Annual Progress Report
to
National Oceanic & Atmospheric Administration

NOAA Award# NA16OAR4320152

Reporting period: 7/01/2017 - 6/30/2018

Oregon State University

Cooperative Institute for Marine Resources Studies

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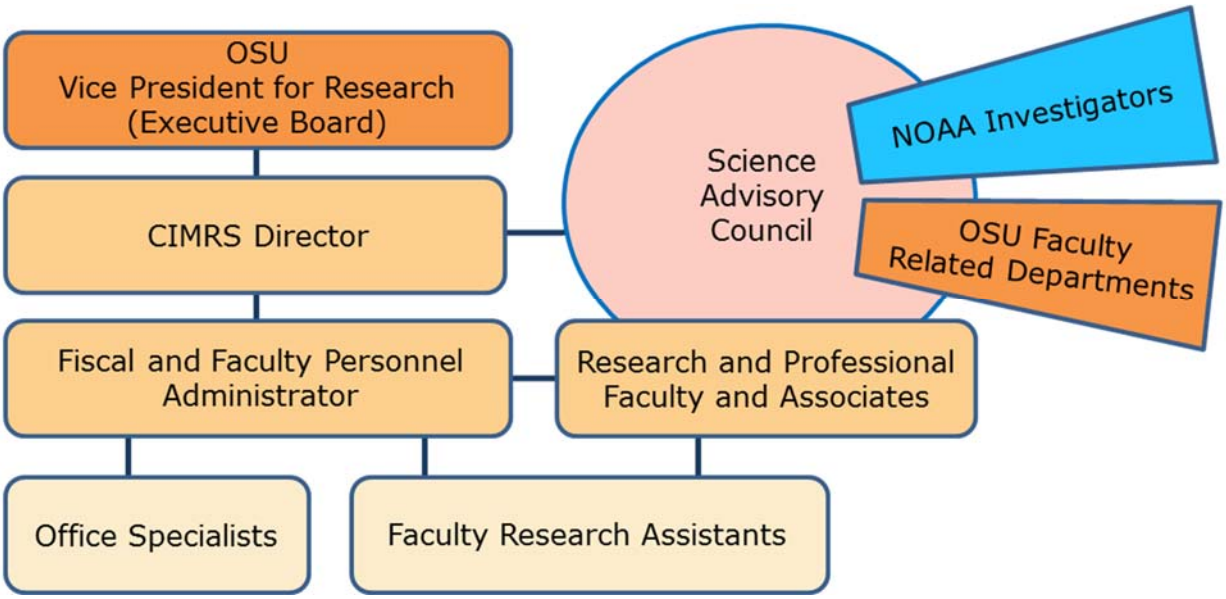
ORGANIZATION

CIMRS is administered through the OSU Research Office with oversight from an Executive Board made up of members from the participating NOAA laboratories and collaborating OSU colleges and programs under the terms of a Memorandum of Agreement between OSU and NOAA/NMFS. A Science Advisory Council (SAC) gives input on research directions, progress, and policy to the Director.



2017/2018 EXECUTIVE BOARD

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Roberta Merinelli Dean, College of Earth, Ocean & Atmospheric Sciences, Oregon State University	**Jeff Napp** Director, Resource Ecology and Fisheries Management Division, Alaska Fisheries Science Center, NOAA
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Michael Banks (Ex Officio) Director, Cooperative Institute for Marine Resources Studies, Oregon State University	

2017/2018 SCIENCE ADVISORY COUNCIL

David Noakes (Chair) Professor, Department of Fisheries and Wildlife, Oregon State University	**Chris Parrish** Associate Professor, College of Engineering Oregon State University
Jerri Bartholomew Professor, Department of Microbiology, Oregon State University	**Clare Reimers** Professor, College of Earth, Ocean, and Atmospheric Sciences, Oregon State University
Brian Burke Estuarine and Ocean Ecology Program Manager Fish Ecology Division, Northwest Fisheries Science Center, NOAA	**Clifford Ryer** Fisheries Biologist, Resource Assessment and Conservation Engineering Division, Alaska Fisheries Science Center, NOAA

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Carol Stepien OERD Division Leader, Ocean Environment Research Division, Pacific Marine Environmental Laboratory, NOAA	**Michael Banks** (Ex Officio) Director, Cooperative Institute for Marine Resources Studies, Oregon State University

Research at CIMRS

CIMRS partnership brings university scientists together with scientists from NOAA Northwest Fisheries Science Center, Alaska Fisheries Science Center, and Pacific Marine Environmental Laboratory.

Current research themes are:

- Marine Ecosystems and Habitat;
- Protection and Restoration of Marine Resources;
- Seafloor Processes; and
- Marine Bioacoustics.

CIMRS' diverse and richly multidisciplinary range of applied and basic research investigations include marine chemistry and geophysics, ocean acidification and hypoxia, trophic dynamics and modeling, fisheries stock/habitat assessment and behavioral ecology, longer term prediction of physical (mesoscale/upwelling/plume/estuarine) and biological (predator/prey, lipid composition) inter-relationships and climate, zooplankton ecology, genomics, passive acoustic monitoring of marine mammals, socio-economic issues related to fisheries, and spatial planning.

The advancement of basic knowledge about ocean ecosystems from local to global scales, the conservation of endangered species, maintaining sustainable commercial and recreational stocks, and predicting and mitigating natural hazards associated with the solid earth (*e.g.*, earthquakes and volcanoes) and climate change (*e.g.*, changing weather, sea level rise, and ocean acidification) are in line with NOAA's mission. Over the next decade, CIMRS expects to assist NOAA in meeting existing and emerging environmental and ecological challenges through research, education and outreach. Our research efforts will promote technological and scientific advancements that lead to ecological health, marine geophysical dynamics, sustainable marine resources, and socioeconomic benefits.

In FY18, CIMRS researchers spent 165 days at sea. In addition, CIMRS researchers conducted nine sampling days on the Newport Hydrographic Line.

RESEARCH PERSONNEL

The following table describes CIMRS research personnel in FY18

Position Category	**# Staff**	**# B.S.**	**# M.S.**	**# Ph.D.**
Research Scientist	4	--	--	4
Research Associates	1	--	--	1
Research Assistants	15	9	6	0
Total Support >50%	**18**	**9**	**5**	**4**
Research Scientist < 50%	**2**	**--**	**1**	**1**

2017-2018 PUBLICATIONS - ALL PEER-REVIEWED

Institute Lead Author	**NOAA Lead Author**	**Other Lead Author**
27	**20**	**20**

TASK 1: ADMINISTRATION, EDUCATION, AND OUTREACH

ADMINISTRATIVE STAFF

Position	FTE	Supported by Award
Director	0.4	Partial
Administrator	1.0	Partial
Purchasing Specialist	0.5	No
Academic Wage Faculty	0.1	No
Travel Specialist	0.25	No

INSTITUTE DIRECTOR ACTIVITIES

National Service

- Lunch host for a visit by our Congressional Deligate to NOAA's Marine Operations Center - Pacific (Sep 6, 2017)
- CA Sea Grant Review panel (Dec 18-20th, 2017)
- National CI Directors meeting, Washington DC, April 3&4th, 2018
- Note taker for National Line Office – CI Engagement discussions and co-wrote/edited NOAA Policy for Cooperative Institute Personnel Matters
- Major theme webpage rewrite to better reflect increasing CIMRS activity with the National Ocean Service Line Office (May 4th and current, 2018)
- External committee member and examiner for Dr. Nadya Mamoozadeh (Virgina Institute for Marine Science) and Dr. Kimani Kitson-Walters (University of the West Indies, Jamaica)

University Service

- OSU Centers, Institutes and Programs meetings
- Convened meetings for CIMRS coordination and oversight:
    - CIMRS long term visioning with OSU VP for Research, Cindy Sagers, Sep 20th, 2017, Feb 21st, 2018)
    - CIMRS All Hands (Dec 13th, 2017, June 12th, 2018)
    - NOAA Labs and Directors visit to their location in Seattle to champion OSU-CIMRS investments (MSI), objectives and potentials (Mar 20&21st, 2018)
    - CIMRS Science Advisory Council meeting, Newport (March 29th, 2018)
    - CIMRS Executive Board, Corvallis, OR (April 13, 2018)

- CIMRS update with Bob Cowen, Director HMSC (various)
- NWFSC Estuarine & Ocean Ecology Program, Newport (Jan 1& Feb 1, 2018)
- Initiated, and named first CIMRS/MSI graduate student fellow (following ranking provided by CIMRS Science Advisory Council)
- Following Executive Committee decision, initiated and convened discussions related to NOAA as a funding partner for MSI faculty position: Cynthia Sagers (April 20, 2018), Jack Barth and Bob Cowen (May 24, 2018, Cisco Werner June 25, 2018)
- Following Cynthia Sager Aquaculture discussion (Aug 1 & Oct 6, 2017) and with Kevin Werner (Dec 7, 2017) explored SK NOAA funding in aquaculture, & long term marine sustainability (lead PI on two FY18 pre-proposals not invited to full proposal review and two pre-proposal currently in review for FY19), among proposals to others funding sources, e.g. FFAR
- Food from the Sea workshop (May 14-16th, 2018), and outreach to World Bank initiatives in Africa – RUFORUM, Strengthening Higher Agricultural Education in Africa
- Annual review with CIMRS faculty and post docs (Sept & Oct, 2017)
- U.S. Congressman Kurt Schrader roundtable in Newport (April 20, 2018)
- Engaged with Kathleen Kellay (OSU) and John Baker of Northwest Management Specialists for CIMRS teamwork enhancement with follow-up workshops
- Candidates review: Associate VP for Research (Oct 2017), Director Marine Mammal Institute Director (May 2018). Director and Faculty Coordinator for COMES (May 2018)
- Initiated and edited letters from OSU Center, Institute and Program Directors – Our Very Strong Support for Research (July 9, 2018)

- Engaged in various HMSC/OSU Marine Studies Campus and Building meetings
- Engaged in HMSC Executive Committee meetings (monthly)

Research:

The Institute Director's research was supported in 2017-18 through grants and state funds awarded through OSU's Coastal Oregon Marine Experiment Station, Department of Fisheries and Wildlife where he holds a faculty appointment at the rank of Professor.

Marine Fisheries Genetics & Conservation				
Principal Investigators	**Funding Agent**	**Title**	**Term**	**Funds**
Banks	Oregon Department of Fish and Wildlife	AMS ODFW 617 Banks Colab Htchry Rsc	03/22/2016 – 06/30/2019	$889,333
Jander/other coPIs including Banks	NSF	MRI: Acquisition of a SQUID magnetometer to support research and education in engineering, physical, biological and geological sciences	Fed FY18	$499,791
Banks	USDA	AMS - USDA Banks Gentcs Pac Oysters	09/28/2015 – 09/27/2018	$143,546
Ciannelli et al (Banks as core member)	NSF	NRT-DESE: Risk and Uncertainty Quantification in Marine Science and policy	FY16-FY21	$2,999,829
		TOTAL		$4,532,499

Grant and Journal Reviews:

CIMRS, *Envir Biol of Fishes, WA Sea Grant Panel, Biology Letters, Canadian Journal of Fisheries and Aquatic Sciences.*

PUBLICATIONS

MARINE FISHERIES GENETICS & CONSERVATION
*Papers by students or postdoctoral advisees, whom I offer first authorship as a matter of policy.

*Hemstrom W, Banks MA, Van deWetering S. 2018. Fish ladder installation across a historical barrier asymmetrically increased conspecific introgressive hybridization between wild winter and summer run steelhead salmon in the Siletz River, Oregon. *CJFAS* dx.doi.org/10.1139/cjfas-2016-0411

*Davis CD, Epps CW, Flitcroft RL, Banks MA. 2018 Refining and defining riverscape genetics: how rivers influence population genetics structure. *WIREs Water DOI: 10.1002/wat2.1269*

* Johansson ML, Litz MNC, Brodeur RD, Britt TD, Vanegas CA, Hyde JR, Banks MA. 2018. Seasonal distribution of late larval and juvenile rock sh (*Sebastes* spp.) and associated environmental conditions off Oregon and Washington: new insights based on genetics. *Fish. Bull.* 116:266-280

In Review/revision:

Thompson TQ, Bellinger RM, O'Rourke SM,Prince DJ, Stevenson AE, Rodrigues AT, Sloat MR, Speller CF, Yang DY, Butler VL, Banks MA, Miller MR. Anthropogenic habitat alteration leads to rapid loss of adaptive variation and restoration potential in wild salmon populations. *PNAS*

*Auld HL, Noakes DLG, and Banks MA.. Advancing mate choice studies in salmonids and other polyploids. *Reviews in Fish Biology and Fisheries*

* Hemstrom W, Meyer E, Banks MA Macro-evolutionary events enhance adaptive capacity during spread in invasive Three- spined Stickleback.

Brandes PL, Pyper B, Banks MA, Jacobson DP, Garrison T, and Cramer S. Comparison of Length of Date Criterion to genetic assignments for juvenile winter and spring run Chinook salmon caught at Sacramento and Chipps Island in the Sacramento-San Joaquin Delta of California.

Jacobson KC, Baldwin RE, Banks MA, and Emmett R. Parasites of Pacific sardine (*Sardinops sagax*) help identify residency and migration patterns in the California Current

Other Technical Writing, Progress, Completion Reports and Research archives:

Banks, MA, CIMRS 2018 Executive Board meeting agenda and director overview

Administrative Tasks

Dr. Banks and the CIMRS Administrator were responsible for submission of 20 proposals under the Institutional award during the period 7/1/17 – 6/30/18. CIMRS Administrator, Ms. LeAnne Rutland, attended the CI Administrators Meeting held in Fairbanks Alaska on August 29-30, 2017. CIMRS received $205,663 in Task 1 funding for FY18.

CIMRS Education

Graduate Students Advised by CIMRS Faculty

CIMRS Faculty also advise students on projects independent of NOAA funding. The Hatfield Marine Science Centers offers a wide variety of scholarships, fellowships and awards that help supplement student research (http://hmsc.oregonstate.edu/academics/hmsc-scholarships-fellowships-and-awards) .

Selene Fregosi: "Passive-acoustic monitoring of mid-frequency cetaceans using gliders and floats" Dept. Fisheries &Wildlife, David Mellinger

Michelle Fournet: "Humpback whale acoustic ecology and the impacts of large vessel noise on non-song vocal behavior in Glacier Bay National Park" Dept. Fisheries &Wildlife, David Mellinger

CIMRS Undergraduate Students Projects

The Hatfield Marine Science Center has successfully received long-term funding from the National Science Foundation for a summer Research Experience for Undergraduates (REU) program (http://hmsc.oregonstate.edu/academics/internships/research-experiences-undergraduates-reu). Several CIMRS faculty have teamed up with undergraduate students from around the country who wish to explore research opportunities in the marine field. In the summer of 2018, Charles Leal, Oregon State University, visited for a summer internship with CIMRS Faculty Research Assistant, Jennifer Fisher, for a project: "Long-term observations of physical and biological oceanographic conditions in the coastal waters off Oregon; hydrography and zooplankton"

CIMRS Outreach Activities

Educational and scientific outreach is important in all aspects of CIMRS research. Websites are a venue that reach an enormous audience. CIMRS investigators feature their collaborative research efforts in the fields of fisheries oceanography, geophysical and acoustic monitoring of spreading centers, ocean exploration, and bioacoustic monitoring of marine mammals at several websites hosted by NOAA and CIMRS. Research activities, contributions, and news stories throughout the year are posted on CIMRS website, http://hmsc.oregonstate.edu/cimrs/. Owing to the collaborative nature of CIMRS, a large component of outreach provided by CIMRS investigators is on the award winning website, http://www.pmel.noaa.gov/eoi, which continues to feature educational curricula, video clips of *in situ* seafloor experiments, and animated 3-dimensional fly-through videos of seafloor ridges. CIMRS investigators continually update two

blogs this year: www.blogs.oregonstate.edu/acoustics/ and Newportal: A gateway to oceanographic information from the Newport Line and beyond

Active CIMRS research projects are featured at OSU Hatfield Marine Science Center's (HMSC) Visitor Center, which is dedicated to the lifelong exploration and discovery of coastal and marine sciences and resources. Many educational exhibits and programs at the Visitor Center correspond with current research conducted by the multiple federal labs co-located with HMSC and may be viewed by 150,000 attendees annually. CIMRS investigators have collaborated with Oregon Sea Grant educational staff to design and prepare interactive exhibits, covering the entire range of CIMRS research. Among the permanent exhibits, "Ring of Fire" demonstrates submarine volcanism research on the seafloor. "Mysteries of the Deep" and "Burning Ridge" bring the seafloor to life with real volcanic rock specimens and a 3-D mid-ocean ridge model. "CIMRS Acoustic Display" exhibit educates visitors on marine acoustics research. In addition to these permanent exhibits, a real hydrophone and an interactive earthquake/seismic kiosk are on display. "Sensing the Sea" describes various technological methods of monitoring ocean conditions, from satellites to hydrophones. "Endangered Species of Pacific Northwest" exhibit educates visitors on the various regional endangered species. "Riding the Ocean Currents" is a multimedia exhibit that illuminates the relationship between ocean currents and plankton larval dispersal off the Oregon coast; the exhibit includes digital screens depicting ocean currents at various depths. "Sustainable Fisheries" includes an overview of project CROOS which has a goal to improve salmon management through developing near real-time tracking of genetic stocks.

CIMRS researchers provide valuable volunteer hours at K-12 Science Fairs and related activities throughout the year including Marine Science Day that draws over 3,000 visitors to the Hatfield Marine Science Center to discover current research projects at the campus.

TASK 2

(Projects support NOAA Strategic Plan Goal of Healthy Oceans and Climate Adaptation and Mitigation)

Theme: Marine Ecosystem and Habitat

Amendment 5, 26, 20, 33: Indicators of Phenology in the northern California Current

Funded: $590,539

OSU RESEARCH STAFF: *Michael Banks, Director CIMRS; Jennifer Fisher, Faculty Research Assistant; Samantha Zeman, Faulty Research Assistant*

NOAA TECHNICAL LEAD: Bill Peterson, NWFSC; Kym Jacobson, NWFSC

Background: The California Current Integrated Ecosystem Assessment (CCIEA) includes numerous indicators for the ecosystem state of the northern California Current (NCC). Among the most informative are indicators based on copepod community structure measured along the Newport Hydrographic Line (NHL) that correlate with recruitment of salmon (Burke et al. 2013, Peterson et al. 2014), sablefish (Schirippa and Colbert 2006, Peterson et al. 2014), and sardine (Peterson et al. 2014), and have strong potential to support stock assessments and forecasts of commercial fish stocks several years into the future.

The power of copepod-based indicators derives from (1) consistent affinities of different copepod species for cold water versus warm water and for nearshore versus oceanic distributions (Hooff and Peterson 2006), reinforced by (2) qualitative differences in energy content among these groups. Specifically, several cold-water species rich in wax esters and fatty acids, tend to dominate coastal zooplankton communities during the summer upwelling season (typically May through September), and are especially productive when cool conditions prevail throughout the NCC. In contrast, lipid-poor, warm-water taxa are more common during winter or when El Niño events or persistently warm conditions (as indicated by positive Pacific Decadal Oscillation values) disrupt community transitions related to the onset of seasonal upwelling and equatorward flow (Fisher et al. 2015).

Analysis of hydrographic and zooplankton data collected along the NHL has revealed patterns in how the planktonic ecosystem of the NCC responds to forcing over time. This time series spans several “natural experiments” structured by environmental and climate variability, which has allowed detection of climate-ecosystem correlations at inter-annual to decadal scales, and the formulation of mechanistic hypotheses that link ecosystem responses to physical forcing (Keister et al. 2011, Bi et al. 2011, Fisher et al. 2015).

Survey of pelagic and demersal habitats

Project Background: The pelagic environment of the continental shelf and offshore of the shelf, beyond the coastal upwelling zone, are key habitats for juvenile stages of many commercially important species such as sablefish, rockfishes, flatfishes, and small pelagic forage species (e.g., northern anchovy, sardines) as well as ecologically important mesopelagic species such as krill and myctophids. Surveys of both the nearshore and the offshore habitats of fish and their food resources off the Oregon coast were conducted quarterly at 12 stations from 1-85 nautical miles from shore to provide data on the entire shelf-slope habitat. Measurements include vertical profiles of temperature, salinity, oxygen and fluorescence using a Seabird SBE25. Surface water samples are collected for nutrient and chlorophyll concentration. Zooplankton are sampled with a ½ m diameter plankton net (200 µm mesh) hauled from near the sea floor to the surface and euphausiids and ichthyoplankton are sampled with 60 cm Bongo nets (333 µm mesh) at night.

Progress Report: The project has continued its successful collection of hydrography, zooplankton, ichthyoplankton, and juvenile fishes in the Northern California Current ecosystem. Two quarterly cruises were completed on board the commercial fishing vessel F/V Timmy Boy in August and December 2017 and two cruises aboard the NOAA ship BellShimada in February and May 2018. During each cruise, 13 stations were sampled out to 85 nautical miles offshore, along the NH Line. At each station, we collected hydrographic data; water samples for nutrients, chlorophyll-a concentration, zooplankton and ichthyoplankton using neuston, vertical and bongo plankton nets; and juvenile and adult benthic fish, and invertebrate samples using a video equipped beam trawl. Our collaboration with the commercial fishing industry continues to be a positive relationship, with scientists and fisherman contributing knowledge and expertise to goals of the project.

Sample processing continues in all aspects of the project. All CTD data have been processed, quality controlled and uploaded to our MS Access database and posted on our Newportal Blog (https://www.nwfsc.noaa.gov/news/blogs/display_blogentry.cfm?blogid=1.). All nutrient samples have been analyzed and entered in our database and approximately half of the chlorophyll samples have been processed and entered. All zooplankton from NH-5 have been enumerated and entered into our database. Work continues on the backlog of juvenile fish samples, with three successful processing events in Dec 2017 and March 2018.

Data Products:

The data have contributed to updates on "Ocean Ecosystem Indicators of Salmon Marine Survival in the Northern California Current" website:
http://www.nwfsc.noaa.gov/research/divisions/fe/estuarine/oeip/index.cfm

The data have contributed to the Newportal Blog: https://www.nwfsc.noaa.gov/news/blogs/display_blogentry.cfm?blogid=1.

Biological and physical data were uploaded to the California Current IEA ERRDAPP server: <https://www.integratedecosystemassessment.noaa.gov/regions/california-current-region/indicators/climate-and-ocean-drivers.html>

Publications:

Auth TD, Daly EA, Brodeur RD, **Fisher JL** (2018) Phenological and distributional shifts in ichthyoplankton associated with recent warming in the northeast Pacific Ocean. *Global Change Biology*. 24(1):259-72.

Peterson, WT, **JL Fisher**, P Ted Strub, **X Du**, C Risien, J Peterson, and C Tracy 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, *J. Geophys. Res. Oceans*, 122, doi:10.1002/2017JC012952.

Wells BK, Schroeder ID, Bograd SJ, Hazen EL, Jacox MG, Leising A, Mantua N, Santora JA, **Fisher J**, Peterson WT, Bjorkstedt E. State of the California Current 2016–17: Still anything but normal in the north. (2017) *Calif. Coop. Oceanic Fish. Invest. Rep.,* 1;58:1-55.

Long-term observations of physical and biological oceanographic conditions in the coastal waters off Oregon; hydrography and zooplankton

Project Background: OSU researchers monitor ocean conditions using an ecosystem based approach. Continuation of this work is timely because anomalously warm-ocean conditions (as a result of "The Blob"; Bond et al. 2015), known to negatively impact the marine ecosystem, have occurred since fall 2014. Concurrently, one of the strongest El Niños in recent history is occurring at the equator. It is known from past work that the ecosystem recovery time is strongly related to the intensity and duration of warm events (Fisher et al. 2015). It is unknown whether "The Blob" or El Niño will persist for the next year, or whether there will be a transition to La Niña conditions with a different zooplankton community. Sampling during these unprecedented conditions will aid in understanding the ecosystem response to these anomalous events and will allow researchers to determine when the ecosystem has transitioned back to 'normal'.

This research includes continued monitoring of ocean conditions and zooplankton communities along the NHL at twice monthly intervals at 7 stations from 1-25 nautical miles from shore. Routine measurements include vertical profiles of temperature, salinity, oxygen and fluorescence using a Seabird SBE25. Surface water samples are collected for nutrient, chlorophyll and

phytoplankton species composition. Zooplankton are sampled with a ½ m diameter plankton net (200 µm mesh) hauled from near the sea floor to the surface and euphausiids and ichthyoplankton are sampled with 60 cm Bongo nets (333 µm mesh) at night. The physical and biological data are summarized into ecosystem indicators of ocean conditions. These indicators include basin-scale and regional physical properties, as well as local biological indices (e.g., copepod biomass anomalies). All indices are posted to the Ocean Ecosystem Indicators webpage: http://www.nwfsc.noaa.gov/research/divisions/fed/oeip/a-ecinhome.cfm and outlooks of future salmon returns will be generated based on these indices and posted as well. Physical and biological data will also be provided to the CCIEA and will be served on the CCIEA ERRDAPP data server.

Progress Report: Eleven research cruises were conducted aboard the R/V Elakha, two aboard the R/V Pacific Storm, and one aboard the F/V Timmy Boy. Seven stations, or a subset there of, from 1 to 46 km from shore were sampled during each cruise. Additionally, two research cruises were conducted aboard the R/V Bell Shimada in Feb 2018 and May 2018. Six transects were sampled aboard the Shimada from the nearshore, across the shelf, and out to 200 miles off Newport and 150 miles off Crescent City.

