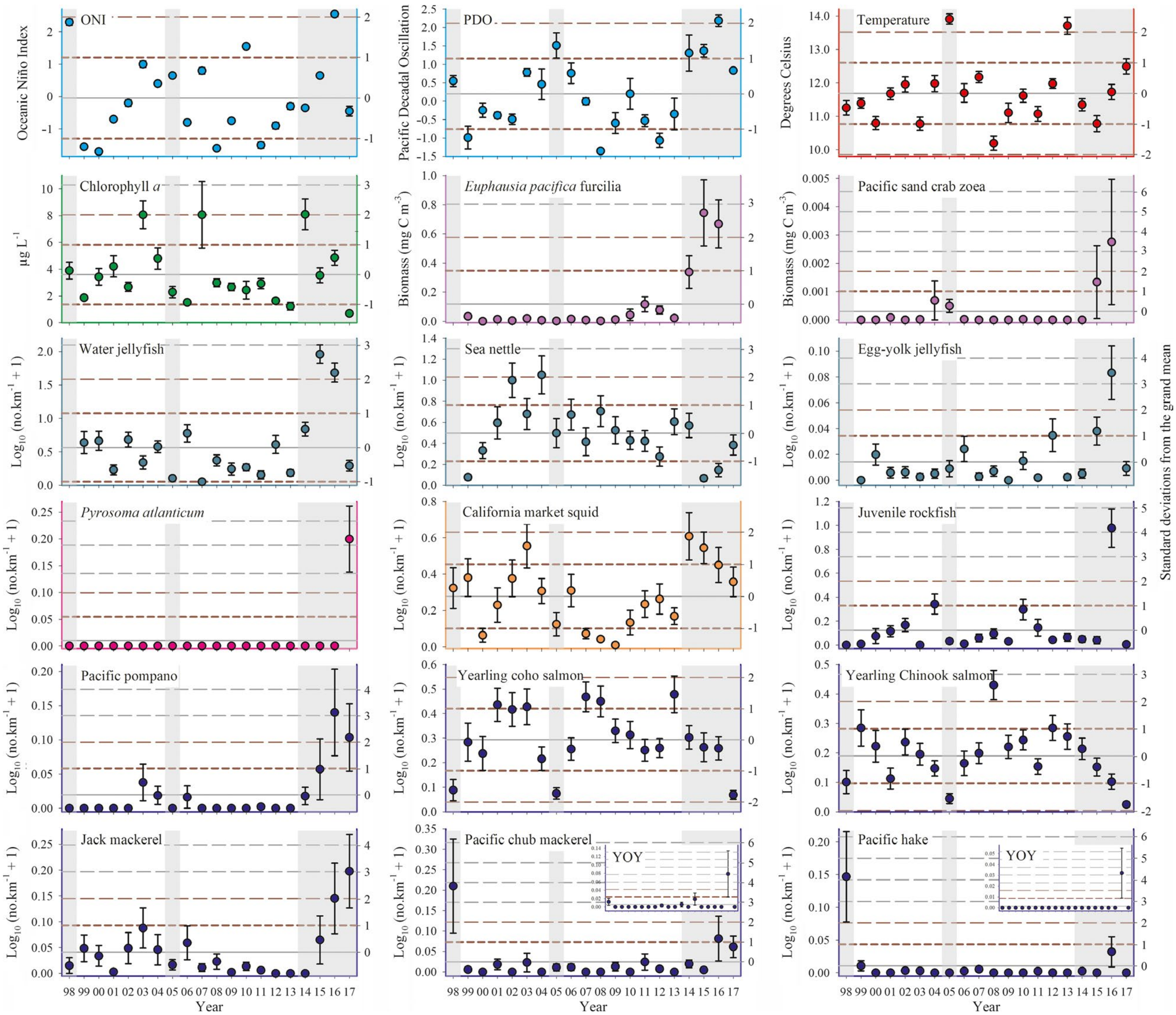

Figure 2. Variables included in the analysis: large-scale physical indices (teal), average temperature (°C) in the top 20 m (red), chlorophyll-*a* concentration (μg/L; green), biomass of two plankton species (mg carbon/m^3; purple), and surface trawl catches (log$_{10}$[number/km + 1]) of jellyfish (cyan), pyrosomes (pink), squid (orange), and fish (blue). Circles indicate the June average for each year; bars represent ±1 SE. The right *y*-axis and the corresponding horizontal lines indicate the number of SDs from the grand mean (dark-red short dash = ±1 SD; dark-red long dash = ±2 SDs; light-gray long dash = 3–6 SDs). The three warm periods (1998, 2005, and 2014–2016; described in this paper) are shaded in light gray. The plots of Pacific Chub Mackerel and Pacific Hake are total catch, with the smaller insets showing only young-of-the-year (YOY; i.e., age 0) catches for those species. The age-0 (YOY) insets follow the same format as other plots, but year shading and SD labels are not shown.