At each station, measurements of hydrography (temperature, salinity, depth, dissolved oxygen, fluorescence) were made throughout the water column using a CTD (Seabird Model 25). Water samples were collected for analysis of chlorophyll and nutrient concentration. Live samples were collected at a nearshore station and brought back to the laboratory for experiments investigating copepod egg production in relation to changing ocean conditions. At least 20 individual *Calanus pacificus* or *Calanus marshallae* were isolated into small jars with ambient seawater. Eggs were enumerated following a 24 hours incubation period. These data are entered into a database and are undergoing analysis with environmental variables for a peer reviewed manuscript. Presently, all of the hydrographic, chlorophyll and nutrient samples have been processed and uploaded into a database, and the zooplankton have been enumerated for all dates from the vertical net for one shelf station along the NH line and zooplankton sample processing for the slope station and euphausiid abundance is ongoing. These two stations represent the shelf and slope habitats and are located 5 miles from shore in 60 m of water and 25 miles from shore in 300 m of water. The copepod species composition and biomass from these two stations are used as indicators of food quality for higher trophic levels. Because we now have 22 years of data that span oscillations in basin scale indices (e.g., PDO and ENSO) and variations in the timing, duration, and magnitude of upwelling, we can better understand how the physical and biological parameters change with these changing ocean conditions. For example, during cold periods (e.g., negative phase PDO and/or La Niña) boreal copepods occur along the Newport Line and these copepods have large lipid stores that fuel a rich food chain. Conversely, during warm periods (positive PDO and/or El Niño) the copepods off Newport have little lipid reserves resulting in a food chain anchored by lipid poor zooplankton.

Beginning in fall 2014, anomalously warm ocean conditions occurred off the Newport Hydrographic Line. These warm waters were deplete of nutrients, and warm water, lipid poor copepods have occupied the shelf and slope waters since 2014. In 2017-18, this warm water still exists, however unlike 2015 and 2016, in 2017 the copepod community transitioned from a warm community to a cold community shortly after the initiation of the summer upwelling season. This transition to a cold, lipid rich community, signals that the zooplankton community is returning to a more neutral state.

Data Products:

The data have contributed to updates on "Ocean Ecosystem Indicators of Salmon Marine Survival in the Northern California Current" website:
http://www.nwfsc.noaa.gov/research/divisions/fe/estuarine/oeip/index.cfm

The data have contributed to the Newportal Blog:
https://www.nwfsc.noaa.gov/news/blogs/display_blogentry.cfm?blogid=1.

Biological and physical data were uploaded to the California Current IEA ERRDAPP server:
<https://www.integratedecosystemassessment.noaa.gov/regions/california-current-region/indicators/climate-and-ocean-drivers.html>

Presentations:

The 13th International Conference on Copepoda, San Pedro, CA, July, 2017. **Jennifer Fisher**; Relative influence of the Pacific Decadal Oscillation and coastal upwelling on copepod communities in the Oregon upwelling zone.

The Fish Ecology Program Meeting Newport OR, January 2018. **Jennifer Fisher**, **Cheryl Morgan**, **Sam Zeman**, and **Xiuning Du**; The Newport Hydrographic Line and Beyond.

Lecture to Portland State University Marine Conservation Science & Management class, February 2018**. Jennifer Fisher**; Environmental forcing and how that affects ecosystems.

The 4th International Symposium on the Effects of Climate Change on the World's Oceans, Washington DC, June 2018. **Jennifer Fisher**, **Louise Copeman**, Jessica Miller, Jay Peterson (Jay Peterson presented); The 'skinny' about how the Blob changed the hydrography, zooplankton, lipid, and fatty acid structure off Oregon.

The Ocean Carbon and Biogeochemistry workshop, Woods Hole, MA, June 27, 2018**. Jennifer Fisher**, **Xiuning Du**, **Sam Zeman**; Two decades of monthly biophysical sampling of the coastal ocean off Newport, Oregon and how this informs fisheries.

Publications:

Auth TD, **Daly EA**, Brodeur RD, **Fisher JL** (2018) Phenological and distributional shifts in ichthyoplankton associated with recent warming in the northeast Pacific Ocean. *Global Change Biology*. 24(1):259-72.

Chao Y, JD Farrara, E Bjorkstedt, F Chai, F Chavez, D Rudnick, W Enright, **JL Fisher**, WT Peterson, GF Welch, CO Davis, RC Dugdale, FP Wilkerson, H Zhang, Y Zhang, E Ateljevich (2017) The origins of the anomalous warming in the California coastal ocean and San Francisco Bay during 2014-2016 *J. Geophys. Res. Oceans 122*(9), pp.7537-7557.

Peterson, WT, **JL Fisher**, P Ted Strub, X Du, C Risien, J Peterson, and C Tracy 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, *J. Geophys. Res. Oceans*, 122, doi:10.1002/2017JC012952.

Wells BK, Schroeder ID, Bograd SJ, Hazen EL, Jacox MG, Leising A, Mantua N, Santora JA, **Fisher J**, Peterson WT, Bjorkstedt E. State of the California Current 2016–17: Still anything but normal in the north. (2017) *Calif. Coop. Oceanic Fish. Invest. Rep.,* 1;58:1-55.

Harvey, C., N. Garfield, G. Williams, K. Andrews, C. Barceló, K. Barnas, S. Bograd, R. Brodeur, B. Burke, J. Cope, L. deWitt, J. Field, **J. Fisher**, C. Greene, T. Good, E. Hazen, D. Holland, M. Jacox, S. Kasperski, S. Kim, A. Leising, S. Melin, C. Morgan, S. Munsch, K. Norman, W. T. Peterson, M. Poe, J. Samhouri, I. Schroeder, W. Sydeman, J. Thayer, A. Thompson, N. Tolimieri, A. Varney, B. Wells, T. Williams, and J. Zamon. (2017) Ecosystem Status Report of the California Current for 2017: A Summary of Ecosystem Indicators Compiled by the California Current Integrated Ecosystem Assessment Team (CCIEA). U.S. Department of Commerce, NOAA Technical Memorandum NMFS-NWFSC-139. https://doi.org/10.7289/V5/TM-NWFSC-139ii

Research Related Press and News Articles:

http://terra.oregonstate.edu/2018/02/towing-the-line/

https://katu.com/news/local/the-invasion-of-the-pyrosomes-continues-oregon-scientists-work-to-unravel-mystery

Project Outreach:

HMSC Marine Science Day, April 2018. The booth had live plankton stations and scientists were available to talk about sampling along the Newport Hydrographic Line and to answer questions about ocean conditions and zooplankton.

Two research cruises in April and June 2018 aboard the R/V Pacific Storm were with local high school students. These cruises allow an opportunity for high school students to interact with scientists, to learn what sampling from a boat it all about, and they provide an opportunity to participate in science at sea.

Amendment 3, 22, 34: Climate and Habitat Effects on Productivity of Important Alaska Fisheries

Funded: $337,387

OSU RESEARCH STAFF: *Louise Copeman, Assistant Professor, Senior Researcher; Michael Banks, Director CIMRS; Michael, Kent, Professor Microbiology & Biomedical Sciences*
NOAA TECHNICAL LEAD: *Tom Hurst, NWFSC*

Effects of ocean acidification on Alaskan fishes

Project Background: This project directly addresses NOAA Ocean and Great Lakes Acidification Research Plan's goal of evaluating the ecological effects of ocean acidification. Walleye pollock, Pacific cod, and northern rock sole are principle components of the nation's most valuable Alaskan ground fish fishery and little is currently known about the effects of increased CO_2 on the growth, survival and development of these species. Our work evaluates the direct and indirect physiological effects of ocean acidification that could lead to changes in population productivity of these critical resource species.

Project Progress: OSU Research Technician, Jessica Andrade, completed a manuscript in collaboration with Dr. Tom Hurst (AFSC-NOAA) and Dr. Jessica Miller (COMES & FW, OSU) detailing experiments examining behavioral responses to predation-associated cues and the impact of ocean acidification (OA) on these behaviors of juvenile speckled sanddab, an experimental model flatfish species. Andrade trained REU intern, Megan Hazlett, to conduct similar work on juvenile sanddab examining the same behavioral parameters in response to a different predation-associated cue. Preliminary data have been statistically analyzed by Andrade.

Andrade is working on a number of experiments to examine the effects of high CO_2 on the behavior and physiology of juvenile walleye pollock. She performed experiments examining the effect of OA on the schooling behavior of juvenile walleye pollock. Juveniles were reared and tested at three experimental CO_2 treatments. CO_2 treatments included one at ambient CO_2 (i.e. experimental control) and two at elevated CO_2 levels predicted to occur near the end of the century. We tested 94 fish (i.e. ≥ 30 trials per CO_2 treatment) and none were reused in experiments. Andrade is currently statistically analyzing data from the experiment.

An independent study examining the effects of OA on the growth, development, and energy storage of walleye pollock larvae was conducted in collaboration with NOAA Scientists, Dr. Louise Copeman (CIMRS & CEOAS, OSU), and Dr. Michael Kent (OSU). This study consisted of two experiments in which eggs were spawned (1) at sea and (2) in the lab at Hatfield Marine Science Center. Following hatch, larvae were reared at 7°C for 28 days in either ambient or at elevated CO_2. Andrade was responsible for culture of prey and of walleye pollock larvae, lab maintenance, larval sampling, and growth measurements.

Dr. Louise Copeman continued to work on a manuscript for peer-review. The paper, "Hurst T, Copeman LA, Haines S, Meredith S, Hubbard K. The interactive effects of changes in CO_2 exposure and food quality on the growth and lipid composition of Pacific cod (Gadus macrocephalus) larvae", is currently in internal NOAA review and will be submitted to Climatic Change within the next month.

Optimal overwintering thermal habitat of juvenile walleye pollock (Gadus chalcogrammus) from the Bering Sea and Gulf of Alaska

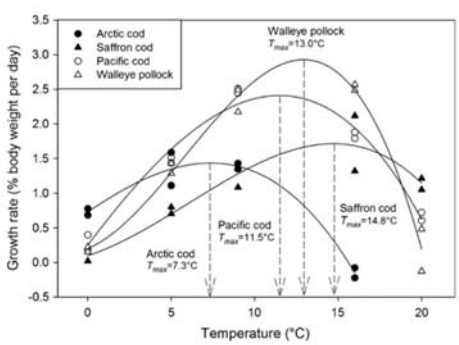


Fig 1: Species-specific thermal response of gadids to a range of possible summer temperatures at the Arctic-boreal interface. (Laurel et al. 2016)

Project Background: Marine fish species are susceptible to changes in temperature, and may avoid otherwise preferred habitats types (e.g., vegetation, coral, eelgrass) when summer temperatures exceed their growth optimum (Attrill & Power 2002) or during winter when overwintering habitats are too cold, especially among species lacking cold-water physiology to survive and remain active at extremely low temperatures (Goddard et al. 1997). The temperature of the surrounding water regulates a number of physiological processes that are manifested collectively in terms of growth, condition (stored lipids & energy) and survival. The thermal habitat in which fish can

efficiently grow (Fig. 1, Laurel et al. (2016)) and store lipids (Copeman et al. 2017) is highly species-dependent. In addition, temperature-dependent metabolic rates are non-linear and are typically 'dome-shaped' in boreal species (Laurel et al. 2016). However, optimal thermal habitats for fish are highly dependent on feeding conditions. In the summer, when food production is high, optimal habitat is defined by temperatures that promote highest growth and energy storage for individual species (Fig. 1). In contrast, in the winter when food production is low, optimal habitats are more broadly understood as the range of cooler temperatures that balance energetic loss with predation exposure. Therefore, optimal overwintering habitat is a complex interplay between intrinsic factors of the fish (size and energy storage), extrinsic habitat conditions (temperature, food availability, winter duration) and ecological processes such as predation rate (Sogard 1997, Hurst 2007).

Project Progress: Dr. Louise Copeman and OSU contractor, Carlissa Salant, received walleye pollock tissues after the completion of overwintering experiments by NOAA-AFSC collaborators. Dr. Copeman is currently working to analyze two size classes of age-0 walleye pollock that were reared at five temperatures ranging from -1 ºC to 7 ºC. Dissections have been completed and hepatosomatic indices have been measured for all experimental fish. OSU staff are working to finish tissue specific lipid class analyses by TLC-FID from frozen specimens. Samples are currently being extracted in chloroform and methanol according to methods in Copeman et al. (2016). Prelimiary data from this project was reported in a co-authored presentation given by Dr. Laurel (NOAA-AFSC) at the Ecosystem Studies of Arctic and SubArctic Seas in Fairbanks, Alaska in June, 2018.

Effects of juvenile flatfish habitat in the northern Bering Sea on fish condition and trophic markers

Project Background: The main hypothesis of this juvenile flatfish habitat research is based on the distributions of age-0 and age-1 (early juvenile) northern rock sole (NRS) from recent beam trawl surveys (Cooper & Nichol 2016). The shallow Eastern Bering Sea (EBS) inner shelf areas around Nunivak Island (NI) in the north (hereafter referred to as the "northern EBS" habitat) and Bristol Bay (BB) in the south (hereafter referred to as the "southern EBS" habitat) are hypothesized to be the main juvenile NRS habitats in the EBS (Fig. 2). The dependency on each area may vary with the thermal regime - juveniles may utilize the northern EBS in warm years, but remain in southern EBS in cold years (Cooper et al. 2014). According to this hypothesis, the northern EBS will become increasingly important with continued ocean warming, and this may be reflected in greater densities, higher growth rates, or better nutritional condition of juvenile flatfish in the northern EBS.

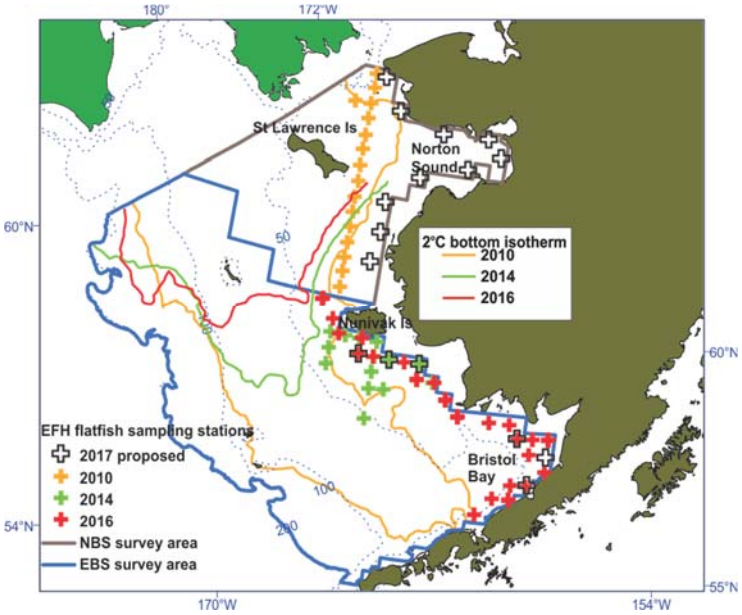


Figure 2. Sampling stations of juvenile flatfish habitat studies in the northern Bering Sea (NBS) in 2010, in the eastern Bering Sea (EBS) in 2014 and 2016, and proposed for 2017 in the NBS (Norton Sound - 10 stations) and the EBS (Nunivak Island - 3; Bristol Bay – 3). The approximate locations of the 2ºC isotherm of bottom water for 2010, 2014, and 2016 are depicted.

Project Progress: Dr. Louise Copeman along with OSU contractors, Carlissa Salant and Michelle Stowell, have completed morphometric and biochemical measurements of flatfish nutritional condition from frozen specimens that were sampled and shipped by NOAA-AFSC staff in July 2017. We analyzed over 120 representative samples of juvenile fish for indices such as hepatosomatic index, Fulton's K and length-weight residuals. Further, muscle was then removed after morphometric measurements for biochemical analyses of the water content. Measurements of total lipids, lipid classes (TLC-FID) and fatty acids (GC-FID) have been completed by OSU research technicians in the Marine Lipids Laboratory at the Hatfield Marine Science Center, OSU (methods as in Copeman et al. 2016).

Dr. Copeman is currently analyzing trends in flatfish condition to understand how regional trophic difference affect the energetic condition of these juvenile fish. Biochemical data will be paired with environmental and gut content analyses to understand spatial drivers in flatfish condition. Dr. Copeman is currently working on this data set using a multivariate stats package called Primer v7 with PERMANOVA. We have finished all analyses from this first year of proposed research and are awaiting samples from a second year of funded research on this topic. Ultimately, we aim to analyze trends in fish condition and trophic markers for both inter-annual and species-specific effects.

Toxicity of oil and dispersants to developing Arctic cod Oil

Project Background: Oil and gas development in the Chukchi and Beaufort Seas has the potential to introduce petroleum hydrocarbons into Arctic habitats with uncertain impacts on food production. BOEM and NOAA both recognize Arctic cod (*Boreogadus saida)* as the primary link between lipid-rich plankton and the higher tropic level fish, birds and mammals that feed the people living in the high Arctic. Understanding the potential impacts of crude oil to cod is therefore essential for an ecosystem-based approach to managing oil spill risks in the region.

The objectives of our current research project are as follows:

1. To determine the sensitivity of Arctic cod energy storage to embryonic exposure to Alaskan crude oil.
2. Identifying delayed lipid metabolism effects in Arctic cod larvae that may occur due to embryonic exposure with variable doses of oil.

Project Progress: Dr. Copeman received cod embryos and larvae that were exposed to four controlled doses of dispersed oil. Dr. Copeman and OSU technician, Michelle Stowell, analyzed samples from the following developmental stages: time-0 eggs (before oil exposure), eggs at the end of the 10-day exposure, larvae at hatch, larvae after 3 weeks of feeding and larvae after 2 months of feeding. In total >80 samples of eggs and larvae were analyzed for total lipids, lipid classes, as well as detailed fatty acids.

Dr. Copeman is currently collaborating with NOAA scientist to write peer-reviewed manuscripts on the delayed sub-lethal physiological responses of Arctic cod eggs and larvae to hydrocarbon exposure. Further, Dr. Copeman and other NOAA authors have submitted abstracts to present their research at scientific conferences in the fall of 2018.

Publications:

Copeman L, Ryer C, Spencer M, Ottmar M, Iseri P. Sremba A, Parrish C, Wells J. 2018. Flux of diatom production to benthos controls habitat quality and juvenile Tanner crab growth in shallow water embayments around Kodiak Island Alaska. Marine Ecology Progress Series 597:161-178. *(OSU PI COPEMAN Lead author of the manuscript, designed study and supervised the completion of all the chemical analyses).*

Andrade JF, Hurst TP, Miller JA. 2018. Behavioral responses of a coastal flatfish to predation-associated cues and elevated CO_2. Journal of Sea Research. https://doi.org/10.1016/j.seares.2018.06.013. *(OSU research technician ANDRADE Lead author of the manuscript, contributed to the study design and lab maintenance, conducted*

experiments, and contributed to statistical analyses and manuscript writing and revisions)

CIMRS-based publications to be submitted for Peer-review summer 2018:

Hurst T, **Copeman LA**, Haines S, Meredith S, Hubbard K. The interactive effects of changes in CO_2 exposure and food quality on the growth and lipid composition of Pacific cod (*Gadus macrocephalus*) larvae. For Submission to Climactic Change July 2018. *(Contributed significantly to study design, writing, stats and all lipid data acquisition occurred in my OSU laboratory under my supervision).*

Laurel B, **Copeman** L, Incardona J, Linbo T, Scholz N, Ylitalo G, Iseri P, Nordtug T, Sørhus E, Donald C, Allan S, Spencer M, Cameron J, Meier S. Acute and latent bioenergetic impacts of oil on a keystone Arctic forage fish (Boreogadus saida). For Submission to PNAS in August of 2018. *(Contributed significantly to study design, writing, stats and all lipid data acquisition occurred in my OSU laboratory under my supervision).*

CIMRS-based Presentations:

Laurel B, **Copeman L**, Incardona J, Linbo T, Scholz N, Ylitalo G, Iseri P, Nordtug T, Sørhus E, Donald C, Allan S, Spencer M, Meier S (2018) Lipid, growth and 1st year survival impacts in Polar cod (Boreogadus saida) following embryonic oil exposure to Alaskan and Norwegian oil. Society of Environmental Toxicology and Chemistry North American 39th Annual Meeting, Sacramento, CA, USA, November 4-8th, 2018.

Hurst TP, **Copeman LA** Haines S, Meredith S, Daniels K (2018) Ocean acidification effects on growth and behavior of Pacific cod larvae. Oral Presentation, 42nd Annual Larval Fish Conference, Victoria, Canada, June 24-28,2018.

Laurel BJ, **Copeman LA** (2018) Size- and temperature-dependent overwintering success in age-0 juvenile polar cod (*Boreogadus saida*) and walleye pollock (*Gadus chalcogrammus*). Oral Presentation, Ecosystem Studies of SubArctic Seas Annual Science Meeting, Fairbanks, Alaska, June 11-15, 2018.

Andrade JF, Hurst TP, Miller JA (2017) Behavioral responses of a coastal flatfish to predation-associated cues and elevated CO_2. Poster Presentation, 10th International Flatfish Symposium, Saint-Malo, France, November 11-16, 2017.

Accepted abstracts fall 2018:

Laurel B, **Copeman L**, Incardona J, Linbo T, Scholz N, Ylitalo G, Iseri P, Nordtug T, Sørhus E, Donald C, Allan S, Spencer M, Meier S (2018) Lipid, growth and 1st year survival impacts in Polar cod (*Boreogadus saida*) following embryonic oil exposure to Alaskan and Norwegian oil. Society of Environmental Toxicology and Chemistry North American 39th Annual Meeting, Sacramento, CA, USA, November 4-8th, 2018.

Histology: Effects of Ocean Acidification on Alaskan Fishes

Project Background: Fossil fuel combustion and industrial processes release over six billion metric tons of carbon into the atmosphere each year and CO_2 concentrations in the atmosphere are projected to continue to rise well into the next century. The consequences of these greenhouse gas emissions are often discussed in terms of rising global temperatures, but global warming is not the only threat from increased atmospheric concentrations of CO_2. Ocean acidification, which occurs when CO_2 in the atmosphere reacts with water to create carbonic acid, has already increased ocean acidity by 30 percent. Although the chemistry of this effect is well understood, the full consequences of ocean acidification for marine ecosystems, including fishes, are only just beginning to be revealed.

Endpoints for larval fish exposed to acidified water usually include growth and mortality. Other studies have incorporated non-growth metrics such as identification of developmental anomalies. Histopathology provides the ability to evaluate changes at the tissue and cellular level, which are not possible with evaluation of whole fish.

Research Plan: Larval Walleye Pollock, both from wild fish and laboratory brood stock are exposed to acidified water and controls in the Hurst Laboratory, NOAA, Newport, Oregon. Fish are preserved in Dietrich's formalin based fixative and process for histological evaluation by the Oregon Veterinary Diagnostic Laboratory. Fish are then evaluated by Dr. Kent for the presence of histological changes, comparing acid-exposed fish to controls.. The presence and severity of lesions in all major organ systems will be scored using a ranking system calibrated to the control group. All samples will then be processed "blind" such that the examiner does not know the experimental treatment of the sample being examined.

Progress Report: Funds were awarded for this project late in the reporting period. As of June 2018, working with the OVDL and Dr. Sanders (Kent's colleague at OSU), we have perfected a method to obtain optimal sections for larvae. Preserved fish are embedded in an agar block such

that multiple sagittal sections can be obtained. Twenty-eight larvae are embedded in each block, and multiple sections are then prepared. Method development was based on "spare" fish, and we are now moving forward with processing fish from Dr. Hurst's exposure experiments.

Amendment 14: Improving ecosystem-based fisheries management and integrated ecosystem assessments by linking long-term climatic forcing and the Pelagic Nekton Community in the Northern California Current

Funded: $9,407

OSU RESEARCH STAFF: Lorenzo Ciannelli, Professor, College of Earth, Ocean, & Atmospheric Sciences
NOAA TECHNICAL LEAD: Ric Brodeur, NWFSC

Project Background: The California Current Integrated Ecosystem Assessment (CCIEA) lays out a long-term plan to evaluate the status of a wide variety of ecosystem components (Levin and Schwing 2011). In recent years, the CCIEA has been bolstered by the augmentation of the availability of leading ecosystem indicators for the pelagic ecosystem given our efforts to analyze and summarize the existing pelagic fish data for the Northern California Current region. The work we have been conducting has provided new and needed indicators to assess the status of the wild fisheries and ecosystem health components of IEAs in the California Current.

Our research has been summarizing the changes in the status of the pelagic forage community consisting of fishes and squids for the last 16 years (1998-2017) based on the NWFSC-NOAA Bonneville Power Administration survey surface trawls. Since 2012, we have been consistently updating time series catch per unit effort date of key abundant species (including sardines, herring, smelts) to the forage fish components of the IEA, and we have computed the pelagic diversity and evenness indices for the ecosystem integrity section for these 3 years as well. Additionally, we contributed these time series and community composition analysis to the CalCOFI reports in 2013 and 2014. Data we have provided has been made available to the SSC for the past two years providing a novel pelagic component for their yearly ecosystem status evaluations. Our ongoing research intends to continue providing information to these yearly summary metrics. Extending this contribution to CCIEA is important, as this dataset is one of the few that evaluates the health of the pelagic ecosystem and has provided leading pelagic ecosystem indicators to CCIEA.

Taking advantage of the availability of this unique dataset, we are also assessing the spatio-temporal dynamics of predator-prey associations and their response to changing oceanographic conditions in this region with climate change. Using both fine-scale remotely sensed oceanographic data as well as forecasted climate change scenarios, we are generating species distribution models for forage fish species (herring, mackerel and sardine) off the Oregon and

Washington coasts. Project Researchers are also working jointly with the Dr. Leigh Torres at OSU Marine Mammal Lab to couple our prey species distribution models with distribution models of California sea lions in the same region over the same time period to assess the spatial overlap and spatial shifts of said predator and prey model predictions under various environmental scenarios (average conditions, El Niño/La Niña years, and forecasted climate change). By integrating habitat, prey and predators over space and time, this research will lay the groundwork for integrated ecosystem models between predators and prey species that can be used to assess human impacts, the permeating effects of climate change through the food web and management strategies.

Research Plan: Nekton data to be used for this study is already collected and entered into the database. The graduate student (C. Barceló) will analyze the data using both univariate and multivariate statistics and contribute to the interpretation and writing of the results. Graduate student will continue to provide species diversity indices to the Integrated Ecosystem Assessment team when needed, collaborate as needed on the yearly State of the California Current Report, as well as work as a team for an IEA diversity meta-analysis with NOAA employees.

Progress Report: Last year, Ph.D. student C. Barceló, provided data products to NOAA's Integrated Ecosystem Assessment sections, specifically the Coastal Pelagic Fish section, and participated in a Forage fish summit workshop lead by the CCIEA team, and lead the analysis and writing of multiple ongoing or accepted studies. Barceló has conducted analysis for a California Current wide study lead by Dr. Chris Harvey, aiming to link community dynamics of forage assemblages with predator assemblages. Barceló also lead the analysis and writing of a study recently accepted to Global Change Biology on the stability of species assemblages in the Northern California Current and the local biotic sensitivity to various climate indices. Further, Barceló is writing up the results of a study that focuses on the onshore-offshore gradient in assemblages, and plume-non-plume assemblage dynamics across the continental shelf of the Pacific Northwest. Professor Lorenzo Ciannelli assisted in the interpretation of all results, editing writing and the development of code for analysis. This year, Professor Lorenzo Ciannelli and NOAA collaborators are in development stage of a possible publication based on findings for this research project.

Amendment 19: Essential habitat of flatfish early life stages in the Chukchi Sea

Funded: $38,612

OSU RESEARCH STAFF: *Lorenzo Ciannelli, Professor, College of Earth, Ocean, & Atmospheric Sciences*
NOAA TECHNICAL LEAD: *Dan Cooper, AFSC; Elizabeth Logerwell, AFSC*

Project Background: Habitat of early life stages of flatfish in the Chukchi Sea has not been described. The object of this is to define essential fish habitat (EFH Level 1 and 2 information) for juvenile stages of flatfish species in the Chukchi sea, including the highly valuable commercial species yellowfin sole (Limanda aspera) and Greenland halibut (Reinhardtius hippoglossoides) using data collected in late summer 2017 from a funded arctic survey, combined with retrospective analyses of similar data collected from 2007-2009 and 2012-2013.

Flatfish constitute one of the most abundant fish taxa in plankton, beam trawl, and bottom trawl surveys of the Chukchi Sea (e.g., EIS preliminary reports, Logerwell et al., 2015). Consequently, flatfish are important subsistence and ecological resources in the Chukchi Sea (Grebmeier et al., 2006). From previous ichthyoplankton surveys conducted in the Chukchi Sea in 2012, it became evident that Bering flounder (*Hippoglossoides robustus*) is the most commonly encountered flatfish larvae, followed by yellowfin sole *(Limanda aspera*). Greenland halibut (*Reinhardtius hippoglossoides*) larvae are also common in the Chukchi Sea. Despite frequent occurrences and elevated abundance of flatfish detected in ongoing surveys, there is remarkably little known about their ecology in the Chukchi Sea, particularly during early life history stages. Even though there are no commercial fisheries in the high arctic, these commercially valuable flatfish species occur in the Chukchi Sea, and it is important to characterize habitat for early life stages to determine which areas are essential to production.

The Chukchi Sea is comprised of distinct water masses, including Bering Sea Water and Alaska Coastal Water, which enter the Chukchi through Bering Strait, and Meltwater and Winter Water, which are formed in the Chukchi by the processes of sea ice freezing and melting. These water masses affect the distribution of fauna in the Chukchi, including zooplankton (Eisner et al., 2013), ichthyoplankton (Norcross et al., 2010), pelagic (Day et al., 2013), and benthic (Norcross et al., 2010) fishes, and benthic invertebrates (Day et al., 2013). Norcross et al. (2010) describe ichthyoplankton and demersal fish assemblages in the Chukchi Sea based on water mass and latitude. Assessments of flatfish abundance and association with benthic habitat features have not been made in the Chukchi Sea. These assessments would allow inferences about habitat requirements for successful production of yellowfin sole and Greenland halibut in the Chukchi Sea.

Progress Report: We conducted field sampling during the Arctic IERP cruise aboard the R/V Ocean Starr from 1 August through 28 September 2017. A small-mesh beam trawl was deployed at 58 stations in the Chukchi Sea. Fish were sorted, identified, and measured. Flatfish catch consisted mainly of Bering flounder and yellowfin sole. Bering flounder were distributed throughout the survey area, with higher catches at offshore stations (Figure 1). Yellowfin sole were caught at stations in the southern half of the survey grid (Figure 1). Some newly settled flatfish were also caught in the southern half of the grid, and will be identified in the laboratory (Figure 1).

Only one Greenland halibut was collected during the survey. In place of Greenland halibut diet, condition, and habitat analyses in this study, we will do the same work on Bering flounder and age-0 Pacific cod (Figure 1) collected during the survey.

Habitat data were also collected at each beam trawl site, including bottom temperature and salinity using a CTD; bottom depth and a measure of bottom hardness using an FS-70 acoustic system; and the epibenthic macroinvertebrate community using the beam trawl. Bottom sediment was collected at 39 stations during the survey to determine sediment grain size for habitat descriptions, and to ground truth acoustic bottom hardness data.

Flatfish and the age-0 Pacific cod were frozen at sea and sent to Juneau for body condition analysis. Stomach contents will be removed in Juneau and sent to Seattle for identification and enumeration. Sediment grain size will be measured in Seattle. Fish diet and condition analyses are being completed through Summer 2018 when habitat and condition modeling will begin.
Results: Results to date relate to the exploratory analyses conducted to characterize the spatial distribution of the targeted species, and the relationship with environmental variables. In Figure 1 we show the distribution of juvenile Bering flounder, Yellowfin sole, and Pacific cod. In addition to the 2017 Arctic IERP survey, we also analyzed data from 2012 North Slope Bottom Trawl survey and the ensuing distribution is shown in Fig. 2. In Figure 3 we show surface and bottom water temperature (2012 and 2017) and in Figure 4 we show salinity (only for 2017), interpolated from values at the sampled locations. Visual interpretation of these figures reveal that Bering flounder are found throughout the western portion of the sampled area, which is characterized by intermediate values of surface and bottom water temperature (~6C). In contrast, Pacific cod and yellowfin sole are almost exclusively confined to the southernmost sampled regions, which are influenced by the coastal water masses, characterized by higher temperature (8-10C) and lower salinity (~32 psu). On average, bottom and surface temperatures were warmer in 2017 than in 2012, however, coastal water temperatures in the southern part of the sampled region were higher in 2012.

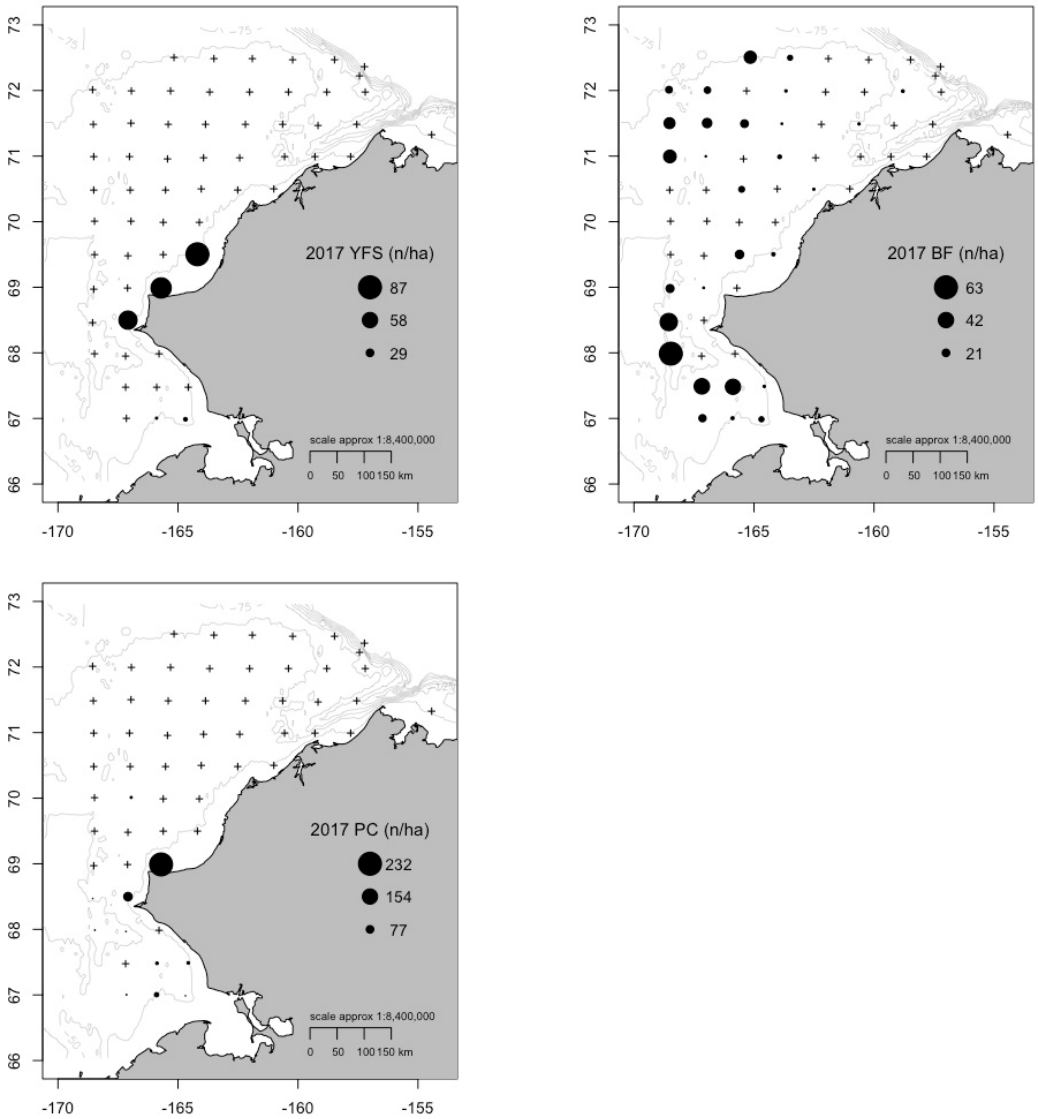


Figure 1. Preliminary Bering flounder, yellowfin sole, and age-0 Pacific cod catch (number of individuals per ha) during the 2017 Arctic IERP cruise.

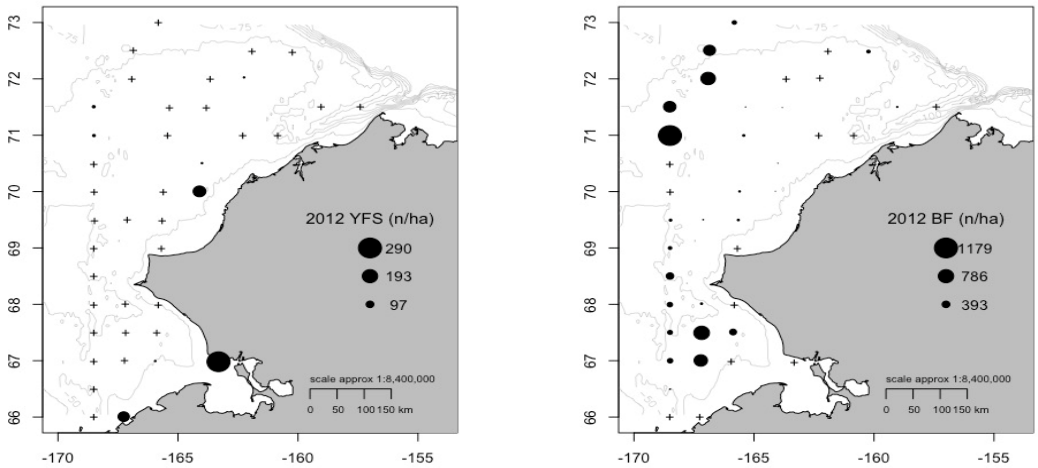


Figure 2. Preliminary Bering flounder, yellowfin sole (number of individuals per ha) during the 2012 North Slope Bottom Trawl survey. No Pacific cod were caught in 2012.

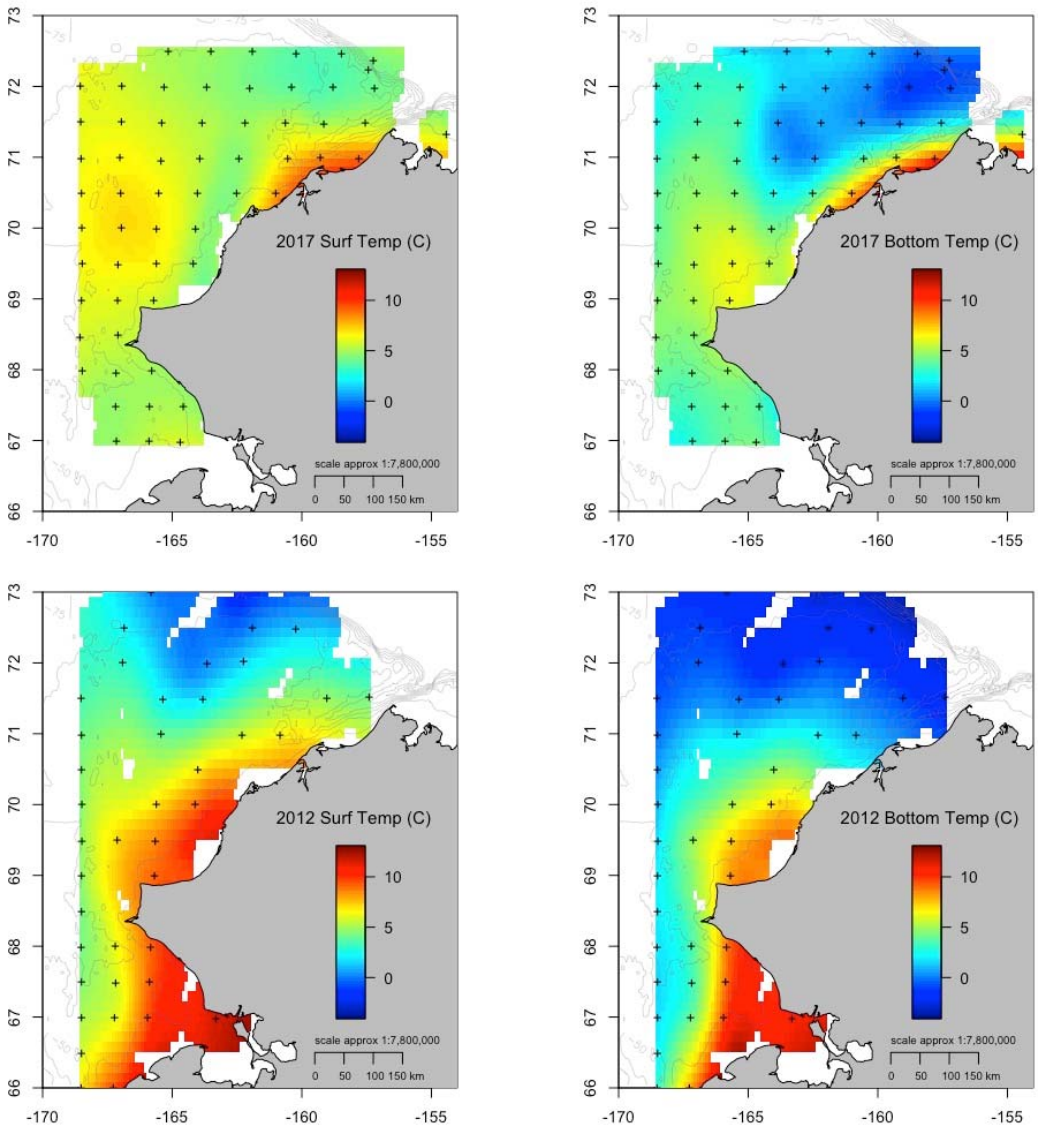


Figure 3. Surface and bottom temperature during the 2017 (top) and 2012 (bottom) surveys.

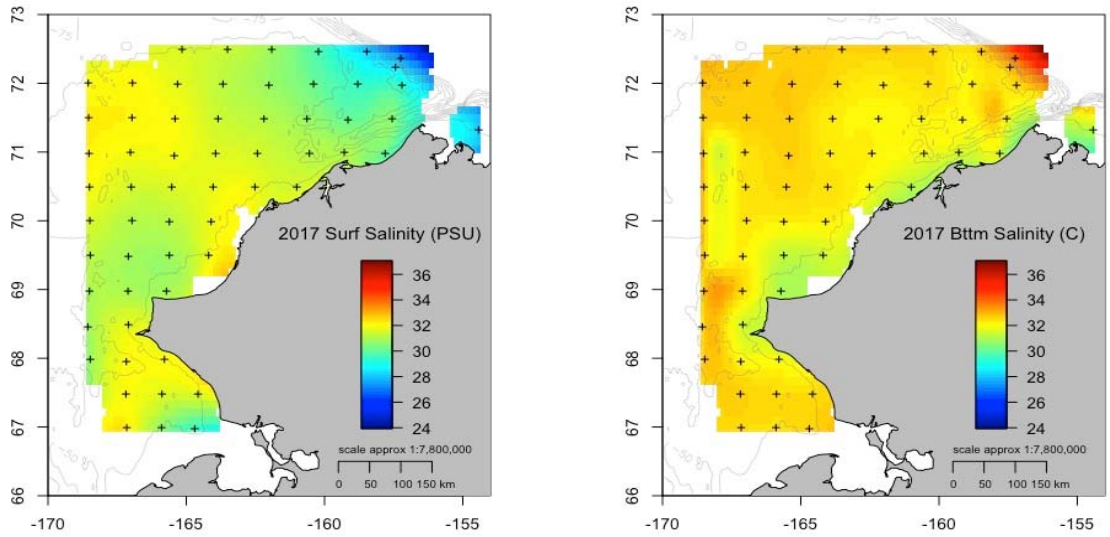


Figure 4. Surface and bottom salinity during the 2012 survey.

Amendment 24, 30: Phytoplankton community of the Northern California Current: implications for the bioenergetics of the food chain

Funded: $102,093

OSU RESEARCH STAFF: *Michael Banks, Director CIMRS; Xiuning Du, Research Associate*
NOAA TECHNICAL LEAD: *Bill Peterson, NWFC; Kym Jacobson, NWFC*

Project Background: The central and southern California Current has been a focal point for fisheries oceanographic studies for decades, due to the collapse of the sardine (*Sardinops caerulea)* population in the 1940s and subsequent replacement by anchovies (*Engraulis mordax*). Indeed, the sardine collapse led to founding of the CalCOFI program (McClatchie 2014). CalCOFI scientists have focused on relationships between environmental variability and recruitment of sardine, anchovy, mackerel, rockfish and squids with emphasis on the relative roles of local upwelling vs. the basin-scale climate cycles such as the El Niño/Southern Oscillation (ENSO), the Pacific Decadal Oscillation (PDO) and the North Pacific Gyre Oscillation (NPGO).

While strong relationships have been indicated between copepods and salmon returns, there is an obvious gap in our understanding of "bottom-up forcing", especially of mechanistic linkages from phytoplankton to copepods and salmon. A limited amount of work has been carried out on the ecology of phytoplankton in the southern and central California Current including Venrick (2012) – quarterly sampling on CalCOFI cruises from 1990-2009; Tont (1987) -- historical data from Scripps Pier, collected from 1920-1939, Bolin and Abbott (1963)– approx. weekly sampling in Monterey Bay 1954-1960; Lassiter et al. (2006) and Wilkerson et al. (2006) – sampling coastal waters off northern California during summers of 2000- 2002 (CoOP-WEST). For the northern California Current, the seasonal cycle of phytoplankton abundance and species composition and interannal variations have been described for the Newport Line (Du & Peterson, 2014) and (Du et al., 2015). Other sampling in the NCC has been done off Washington (Frame & Lessard, 2009; Newton & Horner, 2003) but only during summer months of 2004-2006.

In the NCC, the ultimate factors that determine bioenergetic content of the food chain are lipids and fatty acids. Certain essential fatty acids are needed for fish growth (especially lipid-rich fishes such as salmon, and lance and herring) are passed up the food chain from diatoms (which contain high EPA) and dinoflagellates (higher proportion of DHA), through copepods and krill, hence to fish (Lee et al. 2006; Litzow et al. 2006). Using species composition and abundance data, seasonal covariance of community structure between phytoplankton and copepods was identified (see Figure 1). Qualitatively, a specific type of phytoplankton community with diatom dominance matches with a northern copepod community in spring/summer while another type of

phytoplankton community with dinoflagellates matches with a southern copepod community in fall/winter. A mechanistic explanation of linkages between phytoplankton-zooplankton-fish likely exists for the NCC; a recent study (Miller et al. submitted) shows that changes in phytoplankton community structure co-varied with change signals (indicated by lipid quantity and quality of phytoplankton), and meanwhile, the same covariance was found between copepod community and lipid profiles. Collectively, these results illustrate the promise of using these data on the abundance phytoplankton species as proxies for fatty acid markers of diatoms (such as EPA, 16:1ϕ7 and16:4 ϕ1) and of dinoflagellates (DHA).

Therefore, with this biochemical evidence, OSU Research Associate Dr. Xiuning Du endeavors to use data on abundance of diatom and dinoflagellate species and add these indices to both the Integrated Ecosystem Assessment for the NCC and current NOAA salmon forecasting efforts. These new indices would complement the existing copepod indices by providing proxies for the variations in lipid content that are a function of the relative availability of diatoms and dinoflagellates.

Progress Report: By April 27, laboratory analysis of in situ phytoplankton samples collected from 2015 to 2017 were all finished, quality controlled and archived in NOAA database. Work on samples in details: at the mid-shelf station NH5, 21 phytoplankton samples in 2017 were analyzed and along with 22 samples in 2016 were finalized; at the slope station NH25, 10 samples in 2017 were analyzed and totally 62 samples at this station during 2013-17 were finalized; at further offshore oceanic stations, 50 samples during 2015-17 were analyzed and totally 59 offshore samples were finalized in the database.

Data analysis of phytoplankton species composition and abundance data from the shelf station NH5 and slope station NH25 as well as hydrographic and nutrient data have been conducted in May. A manuscript titled “Characterizing phytoplankton production and community composition from mid-shelf to slope waters off Oregon during 2013-2017” was initiated towards the end of May. Further data analysis and manuscript writing had been continued in June. The study goal and a summary of main findings as below: We examine spatial connections of phytoplankton community characteristics from seasonal and inter-annual perspectives. Diatom, the major biomass contributor to the study system, showed coherent seasonal patterns at both NH5 and NH25, with higher abundance during upwelling season and lower during the downwelling season, except in 2015 when the highest diatom bloom was observed during downwelling periods (January-February) at NH25; dinoflagellate abundance did not present any consistent seasonality during the five-year study. Inter-annually, diatom bloom magnitude was higher in 2017 and 2014 at NH5 but high in 2014-2016 at NH25. Year-season crossed community structure analysis showed little variance during 2015-2017 at either shelf or slope station; however, upwelling mediated year-season analysis indicate higher inter-annual community variability implying that inter-annual differences in community during yearly defined ‘upwelling dominated hydrographic periods’. Regression analysis of all data found diatom and

dinoflagellate abundance at NH5 were linearly significantly ($p = 0.01$) correlated with that at NH25, and diatoms had a stronger shelf-slope correlation than dinoflagellates. At the season scale, surprisingly diatom abundance at NH5 was significantly correlated with NH25 ($p = 0.01$) only during the downwelling season while dinoflagellate abundance was correlated ($p = 0.01$) during the upwelling season. Diatom and dinoflagellate community variability was correlated between shelf and slope ($p = 0.05$) during the upwelling season. Local environment variability was predominantly determined by local nutrient and upwelling variability and secondly by remote forcing drivers represented by PDO and MEI. Correlations between phytoplankton production and community cross-shelf changes with local environment variability associated with upwelling and Ekman transport processes will be further explored for the next steps.

Presentations:

An abstract summarizing the study of phytoplankton production and community structure at the continental shelf and slope in the Oregon upwelling zone was submitted to the Eastern Pacific Ocean Conference 2018, which will be held in September 2018.

Amendment 32: WA & OR Coast-wide GSI – Quantifying Near-real-time Ecosystem Effects on Ocean Distribution of Chinook

Funded: $283,018

OSU RESEARCH STAFF: *Michael Banks, Director CIMRS*
NOAA TECHNICAL LEAD: *Mark Strom, NWFSC*

Project Background: Typical ocean salmon fisheries catch many different stocks at the same time. Less productive stocks are more vulnerable to over-fishing. By law, fisheries are required to reduce overall catch to protect these “weak” stocks. As a result, fishing on more productive “strong” stocks has been severely restricted. Depressed runs of Klamath and Sacramento River fall Chinook have resulted in fishery limits or closures off the coasts of Washington, California and Oregon over the last decade resulting in significant negative impacts on fishery industries in these three states. Research proposed here is based on testing a hypothesis that different Chinook stocks display differential distribution responses to changing environmental conditions and that access to near-real-time knowledge of fine-scale differences in stock distributions will better inform managers and fishermen to enable strategies that target strong stocks while avoiding weak ones.

Approach: The experimental procedure is for commercial salmon trollers to sample their catch at sea, taking fin clips and recording catch location. Fish are identified to stock using genetic stock identification (GSI), and distributions of the different stocks are mapped. Results of Genetic Stock Identification (GSI) can be combined with fishing effort to determine catch and abundance

distributions and combining with biological data (age, length) along with environmental data collected by fishermen and compiled from satellites, buoys, and other sources, to predict relationships between stock distribution patterns and biological and physical parameters in near-real-time. Prior methods applied to assess ocean distribution of Chinook has relied on recoveries from coded wire tags, a method which is limited to hatchery stocks, has significant expansion uncertainties, and most importantly in contrast to GSI, has processing time that only allows 6 or more month delays in assessment. This has precluded options for near-real time application of findings that could modify the fishery according to 'weak' stock threats. GSI methods provide information for every fish sampled and ongoing findings are updated to the web-portal within a week. Recent methods allow calibration of stock-specific catch per unit effort enabling abundance estimates which are comparable across region and time (Bellinger et al (2015). These techniques can be employed to develop management measures that result in greater harvest of strong stocks while monitoring weak stocks to ensure compliance with allowable fishery impacts. Of course, modifying fishing strategies may result in important economic considerations and tradeoffs to fishing and related industries and Otto et al (2016) provide a fitting example of such a scenario using earlier data from our project.
Fishery management applications rely on a consistent time-series of data, an indeed the PNW ocean has expressed some unusually warms conditions in more recent years (Bond et al 2015). Overall funding sought in this proposal will enable the continuation of consecutive year sampling and analysis of stocks on the Washington and Oregon coast and preserve the integrity of the time series across some strikingly different oceanography.