In 2016, 13 species had notable to extreme deviations in abundance (Figure 2; Table 1), which occurred during the period spanning the blob and following a winter with strongly positive sea surface height anomalies and strong poleward flow (Peterson et al. 2017). Two zooplankton species—Pacific sand crab (zoeae) and North Pacific krill (furciliae)—had exceptional deviations in abundance. Pacific sand crab zoeal biomass was higher than in any previous year, while North Pacific krill furcilia biomass was higher than in all previous years except 2015. Two jellyfish species—the water jellyfish and Pacific sea nettle—had exceptional deviations in abundance, whereas the egg-yolk jellyfish had an extreme deviation. Egg-yolk jellyfish numbers were higher in 2016 than in any previous year; water jellyfish numbers were higher than in all previous years except 2015; and Pacific sea nettle numbers were lower than in all but two previous years (2000 and 2014). Three nektonic species had notable deviations in abundance: California market squid, Pacific Chub Mackerel, and yearling Coho Salmon *Oncorhynchus kisutch*. Four nektonic species had extreme deviations: juvenile rockfish *Sebastes* spp., Pacific Pompano, young-of-the-year (age-0) Pacific Hake *Merluccius productus*, and yearling Chinook Salmon *O. tshawytscha*. One nektonic species—the Jack Mackerel—had an exceptional deviation. California market squid, yearling Coho Salmon, and yearling Chinook Salmon declined in abundance, whereas the other five nektonic species were more abundant than in any previous year.

In 2017, the chlorophyll-*a* concentration had a notable deviation, representing the lowest chlorophyll-*a* value obtained during the 20-year time series. Five species had notable to extreme deviations in abundance. The most surprising extreme

Table 1. Number of standard deviations (SDs) by which the annual mean (AM) was above or below the grand mean (GM) for each variable or species examined, 2014–2017 (notable: AM > 1 SD to 2 SDs from the GM; exceptional: AM > 2 SDs to 3 SDs from the GM; extreme: AM > 3 SDs from the GM). Red indicates positive SDs; blue indicates negative SDs. "NA" indicates that data for the variable were not available in the specified year.

Variable or species	2014	2015	2016	2017
Oceanic Niño Index			+2	
Pacific Decadal Oscillation	+1	+1	+2	
Temperature, top 20 m				
Chlorophyll *a*	+2			−1
North Pacific krill *Euphausia pacifica*		+2	+2	NA
Pacific sand crab *Emerita analoga*		+1	+2	NA
Water jellyfish *Aequorea* sp.		+2	+2	
Pacific sea nettle *Chrysaora fuscescens*		−1	−1	
Egg-yolk jellyfish *Phacellophora camtschatica*		+1	+3	
Colonial gelatinous tunicate *Pyrosoma atlanticum*				+4
California market squid *Doryteuthis opalescens*	+1	+1		
Juvenile rockfish *Sebastes* spp.			+4	
Pacific Pompano *Peprilus simillimus*			+3	+2
Yearling Coho Salmon *Oncorhynchus kisutch*				−1
Yearling Chinook Salmon *O. tshawytscha*				−1
Jack Mackerel *Trachurus symmetricus*			+2	+3
Pacific Chub Mackerel *Scomber japonicus* (age 0)			+4	
Pacific Chub Mackerel			+1	
Pacific Hake *Merluccius productus* (age 0)			+4	

deviation was the first-ever occurrence of the colonial gelatinous tunicate *Pyrosoma atlanticum*, which was extremely abundant throughout our entire survey area. Two other nektonic species, yearling Coho Salmon and yearling Chinook Salmon, had notable deviations in abundance and declined to the lowest numbers obtained during the 20-year time series. Two additional nektonic species—the Pacific Pompano and Jack Mackerel—had exceptional deviations in abundance, with Pacific Pompano numbers being the second-highest observed and Jack Mackerel numbers being the highest observed during the 20-year time series.

Potential Mechanisms Leading to Changed Abundance

Multiple physical and ecological mechanisms are likely responsible for the variations in abundance documented among many species (Table 2). Although the survey was not designed to determine the mechanisms that caused these variations, we can make inferences based on three ecological and organismal traits. First, plankton drift passively; as such, when water masses are transported from south to north or from west to east, the distribution of planktonic organisms changes. Second, nekton can actively swim against currents and can thus change their distribution in response to local temperatures and seek out thermally preferred water masses. Third, changes in abundance may be in response to changes in local processes that regulate population abundances (e.g., reproduction and predation). These mechanisms are not mutually exclusive and probably do not represent a complete list of possible processes. Moreover, in most cases, more than one mechanism likely led to the patterns of change we observed (see below).

Planktonic water jellyfish, egg-yolk jellyfish, and Pacific sand crab larvae are normally associated with warmer waters to the south of our study area and/or offshore (Shenker 1984; Suchman and Brodeur 2005). High abundances of these species in our catches from 2014 to 2016 suggest northward and/or eastward transport, corresponding with warmer southern or offshore waters moving onshore (Gentemann et al. 2017). Other planktonic species, such as copepods, have demonstrated similar patterns of unusual advection from southern and offshore waters into the waters off central Oregon during this same time period (Peterson et al. 2017). Northward shifts in the distribution of these species have been also reported during other El Niño events (Pearcy and Schoener 1987; Pearcy 2002; Brodeur et al. 2005).

Thermal preferences, paired with spatial changes in water temperature, may result in active migration by some species from south to north or from west to east. For instance, the California market squid, Pacific Pompano, Jack Mackerel, and Pacific Chub Mackerel *Scomber japonicus* are normally found in warmer southern waters and were observed in high abundances during the warm water years since 2014. Other studies have documented similar changes in the distribution of these species during previous strong El Niño years (Pearcy and Schoener 1987; Pearcy 2002; Brodeur et al. 2005).