Progress Report: Faculty Research Assistant Jonathan Minch who has more than 5-year's experience working on ProjectCROOS (Collaborative Research on Oregon Ocean Salmon) was return recruited to lead laboratory analysis and software upgrade for tablets. A new Marine Resource Management Program MS graduate student named Andrew Teahan was also recruited to join the project and received training from Jonathan. Andrew's thesis topic will focus on this project.

Chinook salmon and associated fine-scale at sea environmental data were collected in Washington, Oregon, and California during the 2018 fishery season in accordance with the West Coast Salmon Genetic Stock Identification Collaboration sampling plan. Participating fishermen were equipped, familiarized and sent out with Samsung tablets loaded with Pacific Fish Trax (PFX) software that enabled them to track their effort and record their own catch. Upon arriving within the range of a wireless connection these fishermen upload their data to the PFX database via the cloud, by reviewing their trip and clicking on a submit button. Several issues are being resolved to streamline efficient use of this technology and information exchange. Washington has 11 fishermen and Oregon has 23 fishermen contracted to participate in the project. June 30th inventory indicated that fishermen collected 588 samples from May through July, 2018 in Washington and 295 samples within the Oregon fishery (Table 1). The fishermen have

completed sampling and are still sending their last samples to the COMES Marine Fisheries Genetics laboratory for analysis.

A report is being generated indicating stock specific catch per unit effort both spatially and temporally that will be available at the http://pacificfishtrax.org/resources/reports-and-publications by August 10th, 2018.

Table 1. Sampling details for Coast-wide GSI 2018

State	Samples		
Washington	588		
Oregon	295		
California	1092		
Total	1975		
Zones	May	June	July
Canadian Border to Cape Alava	0	101	308
Cape Alava to Queets River	0	0	0
Queets River to Leadbetter Pt.	14	54	91
Leadbetter Pt. to Cape Falcon	0	0	20
Cape Falcon to Florence South Jetty	0	51	0
Florence South Jetty to Humbug Mtn.	0	28	2
Humbug Mtn. to OR/CA Border	0	99	115

Amendment 35: Monitoring Pseudo-nitzschia Blooms and Domoic Acid Along the Newport Hydrographic Line

Funded: $23,585

OSU RESEARCH STAFF: *Michael Banks, Director CIMRS; Xiuning Du, Research Associate*
NOAA TECHNICAL LEAD: *Vera Trainer, NWFSC*

Project Background: The diatom species Pseudo-nitzschia (PN) blooms annually on the west coast of the United States. In years when ocean conditions were anomalously warm, these blooms because more likely toxic associated with a potent neurotoxin domoic acid (DA) production by some of the PN species (McCabe et al. 2016, McKibben et al. 2017). DA can

accumulate in shellfish, invertebrates and higher trophic vertebrates via direct feeding and food chain links. Human consumption of shellfish contaminated with DA can result in amnesic shellfish poisoning (ASP). While critical for public health protection, recreational and commercial shellfish harvest closures also disrupt economies of coastal communities. For example, the massive 2015 coastwide DA event resulted in > $100 million loss to US West Coast fisheries.

Since the 2015 toxic PN blooms, DA has been lingering in the Pacific Northwest (PNW) which has caused prolonged razor clamming closures, extra labor effort and cost for state agencies to manage safe harvest and protect public health. These recent events provide evidence for a new norm that toxic PN blooms likely occur on an annual basis, but with a varying timing. For example, toxic PN blooms occurred in fall 2016 and again in the following spring 2017. Because of these multi-year DA events, the opening of commercial Dungeness crab seasons was delayed annually. These consecutive-year impacts deliver a message to state managers, fishery industries and scientists that there is a need to routinely monitor harmful algae at higher spatial and temporal scales, more efficiently assess and deliver risks of HAB potential and be able to forecast initiation and distribution of HAB events in the PNW.

A recently initiated NOAA MERHAB project (2016-2020) -- An early warning system for Pseudo-nitzschia harmful algal blooms on Pacific Northwest outer coast-beaches (PNW HAB Bulletin), was planned to help to improve fisheries regulations and support management decisions that protect our health, our seafood supply, and our ocean environment. This project focuses on HAB issues from Washington to Oregon coast. Among all current observational data components for the Bulletin, beach samplings of PN and DA directly informs whether clams harbor toxic cell contamination. Regular samplings of offshore PN and DA in one HAB hot spot--the Juan de Fuca eddy in WA provides information on HAB transports from offshore waters to WA coast and eventually landing on beaches.

Although beach sampling of PN and DA in OR has been informing HAB monitoring and guiding shellfish harvest regulations, there are still information gaps specifically for the Oregon offshore HAB status, such as initiation, development, cross-shelf distribution and time lags with beach observations. Lacking offshore data on PN and DA, in particular data from the other HAB hotspot, Heceta Bank weakens forecasting of HAB timing and transport. In 2005, a toxic PN bloom sourced from Heceta Bank was transported with currents and the Columbia River Plume to northern OR and southern WA coast (Hickey et al. 2013). Given the large geographic extent of the Oregon/Washington coastal system (approximately 500 miles north to south), the presence of two distinct hot spots for toxic organisms, and complex circulation patterns including reversals of north/south currents, sampling in one state cannot be extrapolated to conditions in the other states. For example, closures occurred in Oregon beaches for crabbing in the fall of 2017, while Washington beaches remained open, which clearly demonstrates that the two states can be experiencing widely differing conditions with blooms having different source regions. As

with the Juan de Fuca eddy sampling, sampling at Heceta Bank provides critical early warning of the presence of toxic organisms and sources to the entire OR and may even be relevant partially to the WA coast. In addition, the current forecast models are not "seeded" by information about Pseudo-nitzschia abundance and toxicity from the known hotspots. Therefore, it is important to accumulate more offshore PN and DA data to improve forecasting accuracy.

The NHL sits on the northern edge of the Heceta Bank, Oregon. Hydrography and plankton conditions have been biweekly monitored for more than two decades since 1996. All topic studies for the NHL are placed in a climate variability/change and oceanographic context. The toxic 2015 PN bloom was well captured from its early initiation in late winter to bloom formation and persistence following the onset of upwelling season (Du et al. 2016). Phytoplankton community response to multi-year "warm ocean events" during 2014-2016 was also well documented (Peterson et al. 2017; Du and Peterson, 2018). These previous practices on HAB and phytoplankton in general demonstrate sampling HAB can be cost effective but provides invaluable early warning messages to other locations in the PNW. A central question we could ask from this effort: How do PN bloom and DA concentration correlate with coastwide HAB observations?

Progress Report: The Newport Hydrographic Line (NHL) off central Oregon (44.6˚N) includes seven stations, NH1, NH3, NH5, NH10, NH15, NH20 and NH25 expanding waters from nearshore to the shelf-break. During Apr-June time period in 2018, four cruises were conducted, two in April (9th and 23rd), one in each of May (21st) and June (6th). PN samples of whole surface sea water and surface horizontal net tows, particulate DA and dissolved DA samples, were collected from each cruise, totally17 samples each. All DA samples and portions of net tow PN samples were safely shipped to the NWFSC PI Vera Trainer's laboratory for toxin quantification and accurate PN species Scanning Electronic Microscopy analysis. PN species light microscopic identification and cells counts were completed at Peterson Newport Lab following each cruise within 48 hours, and data were input to the shared Data Excel file 'NH_HABsampling datasheet 2018' as well as sent out to the PNWHAB team and NHL team after each cruise update. We accomplished the goals of inputting HAB data and information from NH line to the PNWHAB monthly Bulletins scheduled for the spring 2018 (April and May).

PN abundance in the surface seawater samples indicated low magnitudes of bloom species in April but increased to large bloom levels in May. PN species were present mostly as a mix of several larger and small diatomic species. Even though PN have been always present offshore, DA sample analyses indicate that very low to undetectable amount of DA was produced by matching PN blooms. Both bloom and toxin information was incorporated to the PNWHAB bulletins which served as timely HAB reference. Oregon and Washington Fish and Wildlife State agencies to make decisions on shellfish opening/closure regulations.

Publications:

Two PNWHAB bulletins were released on April 13 and May 24 to help WA and OR state agencies in the management of shellfish opening timing and safety.

Outreach Activities:

Marine Science Day annually on April 14, 2018 at Hatfield Marine Science Center. Phytoplankton in general and harmful algal blooms biological and ecological knowledge were presented to the local public community.

Amendment 9, 18: A Multidisciplinary, Integrative Approach to Valuing Ecosystem Services from Natural Infrastructure

Funded: $976,948

OSU RESEARCH STAFF: *Steven Dundas, Assistant Professor, Applied Economics; Daniel Cox, Professor, Civil and Construction Engineering; Sally Hacker, Professor, Integrative Biology; David Kling, Assistant Professor, Applied Economics; David Lewis, Associate Professor, Applied Economics; Christopher Parrish, Associate Professor, Civil and Construction Engineering; Peter Ruggiero, Associate Professor, College of Earth, Ocean, and Atmospheric Sciences*

NOAA TECHNICAL LEAD: *Felix Martinez, NCCOS*

Project Background: This project is advancing the transdisciplinary science of coastal ecosystem services by combining research expertise in environmental and resource economics, ecology, geomorphology, geomatics, and engineering in an integrative framework. Our focus is on natural infrastructure, which we define broadly as a physical stock that constitutes restoration of, or extension to natural ecosystem components. We aim to understand the nature and determinants of socially-optimal investment in natural infrastructure in coasts and estuaries from an economic perspective. The economic theory of investment provides the conceptual foundation for our research. Socially-optimal investment maximizes total economic value (TEV): uncertain benefits of an investment net of costs over time. Focusing on a selection of natural infrastructure types, including estuaries and dunes, we are measuring the expected benefits of an investment to society, expected direct costs, and expected co-benefits from provision of ancillary ecosystem services using a portfolio of empirical and mathematical modeling techniques. Our areas of interest are the coastline and estuaries of the Pacific Northwest.

In order to analyze approaches that maximize the TEV of a natural infrastructure investment, we are conducting primary research on how investments are expected to impact the target

ecosystem, how the modified ecosystem is expected to provide services, and how society values those changes (expected benefits and costs). As with ecosystem service research in other domains, two major methodological challenges we encounter in the course of this research are: a) the problem of quantifying the benefit of an ecosystem service that lacks a market price; and b) understanding the "production" relationship between an investment and expected service provision (plus expected ancillary effects on other service flows). Our research is addressing these two challenges by joining state-of-the-art non-market valuation methods with empirical ecological and engineering-economic models of natural infrastructure investment. Our primary research is yielding exciting and policy relevant results and we anticipate that our in-progress integrated models will yield generalizable methodological insights that will extend the frontier of ecosystem service science.

We divide our research into three methodological tracks. Track I is focused on estimating willingness-to-pay (WTP) for protection services related to any type of coastal infrastructure (green or grey) improvement by analyzing coastal housing market data. In Track II we are developing and implementing choice experiment surveys for the purpose of estimating WTP for ecosystem service benefits that accrue to households. In Track III we are developing a combination of empirical and numerical optimization models to analyze how investment in natural infrastructure may be planned to maximize the value of ecosystem services to the public.

We are investigating four distinct systems on the Pacific Northwest coast that serve as applied pathways for our work. The project pathways focus on: 1) quantifying the value of both private and public coastal protection options, the determinants of private coastal protection decisions, and simulating different future coastal management alternatives (Coastal Protection Pathway); 2) coastal dune and beach management options optimized for ecosystem service provision (Dune Landscape Pathway); 3) restoring coastal wetlands and the resulting implications for anadromous fish (i.e. salmon), water quality, blue carbon, and land markets in estuarine systems (Estuary Pathway); and 4) how to allocate land use and build natural infrastructure to facilitate tsunami evacuation and provide other ecosystem services (Coastal Land Use Pathway).

Progress Report: Our third annual Advisory Board meeting was a two-day event (April 12-13, 2018) including a field trip to three sites on the Oregon Coast (Pacific City, Neskowin, and the Salmon River estuary) reflective of the issues we are researching and a full board meeting at Hatfield Marine Science Center (HMSC) in Newport, Oregon.

On April 12th, members of the advisory board and OSU research team convened in Newport for an overview presentation by PI Dundas to summarize progress on our research agenda since the 2017 meeting. After the opening remarks, we led site visits to Pacific City, Neskowin, and the Salmon River estuary with discussions led by team members and a variety of local stakeholders on dune management, coastal armoring, and estuary restoration. The board meeting took place on April 13th in the Guin Library at HMSC. Research presentations on our research pathways

were made by OSU faculty and graduate students. We also conducted a focus group with the board for our new survey on public preferences for dune habitat restoration. A detailed summary of the meeting that was provided to board members after the event, The Board Meeting Flyers are at the end of this report and original copies can provided to the program office upon request.

The progress made since the beginning of this reporting period (July 2017) is highlighted below by detailing the contributions of each team member:

Environmental economist Dr. Steven Dundas (Assistant Professor, Department of Applied Economics and Coastal Oregon Marine Experiment Station) is the lead PI of this grant responsible for administration and management duties in addition to research output and project outcomes. Dundas has organized team meetings, planned the advisory board meeting, maintained active communication with NCCOS grant manager Martinez, developed a project website, participated in outreach related to grant activities and contributed to research meetings/discussions related to this project. Dundas is also the coordinating economist for both the Coastal Protection and Coastal Land Use Pathways.

In terms of project outcomes and outreach/engagement activities for the current reporting period, Dundas, as a direct result of this project, was invited to join the Social Science Advisory Committee for the Puget Sound Partnership (PSP) to provide expertise on economic aspects of provision of coastal ecosystem services to guide the best possible social science in support of Puget Sound recovery goals and strategies. In this role, Dundas was the lead discussant for a webinar, Best Practices in Ecosystem Service Valuation, held by the PSP on 31 August 2017 and has participated in monthly board meetings to communicate findings of this project to help the PSP stay informed on our related research efforts. Dundas has also secured an end-user for the models/results of the Estuary Pathway. The Wild Rivers Coast Alliance and board member Parry are planning to use economic value results from our Oregon Coast coho choice experiment survey and our coho Bayesian habitat model to aid in development of a “salmon calculator” to better inform their efforts to target potential riparian and estuarine restoration investments in Oregon’s South Coast region. Dundas is also currently in conversations with Oregon DLCD about participation as a technical advisor for a new Oregon State Planning Goal 18 Policy Work Group to discuss potential future changes to this coastal management policy informed by research described below. Lastly, Dundas met with a US Forest Service representative (Lisa Romano) to discuss valuation of dune restoration in Oregon on 16 November 2017. USFS manages nearly 50 miles of dune habitat and our valuation project on dune restoration will help inform a missing piece (public preferences) for their planned restoration options. Romano participated in the 2018 Advisory Board meeting and expressed interest in utilizing our research outputs to inform USFS decision-making.

On the research front, Dundas and co-PI Lewis have submitted a manuscript for publication that estimates economic values for future coastal protection options from irreversible loss under

Oregon's Goal 18 land-use policy (Dundas and Lewis 2018). Dundas and graduate student Beasley (Dundas, advisor) have developed an empirical model of coastal landowners' investment in grey infrastructure and are currently evaluating simulation models of future shoreline policies as a result of this private decision-making (Beasley and Dundas 2018). Results from the both of these efforts described above will be integrated into geomorphological models of shoreline change from co-PI Ruggiero and his graduate students to test different coastal management policy options and optimize ecosystem service provision (Track III).

Dundas, co-PIs Kling and Cox, and graduate student Beasley are developing an agent-based benefit-cost model of natural infrastructure that facilitates tsunami evacuation. The model will focus on natural infrastructure investment opportunities in Seaside, Oregon, including green belt escape routes and high-rising parks. Work on integrating evacuation, transportation, and economic models is currently in process. Results from a baseline integrated model are expected before the end of 2018.

Dundas has also contributed to the development of survey instruments and coordination of focus group testing in both Oregon Coast Coho salmon survey (Estuary Pathway) and the coastal dune and beach habitat survey (Dune Landscape pathway). Dundas is currently developing a third survey instrument (with co-PIs Lewis, Hacker, and Ruggiero) designed to elicit preferences for coastal access and protection under future sea-level rise scenarios for a general population sample of Oregon residents. It is anticipated this survey will reach the focus group stage in late 2018 and be in the field by mid-2019.

Environmental economist Dr. David Lewis (Professor, Department of Applied Economics) is the coordinating economist for the Estuary Pathway of research and has collaborated with PI Dundas, co-PIs Kling and Hacker, and NOAA economist and Board member Lew to develop and conduct a choice experiment survey on restoring Oregon Coast Coho salmon through estuarine conservation (Track II). The survey was sent to 5,000 randomly selected households in the Pacific Northwest between September and November of 2017. The survey results form the foundation for placing non-market values on estuary conservation actions that generate public goods, and we received 941 usable survey responses. Lewis is leading the data analysis of the Coho survey and multiple co-PIs and Board member Lew have collaborated on a first draft manuscript that analyzes the survey results (Lewis et al. 2018). Results from this manuscript demonstrate estimated aggregate annual WTP for Pacific Northwest Residents for Coho restoration scenarios (see Fig. 1).

This work is being presented in multiple professional settings in 2018 and we hope to submit the manuscript for publication in fall of 2018. Lewis and co-PI Hacker have recruited fisheries ecologist Mark Scheurell from NOAA to help develop a new data-driven Bayesian model that links habitat investments such as salt marsh restoration to populations of Oregon Coast coho salmon. Scheurell and graduate student Magel (Hacker, advisor) have put together a large dataset

and have been working together on the Bayesian model. They will have preliminary results by the end of this summer (2018). Lewis and graduate student Finer (Lewis, advisor) have developed a research strategy for estimating the effects of estuarine investments on housing markets through incorporation of parcel-level hedonic models of the value of land. Using data on every land transaction in Oregon estuaries since 2005, preliminary results from the hedonic analysis of estuarine land markets have been developed and scenario analysis is currently being conducted. The three major project pieces in the Estuary Pathway (choice experiment, Bayesian habitat model, estuarine hedonic model) are expected to produce multiple scholarly publications, including an analysis that combines all three pieces to assess the economic value of salt marsh habitat as a natural capital stock.

Coastal ecologist, Dr. Sally Hacker (Professor, Department of Integrative Biology), has worked with the Estuary and Dune Landscape pathways research teams to provide information on the ecosystem function and services portion of the projects. With extensive experience working in Pacific Northwest estuaries and coastal dunes, Hacker is providing basic ecological information on the important services associated with these ecosystems and has helped with drafts of the three choice experiment surveys. She is also working with the other members of each of the pathways to conceptualize and quantify models that tie the important ecosystem service production functions to the economic information gained from the surveys to understand a set of empirically-based natural coastal infrastructure issues in dunes and estuaries on the Oregon Coast. She is also leading an effort to develop a dune conceptual model that considers the relative importance of dune ecosystem services in natural and managed systems (see Fig. 2). The goal is to write a paper about this model to be submitted in the upcoming academic year. Hacker has recruited two graduate students (Magel and Jay) to help provide research and logistical support for each of the pathways. In the Estuary pathway, Magel is working with Dr. Mark Scheuerell (NOAA, Seattle) to determine the relationship (using Bayesian statistics) between salt marsh natural infrastructure (both current and restored) and the production of endangered Oregon coho salmon in 21 estuaries on the Oregon Coast. They have gathered salmon and environmental data, including conducting GIS analysis of salt marshes in Oregon estuaries with the help of Dr. Laura Brophy, a consultant for GreenPoint Consulting (Corvallis). As described above, building the Bayesian model is underway and they should have preliminary results at the end of summer (2018). For the dune pathway, graduate student Jay is working with co-PI Ruggiero's graduate student (Hovenga) to gather ecological and geomorphic data to be used in modeling the dune coastal protection and restoration production function. This model will be used with survey information to explore various management scenarios relevant to the Pacific Northwest coast.

Coastal Geomorphologist Dr. Peter Ruggiero (Professor, College of Earth Ocean and Atmospherics Sciences) continued to work with the rest of the team to develop and refine the Dune Landscape pathway and to work on the Coastal Protection pathway. Ruggiero continues to work with Civil and Construction Engineering PhD student Hovenga on research and logistical

support for these pathways. Together, along with other graduate students in Ruggiero's lab, they developed a simple model for dune restoration projects under the influence of sea level rise (SLR). This model tracks simple beach and dune morphometrics through time as SLR erodes and lowers dunes and/or management actions raise dunes and increase beach and dune volume. This model was implemented recently in the modeling software Envision as part of the Grays Harbor Coastal Futures project, another NOAA funded effort. Ruggiero's group continued to make significant progress on the development and implementation of a new numerical modeling framework that simultaneously accounts for both subaqueous and subaerial transport mechanisms, which together are necessary for fully understanding backshore evolution (beaches and dunes). The Coastal Recovery from Storms Tool (CReST) is a graphical user interface which aims to expand the capabilities and usability of Windsurf, a process-based numerical modeling system which simulates the evolution of dune-backed sandy coastal systems in response to both wave and wind forcings, to better account for the complex dynamics of managed coastlines. The ability to incorporate dune grass planting scenarios, beach nourishment and dune construction, beach scraping, dune grass removal, and the presence of hard engineering structures into CReST/Windsurf provides a new research tool to explore the implications of management decisions on coastal vulnerability. Using the Windsurf/CReST modeling system we are exploring optimum beach nourishment strategies which (1) promote the natural development of dunes and (2) have the longest project lifecycles. Additional targeted modeling questions are being developed in conjunction with local stakeholders at study sites in Bogue Banks, NC and in the US Pacific Northwest in order to help guide effective and economic management strategies for beach/dune nourishment and vegetation planting campaigns.

Consistent with field measurements, recent Windsurf applications have shown skill at simulating coastal change by winds and waves at time scales of hours to years. CReST extends the Windsurf model capabilities to explore implications of management decisions on coastal evolution. This in-development tool will provide a valuable asset for scientists and managers struggling to synthesize coastal evolution in response to environmental, ecological, and anthropogenic factors. This modeling framework will ultimately inform the spatially explicit empirical landscape model being developed by the Dune Landscape Pathway.

Finally, Ruggiero has worked with PI Dundas and graduate student Beasley on the Coastal Protection pathway by computing hours of wave impacts per year metrics for Tillamook County, OR. These data will comprise part of Beasley's coastal armoring simulation model (Beasley and Dundas 2018).

Natural resource economist Dr. David Kling (Assistant Professor, Department of Applied Economics) continued collaboration with PI Dundas and co-PI Lewis to implement the economic research component of the project. Working with PI Dundas and co-PIs Hacker and Ruggiero, and graduate student Nguyen, Kling was the primary author of a revised nonmarket valuation survey focusing on natural infrastructure and ecosystem services provided by Pacific Northwest

coastal dunes and sandy beaches (hereinafter the "dune survey") (Track II). Revisions to an earlier instrument on the same subject were initiated in response to focus group and stakeholder feedback received in late 2016/ early 2017. Kling oversaw focus-group testing of a revised draft survey instrument in March 2018. He also continued work on a dynamic ecological-economic model of coastal dune capital management (Track III). In addition, with PI Dundas and co-PI Cox, and graduate student Beasley, he contributed to the agent-based model benefit-cost model of tsunami risk mitigation provided by green infrastructure. In the next academic year, Kling will lead work on the IRB approval process, field testing, and dissemination of the dune survey to a random sample of the general public. Survey dissemination is expected by late 2018. Kling will also work on the ecological-economic model of coastal dune capital management, with preliminary results expected in early 2019.

Geomatics Engineer Dr. Chris Parrish and his students (Laura Barreiro Fernandez, Shane O'Hara and Zachary Grubb) have assembled a coastal geospatial database designed to support a wide range of project needs and are currently conducting geospatial analysis for the Coastal Protection and Dune Habitat Pathways. Data sets incorporated into the geodatabase include multi-temporal, tidally-referenced shoreline derived from LIDAR data and imagery, LIDAR- derived digital elevation models, shoreline protection structures, and coastal tax lots. A number of parameters have been calculated and added to the tax lot layer as attributes, including: elevation with respect to tidal datums (e.g., mean high water), tsunami zone information, structure information (e.g., centroid location, year built), distances from structure(s) to shoreline, distance to shoreline protection structures, Goal 18 status, vegetation, soil, and nearby coastal features of interest (e.g., lighthouses and sea stacks). In collaboration with OPRD and advisory board member Callahan, the team is also investigating the use of LIDAR data and imagery for automated identification and analysis of shore protection structures along the Oregon Coast. Multi-temporal data (e.g., coastal LIDAR data spanning nearly 20 years), including data collected before and after shoreline stabilization measures were enacted along various portions of the Oregon coast have been assembled and are anticipated to assist in evaluating relationships between coastal geomorphology (including changes resulting from shoreline stabilization measures) and property value.

In the current reporting period, processing and analysis was performed to add the following per-parcel attributes to the Goal-18-eligible tax lot data set:

1. Number of neighboring parcels armored at five different epochs, which correspond to LIDAR data collected in the following years: 1998, 2002, 2009, 2014, and 2016 (Fig. 3).
2. Distance from building centroid to LIDAR-derived shoreline for the epochs listed above. (This attribute is used in conjunction with setback distance, defined as the distance from the building centroid to the shoreline protection structure, to assess coastal erosion over time.)

3. Application year, defined as the year a permit application for a protective structure was filed.
4. Another new data set that was generated and added to the project geodatabase consists of a current, best-available shoreline, covering both outer coast and estuaries, with tax parcel and shoreline protection attributes (Fig. 4). The geospatial team is also continuing to investigate computation of an ocean-view attribute for each property in the Goal 18 database.

Parrish met with NOAA's OAA's Office for Coastal Management to discuss disseminating the outputs of the project via NOAA's Digital Coast. To facilitate distribution via Digital Coast, the team has been consolidating and documenting all data layers and Python scripts created during this project.

Coastal engineer Dr. Daniel Cox has worked with PI Dundas, co-PI Kling and graduate student Beasley on the Coastal Land Use Pathway. This pathway focuses on land use and tsunami evacuation routes in coastal communities, with a focus on greenbelts and open space. Cox, Dundas and Kling have identified the city of Seaside as an area to explore a model for valuing expected tsunami risk benefits provided by green infrastructure. Cox has worked with colleagues on implementing several changes to the Agent-Based Tsunami Evacuation Model (ABTEM) including (1) modules to insert Vertical Evacuation Options, (2) agent confidence, (3) and agent grouping. See Figure 5 for an example of model output.

Publications:

Biel R.G., **S.D. Hacker, P. Ruggiero**, N. Cohn, and E.W. Seabloom. 2017. Coastal protection and conservation along sandy beaches and dunes: context-dependent tradeoffs in ecosystem services. Ecosphere 8: e01791. 10.1002/ecs2.1791.

Biel, R.G., **S.D. Hacker**, and **P. Ruggiero**. In Review. Elucidating coastal foredune ecomorphodynamics in the US Pacific Northwest via Bayesian networks. Journal of Geophysical Research: Earth Surface.

Dundas, S.J. 2017. Benefits and Ancillary Costs of Natural Infrastructure: Evidence from the New Jersey Coast. Journal of Environmental Economics and Management. 85: 62-80.

Mostafizi, A., Wang, H., **Cox, D.T**., Dong, S. In Review. An Agent-based Model of Vertical Tsunami Evacuation Behavior and Shelter Locations: A Multi-Criteria Decision-Making Problem, Natural Hazards.

Ruggiero, P., **S.D. Hacker**, E. Seabloom, P. Zarnetske. 2018. The role of vegetation in determining dune morphology, exposure to sea level rise, and storm-induced coastal

hazards: A U.S. Pacific Northwest perspective. Chapter 11. Pages 337-362 in Moore, L., B. Murray. Barrier Dynamics and the Impacts of Climate Change on Barrier Evolution, Springer.

Cohn, N., **Ruggiero, P**., Garcia-Medina, G., Anderson, D., Serafin, K., and Biel, R., in review. Environmental and Morphologic Controls on Wave Induced Dune Response. Submitted to Geomorphology

Preliminary manuscripts being prepared for publication:

Beasley W.J., and **S.J. Dundas**. 2018. "Identifying the Determinants of the Decision to Install Beachfront Protective Structures." Working Paper.

Dundas, S., and **D.J. Lewis**. 2018. "Estimating option values and spillover damages for coastal protection." Working Paper.

Lewis, D.J., **Dundas, S.J**., **Kling, D.M**., Lew, D.K., and **S.D. Hacker**. 2018. "Public preferences for natural capital investments that help threatened species: The case of Oregon Coast Coho salmon." Working Paper.

Lewis, D.J., and S. Polasky. 2018. "An auction mechanism for the optimal provision of ecosystem services under climate change." Working Paper.

Presentations:

Beasley W.J., **S.J. Dundas**. 2018. Identifying the determinants of the decision to install beachfront protective structures. Western Economic Association International, Vancouver, British Columbia.

Beasley W.J., **S.J. Dundas**. 2018. Identifying the determinants of the decision to install beachfront protective structures. Agricultural and Applied Economics Association Annual Meeting, Washington, DC.

Beasley W.J., **S.J. Dundas**. 2018. Identifying the determinants of the decision to install beachfront protective structures. Camp Resources, Wrightsville Beach, NC.

Dundas, S.J. 2017. A transdisciplinary approach to valuing ecosystem services from coastal natural infrastructure. Part of an Organized Symposium on Linking Biodiversity, Material Cycling, and Ecosystem Services in Coastal Ecosystems at the Ecological Society of America Annual Meeting, Portland, OR.

Dundas, S.J., S.D. Hacker, D. Kling, D.J. Lewis, P. Ruggiero. 2018. NOAA NCCOS Advisory Board Meeting. Hatfield Marine Science Center, Newport, OR.

Dundas, S.J. D.J Lewis. 2018. Estimating option values and spillover damages for coastal protection. W-4133 Annual Meeting, Austin, TX.

Dundas, S.J., D.J. Lewis. 2018. Estimating option values and spillover damages for coastal protection. Western Economic Association International, Vancouver, British Columbia.

Hacker, S. D., P. Ruggiero, E. Seabloom, P. Zarnetske, and R. Biel. 2018. Beachgrass invasions, climate change, and effects on dune ecosystem functions and services in the US Pacific Northwest. Ecological Society of America meeting, New Orleans, LA.

Lewis, D.J., Dundas, S.J., Kling, D.M., Lew, D.K., and **S.D. Hacker**. 2018. Public preferences for natural capital investments that help threatened species: The case of Oregon Coast Coho salmon. Agricultural and Applied Economics Association Annual Meeting, Washington, DC.

Lewis, D.J., Dundas, S.J., Kling, D.M., Lew, D.K., and **S.D. Hacker**. 2018. Public preferences for natural capital investments that help threatened species: The case of Oregon Coast Coho salmon. The International Institute of Fisheries Economics & Trade, Seattle, WA.

Project Outcomes:

- Here, we provide a summary how our research agenda and the anticipated results of our research program are leading to changes in the knowledge or actions of stakeholders and policymakers:

- Co-PI Parrish organized a meeting with NOAA's OAA's Office for Coastal Management on July 13, 2017 to discuss disseminating outputs of the project via NOAA's Digital Coast (https://coast.noaa.gov/digitalcoast/). The OCM team, including Miki Schmidt, Kirk Waters, Lori Cary-Kothera, Rebecca Love, and Mary Culver, indicated that the project aligns well with the interests and needs of the coastal management community, which comprises Digital Coast's main user group. Future discussion with NOAA Digital Coast and other potential outlets for the research will continue as the research progresses.

- Co-PI Ruggiero met with the Pacific City Dune Management Committee on 2 August 2017 to discuss plans for updating the Pacific City Dune management plan. Ruggiero is being asked to aid in developing an updated Scientific Background report which will be used to develop strategies for sand management practices in the area. Ruggiero will use

results of the Dune Landscape Pathway in this process. This connection was a direct result of our 2017 Advisory Board meeting and was facilitated by board member Yamamoto (Tillamook County Commissioner).

- PI Dundas is now a member of the Social Science Advisory Committee for the Puget Sound Partnership to provide expertise on economic aspects of provision of coastal ecosystem services to guide the best possible social science in support of Puget Sound recovery goals and strategies. He was the lead discussant for a webinar, Best Practices in Ecosystem Service Valuation, held by the Puget Sound Partnership (PSP) on 31 August 2017.

- Co-PI Ruggiero and PI Dundas organized 3 workshops on coastal resilience on the Oregon Coast (29 Sept 2017 – Seaside; 03 Oct. 2017 – Coos Bay; 10 Oct. 2017 Newport) in which we included knowledge derived from the Coastal Protection and Dune Landscape Pathways to frame the conversation. We engaged with a new set of local stakeholders in each region to investigate potential channels for future coastal infrastructure investments and research projects.

- PI Dundas met with a US Forest Service representative (Lisa Romano) to discuss valuation of dune restoration in Oregon on 16 November 2017. USFS manages nearly 50 miles of dune habitat and our valuation project on dune restoration will help inform a missing piece (public preferences) for their planned restoration options. Romano now serves on the board and anticipates utilizing our models and results to plan dune restoration projects in Suislaw National Forest.

- Co-PI Hacker attended a Saltmarsh NET working group meeting in Wales, UK, in mid-December 2017 that is integrating research on salt marshes in different regions (Hacker is focused on Pacific Northwest marshes) to understand the ecosystem services and values of salt marshes around the world. The research we are conducting in the estuary pathway could serve as a PNW case study for the importance and value of salt marshes as habitat for fisheries and coastal protection.

- The Wild Rivers Coast Alliance and board member Parry are planning to use economic value results from our Oregon Coast coho choice experiment survey and our planned coho biological model to aid in development of a “salmon calculator” to better inform their efforts to target potential riparian and estuarine restoration investments in Oregon’s South Coast region.

- Results from a housing market analysis of Oregon State Planning Goal 18 by PI Dundas and co-PI Lewis and a land-use change model by graduate student Beasley and Dundas have been shared with Oregon DLCD and this state agency is now forming a Goal 18

Policy Work Group to discuss the future of this policy and how it might be changed to the benefit of all Oregonians. Dundas is likely to join the technical advisory board of this Work Group in late 2018.

- Results from a general population survey of residents of the PNW about estuarine habitat restoration/coho salmon are now being generated. We sent 5,000 surveys and achieved our target response rate of 20%. Co-PI Lewis interacted with numerous members of the general public who were survey respondents and had questions about the estuarine/coho survey. We are currently seeking guidance from Oregon Sea Grant and Board member Walker (Director, Oregon Sea Grant) to effectively target our outreach efforts. Results are anticipated to inform numerous agencies and organizations involved in conservation of Oregon Coast Coho, including NOAA, the Oregon Department of Forestry, and the U.S. Forest Service, among others.

Figures:

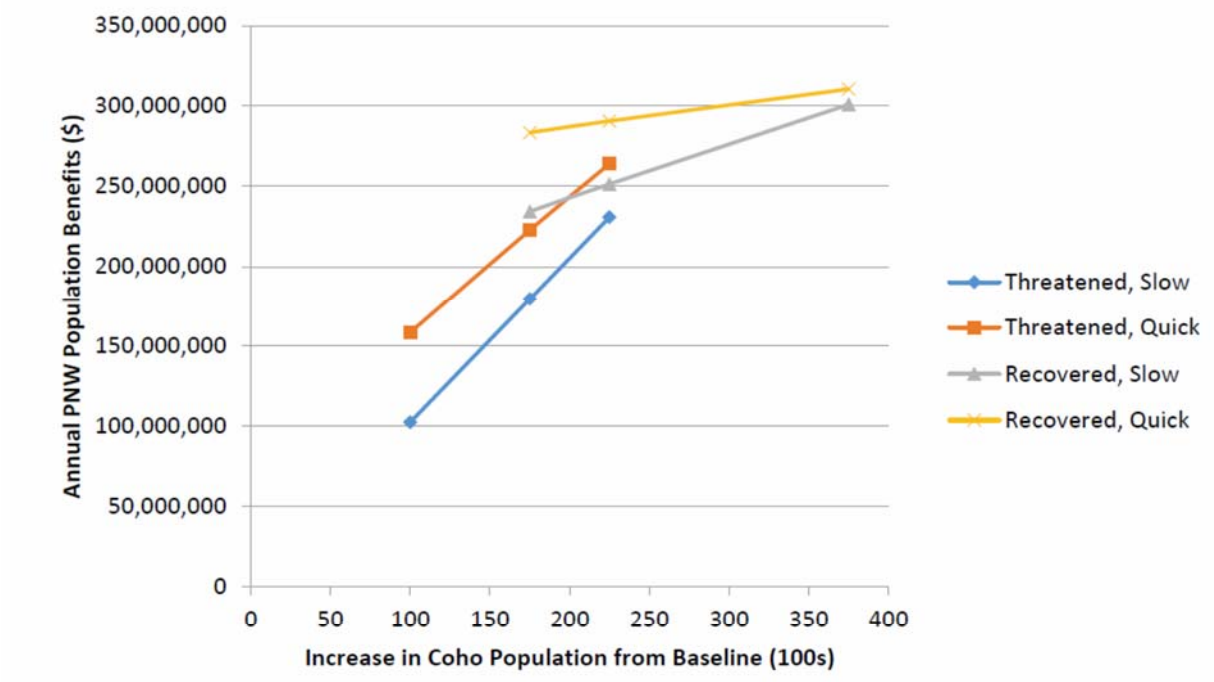


Fig.1. Estimated Aggregate Annual Willingness-to-Pay for Pacific Northwest Residents for Coho restoration Scenarios.

Notes: ESA Status and speed of restoration are held fixed along each given line. ESA status and/or speed varies across the lines in the figure. Fishing regulations are held fixed at current levels in this graph (open occasionally with 5 fish/year bag limit). Aggregation is for the general population of Washington, Oregon, Idaho, and northern California.

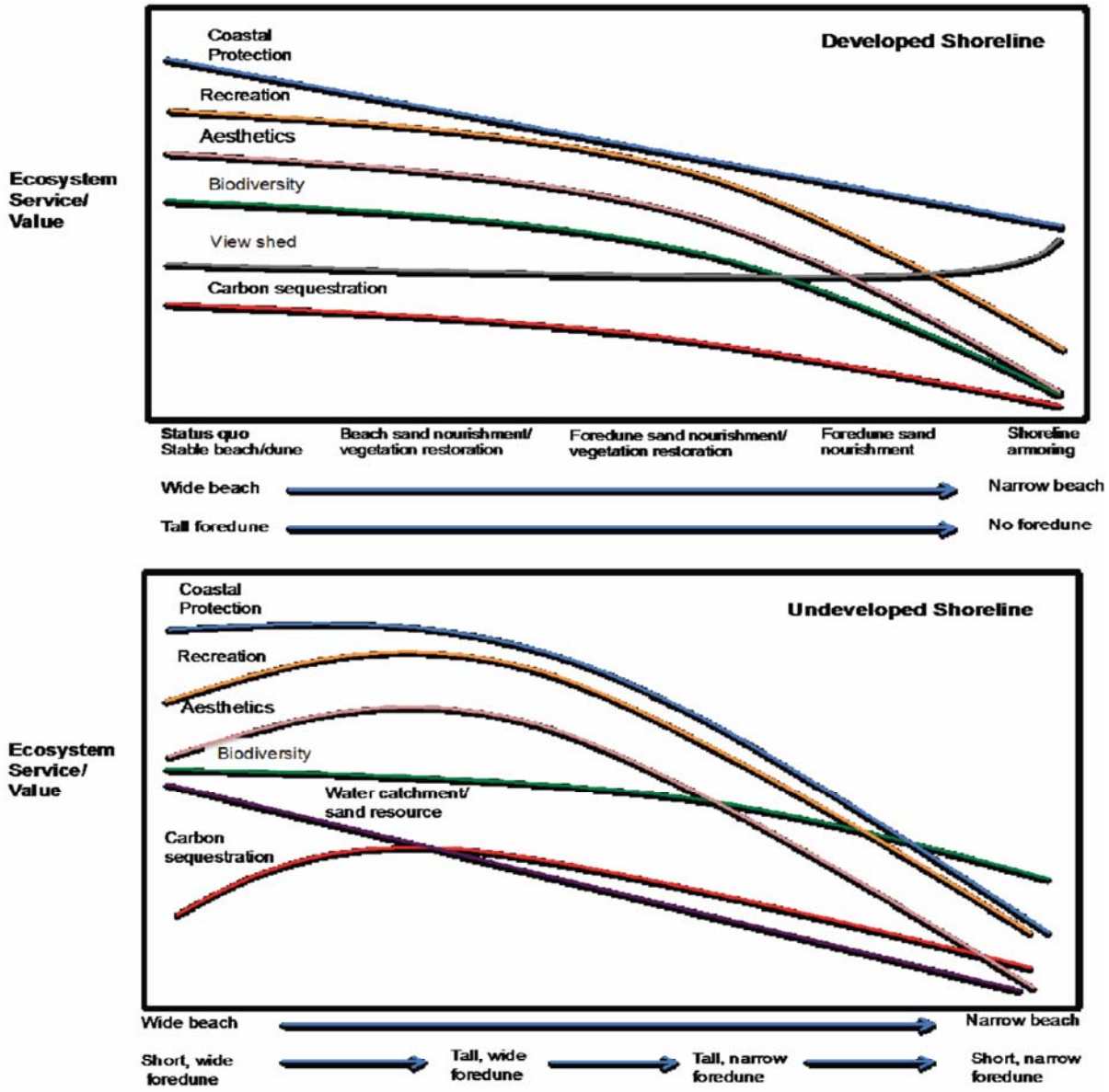


Fig. 2. Generalized dune conceptual model for important ecosystem services on both undeveloped (top) and developed shorelines (bottom).

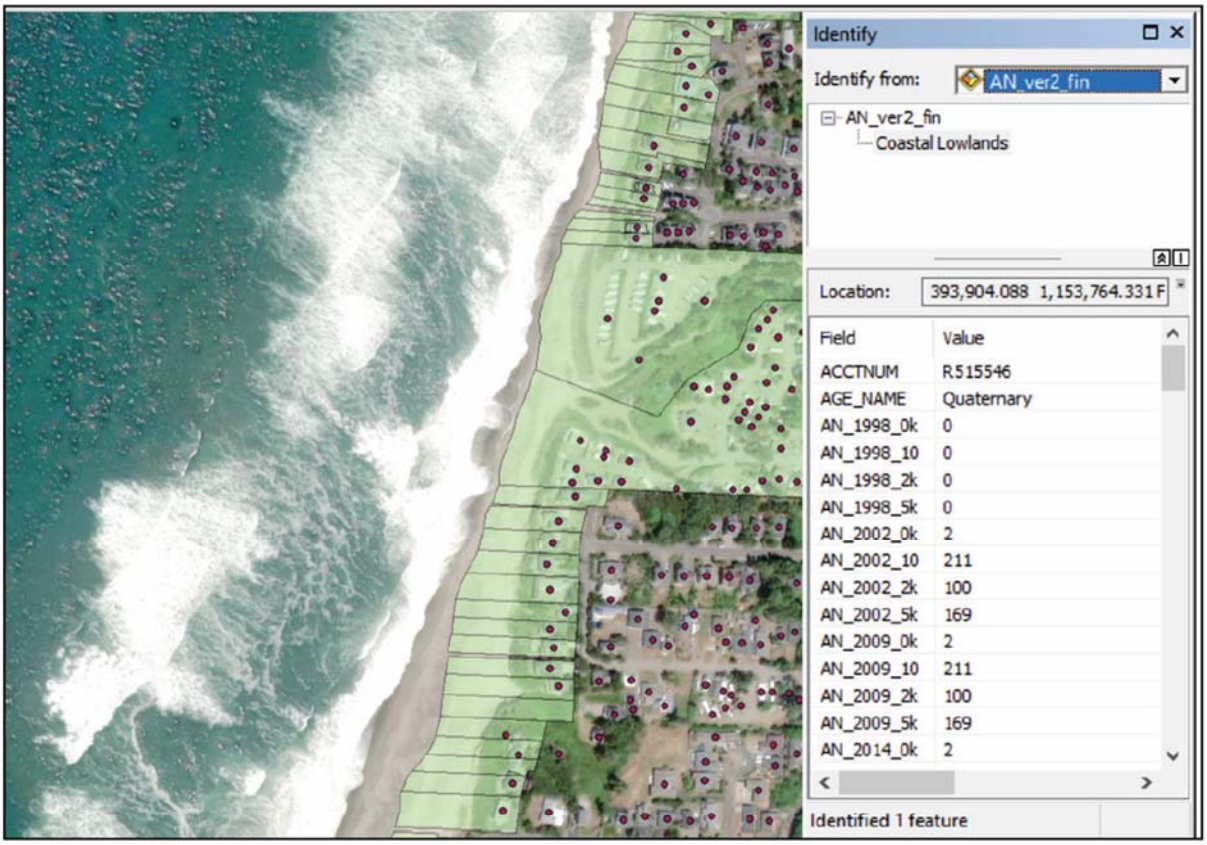


Fig. 3. Number of neighboring tax lots protected by coastal armoring at different epochs, and using different distances to define neighbors. The area depicted is in the vicinity of Gleneden Beach and Lincoln Beach, Oregon. (Note: 'AN' denotes armored neighbors.)

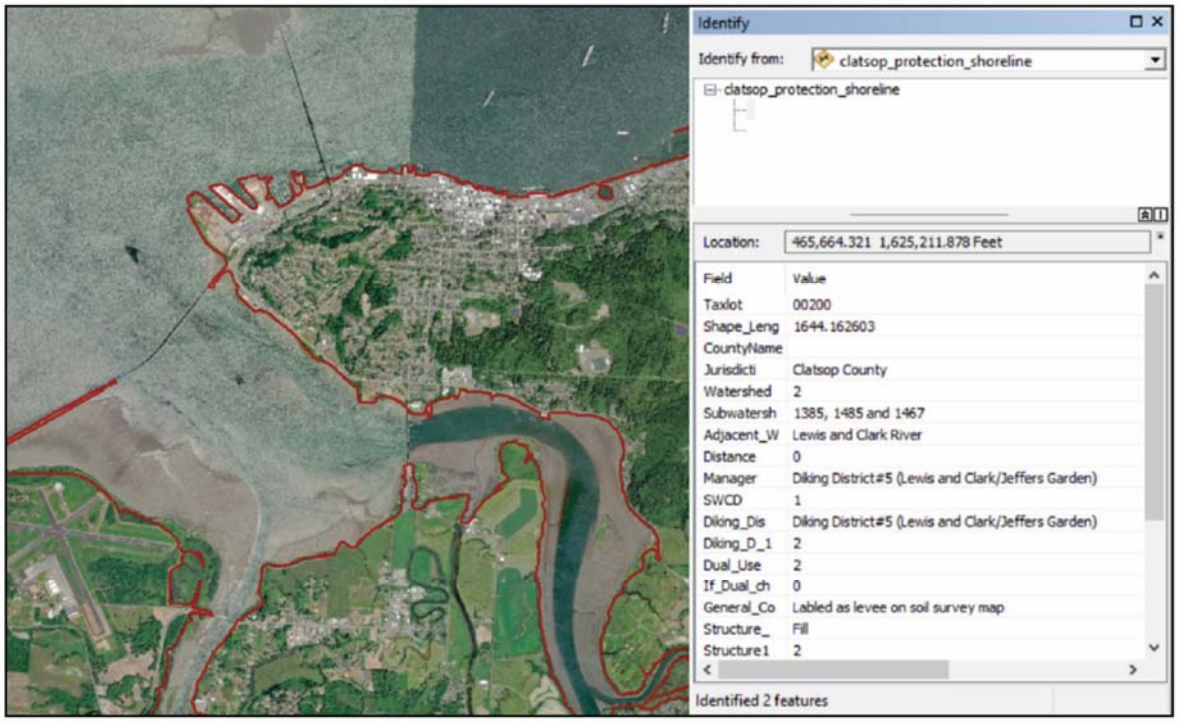


Fig. 4. Shoreline protection structure information added to Clatsop County shoreline in the vicinity of Youngs Bay and the city of Astoria, Oregon.

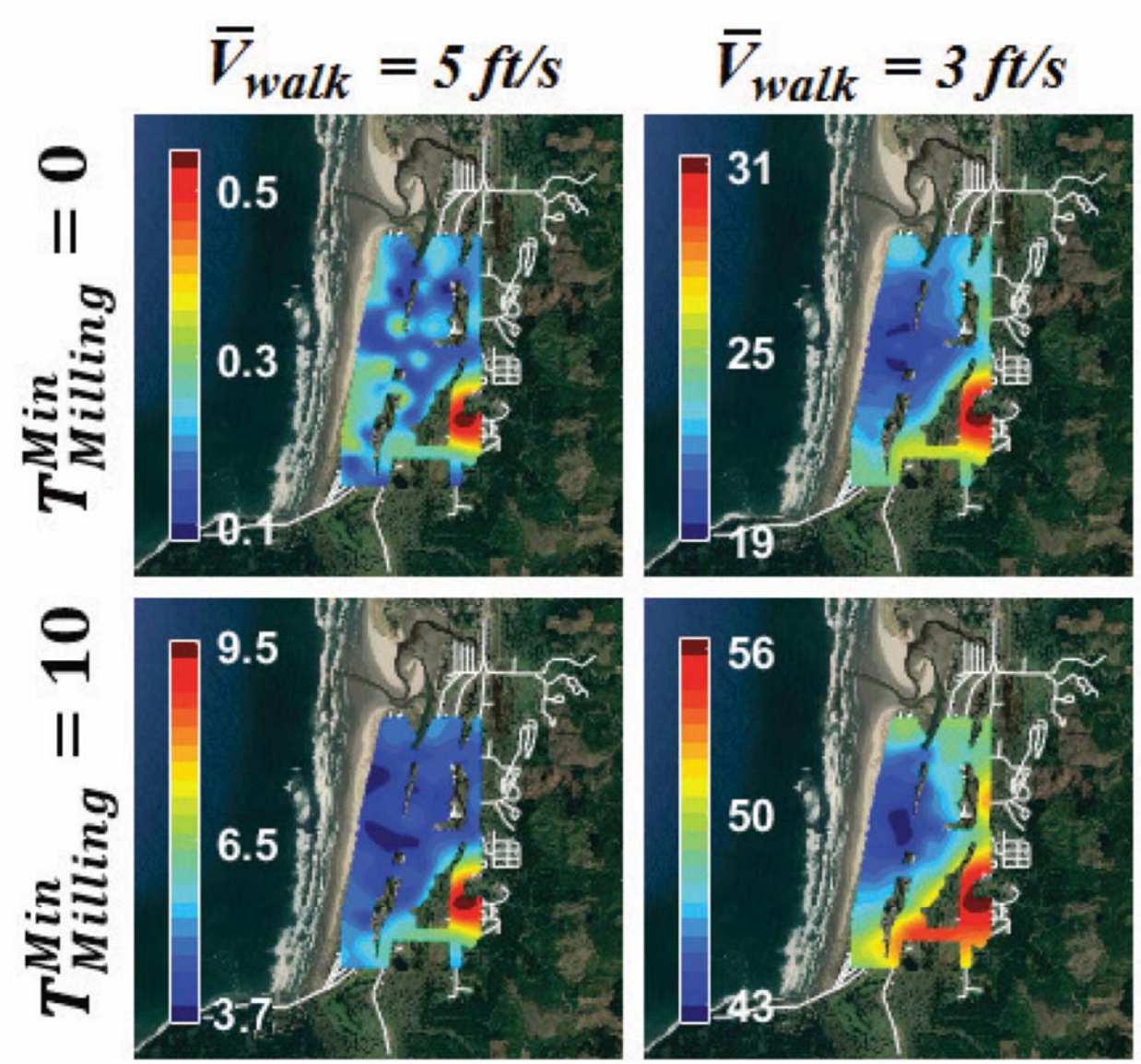


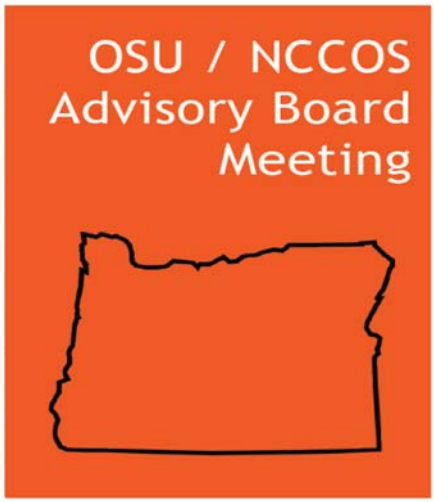
Fig.5. Example optimization of vertical evacuation refuge locations within the inundation zone of Seaside, Oregon. Cool colors show optimal locations. Optimal locations vary with walking speed and milling time. (Mostafizi, et al., submitted)

Board Meeting Flyers:

COASTAL NATURAL INFRASTRUCTURE ADVISORY BOARD MEETING SUMMARY

April 12-13, 2018

COASTAL PROTECTION: RIP-RAP IN NESKOWIN (TOP) AND DUNES IN PACIFIC CITY (BOTTOM)



APRIL 2018

3rd Annual Advisory Board Meeting

Researchers from Oregon State University (OSU) are investigating economic, ecological, and geomorphologic outcomes of investments in coastal natural infrastructure with funding from a 2015 – 2019 NOAA National Centers for Coastal Ocean Science grant. Our 2018 Advisory Board meeting was a two-day affair consisting of a field trip to three locations along the Oregon Coast illustrative of coastal issues that are the focus of our research efforts and a full day of presentations and outreach and engagement discussions at Hatfield Marine Science Center (HMSC) in Newport, Oregon.