We sampled only the top 20 m of the water column with the trawl and plankton nets during this survey. Therefore, we cannot exclude the possibility that changes in abundance of some organisms captured by our gear were due to changes in their vertical distribution within our study area rather than horizontal transport or active migration into the study area from other locations. For example, some sea nettle species are known to undergo diel vertical migration, although this behavior has not been documented for the species in our region (Suchman and Brodeur 2005; Suchman et al. 2012), and juvenile Chinook Salmon may move deeper in the water column

Table 2. Description of the persistence of a given species within our 20-year survey (continuous, sporadic, or novel during the marine heat wave of 2014–2017) and change in abundance during the marine heat wave (increase or decrease). Also provided are a description of whether the organism drifts with currents (plankton) or can swim against currents (nekton), inferred changes in spatial distribution during the marine heat wave, and whether changes in abundance during the marine heat wave might be attributed to local ecological processes. A question mark indicates that changes in abundance might be due to a change in depth distribution, but we had no data with which to test that possibility.

Species	Presence	Recent abundance (heat wave)	Plankton or nekton	Inferred distribution change: South to north	West to east	Shallow to deep	Local processes
Euphausia pacifica (larvae)	Continuous	Increase	Plankton				✓
Pacific sand crab (larvae)	Sporadic	Increase	Plankton	✓			✓
Water jellyfish	Continuous	Increase	Plankton	✓	✓		
Pacific sea nettle	Continuous	Decrease	Plankton			?	✓
Egg-yolk jellyfish	Continuous	Increase	Plankton	✓	✓		
Pyrosoma atlanticum	Novel	Increase	Plankton	✓	✓		✓
California market squid	Continuous	Increase	Nekton	✓			
Juvenile rockfish	Continuous	Increase	Nekton				✓
Pacific Pompano	Sporadic	Increase	Nekton	✓			
Yearling Coho Salmon	Continuous	Decrease	Nekton			?	✓
Yearling Chinook Salmon	Continuous	Decrease	Nekton			?	✓
Jack Mackerel	Continuous	Increase	Nekton	✓			✓
Pacific Chub Mackerel (age 0)	Sporadic	Increase	Nekton				✓
Pacific Chub Mackerel	Sporadic	Increase	Nekton	✓			✓
Pacific Hake (age 0)	Novel	Increase	Nekton	✓			✓

in response to warmer surface water (Orsi and Wertheimer 1995). However, we currently lack the data to directly test for changes in depth distribution.

Information from other studies suggests that local processes rather than different migration patterns may have been responsible for the low abundance of juvenile Coho Salmon and Chinook Salmon in our catches during 2017. Juvenile Coho Salmon are not known to change depth preference in response to warm water (Orsi and Wertheimer 1995; Beamish et al. 2007, 2018), yet abundance trends for this species were similar to those for juvenile Chinook Salmon in our study. In contrast to the low catches in our coastal samples, which mostly consist of Columbia River fish (Van Doornik et al. 2007; Teel et al. 2015), abundances of both juvenile Coho Salmon and Chinook Salmon in the Columbia River during 2017 were at least average based on Bonneville Dam smolt counts (the source of most of the juvenile salmon in our survey; Fish Passage Center 2017) as well as estuary purse seine smolt catches (L.A.W., unpublished). We also conduct a separate survey in May, as smolts are entering the ocean and before any potential changes in northward migratory tendency could change their abundance. Our catches of juvenile salmon of both species in May 2017 were quite low relative to previous May survey catches (Morgan et al. 2017), which have been conducted since 1999 (Jacobson et al. 2012; Teel et al. 2015).

In contrast to Coho Salmon and Chinook Salmon, the notable and extreme abundance increases in Pacific sand crab larvae that were observed in 2015 and 2016, respectively, were likely due to both local processes and northward transport. Adult Pacific sand crabs live in the wash zone of sandy beaches, spawn in summer and fall, and produce larvae that are planktonic for approximately 4 months (Johnson 1939; Efford 1970, 1976). Larval Pacific sand crabs in our catches had a bimodal age distribution caused by the presence of both early (zoeal stage I [ZI]) and late-stage (ZV) larvae, with both stages sometimes present in the same sample. We never found any intermediate-stage (ZII–ZIV) larvae. We assume that ZI larvae represented local production of eggs, as these larvae were too young to have undergone long-range transport. The presence of older, ZV larvae, coupled with the absence of ZII–ZIV larvae, indicates that the ZV larvae were transported from the south, as was suggested to have occurred during other warm periods, such as the El Niño of 1997–1998 and the warm period of 2004–2005 (Sorte et al. 2001; Figure 2).

The first observation of age-0 Pacific Hake in our survey occurred in June 2016. During February 2016, Auth et al. (2017) found larval Pacific Hake at every station from 64.82 to 194.46 km (from 35 to 105 nautical mi) off the coast of Newport, Oregon, 4 months prior to and well offshore of our sampling. This indicates that age-0 Pacific Hake were relatively abundant off the Oregon and Washington coasts in 2016. Since this species usually spawns further south (i.e., off California; Ressler et al. 2007), the presence of age-0 Pacific Hake suggests that spawning may have shifted northward. Similarly, increased abundance of age-0 Pacific Chub Mackerel in our June 2016 survey may have been due to a northward shift in adult distribution and spawning (Auth et al. 2017).