On April 12th, members of the advisory board and OSU research team convened in Newport for an overview presentation by lead PI Steven Dundas to summarize progress on our research agenda since the 2017 meeting. After the opening remarks, we traveled to Pacific City, Neskowin, and the Salmon River estuary for site visits and constructive conversations on dune management, coastal armoring, and estuary restoration led by OSU faculty, graduate students and a number of local stakeholders.

The board meeting took place on April 13th in the Guin Library at HMSC. Research presentations on our three research pathways – Estuary Restoration, Coastal Protection, and Dune Landscapes – were made by OSU faculty David Lewis, Sally Hacker, Steven Dundas, and David Kling and OSU graduate students Caitlin Magel, Cassie Finer, Jason Beasley, Tu Nguyen, and Paige Hovenga. We also conducted a focus group with the board for our new survey on public preferences for dune habitat restoration.

This document provides a summary of the events and conversations that took place at the 2018 meeting.

Bob Straub State Park
Members of the advisory board and OSU research team walking on a large dune in Bob Straub State Park in Pacific City, Oregon.

Pelican Brewing Company
Active dune grading on beachfront property at the Pelican Brewing Company in Pacific City, Oregon.

Oregon State University CIMRS NCCOS NATIONAL CENTERS FOR COASTAL OCEAN SCIENCE

Restoring Estuaries for Pacific Salmon

Loss of tidal wetlands in Oregon is a significant issue, but estuary habitat restoration has potential to reverse the damages by re-establishing functionality for juvenile salmon and other estuary-dependent species. Most tidal wetlands in the Salmon River estuary were previously diked for agricultural use. Fortunately in 1978, the US Forest Service began working to restore the natural functions of the estuary to improve conditions for salmon, plants, birds, and animals reliant on this ecosystem.

The last stop on our field trip included discussions led by Sally Hacker, Caitlin Magel, and Cassie Finer about the colorful history of the Salmon River Estuary. We learned about the ill-fated Pixieland amusement park constructed on diked wetlands and how the straightening of US Highway 101 that has left two "orphan" creeks that are no longer tidally influenced.

SALMON RIVER ESTUARY – Caitlin Magel, Ph.D. student in Integrative Biology, discusses estuary restoration that has returned nearly 75 percent of the Salmon River estuary back to wetlands in recent years.

Work on this grant will contribute to our understanding of public preferences for estuary restoration, how restoration "produces" more salmon, land market responses to changes in shoreline composition in estuaries, and the total economic value of an acre of restored salt marsh.

Day 2: Annual Board Meeting

The board convened at HMSC on April 13th for a day of research presentations and discussion of future outreach and engagement activities. The first set of presentations discussed new results and reported progress on research outputs in the Estuary Pathway. Highlights of this session included 1) Survey results suggesting residents of the Pacific Northwest are willing-to-pay for more returning coho salmon, quick restoration efforts that restore salmon faster, and for removal of the species from the Endangered Species Act; 2) A progress report on development of a population model that will determine the variance explained by various habitat and ocean factors on coho salmon production to help predict the number of fish produced under future restoration scenarios; and 3) Updates about construction of a model of estuary land market responses to altered shoreline geography from salt marsh restoration.

Outreach discussions generated ideas ranging from small focus groups to improve messaging of the research for target audiences to development of a payment for environmental services scheme to incentive agricultural land owners to 'farm' fish.

The Coastal Protection Pathway group presented new results on studies about Oregon's State Planning Goal 18 including 1) Housing markets significantly value the option to install coastal armoring if a property is vulnerable to erosion risk; and 2) Spatial spillover effects may offset some of these benefits and may influence the armoring decision. Plans for a public survey about coastal management options and a benefit-cost analysis of natural infrastructure investments that improve life safety in a tsunami event were also covered.

The working lunch included time for networking and an informal focus group test of our draft dune landscape restoration survey instrument. Feedback from the group discussion will be incorporated into the final version of the survey. The last session of the day include three presentations about on-going research on dune landscapes including 1) A conceptual model of ecosystem services provided by dunes; 2) A spatial targeting model of investment in dunes that seeks to maximize economic returns from ecosystem services; and 3) dynamic optimization of cost-effective dune management plans for a variety of scenarios.

Oregon State University CIMRS NCCOS NATIONAL CENTERS FOR COASTAL OCEAN SCIENCE

Project Summary

This project advances the transdisciplinary science of coastal ecosystem services by combining research expertise from Oregon State University in environmental and resource economics, ecology, geomorphology, geomatics, and engineering in an integrative framework. Our areas of interest are the coastline and estuaries of the Pacific Northwest. Our focus is on coastal natural infrastructure, which we define broadly as a physical stock that constitutes restoration of, or extension to, natural ecosystem components. We aim to understand the nature and determinants of socially-optimal investment in natural infrastructure in coasts and estuaries from an economic perspective. The economic theory of investment provides the conceptual foundation for our research. Socially-optimal investment maximizes *total economic value*: uncertain benefits of an investment net of costs over time. Focusing on a selection of natural infrastructure types, including estuaries and dunes, we are measuring the expected benefits of an investment to society, expected direct costs, and expected co-benefits from provision of ancillary ecosystem services using a portfolio of empirical and mathematical modeling techniques.

Neskowin Armoring

Erosion is a serious issue in Neskowin, Oregon. Many homes in this community have exercised the option to install rip-rap as a protective measure against coastal hazards.

Salmon River Estuary

Most tidal wetlands in the Salmon River estuary were previously diked for agricultural use. Restoration projects have removed dikes and tide gates and restored salmon access to about 75 percent of the historical wetland habitat.

Principal Investigator
Steven J. Dundas
Steven.Dundas@oregonstate.edu

Co-PIs
Daniel Cox
Sally Hacker
David Kling
David Lewis
Christopher Parrish
Peter Ruggiero

Faculty Research Assistant
Laurie Houston

Graduate Students
Jason Beasley
Cassie Finer
Paige Hovenga
Katya Jay
Caitlin Magel
Rebecca Mostow
Tu Nguyen

Program Manager
Felix Martinez
Felix.Martinez@noaa.gov

Advisory Board
Sarah Absher
Jonathan Allan
Brady Callahan
Aaron Jenkins
Dan Lew
Jarod Norton
Cam Parry
Charlie Plybon
Patty Snow
Trevor Taylor
Shelby Walker
David Yamamoto

We are grateful for the funding that supports this research from the NOAA National Centers for Coastal Ocean Science Competitive Research Program through NOAA Cooperative Institutes Program award numbers NA11OAR4320091A and NA16OAR4320152 to CIMRS at Oregon State University.

Oregon State University CIMRS NCCOS NATIONAL CENTERS FOR COASTAL OCEAN SCIENCE

Theme: Protection & Restoration of Marine Resources

Amendment 8: Atlantic Kemp's Ridley age, growth dynamics, habitat use, and trophic ecology, with comparison to the Gulf of Mexico

Funded: $78,369

OSU RESEARCH STAFF: *Selina Heppell, Professor, Fisheries and Wildlife; Matthew Ramirez, Graduate Student, Fisheries and Wildlife*
NOAA TECHNICAL LEAD: *Larisa Avens, SEFSC*

Project Background: Although Kemp's ridley sea turtles nest almost solely in the western GOM, juveniles inhabit foraging areas throughout the GOM, as well as along the Atlantic US coast, regularly occurring seasonally as far north as New England (1, 2). Sequential isotopic and elemental analysis of inert tissues can complement skeletochronology (3, 4), providing geochemical information that reflects cumulative prey consumption and habitat occupation on an annual basis (5).

The utility of geochemical markers to ecological studies is derived from the fact that isotopes of elements either fractionate predictably or do not fractionate within food webs (6-8). Recent skeletochronological analyses of neritic juvenile loggerheads in the Northwest Atlantic have incorporated growth increment-specific isotopic sampling (δ13C as an indicator of foraging location and δ15N as an indicator of trophic position) and provided new insights into trophic status, ontogenetic stage durations, and habitat shifts (4, 9).

Ongoing analyses are focused on integrating stable isotope and trace element analysis with skeletochronology for GOM Kemp's ridley humeri collected from turtles stranded subsequent to the DWH oil spill to examine trends in growth patterns and foraging ecology relative to pre-spill baseline data. However, it has not been possible to conduct similar analyses to provide updated data for the US Atlantic and allow comparison with the GOM.

Project Progress: In the past calendar year most laboratory analyses were completed for this project. The equipment necessary for sampling was out of service from July 2017 to October 2017, so sampling began in earnest in November 2017. Bone dust was collected from 508 unique bone growth layers in a total of 157 Kemp's ridley turtles using a micromill. These samples were analyzed for stable carbon and nitrogen isotope values. Due to delays in sample processing in the stable isotope facility, these data just became available in July 2018. These data are being used to reconstruct turtle foraging ecology across space (turtles stranded from Virginia to Texas) and time (1995 to 2016). Preliminary analyses suggest unique differences in isotopic signatures among stranding locations, which may be indicative of diet differences. Ongoing analyses are working towards clarifying the mechanism underpinning these differences and how they relate to turtle growth rates.

Samples for lead isotope analyses were collected from 24 turtles, 12 stranded in U.S. Atlantic Coast states and 12 in U.S. Gulf Coast states. Sample processing and data analysis is ongoing, but preliminary analyses suggest there are difference in 208Pb:206Pb between these regions, which may allow for reconstruction of regional habitat use within Kemp's ridley turtles.

Laser ablation-inductively coupled plasmas-mass spectrometry (LA-ICP-MS) was used to collect trace element data from 123 of these Kemp's ridley turtles. Data processing is ongoing. Similar to the lead isotope analyses, these data will be used to try to "fingerprint" Gulf of Mexico vs. Atlantic Coast habitat use for life history reconstruction. Such a fingerprint would allow for the reconstruction of ontogenetic shifts within nearshore habitats, which has previously not been possible.

Depending on the outcome of the lead and trace element analyses, additional samples may be analyzed in upcoming months. Data analyses for all aspects of the project are ongoing and will continue into winter term 2019. Manuscript writing for the stable isotope aspect of the project will commence in fall 2018.

Presentations:

Ocean Science Meeting, held in Portland, OR, USA, February 11-16, 2018. M. Ramirez presented results of ongoing research in a poster presentation. The symposium attracted 3,000 – 4,000 attendees.

Publications:

Ramirez, M.D., J.A. Miller, E. Parks, L. Avens, L.R. Goshe, J.A. Seminoff, M.L. Snover, and **S.S. Heppell**. In review. Reconstructing ontogenetic habitat shifts in sea turtles using trace elements. Marine Ecology Progress Series.

Amendment 6, 29: Stock Assessment Research Review of Pacific Hake

Funded: $37,919

OSU RESEARCH STAFF: David Sampson, Professor, Fisheries and Wildlife
NOAA TECHNICAL LEAD: Sheryl Robinson, WC Region

Project Background: Dr. David Sampson conducted a review of the new assessment of stock status and potential yield for each of the next three years (2018-2020) of the fishery on offshore Pacific Hake, also known as Pacific whiting. Of the 90 species of fish managed under the Pacific Groundfish Fishery Management Plan hake account for the largest single-species landings by

volume. Hake are taken by catcher boats delivering to shore-based processing plants and to at-sea mothership processors, and by large catcher- processor vessels. The US-Canada Pacific Hake/Whiting Treaty was signed in 2003 to establish agreed percentage shares of the transboundary Pacific hake stock and the Treaty was fully implemented in 2012. With this agreement, U.S. and Canadian fisheries scientists and managers are to have significant input on the assessment and management of the shared Pacific hake stock.
The stock assessment for each year (2018-2020) will be conducted during summer and fall of that year. Dr. Sampson has been officially appointed to the Scientific Review Group, which is charged with reviewing the annual hake stock assessments and related analyses developed by the Joint Technical Committee under the auspices of the US-Canada Pacific Hake/Whiting Treaty. The Scientific Review Group's review of the each year's assessment and management strategy evaluation is scheduled for mid-February each year and will be held in Seattle, Washington (2018 and 2020) and Vancouver or Victoria, BC, Canada (2019).

Dr. Sampson will participate as an independent reviewer in the Scientific Review Group' s activities. Prior to the meeting, he will review the new Pacific hake stock assessment report and supporting documents. He will actively participate in person in the week-long science review meeting, including making written contributions to the Scientific Review Group's formal report to the Joint Management Committee. After the conclusion of the review meeting, he will participate in finalizing the report of the Scientific Review Group.

Progress Report: Dr. Sampson's primary activity for this project was participation in a three-and-a-half-day meeting of the SRG held at the Lynnwood Convention Center in Lynnwood, WA on 26 Feb. to 1 March 2018. The meeting began at 1pm on the 26th. The extra half-day scheduled on the meeting agenda for 2nd March was not needed. Additional activities included preparing for the meeting by reading the draft 2018 stock assessment document, contributing text to the SRG's 2018 report to the Joint Management Committee, and subsequently finalizing the SRG report by email correspondence. Dr. David Sampson participated in the 2018 meeting of the Pacific Whiting treaty's Scientific Review Group (SRG), which conducted a peer-review of the draft 2018 stock assessment for the coastal stock of Pacific whiting (hake) that occurs in the western waters off the U.S. and Canada. Dr. David Sampson was an active participant in discussions during the review, contributed text for inclusion in the SRG report of the review, and assisted in editing and finalizing the SRG report. Dr. Sampson reviewed Joint Technical Committee of the Pacific Hake/Whiting Agreement between the Governments of the United States and Canada, 2016. Status of the Pacific Hake (whiting) stock in U.S. and Canadian waters in 2018. Draft document dated 02/12/2018.

Assessment Summary:

The 2018 assessment for the coastal Pacific hake stock and related analyses had been conducted during the summer and fall of 2017 and early winter 2018 by the members of the JTC, consisting

of two U.S. stock assessment biologists from the National Marine Fisheries Service, Northwest Fisheries Science Center (Ian Taylor and Aaron Berger) and two Canadian stock assessment biologists from the Pacific Biological Station, Fisheries and Oceans Canada (Chris Grandin and Andrew Edwards). The assessment model maintained a structure similar to the 2017 assessment: a single coastwide fleet, empirical weights-at-age for the fish caught by the fishery, and non-parametric selectivity curves that were time-varying for the fishery and time-invariant for the survey. Compared to the 2017 model the 2018 model had one more year of landings and age-composition data for the commercial fishery and a biomass index value associated age-composition data for the 2017 acoustic survey. The model was constructed using a new approach for weighting the age-composition data (using so-called Dirichlet multinomial weighting) and it included a new age-based maturity ogive as recommended in the 2017 SRG report. As it happened, much of the discussion during the assessment review focused on issues related to the new age-based maturity ogive (see next section).

Stock Assessment Review

The review of the stock assessment, which occurred during the first two days of the meeting, was structured around a series of presentations by JTC members and members of the acoustic survey team. The formal presentations included (1) an overview of the fishery performance during 2017 and the fishery data series included in the 2018 assessment model, (2) changes made to the assessment model (including bridging from the 2017 model to the new model), results from the preliminary base model, and the JTC's responses to 2017 SRG recommendations, (3) analyses of model sensitivity to key structural assumptions, and (4) projections into the future under different management choices for harvests in 2018, 2019 and 2020. The assessment presentations were followed by presentations on (5) research to develop seasonal forecasts of the spatial distribution of Pacific hake, (6) plans for the Management Strategy Evaluation (MSE) process, (7) presentations on the 2016 and 2017 winter cruises to explore the possibility of conducting direct surveys of Pacific hake spawning biomass, and several additional presentations related to working up the 2017 survey data used in the 2018 assessment and responding to 2017 SRG recommendations regarding the survey.

Following the initial presentations on the 2018 stock assessment there were discussions between the members of the SRG and JTC regarding potential issues that should be considered in the short-term, the main one being the JTC's new approach to modeling age-based maturity. This change brought into focus an issue that had not been previously considered by the SRG. In the assessment model spawning biomass is calculated as the sum across ages of female numbers-at-age * maturity-at-age * fecundity-at-age * weight-at-age. In previous assessments (starting in 2011) the calculation assumed time-invariant fecundity-at-age (based on the average vector of weights-at-age, averaged across all years). The SRG requested that the JTC explore an alternative model that had time-varying fecundity-at-age calculated using annual estimates of mean weights-at-age. The alternative model, which produced very different estimates of stock status, was included as an appendix in the final version of the stock assessment document. For

the base-case model (based on using time-averaged weights-at-age) the probability that 2018 spawning biomass is below the B40 reference point was estimated as 7%. The alternative model estimated the same probability as 48%. Despite considerable discussion amongst the SRG and with the JTC, the SRG was unable to resolve which model is more plausible. The review concluded at about 5 pm on 1st March.

SRG Report Preparation:

The SRG report summarizing the review meeting was prepared jointly by the members of the SRG, with John Homes, the Canadian co-chair, taking the lead on assembling the draft report and circulating it to the rest of the SRG. The report was finalized by email correspondence following the SRG meeting and was sent to the JMC on March 3rd.

Dr. Sampson fully agrees with the findings and conclusions as stated in the Joint U.S.-Canada Scientific Review Group Report, which can be obtained on-line from the following web-site, http://www.westcoast.fisheries.noaa.gov/fisheries/management/whiting/pacific_whiting_treaty.html.

Amendment 12: A Novel Approach to Habitat Identification Using Detections of Acoustically Tagged Marine Species

Funded: $139,173

OSU RESEARCH STAFF: John Barth, Professor, College of Earth, Ocean, & Atmospheric Sciences
NOAA TECHNICAL LEAD: Mary Moser, NWFSC

Project Background: Identifying essential fish habitats in nearshore marine environments is time-consuming and expensive. However, the documentation of species-habitat associations is needed for effective site selection and evaluation of marine reserves, ocean energy projects, dredge disposal sites, closed fishing areas, etc. For species listed under the ESA, conservation of critical habitats requires detailed information on both temporal and spatial patterns of habitat use and, ideally, the relative importance of migration corridors, aggregation and foraging areas, or spawning grounds. Understanding where, when, and why these animals occupy specific habitats (e.g., depth, distance from shore, bottom type, temperature, DO, current, associations with geographic features, etc.) is necessary to improve the effectiveness of marine spatial planning. A novel approach for pairing marine habitat associations with aquatic organisms (e.g., shark and sturgeon) was recently introduced by Oliver et al. (2013) and Haulsee et al. (2015). These studies used autonomous underwater vehicles (AUVs) equipped with a VEMCO acoustic receiver to detect fishes carrying coded acoustic transmitters. Their trials were successful, and demonstrated the efficacy of obtaining fine-scale habitat associations of marine organisms over large areas. For example, an AUV carrying a VEMCO receiver detected 97% of acoustic

transmissions when within 250 m of test tags, while simultaneously recording depth profiles of temperature, salinity, dissolved oxygen, turbidity, current, and chlorophyll (Haulsee et al. 2015). Underwater gliders have been used successfully off the Oregon coast to study coastal ocean dynamics (Adams et al. 2013; Mazzini et al. 2014). They can be flown from the sea surface to within a few meters of the bottom in water depths as shallow as 20 m. The maximum operational depth of the gliders is 200 m and their ground speed is about 15-20 km/day.

Progress Report: Dr. Barth and his research staff have successfully integrated and tested a custom-engineered underwater glider science bay with VEMCO acoustic receivers and a Conductivity-Temperature-Depth (CTD) sensor into one of our OSU 200-m underwater gliders. In March 2018, we conducted a field test of the system off Newport, Oregon, and successfully detected acoustic tags up to distance of about 700 m between the glider and the acoustic tag. In May 2018, in close coordination with our NOAA partners, we conducted a 2-week test of the underwater glider flying it from Newport, Oregon, south past a fixed array of acoustic moorings off Winchester Bay, Oregon, with eventual recovery off Coos Bay, Oregon. The glider detected acoustic tags along its path, including fish tags that were detected by the fixed mooring array when the glider was flying close to the fixed array. This demonstrates that the glider-based hydrophone can effectively detect acoustic tags. We are presently analyzing the acoustic tag detections by both the glider and the fixed array, and placing them in the environmental context (temperature, dissolved oxygen) as measured by the glider. We plan a second field experiment from late August through September 2018, this time flying the glider from Astoria, Oregon, south to the fixed array off Winchester Bay.

Amendment 21: Gulf Watch Alaska: Science Coordination for Long-Term Monitoring of Marine Conditions and Affected Resources

Funded: $143,631

OSU RESEARCH STAFF: Michael Banks, CIMRS Director; Robert Suryan, Associate Professor Oregon State University
NOAA TECHNICAL LEAD: Mandy Lindeberg, AFSC

Project Background: The Exxon Valdez Oil Spill (EVOS) Trustee Council (EVOSTC) initiated funding for the Gulf Watch Alaska (GWA) long-term monitoring program in 2012. The program is a consortium of 15 projects ranging in focus from ocean physics to top predators. Collectively, the 24 scientists involved in GWA represent unsurpassed expertise and knowledge of the Gulf of Alaska (GOA) ecosystem and spill-affected region. Integrating numerous multi-disciplinary long-term monitoring and research projects under the GWA program has proven highly successful during the first 5 years, and the program has been funded for a second five-year period starting in March 2017. As GWA embarks on the second 5 years of monitoring and research, the administrative structure is being revised to include a Science Coordinator who will

oversee integration and synthesis across all GWA programs and outreach to potential collaborators outside of GWA.

Progress Report: Dr. Robert Suryan led Oregon State University's participation in science coordination for Gulf Watch Alaska (GWA). Dr. Suryan worked in collaboration with members of the GWA project management team (PMT) to complete all deliverables during the March 2017- February 2018 project period. The seven project deliverables are listed below with details of how each deliverable was met.

1. **Coordinate with PIs to improve integration of multi-disciplinary monitoring activities within geographic regions (PWS, outer Kenai Peninsula coast, lower Cook Inlet) and of monitoring within single disciplines between different regions.**

R. Suryan and the PMT held four quarterly Principal Investigator (PI) meetings; two meetings by phone and two in person. One in person meeting included the annual 3-day PI meeting in Cordova, Alaska (November 15-17, 2017) and a second at the Alaska Marine Science Symposium in Anchorage, Alaska (January 23, 2018). Two of the three days during the annual PI meeting were focused on science synthesis, where R. Suryan and the PMT proposed a framework for science synthesis during the current 5-year funding period (FY2017-2021). The meeting included hosting invited speakers to discuss long-term ecosystem research and monitoring programs and how to develop ecosystem indicators to inform stakeholders. Proposed science synthesis efforts included integration across all GWA regions (Katmai Peninsula to Prince William Sound) and all three science components (Environmental Drivers, Pelagic Ecosystems, Nearshore Ecosystems). R. Suryan also held an additional half-day workshop on integrating water bird survey data across GWA projects. Science synthesis data analysis and projects are outlined below.

2. **Author and lead production of program synthesis products and promote integration of GWA projects.**

R. Suryan and the PMT proposed two possible cross-component synthetic publications to pursue for the science synthesis workshop in 2020. The first received unanimous support from GWA PIs and the GWA Science Review Panel and has a green light for moving forward. The second received mixed reviews and is currently on hold, while three other contributing manuscripts are being developed (see below).

1) *Biological Responses to the Marine Heatwave in the Gulf of Alaska (Suryan - lead author)*

All attendees agreed that GWA and the Herring Research and Monitoring Program can provide unique perspectives and analyses of physical conditions and biological responses to the recent marine heat wave in the Gulf of Alaska, 2014-2016, from the nearshore intertidal to offshore

oceanic domains. Both programs will have collected data before, during, and "after" (depending on when "after" occurs) this large scale ecosystem perturbation. We anticipate including data through 2018. If we do not observe a clear post event ("after") indicator for some metrics by 2018, we will propose testable hypotheses for how the system will respond. This is intended to be a Gulf of Alaska-wide effort and the lead author is reaching out to all groups to collaborate, including non-*Exxon Valdez* Oil Spill Trustee Council (EVOSTC**)** programs such as the Gulf of Alaska Integrated Ecosystem Research Program, National Oceanic and Atmospheric Administration's Alaska Fisheries Science Center, and the Alaska Department of Fish and Game, among others.

There will be at least three GWA cross-component publications, one each lead by one of the three components, that contribute to this overarching synthetic manuscript. Draft proposals for these supporting manuscripts include:

i) Environmental drivers and declines in prey abundance and condition leading up to the 2015-16 common murre die-off in the Gulf of Alaska (Y. Arimitsu – lead author)
ii) Coherence in sea surface temperatures from the intertidal to oceanic domains in the northern Gulf of Alaska (D. Monson/S. Danielson/R. Suryan – lead authors).
iii) Synchronous region-wide responses in intertidal community structure to a marine heat wave in the Gulf of Alaska (T. Dean – lead author).

R. Suryan has begun contributing to data integration and analyses for all three of these supporting manuscripts.

2) Identifying Natural vs. Anthropogenic Impacts in the Gulf of Alaska: Lessons learned 30 years after the Exxon Valdez Oil Spill (Suryan – lead author if continued)

This proposed manuscript received mixed support and has not moved forward since the PI meeting in November 2017. While some felt that there was still much to be published on this important topic, others felt that publications by the NCEAS working group and the recent GWA Deep-Sea Research special issue effectively covered this topic. R. Suryan is working with PIs to determine if a need still exists for such a synthesis.

Science synthesis efforts also included planning to future proposal and funding cycles of GWA (FY2017-2032), including legacy projects, ecosystem indicators and ecosystem modeling.

Time Series Indicators for the Gulf of Alaska Ecosystem and Stakeholder Interests

Our goal is for each GWA project to have at least one signature time series that best indicates the state of their part of the Gulf of Alaska ecosystem. Collectively, these would provide GWA's best assessment of the state of the Gulf of Alaska each year. This follows similar efforts for large marine ecosystems throughout Alaska and elsewhere. Several GWA time series already contribute to these efforts, but we would like to increase our participation. Moreover, unlike GWA which samples annually, several other major programs in the Gulf of Alaska are no longer

sampling (NPRB's Gulf of Alaska Integrated Ecosystem Research Program) or sample every other year (some NOAA surveys). Therefore, GWA is uniquely positioned to contribute to an annual ecosystem status assessment.

Time series indicators can also be used to inform Trustee and non-Trustee entities by providing timely assessments of stakeholder-specific metrics. For example, GWA could generate an annual spatially explicit marbled murrelet abundance and trend index that would likely be of interest to the U.S. Forest Service.

Ecosystem Modeling:

Discussion between PMT and GWA Science Review Panel identified the importance of including a modeling component within GWA. Two perspectives emerged, one suggesting a modeler was needed immediately, the other that the current 5-year focus should be on identifying key processes and time series development to better inform a modeling effort that would occur during the second 10-years of GWA. We are currently considering a hybrid approach, where during the current 5-year period we design the content and integration of a GWA modeling component and, if funding is available, begin customizing existing physical models for GWA from which other modeling efforts will build upon in years 10-20. The PMT needs to continue discussions with review panels, collaborators, and funders.

3. Integrate GWA data and platforms with external programs

R. Suryan served on several committees and attended workshops to expand the collaboration and integration of GWA with other research and management programs, including:

I. Serving on the review committee for selecting two postdoctoral scholars to work with the Herring Research and Monitoring Program and enhance collaboration with GWA.
II. Attending two workshops for ecosystem based fisheries management within the NOAA Alaska Fisheries Science Center; 1) Integrated Ecosystem Assessments, 2) Recruitment Processes Alliance
III. Co-convening a workshop and co-authoring a report on current and future research in the Gulf of Alaska. The workshop was held in conjunction with the Ocean Sciences Meeting, Portland, Oregon.
IV. GWA PIs contributed four time series reports to NOAA's Ecosystems Considerations Report to the North Pacific Fisheries Management Council and also a second, broader effort covering a longer timeframe and larger geographic area for the North Pacific Marine Sciences Organization's (PICES) North Pacific Ecosystem Status Report, 2009-2016.

4. Provide editorial review, website development/ updates, and assistance with coordination of outreach events for each project.

R. Suryan worked with the GWA management team, including the outreach lead and staff to update the GWA website (www.gulfwatchalaska.org). We also began using and Twitter hashtag #GulfWatchAK to expand GWA outreach to various audiences.

5. Attend and present of program information at scientific and Gulf of Alaska ecosystem research and monitoring meetings.

Suryan, R., M. Lindeberg, D. Aderhold, K. Hoffman, M. Arimitsu, H. Colletti, R. Hopcroft. 2018. Gulf Watch Alaska: Taking the pulse of the northern Gulf of Alaska. Kachemak Bay Science Conference, Homer, Alaska. (presented by coauthors)

Suryan, R., M. Lindeberg, D. Aderhold, K. Hoffman, M. Arimitsu, H. Colletti, R. Hopcroft. 2018. Gulf Watch Alaska: Taking the pulse of the northern Gulf of Alaska. Ocean Sciences Meeting, Portland, Oregon.

Suryan, R., M. Lindeberg, D. Aderhold, K. Hoffman, M. Arimitsu, H. Colletti, R. Hopcroft. 2018. Gulf Watch Alaska: Taking the pulse of the northern Gulf of Alaska. Alaska Marine Science Symposium, Anchorage, Alaska.

Monson, D., K. Holderied, R. Campbell, S. Danielson, R. Hopcroft, B. Ballachey, J. Bodkin, H. Coletti, T. Dean, K. Iken, K. Kloecker, B. Konar, M. Lindeberg, B. Robinson, **R. Suryan**. 2018. Congruence of intertidal and pelagic water and air temperatures during an anomalously warm period in the northern Gulf of Alaska; the "Blob" washes ashore. Alaska Marine Science Symposium, Anchorage, Alaska.

6. Compile annual reports on overall science monitoring effort.

R. Suryan and the PMT wrote the FY2012-2016 program management final reports and compiled and reviewed the remaining eleven final reports from individual projects. We also wrote the FY2018 program management annual reports and reviewed and standardized eleven individual project reports to improve efficiencies in future reporting.

7. Prepare and compile the Annual Work Plans with PIs and respond to EVOSTC review.

R. Suryan and the PMT wrote three work plans and reviewed and standardized format and content of the remaining eleven FY2018 work plans to help improve efficiencies in GWA PI reporting efforts and EVOSTC review. We also compiled and edited replies to EVOSTC and science panel review comments on the FY2018 work plan.

Amendment 23: Educational Exhibit of Endangered and Threatened Species of the Northwest Pacific Coast

Funded: $9,407

OSU RESEARCH STAFF: Michael Banks, Director CIMRS; Jenifer Fisher, Faculty Research Assistant
NOAA TECHNICAL LEAD: Mary Arkoosh, NWFSC; Rick Brown, NWFSC

Project Background: An educational exhibit will be created for OSU's Visitor Center to depict the Endangered and Threatened (E/T) species of the Northwest Pacific Coast and the 'tools' developed and used to protect and preserve these species. Oregon State University's Hatfield Marine Science (HMSC) Visitor Center creates a unique, dynamic environment for lifelong exploration and discovery. The Visitor Center encourages adults and children to enjoy marine science as they learn more about the natural world. The exhibits, programs, and classes demonstrate how scientific research enhances our ability to interpret the natural patterns and forces that shape our world, and equips us to better appreciate, manage and sustain coastal and marine resources.

Progress Report: An educational exhibit depicting Endangered and Threatened (E/T) species of the Northwest Pacific Coast was created and installed at Oregon State University's Hatfield Marine Science Center (HMSC) Visitor Center. The HMSC Visitor Center creates a unique, dynamic environment for education and discovery. It is open to the public and more than 150,000 people visit annually. The E/T exhibit was installed in the entryway of the Visitors Center and it is a wonderfully visually appealing exhibit that immediately draws your eye. It is comprised of hand crafted ceramic blows, platters, and vases that have E/T species etched into each ceramic piece with their name on each piece. Nautical charts surround the display cases to commemorate the NOAA ships that are integral to studying these E/T species. Exhibit photos on following page.

The exhibit consists of two display cases with ceramic platters, blow, and vases with etched images of endangered and threatened species. The display cases are surrounded by NOAA nautical charts.

Examples of platters with endangered and threatened species illustrations.

Theme: Seafloor Processes

Amendment 7, 10, 13, 28, 31: Impacts of Submarine Volcanism and Hydrothermal Venting on the Global Ocean and Deep-Sea Ecosystems

Funded: $2,619,224

OSU RESEARCH STAFF:	*Tamara Baumberger, Assistant Professor, Senior Research, CIMRS; Haru Matsumoto, Assistant Professor, Senior Research, CIMRS; Andy Lau, Professional Faculty, Applied Mathematician, CIMRS; Joe Haxel, Assistant Professor, Senior Research; David Mellinger, Professor, Senior Research; Andra Bobbitt, Susan Merle, Senior Faculty Research Assistants, CIMRS; Robert Embley, Professor, Sr. Research, CIMRS, ; Leigh Evans, Lauren Roche, Faculty Research Assistants, CIMRS; Samara Haver, Graduate Student*
NOAA TECHNICAL LEAD:	*John Lupton, Bob Dziak, William Chadwick, Carol Stepien, Chidong Zhang, PMEL*

Earth-Ocean Interactions (EOI) – Geologic mapping of seafloor environments and near- and far-field chemical impacts on marine ecosystems

Project Background: CIMRS research involving Earth-Ocean Interactions provides expertise to NOAA for discovering, characterizing, and studying the processes of chemical and physical interactions between the solid Earth and the overlying global ocean. For example, the unique ecosystems that exist at hydrothermal vents are fundamentally different from other life on Earth, because they are based on chemical energy in the hot vent fluids (chemosynthesis) rather than energy from the Sun (photosynthesis). Any holistic understanding of the oceans, and indeed life on Earth, would be incomplete if it excluded these unusual ecosystems. CIMRS researchers discovering new hydrothermal ecosystems in unexplored parts of the oceans characterize the geology, chemistry, and biology of new sites, and track changes in selected systems over time to understand their underlying interrelationships, functions, and resources. Time-series observations show how these ecosystems are perturbed by episodic events and the range of chemical environments shows how they influence the diversity and biogeography of marine life. Potential resources at hydrothermal vents include ore deposits formed by hydrothermal circulation, and novel bio-active compounds that have potential pharmaceutical applications for developing new drugs from the sea. In addition, the emission of CO_2 at submarine volcanoes creates valuable natural laboratories for the study of ocean acidification and its impacts on marine ecosystems.

Progress Report: Work under these projects continued in CIMRS FY18 with a focus on Axial Seamount in the NE Pacific, the NE Lau Basin in the Western Pacific and the U.S. Cascadia

continental margin. Professor Robert Embley joined CIMRS in October 2017, Assistant Professor Tamara Baumberger joined CIMRS in January 2018 and Professor William Chadwick left CIMRS in October 2017 and is now employed by NOAA.

Professor Embley published an article in the Bulletin of Volcanology (Embley et al., 2018) showing that very large siliceous lava flows can erupt on the modern seafloor under the right conditions. New field observations revealed that extensive aphyric, glassy dacite lavas were erupted at multiple sites in the recent past in the NE Lau basin, located about 200 km southwest of Samoa. This discovery of volumetrically significant and widespread submarine dacite lava flows extended the domain for siliceous effusive volcanism into the deep seafloor. Although several lava flow fields were discovered on the flank of a large silicic seamount, Niuatahi, two of the largest lava fields and several smaller ones (the "northern lava flow fields") were found well north of the seamount. The northernmost of these fields is 60 km north of the center of Niuatahi caldera. The large areal extent and relatively small range of compositional variation within the northern lava flow fields imply the existence of large, eruptible batches of differentiated melt in the upper mantle or lower crust of the NE Lau basin. At this site, the volcanism could be controlled by deep crustal fractures caused by the long-term extension in this rear-arc region. Submarine dacite flows exhibiting similar morphology have been described in ancient sequences from the Archaean through the Miocene and in small batches on present-day seafloor spreading centers.

Assistant Professor Baumberger was co-author of three published papers. Two were based on the 2016 Cascadia Margin cruise and published in the journal Deep Sea Research II: Topical Studies in Oceanography. The first paper (Seabrook et al., 2018) focused on the heterogeneity of methane seep biomes in the Northeast Pacific and the second paper (Dziak et al., 2018, including Senior Faculty Assistant Merle) on the use of passive acoustic records of seafloor methane bubble streams on the Cascadia Margin to quantify methane flow rates from the seafloor to the ocean. The third paper was published in Frontiers in Microbiology (Dahle et al., 2018) and discussed energy landscapes in hydrothermal chimneys and how they shape the distribution of primary producers at the Jan Mayen vent fields of the Arctic mid-ocean ridge at 71° N.

Senior Faculty Research Assistant Susan Merle was co-author on a paper on the effect of arc proximity on hydrothermal activity along back-arc spreading centers with a focus on the Mariana region, published in G-cubed (Baker et al., 2017). The study found that increased spreading rates in some arc-proximal segments may generate increased decompressional melting. Thus, the enhanced magma budget affects hydrothermal, as well as previously recognized morphological, characteristics of these ridge sections.

Professor William Chadwick was co-author on five papers. The first paper (Schnur et al., 2017) presented the results of repeated high-resolution bathymetric surveys and ROV dive visual observations to make geologic maps of the summit of NW Rota submarine volcano in the

Mariana arc before and after a major landslide. These time-series observations illuminate the processes of construction and destruction at submarine arc volcanoes. This paper was part of the PhD work of OSU graduate student Susan Schnur, and Professor Chadwick was on her graduate committee. The second paper (Anderson et al. 2017) interpreted the geology of volcanism and segmentation of the Mariana back-arc spreading center between 12.7°N and 18.3°N, based on newly collected multibeam sonar bathymetry. The paper presented geologic maps of each spreading center and interpreted them in terms of the relative importance of recent volcanic and tectonic processes. The third paper (Clague et al., 2017) highlights the results of high-resolution mapping by autonomous underwater vehicles (AUVs) at Axial Seamount. The fourth paper (Spietz et al., 2018) describes the microbes found in hydrothermal plumes found over the lava flows erupted in 2015 at Axial Seamount. The fifth paper (Wilcock et al., 2018) compares the geophysical monitoring data collected at Axial Seamount during the 1998, 2011, and 2015 eruptions.

Professor Chadwick, Assistant Professor Baumberger, Senior Faculty Research Assistants Susan Merle and Andra Bobbitt, and Faculty Research Assistant Camilla Wilkinson participated in a research cruise to Axial Seamount on the *R/V Revelle* from July 13-23, 2017. Chadwick was Chief Scientist on the cruise. ROV dives were devoted to making pressure measurements for the monitoring of volcanic inflation and to collecting vent fluids and sulfide chimneys at hydrothermal vent fields. The pressure measurements revealed that Axial Seamount had re-inflated ~1.25 m since the last eruption in April 2015. That is half of the 2.5 m of deflation that occurred during that eruption. The “mini-smoker” vent field, discovered by MBARI in 2016 on Axial’s north rift, was found to have a very different chemistry than the other Axial hydrothermal vents. AUV dives were performed to collect repeat high-resolution bathymetry to document volcanic ground deformation both inside and outside the caldera. The cruise was featured on this web site: axial2017.blogspot.com

Another major research expedition took place from November 10 to December 18, 2017 in the NE Lau Basin on *R/V Falkor* (operated by the Schmidt Ocean Institute). The cruise was split up in two legs. Senior Faculty Research Assistant Merle and Assistant Professor Baumberger participated in both cruise legs, whereas Faculty Research Assistant Camilla Wilkinson participated only on Leg 1. The cruise staged out of Apia, Samoa, and focused on the submarine Mata volcano group in the Pacific in waters of Tonga. It built on results from expeditions conducted in 2008, 2009, 2010, and 2012 as well as on repeated bathymetric mapping between 1996 and 2016. ROV dives were used to characterize the geology, chemistry, biology, and microbiology of these submarine volcanoes to reveal the interplay between volcanic and hydrothermal activity and the evolving ecosystem. The cruise was highlighted on this web site: https://schmidtocean.org/cruise/underwater-fire-studying-submarine-volcanoes-tonga/

In June 2018, Assistant Professor Tamara Baumberger, Senior Faculty Research Assistant Susan Merle, and Faculty Research Assistant Camilla Wilkinson participated in a research cruise along

the Cascadia continental margin, offshore Oregon and northern California, conducted on the Ocean Exploration Trust ship *E/V Nautilus* (NA095). Baumberger was lead scientist. The cruise started in San Francisco, CA on June 12 and ended in Astoria, OR on June 29. The cruise continued the successful exploration and research of methane seeps on the U.S. Cascadia Margin that started in 2016. Despite losing 4 days at the beginning due to ship-power problems, the cruise was very successful, completing 13 dives with *ROV Hercules* at sites from northern California to northern Oregon, including Eel River, Or-Cal, Coquille (4), mud volcano, Heceta (4) and Astoria/Nehalem (2). During these dives 170 samples were collected, including methane gas and hydrates, seep fluids, seawater, sediments, fauna, and rocks. The dives included the first successful use of a new hydrate sampler, which takes a small core of hydrate and keeps the sample sealed under pressure even during ascent so no gases escape before they are extracted and analyzed. The goal is to see if "noble gas fingerprinting" can distinguish methane coming from the dissociation of hydrate versus from free gas. This is important because the rate of hydrate dissociation may be changing in a warming ocean, and if the released methane reaches the atmosphere it could have consequences for climate. Professor Robert Embley supported the expedition in the role of the lead scientist on-shore.

Professor Robert Embley and Senior Faculty Research Assistant Susan Merle also planned three mapping expeditions at the Cascadia Margin for the *E/V Nautilus* expedition season in 2017 (NA080, NA082, and NA088) and supported the ship-based mapping team from shore. Mapping in 2017 added over 300 methane seep locations to the existing database. The new data enhanced the baseline information on the abundance and distribution of methane bubble streams on the US continental margin.

CIMRS research results were published as papers in scientific journals listed below and were presented at the following scientific meetings: 2017 Fall Meeting of the American Geophysical Union (AGU) in New Orleans, LA, the IAVCEI 2017 General Assembly in Portland, OR, the 2018 Ocean Sciences Meeting in Portland, OR, and the Gordon Research Conference in Galveston, TX.

Presentations at National and International Meetings:

Baker, E. T., S. L. Walker, J. A. Resing, **W. W. Chadwick**, **S. G. Merle**, M. O. Anderson, and D. A. Butterfield (2018) Hydrothermal activity along back-arc spreading centers: The importance of arc proximity. Abstract presented at 2018 Ocean Science Meeting, Portland, OR, USA, 11-16 February.

Baumberger, T., **S. G. Merle**, **R. W. Embley**, N. Raineault, M. D. Lilley, B. J. Phrampus, A. M. Trehu, and J. E. Lupton (2018), Chemical composition of methane seep bubbles distributed along the Cascadia Margin. Abstract presented at 2018 Ocean Science Meeting, Portland, OR, USA, 11-16 February.

Baumberger, T., **R. W. Embley**, **S. G. Merle**, and J. E. Lupton (2018) Mantle derived helium and multiple methane sources in gas bubbles seeping from the Cascadia continental margin. Abstract presented at 2018 Gordon Research Seminar, Galveston,TX, USA, 24-25 February.

Baumberger, T., **R. W. Embley**, **S. G. Merle**, and J. E. Lupton (2018) Mantle derived helium and multiple methane sources in gas bubbles seeping from the Cascadia continental margin. Abstract presented at 2018 Gordon Research Conference, Galveston,TX, USA, 25 February - 2 March.

Butterfield, D. A., **W. Chadwick**, B. I. Larson, V. Tunnicliffe, A. E. Bates, K. K. Roe, **T. Baumberger**, J. E. Lupton, and M. D. Lilley (2018), Exploration shows contrasting fluid chemistry and hydrothermal vent communities between the Mariana Arc and Back-Arc. Abstract presented at 2018 Ocean Science Meeting, Portland, OR, USA, 11-16 February.

Chadwick, W. W., Jr. (2017), Axial Seamount: Recent results from the most active volcano in the US Pacific Northwest. Invited plenary talk presented at IAVCEI 2017 General Assembly, 14-18 August, Portland, Oregon, USA

Chadwick, W. W., Jr., S. G. Merle, C. L. Kaiser, E. T. Baker, S. L. Walker, J. A. Resing, D. A. Butterfield, **T. Baumberger**, M. O. Anderson, P. Shore, D. A. Wiens, and K. H. Rubin (2017), A recent volcanic eruption discovered on the central Mariana back-arc spreading center. Abstract presented at IAVCEI 2017 General Assembly, 14-18 August, Portland, Oregon, USA

Embley, R. **W**., **S. G. Merle**, N. Raineault, and L. Gee (2018) Geologic setting of numerous newly discovered methane bubble stream sites along the Cascadia margin. Abstract presented at 2018 Ocean Science Meeting, Portland, OR, USA, 11-16 February.

Gee, L. J., N. Raineault, R. Kane, M. Saunders, E. Heffron, **R. W. Embley**, and **S. G. Merle** (2017) Seep detection using E/V Nautilus integrated seafloor mapping and remotely operated vehicles on the United States West Coast. Abstract presented at 2017 AGU Fall Meeting, New Orleans, LA, USA, 11-15 December.

Lupton, J. E., R. J. Arculus, M. Coffin, A. Bradney, **T. Baumberger**, **C. Wilkinson** (2017) Hydrothermal venting on the flanks of Heard and McDonald islands, southern Indian Ocean. Abstract presented at 2017 AGU Fall Meeting, New Orleans, LA, USA, 11-15 December.

Lupton, J. E., **T. Baumberger**, **R. W. Embley**, **S. G. Merle**, and C. Young (2018) A rationale for in-situ sampling of methane hydrates on the seafloor. Abstract presented at 2018 Ocean Science Meeting, Portland, OR, USA, 11-16 February.

Merle, S. G., **R. W. Embley**, H. P. Johnson, **T. K. Lau**, E. Sampaga, N. Raineault, and L. Gee (2018) Compilation of water column methane emission sites on the U. S. Cascadia Margin from five recent expeditions and a historical database. Abstract presented at 2018 Ocean Science Meeting, Portland, OR, USA, 11-16 February.

Nooner, S. L., **W. W. Chadwick, Jr**., D. W. Caress, J. B. Paduan, and D. A. Clague (2017), Using high-resolution repeat AUV bathymetry to constrain magma dynamics at Axial Seamount. Abstract presented at IAVCEI 2017 General Assembly, 14-18 August, Portland, Oregon, USA

Phrampus, B., R. N. Harris, A. M. Trehu, **R. W. Embley**, and **S. G. Merle** (2017) Along-strike analysis of contemporary ocean temperature change on the Cascadia margin and implications to upper slope hydrate instability. Abstract presented at 2017 AGU Fall Meeting, New Orleans, LA, USA, 11-15 December.

Phrampus, B., R. N. Harris, A. M. Trehu, **R. W. Embley**, and **S. G. Merle** (2018) Variations in Ocean Temperatures on the Cascadia margin: Implications for Hydrate Instability. Abstract presented at 2018 Ocean Science Meeting, Portland, OR, USA, 11-16 February.

Rubin, K. H., **R. W. Embley**, D. A. Clague, and **W. W. Chadwick, Jr**. (2017), Eruption styles at 1.2 km deep West Mata Submarine Volcano summit revealed by video observations and deposit mapping. Abstract presented at IAVCEI 2017 General Assembly, 14-18 August, Portland, Oregon, USA

Rubin, K. H., **R. W. Embley**, W. W. Chadwick, J. A. Resing, D. A. Butterfield, T. M. Shank, J. A. Huber, **T. Baumberger**, C.E.J. de Ronde, S. G. Merle, J. E. Lupton, and S. L. Walker (2018) Submarine volcanoes, ecosystems and landscape evolution in the NE Lau Basin. Abstract presented at 2018 Ocean Science Meeting, Portland, OR, USA, 11-16 February.

Tepp, G., M. Haney, J. Lyons, **W. W. Chadwick, Jr**., **S. G. Merle**, R. P. Dziak, and D. Bohnenstiehl (2017), Hydroacoustic and Seismic Observations of the 2014 Submarine Eruption at Ahyi Seamount, Mariana Arc. Abstract presented at IAVCEI 2017 General Assembly, 14-18 August, Portland, Oregon, USA

Trembath-Reichert, E., D. A. Butterfield, B. Larson, W. W. Chadwick Jr., and J. Huber (2018), Application of stable isotope probing coupled with -omics to examine thermophilic autotrophy in newly discovered hydrothermal vents along the Mariana back-arc spreading center. Abstract presented at 2018 Ocean Sciences Meeting, Portland, OR, 11-16 Feb.

Walker, S. L., **T. Baumberger**, **S. G. Merle**, and **R. W. Embley** (2018) The near-bottom distribution of ORP anomalies at methane seeps along the U. S. Cascadia continental margin. Abstract presented at 2018 Ocean Science Meeting, Portland, OR, USA, 11-16 February.

Publications in Scientific Journals:

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Marine Acoustics: Evaluating the impacts of sound generated from human activities and natural processes on marine ecosystems

Project Background: CIMRS researchers develop acoustic tools, technologies and services that can be used to address a wide variety of NOAA missions and research priorities. Using autonomous moored hydrophones, mobile platforms such as ocean gliders and floats equipped with acoustic sensors, as well as cabled observatories, the Acoustics Program studies environmentally, anthropogenically and biologically generated sounds in the marine environment. CIMRS researchers in the acoustics field have made recordings in every major ocean basin on Earth and are currently developing novel systems to efficiently study large ocean areas and their living marine resources over extended time periods.

Using underwater acoustics the scientific objectives of the program seek to [a] quantify ambient sound levels from man-made sources, such as commerce and energy production and development, as well as naturally generated sounds from wind, waves, and polar ice break-up [b] monitor processes and potential hazards related to marine volcano-seismic activity, and [c] assess potential changes in the abundance and distribution of endangered marine mammal populations due to anthropogenic noise and climate-related changes in the marine environment.

CIMRS research on marine mammal acoustics and assessment of man-made ambient sound levels has led to ongoing collaborative projects with scientists at all of the nation's NMFS science centers as well as with PMEL's Eco-FOCI Program.