Comparisons with Other Studies

Since different ocean sampling studies may have dissimilar objectives and methods, using results from these studies to create a coherent picture of the NCC during the recent marine heat wave is much like the classic parable of blind people studying an elephant: each person touches a different part of the animal and thus describes a different creature. We suggest that common trends across studies may reflect large-scale patterns, whereas differences among studies may simply be due to differences in local distribution, sampling design, or methodology; alternatively, they may reflect real differences.

Increased abundances of species such as the California market squid, age-0 Pacific Hake, age-0 rockfish, and pyrosomes were observed off the California coast before similar changes occurred in our more northern survey region (Sakuma et al. 2016; Brodeur et al., 2019). Warmwater anomalies first occurred in southern California coastal waters during spring 2014 and were subsequently detected farther north later in that year (Gentemann et al. 2017). Similarly, northerly occurrences of more southern species were observed first in California and then later to the north in our survey area.

Several studies in the NCC have reported very low abundances of adult euphausiids during the past few years (Sakuma et al. 2016; Peterson et al. 2017; Brodeur et al., 2019). In strong contrast, we found an anomalously high biomass of *E. pacifica* furcilia larvae during our study in 2014–2016. In addition, we counted but do not report on several other larval stages of crustaceans in the same plankton samples. We found that abundances of an earlier larval stage (calyptopis) of *E. pacifica* were also the highest ever observed during this same time period, and larvae of another common euphausiid (*Thysanoessa spinifera*) as well as shrimp (Caridea) larvae had similarly high abundance patterns during this time period (C.A.M., unpublished). Given the short larval duration of *E. pacifica* (20–35 d from hatching to early furcilia stages; Bi et al. 2011), adult euphausiids must have been present to release eggs in the NCC. Therefore, the presence of larval euphausiids and the absence of adult euphausiids might have been the result of adults moving to cooler waters, either deeper or farther offshore.

The extraordinary increase in age-0 rockfish (4 SDs above the mean) in our 2016 catches was a coastwide event, documented from California (McClatchie et al. 2016) to Alaskan waters (Strasburger et al. 2018). This suggests that whatever factors caused the increase in age-0 rockfish operated over an extremely large area. However, the juveniles of the more than 70 species of northeast Pacific rockfish are extremely difficult to distinguish (Love et al. 2002); therefore, we could not document which species were involved, and we did not attempt to identify the mechanism(s) responsible for the increase. Continued assessment of older, easier-to-identify rockfish may provide more focus to our current observation.

Pyrosomes were extremely abundant in our 2017 catches, while other gelatinous species returned to more typical abundance levels (Figure 2). In 2014, other surveys encountered low numbers of pyrosomes further south of our study area as well as offshore (Wells et al. 2017; Brodeur et al. 2018, 2019). By 2015, the surveys captured pyrosomes at least as far north as Willapa Bay, Washington, but well off the continental shelf. Pyrosomes were also caught for the first time, and in high numbers, within Alaskan waters during the winter of 2016–2017 and through summer 2017 (NOAA-AFSC 2017; Brodeur et al. 2018). This dramatic expansion in range and abundance clearly represents favorable conditions for pyrosomes and suggests that their exceptionally high and widespread abundance was not solely due to changes in water transport.

Consequences of Species Abundance Changes

Understanding the consequences of extreme changes in species abundance in the NCC is challenging. Ruzicka et al. (2012) explored changes in abundances of different trophic groups in the NCC and used modeling to predict how these changes would impact energy flows through the food web. Many of the taxonomic groups they identified as important nodes of energy flow (Figure 3, boxes) are ones we found to have undergone large increases (e.g., water jellyfish, euphausiids, California market squid, Pacific Chub Mackerel, Jack

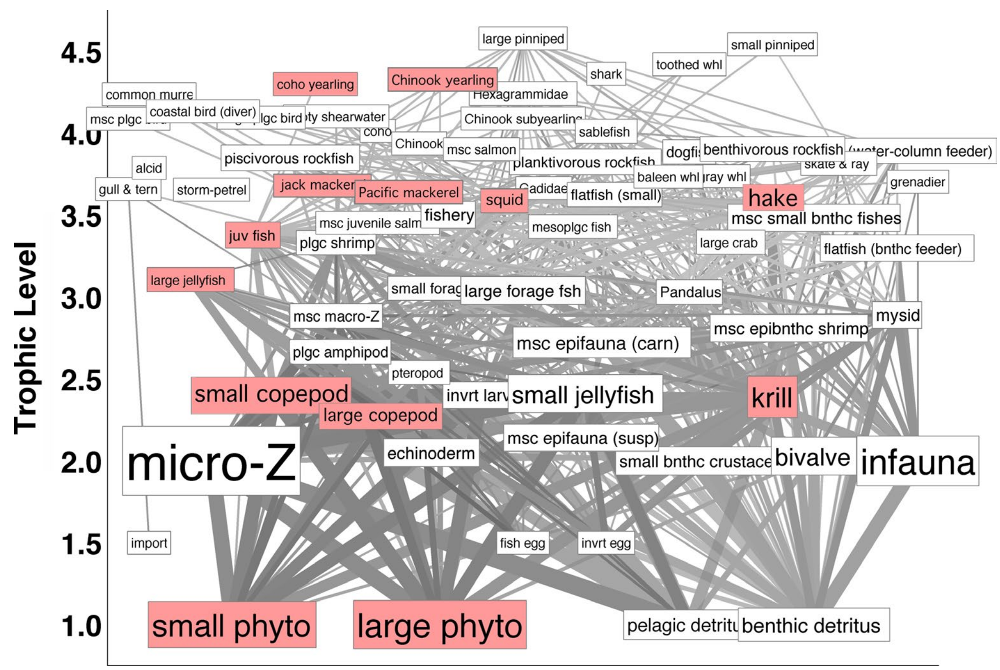

Figure 3. Energy flow pathways between major functional groups in the Northern California Current food web (modified by J. Ruzicka from Figure 6a in Ruzicka et al. 2012). Box size is proportional to group production rates (whl = whales; msc = miscellaneous; plgc = pelagic; mesoplgc = mesopelagic; bnthc = benthic; epibnthc = epibenthic; juv = juvenile; macro-Z = macrozooplankton; micro-Z = microzooplankton; invrt = invertebrate; carn = carnivorous; susp = suspension-feeding; phyto = phytoplankton). Red shading indicates species identified in this paper that have greatly increased or decreased during the recent marine heat wave.

Mackerel, and Pacific Hake) or decreases (e.g., Pacific sea nettles, juvenile Chinook Salmon, and juvenile Coho Salmon) in abundance. However, our survey focused on the upper water column during the day and did not sample all of the species included in the food web analysis.

Decreased Pacific sea nettle abundance during 2015–2017 coincided with increased abundance of zooplankton prey species. Sea nettles are known to feed on early stage euphausiids (Suchman et al. 2008), so the decline in Pacific sea nettles may have resulted in the high abundance of larval euphausiids in 2015 and 2016. The high juvenile rockfish abundance in 2016 may have been partly influenced by the very low numbers of Pacific sea nettles in 2015 due to both decreased predation on larval rockfish in 2015 as well as decreased competition for food between Pacific sea nettles and larval rockfish.

The sudden presence and extremely high abundance of pyrosomes may be the best example of an ecosystem consequence. Pyrosomes were not a component of the Ruzicka et al. (2012) ecosystem analysis, as these organisms had never been observed in the NCC (Welch 2017; Brodeur et al. 2018). *P. atlanticum* was found to be an extremely effective grazer, with clearance rates among the highest recorded for any pelagic grazer (Perissinotto et al. 2007). The high abundance of pyrosomes could explain the extremely low chlorophyll-*a* concentrations we observed in 2017 and could have caused a reduction in energy flow to higher trophic levels. If this organism remains abundant in subsequent years, it could produce lasting effects upon the NCC ecosystem by outcompeting other filter feeders, which in turn might reduce the food supply to organisms higher in the food web.

Finally, changes in abundance of various juvenile fish species, including Pacific Hake, rockfish, Coho Salmon, and Chinook Salmon, will affect top predators, such as sharks, pinnipeds, toothed whales, and humans. We believe that the increased abundances of age-0 Pacific Hake and Pacific Chub Mackerel in our 2016 samples were probably due to shifts in adult spawning distribution (Auth et al. 2017) and thus may not be indicative of increased abundances on a broad, regional scale. If this is true, we do not expect the adult abundances of these species to greatly increase in the future. In contrast, we think that the very high abundance of juvenile rockfish in our 2016 samples and the very low abundances of yearling Coho and Chinook Salmon in our 2017 samples represent real changes in abundance that will likely affect adult recruitment. Low catches of juvenile salmon in our June surveys have already been associated with poor adult returns (Burke et al. 2013; Peterson et al. 2014), so we anticipate poor returns of Coho Salmon to the Columbia River in 2018 and poor returns of Chinook Salmon in 2019. The high abundance of juvenile rockfish in 2016 was an extraordinary event, spanning at least 2,500 km of coastline along the west coast of North America. Although Ralston et al. (2013) suggested that pelagic abundance of juvenile rockfish is a good indicator of adult recruitment in central California, the actual consequences of high juvenile rockfish abundance in 2016 remain to be seen in future years.

Conclusion

We have documented recent dramatic changes in abundance of fish and invertebrates in the surface waters of the NCC since 2014. These changes likely reflect changes in physical processes and ecological mechanisms (Table 2). Some of what we observed was due to a shift of organisms from south to north and from west to east, whereas other changes may be the result of alterations in biological processes for organisms that have not changed their distributions. It is notable that we have not seen a complete changeover of species within the NCC ecosystem—rather, we have seen the novel occurrence of some organisms mixed with other species that are normally present (Table 2). Mixing of organisms from different regions may result in novel trophic interactions with unpredictable results (Naiman et al. 2012). We are particularly interested in potential continued ecological effects of the occurrence and abundance of pyrosomes in the NCC during 2017 and beyond.

The value of this paper lies not only in the specific results we described, but also in its role as a reminder of the importance of obtaining and maintaining long-term baselines to measure biological change (McClatchie et al. 2014). We have already described clear ecosystem-scale change in response to large-scale climatic changes (the Blob and El Niño). The National Marine Fisheries Service's current emphasis on ecosystem management will only be successful if robust field surveys of those ecosystems continue (Levin et al. 2009).

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REFERENCES

Auth, T. D., E. A. Daly, R. D. Brodeur, and J. L. Fisher. 2017. Phenological and distributional shifts in ichthyoplankton associated with recent warming in the northeast Pacific Ocean. Global Change Biology 24(1):259–272.

Beamish, R. J., M. Trudel, and R. Sweeting. 2007. Canadian coastal and high seas juvenile Pacific salmon studies. North Pacific Anadromous Fish Commission Technical Report 7:1–4.

Beamish, R. J., L. A. Weitkamp, L. D. Shaul, and V. I. Radchenko. 2018. Ocean ecology of Coho Salmon. Pages 391–554 *in* R. J. Beamish, editor. The ocean ecology of Pacific salmon and trout. American Fisheries Society, Bethesda, Maryland.

Bi, H., L. Feinberg, C. T. Shaw, and W. T. Peterson. 2011. Estimated development times for stage-structured marine organisms are biased if based only on survivors. Journal of Plankton Research 33(5):751–762.

Bond, N. A., M. F. Cronin, H. Freeland, and N. Mantua. 2015. Causes and impacts of the 2014 warm anomaly in the NE Pacific. Geophysical Research Letters 42(9):3414–3420.

Brodeur, R. D., T. D. Auth, and A. J. Phillips. 2019. Major shifts in pelagic micronekton and macrozooplankton community structure in an upwelling ecosystem related to an unprecedented marine heatwave. Frontiers in Marine Science 6(212).

Brodeur, R. D., J. P. Fisher, R. L. Emmett, C. A. Morgan, and E. Casillas. 2005. Species composition and community structure of pelagic nekton off Oregon and Washington under variable oceanographic conditions. Marine Ecology Progress Series 298:41–57.

Brodeur, R., I. Perry, J. Boldt, L. Flostrand, M. Galbraith, J. King, J. Murphy, K. Sakuma, and A. Thompson. 2018. An unusual gelatinous plankton event in the NE Pacific: the Great Pyrosome Bloom of 2017. PICES Press 26(1):22–27.

Burke, B. J., B. R. Beckman, W. T. Peterson, C. A. Morgan, E. A. Daly, and M. Litz. 2013. Multivariate methods to forecast Pacific salmon returns. PLoS One 8(1):e54134.

Daly, E. A., R. D. Brodeur, and T. D. Auth. 2017. Anomalous ocean conditions in 2015: impacts on spring Chinook Salmon and their prey field. Marine Ecology Progress Series 566:169–182.

Di Lorenzo, E., and N. Mantua. 2016. Multi-year persistence of the 2014/15 North Pacific marine heatwave. Nature Climate Change 6:1042–1047.

Efford, I. E. 1970. Recruitment to sedentary marine populations as exemplified by the sand crab *Emerita analoga* (Decapoda, Hippidae). Crustaceana 18(3):293–308.

Efford, I. E. 1976. Distribution of the sand crabs in the genus *Emerita* (Decapoda, Hippidae). Crustaceana 30(2):169–183.

Fish Passage Center. 2017. Smolt data. Fish Passage Center, Portland, Oregon. Available: http://www.fpc.org/smolt/smp_queries.php. (December 2017).

Fisher, J. L., W. T. Peterson, and R. R. Rykaczewski. 2015. The impact of El Niño events on the pelagic food chain in the Northern California Current. Global Change Biology 21(12):4401–4414.

Gentemann, C. L., M. R. Fewings, and M. García-Reyes. 2017. Satellite sea surface temperatures along the West Coast of the United States during the 2014–2016 northeast Pacific marine heat wave. Geophysical Research Letters 44(1):312–319.

Jacobson, K. C., W. T. Peterson, M. Trudel, J. Ferguson, C. A. Morgan, D. W. Welch, A. M. Baptista, B. R. Beckman, R. D. Brodeur, E. Casillas, R. L. Emmett, J. A. Miller, D. J. Teel, T. C. Wainwright, L. A. Weitkamp, J. E. Zamon, and K. Fresh. 2012. The marine ecology of juvenile Columbia River basin salmonids: a synthesis of research 1998–2011. Northwest Power and Conservation Council, Portland, Oregon.

Jacox, M. G., E. L. Hazen, K. D. Zaba, D. L. Rudnick, C. A. Edwards, A. M. Moore, and S. J. Bograd. 2016. Impacts of the 2015–2016 El Niño on the California Current System: early assessment and comparison to past events. Geophysical Research Letters 43(13):7072–7080.

Johnson, M. W. 1939. The correlation of water movements and dispersal of pelagic larval stages of certain littoral animals, especially the sand crab, *Emerita*. Journal of Marine Research 2:236–245.

Leising, A. W., I. D. Schroeder, S. J. Bograd, J. Abell, R. Durazo, G. Gaxiola-Castro, E. P. Bjorkstedt, J. Field, K. Sakuma, R. R. Robertson, R. Goericke, W. T. Peterson, R. Brodeur, C. Barcelo, T. D. Auth, E. A. Daly, R. M. Suryan, A. J. Gladics, J. M. Porquez, S. McClatchie, E. D. Weber, W. Watson, J. A. Santora, W. J. Sydeman, S. R. Melin, F. P. Chavez, R. T. Golightly, S. R. Schneider, J. Fisher, C. Morgan, R. Bradley, and P. Warybok. 2015. State of the California Current 2014–15: impacts of the warm-water "Blob". California Cooperative Oceanic Fisheries Investigations Reports 56:31–68.

Levin, P. S., M. J. Fogarty, S. A. Murawski, and D. Fluharty. 2009. Integrated ecosystem assessments: developing the scientific basis for ecosystem-based management of the ocean. PLoS Biology 7(1):e1000014.

Lindley, S. T., C. B. Grimes, M. S. Mohr, W. T. Peterson, J. Stein, J. T. Anderson, L. W. Botsford, D. L. Bottom, C. A. Busack, T. K. Collier, J. Ferguson, J. C. Garza, A. M. Grover, D. G. Hankin, R. G. Kope, P. W. Lawson, A. Low, R. B. McFarlane, K. Moore, M. Palmer-Zwahlen, F. B. Schwing, J. Smith, C. Tracy, R. Webb, B. K. Wells, and T. H. Williams. 2009. What caused the Sacramento River fall Chinook stock collapse? NOAA Technical Memorandum NMFS-SWFSC-447.

Love, M. S., L. Thorsteinson, and M. Yoklavich. 2002. The rockfishes of the northeast Pacific. University of California Press, Berkeley.

Mantua, N. J., S. R. Hare, Y. Zhang, J. M. Wallace, and R. C. Francis. 1997. A Pacific interdecadal climate oscillation with impacts on salmon production. Bulletin of the American Meteorological Society 78(6):1069–1079.

McClatchie, S., J. Duffy-Anderson, J. C. Field, R. Goericke, D. Griffith, D. S. Hanisko, J. A. Hare, J. Lyczkowski-Shultz, W. T. Peterson, and W. Watson. 2014. Long time series in U.S. fisheries oceanography. Oceanography 27(4):48–67.

McClatchie, S., R. Goericke, A. Leising, T. D. Auth, E. Bjorkstedt, R. R. Robertson, R. D. Brodeur, X. Du, E. A. Daly, C. A. Morgan, F. P. Chavez, A. J. Debich, J. Hildebrand, J. Field, K. Sakuma, M. G. Jacox, M. Kahru, R. Kudela, C. Anderson, B. E. Lavaniegos, J. Gomez-Valdes, S. P. A. Jiménez-Rosenberg, R. McCabe, S. R. Melin, M. D. Ohman, L. M. Sala, B. Peterson, J. Fisher, I. D. Schroeder, S. J. Bograd, E. L. Hazen, S. R. Schneider, R. T. Golightly, R. M. Suryan, A. J. Gladics, S. Loredo, J. M. Porquez, A. R. Thompson, E. D. Weber, W. Watson, V. Trainer, P. Warzybok, R. Bradley, and J. Jahncke. 2016. State of the California Current 2015–16: comparisons with the 1997–98 El Niño. California Cooperative Oceanic Fisheries Investigations Reports 57:1–57.

Morgan, C. A., A. De Robertis, and R. W. Zabel. 2005. Columbia River plume fronts I: hydrography, zooplankton distribution, and community composition. Marine Ecology Progress Series 299:19–31.

Morgan, C. A., D. M. Van Doornik, and C. A. Bucher. 2017. Cruise report: NWFSC/NOAA Fisheries *FV Frosti*, Cruise 17-01, May 22–27, 2017. Available: https://www.cbfish.org/Document.mvc/Viewer/P158503.

Naiman, R. J., J. R. Alldredge, D. A. Beauchamp, P. A. Bisson, J. Congleton, C. J. Henny, N. Huntly, R. Lamberson, C. Levings, E. N. Merrill, W. G. Pearcy, B. E. Rieman, G. T. Ruggerone, D. Scarnecchia, P. E. Smouse, and C. C. Wood. 2012. Developing a broader scientific foundation for river restoration: Columbia River food webs. Proceedings of the National Academy of Sciences 109(52):21201–21207.

NOAA-AFSC (NOAA Alaska Fisheries Science Center). 2017. Researchers Investigate Explosion in the Number of Pyrosomes off Alaska. Available: https://www.fisheries.noaa.gov/feature-story/researchers-investigate-explosion-number-pyrosomes-alaska (May 2019).

Orsi, J. A., and A. C. Wertheimer. 1995. Marine vertical distribution of juvenile Chinook and Coho Salmon in southeastern Alaska. Transactions of the American Fisheries Society 124(2):159–169.

Pearcy, W. G. 2002. Marine nekton off Oregon and the 1997–98 El Niño. Progress in Oceanography 54(1–4):399–403.

Pearcy, W. G., and A. Schoener. 1987. Changes in the marine biota coincident with the 1982–1983 El Niño in the northeastern subarctic Pacific Ocean. Journal of Geophysical Research: Oceans 92(13):14417–14428.

Perissinotto, R., P. Mayzaud, P. D. Nichols, and J. P. Labat. 2007. Grazing by *Pyrosoma atlanticum* (Tunicata, Thaliacea) in the south Indian Ocean. Marine Ecology Progress Series 330:1–11.

Peterson, W. T., J. L. Fisher, J. O. Peterson, C. A. Morgan, B. J. Burke, and K. L. Fresh. 2014. Applied fisheries oceanography: ecosystem indicators of ocean conditions inform fisheries management in the California Current. Oceanography 27(4):80–89.

Peterson, W. T., J. L. Fisher, P. T. Strub, X. Du, C. Risien, J. Peterson, and C. T. Shaw. 2017. The pelagic ecosystem in the Northern California Current off Oregon during the 2014–2016 warm anomalies within the context of the past 20 years. Journal of Geophysical Research: Oceans 122(9):7267–7290.

Peterson, W. T., C. A. Morgan, J. P. Fisher, and E. Casillas. 2010. Ocean distribution and habitat associations of yearling Coho *Oncorhynchus kisutch* and Chinook *O. tshawytscha* Salmon in the Northern California Current. Fisheries Oceanography 19(6):508–525.

Peterson, W. T., M. Robert, and N. Bond. 2015. The warm Blob continues to dominate the ecosystem of the Northern California Current. PICES Press 23(2):44–46.

Peterson, W. T., and F. B. Schwing. 2003. A new climate regime in northeast Pacific ecosystems. Geophysical Research Letters 30(17):1896.

Ralston, S., K. M. Sakuma, and J. C. Field. 2013. Interannual variation in pelagic juvenile rockfish (*Sebastes* spp.) abundance—going with the flow. Fisheries Oceanography 22(4):288–308.

Ressler, P. H., J. A. Holmes, G. W. Fleischer, R. E. Thomas, and K. C. Cooke. 2007. Pacific Hake *Merluccius productus* autecology: a timely review. Marine Fisheries Review 69(1–4):1–24.

Ruzicka, J. J., R. D. Brodeur, R. L. Emmett, J. H. Steele, J. E. Zamon, C. A. Morgan, A. C. Thomas, and T. W. Wainwright. 2012. Interannual variability in Northern California Current food web structure: changes in energy flow pathways and the role of forage fish, euphausiids, and jellyfish. Progress in Oceanography 102:19–41.

Sakuma, K. M., J. C. Field, N. J. Mantua, S. Ralston, B. B. Marinovic, and C. N. Carrion. 2016. Anomalous epipelagic micronekton assemblage patterns in the neritic waters of the California Current in spring 2015 during a period of extreme ocean conditions. California Cooperative Oceanic Fisheries Investigations Reports 57:163–183.

Shenker, J. M. 1984. Scyphomedusae in surface waters near the Oregon coast, May–August 1981. Estuarine, Coastal and Shelf Science 19(6):619–632.

Sorte, C. J., W. T. Peterson, C. A. Morgan, and R. L. Emmett. 2001. Larval dynamics of the sand crab *Emerita analoga* off the central Oregon

coast during a strong El Niño period. Journal of Plankton Research 23(9):939–944.
Strasburger, W. W., J. H. Moss, K. A. Siwicke, and E. Yasumiishi. 2018. Results from the eastern Gulf of Alaska ecosystem assessment, July through August 2016. NOAA Technical Memorandum NMFS-AFSC-363. Available: https://www.afsc.noaa.gov/Publications/AFSC-TM/NOAA-TM-AFSC-363.pdf.
Suchman, C. L., and R. D. Brodeur. 2005. Abundance and distribution of large medusae in surface waters of the Northern California Current. Deep Sea Research Part II: Topical Studies in Oceanography 52(1):51–72.
Suchman, C. L., R. D. Brodeur, E. A. Daly, and R. L. Emmett. 2012. Large medusae in surface waters of the Northern California Current: variability in relation to environmental conditions. Hydrobiologia 690(1):113–125.
Suchman, C. L., E. A. Daly, J. E. Keister, W. T. Peterson, and R. D. Brodeur. 2008. Feeding patterns and predation potential of scyphomedusae in a highly productive upwelling region. Marine Ecology Progress Series 358:161–172.
Teel, D. J., B. J. Burke, D. R. Kuligowski, C. A. Morgan, and D. M. Van Doornik. 2015. Genetic identification of Chinook Salmon: stock-specific distributions of juveniles along the Washington and Oregon coast. Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science 7(1):274–300.
Van Doornik, D. M., D. J. Teel, D. R. Kuligowski, C. A. Morgan, and E. Casillas. 2007. Genetic analyses provide insight into the early ocean stock distribution and survival of juvenile Coho Salmon off the coasts of Washington and Oregon. North American Journal of Fisheries Management 27:220–237.
Welch, C. 2017. Bizarre, glowing sea creatures bloom in the Pacific. National Geographic. Available: https://news.nationalgeographic.com/2017/06/pyrosome-fire-body-bloom-eastern-pacific-warm-water/. (November 11, 2017).
Wells, B. K., I. D. Schroeder, S. J. Bograd, E. L. Hazen, M. G. Jacox, A. Leising, N. Mantua, J. A. Santora, J. Fisher, B. Peterson, E. Bjorkstedt, R. R. Robertson, F. P. Chavez, R. Goericke, R. Kudela, C. Anderson, B. E. Lavaniegos, J. Gomez-Valdes, R. D. Brodeur, E. A. Daly, C. A. Morgan, T. D. Auth, J. Field, K. Sakuma, S. McClatchie, A. R. Thompson, E. D. Weber, W. Watson, R. M. Suryan, J. Parrish, J. Dolliver, S. Loredo, J. M. Porquez, J. E. Zamon, S. R. Schneider, R. T. Golightly, P. Warzybok, R. Bradley, J. Jahncke, W. Sydeman, S. R. Melin, J. Hildebrand, A. J. Debich, and B. Thayre. 2017. State of the California Current 2016–17: still anything but "normal" in the North. California Cooperative Oceanic Fisheries Investigations Reports 58:1–55. AFS