Progress Report: Associate Professor Haru Matsumoto continues technological development on a hydrophone winch system with in-water testing at a site 10 miles off the coast of Newport, OR . Additionally, H. Matsumoto continues development of a 24 bit data acquisition system with onboard processing controls and multi-channel capability for future integration with a real-time surface buoy system and coastal applications at the PacWave marine renewable testing center scheduled to come online in 2021. The new system will be adapted for higher data transmission rates using the cellular network and an inductive modem system from the surface buoy to the seafloor sensor package.

Assistant Professor J. Haxel participates in monthly Ocean Noise Reference Station project organizational meetings and logistical operations. He also led processing and analysis for a study on the acoustic characterization of the Terra Nova Bay coastal polynya in the Ross Sea, Antarctica. J. Haxel also led a study on the acoustic reverberation characteristics a seismic airgun array off the Washington coast using an acoustic glider.

Professor David Mellinger led efforts to further software development of marine mammal acoustic detection and density estimation algorithms with intent toward making them freely available to users through a variety of existing software platforms. He led a workshop in Rhode Island in June 2018 aimed at Ishmael software use and applications for marine mammal studies. D. Mellinger also led a project to record marine mammal vocalizations in the Gulf of Mexico from an acoustic glider.

Applied Mathematician T-K Lau developed software for first order data processing and analysis of acoustic recordings of the Ocean Noise Reference Station (NRS) network, signal processing in coordination with J. Haxel's seismic reverberation study off the Washington coast, and H. Matsumoto's iceberg disintegration study.

Graduate Research Assistant, Samara Haver, collaborated with the Ocean Noise Reference Station (ONRS) steering group to organize and submit first order analysis plots, acoustic data and meta data for archival at NOAA's National Centers for Environmental Information (NCEI). She also authored a paper introducing the ONRS project as a key piece of NOAA's Ocean Noise Strategy for submittal to the journal of Marine Policy.

Faculty Research Assistant, Lauren Roche, assisted in the organization and logistical operations of the NRS hydrophone network, Ross Sea hydrophone arrays, and Marianas hydrophone array projects.

Cruises:

L. Roche**,** February 2018 – April 2018, *R/V* Araon, expedition to the Ross Sea, Antarctica supporting the recovery/ re-deployment Acoustics Program hydrophone mooring arrays for research of ice dynamic processes.

L. Roche, June 2018, USCG Sequoia, expedition to the Marianas basin to recover 4 element hydrophone array studying volcanic activity along the Mariana Arc.

Publications:

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Dziak, R., D. Bohnenstiehl, **A. Lau**, J. Conder, **H. Matsumoto, J. Haxel**, and **A. Semple** (2018): Lau Basin T-wave earthquake location catalog, 2009-2010 (investigators Dziak, Bohnenstiehl, Lau, Condor, Matsumoto, Haxel, Semple). Interdisciplinary Earth Data Alliance (IEDA), Marine Geoscience Data System (MGDS), doi: 10.1594/IEDA/324411

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Amendment 11: Curation of ROV-collected Rock Samples in the OSU Marine Geology Repository for the 2016 and 2017 CAPSTONE Expeditions using R/V Okeanos Explorer

Funded: $210,784

OSU RESEARCH STAFF: *Anthony Koppers, Professor, College of Earth, Ocean, & Atmospheric Sciences*
NOAA TECHNICAL LEAD: *Alan Leondardi, OAR*

Project Background: The NOAA office of Ocean Exploration and Research (OER) started to carry out a systematic exploration Campaign to Address Pacific monument Science, Technology, and Ocean NEeds (CAPSTONE) with NOAA's Ship the R/V Okeanos Explorer during the 2015-2017 field seasons. CAPSTONE included a major effort focused on addressing priority NOAA science and management needs in and along the Hawaiian Archipelago and Johnston Atoll from July to September 2015. In total four legs were carried out, three of which included collection of biological and rock samples using NOAA's two-body 6000 m Remotely Operated Vehicle (ROV) from the ocean floor and seamounts in these regions.

While the biological samples are being curated by the Smithsonian in Washington DC, the ROV-collected rock samples will be curated in the OSU Marine Geology Repository (OSU-MGR; see

http://osu-mgr.org for more details). In total 107 rock samples were collected during the 2016 CAPSTONE legs and for the 2017 CAPSTONE legs another ~300 samples are planned to be collected, making a total of 407 samples for the 2016-2017 CAPSTONE years. These rock samples will be send to the OSU-MGR for curation, sample description and they will be made available for sampling to the wider national and international research community for carrying out further science projects. In general, the OSU-MGR adheres to NSF data and sample policies as developed by a consortium of NSF-sponsored repositories over multiple decades. However, in the case of the CAPSTONE ROV rock samples, which are typically small and of high scientific value, we will follow sample policies implemented by the International Ocean Discovery Program (IODP) that (1) ensures retaining of a small sample archive for each sample for longevity, (2) redistribution of samples based on a detailed sample request that highlights science objectives, proposed use of analytical techniques, a work plan, and funding availability, and (3) the expectation that the sample request results in a peer-reviewed publication. Sample requests will be reviewed by the OSU-MGR personnel and signed off by PI Koppers.

Project Progress: In 2015, we started the curation efforts in the OSU Marine and Geology Repository (OSU-MGR) for the ROV rocks collected with the R/V Okeanos Explorer. In 2015, we set up all protocols and started intake of the first samples. Since then we have been processing the incoming rocks from the 2016 and 2017 seasons in fast order as soon as the samples arrived in our facility. The long 2017 season with five ROV expeditions has kept us very busy into 2018.

On top of the standard rock, processing the OSU-MGR in 2017/2018 is moving its facility from our 45- year-old on-campus OSU location to a new facility in Corvallis, Oregon. This new facility will greatly expand our storage capacity (with >10x more storage) and it adds expanded analytical capabilities based on a $6.5M renovation. All NOAA ROV rocks have been prepped to be moved over into the new facility. This new facility will be handed over to the OSU-MGR by the end of August 2018 and the grand opening is expected in the first months of 2019. NOAA curation efforts will continue during this move.

Once the rocks arrive at the OSU-MGR, Dr. Anthony Koppers with assistance from his research assistant Dr. Kevin Konrad work to verify that all samples were received in accordance with the documentation and database. Samples are boxed, labeled with QR codes and IGSN numbers, photographed, and bagged. Samples are cut, putting 1/3 away as ARCHIVE and the rest as WORKING halves. Samples are stored in plastic boxes for long-term curation and archiving.

Thin section billets are cut from the working halves and send out for the making of double-polished thin sections. Upon their return, the thin sections are photographed in plain polarized light and cross polarized light, and then described for their petrology (e.g. mineral contents, alteration, volcanic features, vesicles). All samples then will be made available online.

Thus far, we have curated 280 samples for in total 12 expeditions or legs:

2016	EX1603	14	http://osu-mgr.org/noaa-ex1603/
2016	EX1605L1	27	http://osu-mgr.org/noaa-ex1605/
2016	EX1605L3	42	http://osu-mgr.org/noaa-ex1605/
2016	EX1606	20	http://osu-mgr.org/noaa-ex1606-2/
2017	EX1702	30	http://osu-mgr.org/noaa-ex1702/
2017	EX1703	5	http://osu-mgr.org/noaa-ex1703/
2017	EX1705	13	http://osu-mgr.org/noaa-ex1705/
2017	EX1706	25	http://osu-mgr.org/noaa-ex1706/
2017	EX1708	36	http://osu-mgr.org/noaa-ex1708/
TOTAL	12 Expeditions	280 Samples	

Data Sets:

http://osu-mgr.org/ - Home page for the OSU-MGR

http://osu-mgr.org/noaa-ex/ - Home page for all of the NOAA Okeanos Explorer ROV rock collection (map interface)

http://osu-mgr.org/noaa-ex1603/ - Expedition page for the collection of the EX1603 expedition to the Papahānaumokuākea Marine National Monument Hohonu Moana: Exploring the Deep Waters Off Hawai‘i (map interface)

http://osu-mgr.org/noaa-ex1605/ - Expedition page for the collection of the EX1605 expedition to the Commonwealth of the Northern Mariana Islands and the Marianas Trench Marine National Monument (map interface)

http://osu-mgr.org/noaa-ex1606/ - Expedition page for the collection of the EX1606 expedition to the Pacific Remote Islands Marine National Monument (map interface)

http://osu-mgr.org/noaa-ex1603-table/ - Expedition page for the collection of the EX1603 expedition to the Papahānaumokuākea Marine National Monument Hohonu Moana: Exploring the Deep Waters Off Hawai‘i (table interface)

http://osu-mgr.org/request-samples/ - Home page with instructions for making sample requests to the OSU-MGR

Sample request have been opened since May 2017 following a detailed protocol. We have received many emails from researchers that are now preparing sample requests; in total we processed three sample requests in 2017/18:

DATE	EXPEDITION	SUBSAMPLES	PI (AFFILIATION)
2017-12-20	EX1702	19	Matt Jackson (UCSB)
2018-01-09	EX1605L1 EX1605L3 EX1504L2 EX1504L3	36	Julia Ribeiro (China University of Geoscience)
2018-03-08	EX1606	11	Jasper Konter (UH)
TOTAL	6 Expeditions	66 Subsamples	

Amendment 16: Higher Resolution Deep Ocean Assessment and Reporting of Tsunamis

Funded: $39,640

OSU RESEARCH STAFF: Michael Banks, Director, CIMRS
NOAA TECHNICAL LEAD: Paul Kunicki; PMEL

Project Background: Recent advancements in sensors, software and power management hold promise that detection and measurement of near-field tsunamis with unprecedented resolution is

now possible. This improved nano-resolution pressure sensor and algorithm will allow the separation of the tsunami signal from the earthquake "noise." The NOAA DART (Deep Ocean Assessment and Reporting of Tsunamis) 4G design builds on the DART-ETD (Easy-to-Deploy), which consists of a surface buoy connected to a subsurface tsunameter via an acoustic link. Real-time communications latencies from seafloor-to-shore have been reduced, while high-resolution tsunami height measurements have been increased. Successful laboratory testing of the sensor and algorithm has progressed and ocean testing is in the planning stages to demonstrate and validate the DART Near Field design.

The enhancements include a new pressure sensor and software that run a detection and filter algorithm to transmit tsunami height data while the earthquake is rupturing. The new algorithms have been developed by studying near-field tsunami data and applying the most effective techniques. Advancements in power management allow for a system endurance of four years for the tsunameter and two years for the surface buoy. Shore-side software has also been upgraded to receive the higher-frequency observations during events.

Progress Report: On September 6th, 2018 a two day research cruise on the Oregon State University R/V Pacific Strom swapped out the DART 4G Buoy in its current location and deployed a subsurface Bottom Pressure Record (BPR) morning. The location of the deployment site is approximately 80 nautical miles West of Newport, Oregon.

Theme: Marine Bioacoustics

Amendment 15: Measuring physiological effects of changing noise levels on Pacific gray whales (Eschrichtius robustus)

Funded: $70,554

OSU RESEARCH STAFF:	*Joe Haxel, Assistant Professor, Senior Research, CIMRS; Lauren Roche, Faculty Research Assistants, CIMRS; Sharon Niuekirk, Sr. Faculty Research Assistant, CIMRS; Leigh Torres, Marine Mammal Institute, Oregon State University*
NOAA TECHNICAL LEAD:	*Bob Dziak; PMEL*

Project Background: The effects of long-term exposure to increasing ambient sound levels resulting from anthropogenic sources are not well known, and may not be easily recognized from short-term observation of behavioral changes. Rather, chronic stress effects may potentially manifest as a physiological response within animals (Wright et al. 2007, Rolland et al. 2012). For cetaceans that are acoustically active, dependent and sensitive to the surrounding soundscape, understanding the scales, intensities and types of impacts from ocean noise on their ecology and populations is a critical step toward improved management and protection (Weilgart

2007). This study aims to assess the variation in stress hormones (glucocorticoids) of gray whales in response to measured, changing ocean noise levels through the non-invasive collection and analysis of fecal samples.

Field data collection and hydrophone moorings will be used to assess the physiological effects of underwater noise exposure on eastern Pacific gray whales (Eschrichtius robustus) in the Pacific Coast Feeding Aggregation (PCFA) that are commonly found along the Oregon coast. Methods include ambient noise level measurements with hydrophones deployed from June-October 2017, fecal sample collection for hormone level and genetic analysis, body health condition through unmanned aerial system (UAS) photogrammetry, individual photo-identification, and video-based prey availability sampling.

Progress Report: Assistant Professor J. Haxel led hydrophone and acoustic data collection efforts including assembly, testing, deployment, and recovery operations. He also leads data processing and analysis for characterizing time and space dependent variability in ambient noise level measurements at the 4 hydrophone stations along the Oregon coast. J. Haxel presented results from 2016 acoustic data at the Ocean Sciences Meeting in Portland, Oregon in February 2018.

Sr. Faculty Research Assistant II, Sharon Niuekirk, analyzed UAS drone video imagery for a gray whale behavioral study and presented research at the Society for Marine Mammals biannual meeting in Nova Scotia in October 2017.

Presentations:

L. Lemos and **L. Torres** - Society for Marine Mammalogy Conference, Halifax, Canada, October 2017: Combining traditional and novel techniques to link body condition and hormone variability in gray whales

L. Torres, **S. Nieukirk**, L. Lemos - Society for Marine Mammalogy Conference, Halifax, Canada, October 2017: Drone up! Quantifying whale behavior and body condition from a new perspective

J. Haxel, **L. Torres**, **S. Nieukirk**, L. Lemos, A. Lau – Ocean Sciences Conference, Portland, Oregon, February 2018: Snapping hrimp in Oregon? A potential acoustic cue for marine predators

Publications:

Burnett, J. D., L. Lemos, D. R. Barlow, M. G. Wing, T. E. Chandler and **L. G. Torres**. (in press). Estimating morphometric attributes of baleen whales with photogrammetry from small UAS: A case study with blue and gray whales. Marine Mammal Science.

Theme: Seafloor Reflectance Mapping

Amendment 1, 17: Seafloor Reflectance Mapping for the U.S. Virgin Islands
Funded: $94,628

OSU RESEARCH STAFF: Christopher Parish,
NOAA TECHNICAL LEAD: Tim Battista, NOS

Project Background: In 2014, NOAA's National Centers for Coastal Ocean Science (NCCOS), Center for Coastal Monitoring and Assessment (CCMA) partnered with the U.S. Geological Survey (USGS) to acquire topobathymetric lidar data for priority habitat sites in the U.S. Virgin Islands (USVI). The data acquisition was performed with the Experimental Advanced Airborne Research Lidar, version B (EAARL-B). This system provides a number of performance enhancements over the original NASA EAARL system (Wright et al., 2016), including a 300% increase in point density and an extended depth measurement range (up to 44 m in clear water). While the system produced accurate (see spatial accuracy assessment in Wright et al., 2016), dense bathymetric coverage for CCMA's project sites, the EAARL-B processing software, known as ALPS, lacked functionality for utilizing the digitized return waveforms to obtain additional information about benthic composition and coral reef biophysical parameters. The desire to add this functionality to ALPS and to investigate the use of the output data products in benthic habitat mapping and biological assessments led to a two-year research partnership between NCCOS/CCMA, Oregon State University (OSU), and University of New Hampshire (UNH). Work conducted by the OSU project team in the first year of the project (FY2016) included the development of new algorithms and procedures for seafloor relative reflectance mapping from EAARL-B data. The procedures were initially tested on a relatively small project site surrounding the Buck Island Reef National Monument, St. Croix.

In the current project year (FY2017), the Oregon State University Researchers earlier work was extended to generate seafloor relative reflectance mosaics for a much larger project site south of St. Thomas. The spatial extent of this project site, combined with the number of flight days and data acquisition conditions spanned by the lidar acquisition, necessitated additional correction procedures. Another focus of the OSU team in FY2017 was the generation of a full suite of waveform shape features for a priority habitat site in Flat Cays. The following sections of this report highlight these major accomplishments made by the OSU team between July 1, 2016 and June 30, 2017.

Progress Report: Project activities to date are:

- Built and instrumented custom UAS (S900) for shallow-water mapping (Figure 1, right)

- Performed simulations and tested numerous parameters and acquisition settings using simUAS
- Acquired 16,625 UAS images in the USVI
- Organized the data, produced trip reports, and initiated data processing

The first task involved developing a custom UAS payload using a DJI S900 airframe, a Sony A6000 camera, and a Piksi carrier-phase GNSS. The carrier-phase GNSS was used to obtain an estimated camera position in order to assess how camera pose accuracy effects resultant pointcloud accuracy.

Figure 2: Unmanned aircraft used to collect imagery in the USVI. All flights were conducted by FAA Part 107 certified remote pilots.

The simUAS simulations were designed to test the impacts of varying a number of parameters, including ground sample distance, sensor size and quality, focal length, image overlap, off-nadir viewing angle, and global navigation satellite system (GNSS) accuracy. Figure 2 depicts the results of varying the camera field of view (FOV) and the depth/altitude ration on mean depth error, as computed from the simUAS simulations.

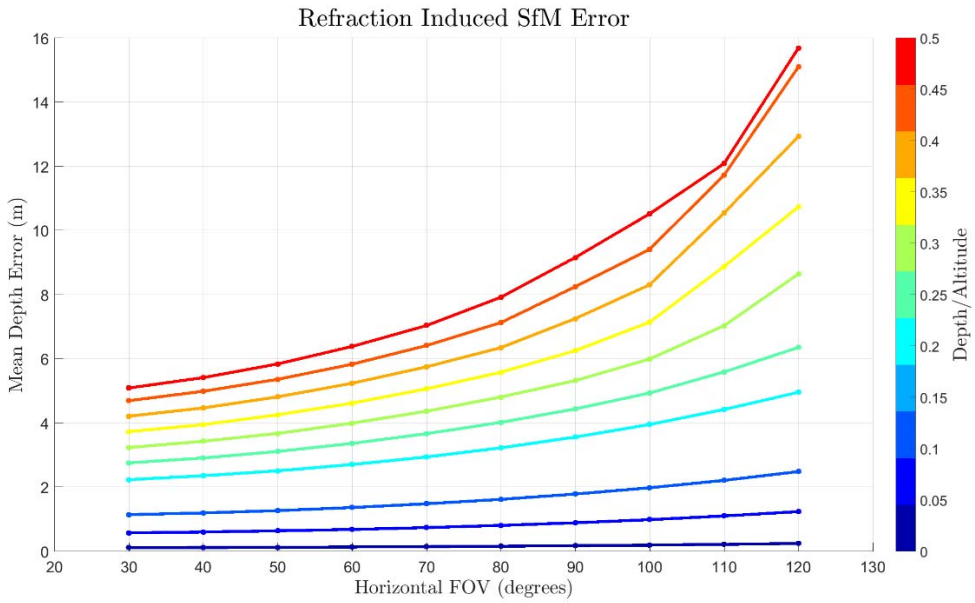

Figure 3: Example of using simUAS to investigate the effects of camera FOV and the ratio of water depth to UAS flight altitude on mean depth error from SfM software.

OSU personnel Chris Parrish, Chase Simpson, and Richie Slocum conducted fieldwork in St Croix, USVI, between March 19, 2018 and April 4, 2018. Government project team members included Tim Battista (NOAA NCCOS), Bryan Costa (NOAA NCCOS), Clayton Pollock (NPS), Nate Holloway (NPS), Matt Sharr (NOAA), and Wayne Wright (Wayne Wright Consulting, contractor to NOAA NGS). Data acquisition at Buck Island was performed from March 19 - 27, while data acquisition at locations in the East End Marine Park (EEMP) on the Eastern side of St Croix was performed from March 28 - April 2 2018.

The OSU team performed a total of 82 flights to acquire data using the two remote aircraft described above. Each flight was conducted with a visual observer and a pilot in command (PIC) with an FAA Part 107 remote pilot certificate. Additional waivers were attained for the flights on Buck Island, as it is a national monument maintained by the National Park Service (NPS). In order to develop the best practices document, a number of flight plans were generated, varying the acquisition parameters, such as sidelap/overlap, camera resolution, camera field of view, ground sample distance, oblique camera angle, and UAS GNSS accuracy. These parameters were selected, based on the results from simUAS, which indicated that these parameters correlate with the accuracy of the derived bathymetry. The results of the experiments performed in the USVI will serve to test the validity of the initial simUAS results, as well as direct future simUAS experiments.

The OSU team also conducted field surveys with conventional surveying equipment, including two Trimble R8-2 GNSS Receivers, a Leica TS15P 1" Total Station with a 360 degree prism, and a Hydrolite-TM echosounder. In collaboration with the NOAA project partners, ground control points (GCPs) were surveyed and ground truth datasets were acquired at each of the USVI project sites. These reference data sets will be used in empirically validating the bathymetry derived from the UAS-based imagery and SfM software. Additionally, the results will used in combination with the simUAS results as the qualitative foundation for the standard operating procedures (SOPs) for bathymetric mapping using UAS imagery.

Figure 4: OSU project team member and PhD student, Richard Slocum, collects data with a Trimble R8-2 GNSS receiver for an underwater photo target.

The OSU project team participated in biweekly to monthly teleconferences with the NOAA collaborators, Tim Battista, Bryan Costa, and Wayne Wright.

Amendment 2, 17: Towards Optimizing the Determination of Accurate Heights using GNS
Funded: $141,831

OSU RESEARCH STAFF: Jihye Park, Asst. Professor, Civil & Construction Engineering
NOAA TECHNICAL LEAD: Steve Hilla, NOS

Project Background: Over the past two fiscal years in collaboration with National Geodectic Survey (NGS) scientists, Oregon State University (OSU) has researched the capabilities of these new GNSS techniques for determining heights under a variety of data acquisition and processing procedures. In FY14, OSU conducted a detailed static and real-time GNSS height modernization survey in Oregon on numerous passive marks in the NGS Integrated Database (NGSIDB). The static data were post-processed following NOS NGS-58 guidelines. The data were then post-processed in OPUS-Projects following recommendations in Armstrong et al. (2015). After finding the resulting heights on the marks from the two methods were similar to within ± 1 cm, it was concluded that OPUS-Projects is a valuable tool for height modernization surveys, and a new workflow was recommended for processing static GNSS surveys in OPUS-Projects (Gillins and Eddy 2015; Gillins and Eddy 2016). In ongoing research in FY15, OSU is currently evaluating the real time GNSS survey data collected during the aforementioned FY2014 survey in Oregon, as well as during previous NGS research studies in South Carolina, Iowa, and Texas. The real-time GNSS data have been found to be quite accurate, and OSU is currently researching methods for using real-time GNSS observations in combination with static GNSS observations in order to more efficiently complete height modernization surveys. The combination of static and real-time data have great potential to significantly reduce the amount of necessary time spent in the field performing the survey.

Based on the results of the past research studies, updated written draft procedures for using other GNSS positioning methods (e.g., OPUS-Projects, Real-Time Kinematic observations, Real-Time Networks) and technologies have been proposed. Comprehensive written procedures based on the research findings could assist NGS in evaluating whether to proceed with a new or updated guidelines document, as well as provide wording that NGS could decide to adapt or use (in whole or in part) in developing new, published guidelines. To this end, this project seeks to synthesize and leverage the current state-of-knowledge from this research on GNSS-derived ellipsoid heights to provide a detailed, written procedures document to assist NGS in the potential development and publication of any new or updated surveying guidelines documents.

Project Progress: The main objective of this research project is to develop the positioning algorithms for multi-GNSS data. During the first part of the project, state of the art of multi-GNSS routines and algorithms will be investigated. Based on the findings, the routines for pre-processing, broadcast orbit determination, and code-based / phase-based point positioning for GPS, GLONASS, Galileo, and BeiDou will be coded. This proposed research within FY2018

will significantly contribute towards the NGS strategic plans by providing a multi-GNSS data processing infrastructure, which will facilitate the transition to the new generation multi-GNSS service of NGS for worldwide geodetic communities. The research objectives to be accomplished within FY2018 will be the following:

1) State of the art multi-GNSS algorithms and processing tools will be investigated and documented.
2) The initial multi-GNSS data processing routines including pre-processing and broadcast orbit calculation will be coded.
3) A basic point positioning tool, which uses pseudorange and carrier phase data, will be developed and tested.

Literature review:

Since the purpose of this project is to develop the advanced multi GNSS processing software, thorough investigation of the state of the art is the most crucial. Therefore, the literature review has been conducted for the various aspects of the multi-GNSS positioning algorithms and submitted as the first deliverable. The following sections briefly describe the topics covered in the submitted deliverable.

Multi-GNSS observations and parameters:

Two types of observables including pseudo-range (code) and carrier-phase measurements in four types of constellations (GPS, GLONASS, Galileo and BeiDou) have been investigated. The observations type, code, frequencies and signal noise level were summarized based on different RINEX versions. Also, the parameters in GNSS observables and the corresponding correction models were described. The parameters include solid earth tides, solid earth pole tides, ocean tide loadings, earth rotation parameters, satellte antenna offsets, pahse wind p corrections, hardware baises and atmospheric corrections.

Algorithms for pre-processing and error mitigation:
Preprocessing and error mitigation algorithms were reviewed in following topics:

- ✓ Data screening including satellite availability and dilution of precision
- ✓ Strategies for optimal weighting
- ✓ Cycle slip detection and repair
- ✓ Atmospheric error mitigation
- ✓ Code and phase biases
- ✓ Multipath
- ✓ Ambiguity resolution

Multi-GNSS positioning algorithms:

Considering the error sources of PPP described in the previous sections, the positioning has been determined by taking mathematical models. Two most widely used positioning solutions, LEast Squares Solution (LESS) and Kalman filter, were reviewed and summarized in the literature review reports. Finally, batch processing and sequential adjustment strategies were also included in the report.

Multi GNSS database:

In order to store and retrieve the observations and a number of required parameters in the positioning solution, a database was designed and implemented. The structure of the databased was finalized by considering the use of GNSS observations for mitigating errors and applying the positioning algorithms. The database attributes include different observation measurements, satellite positions in the earth-centered-earth-fixed (ECEF) coordinate system, satellite elevation and azimuth angle and tropospheric corrections. The raw observation in RINEX observation and navigation files were imported and stored in the database for each epoch with the proper computation of satellite positions. The major routines used for creating the database are included:
Transformation of time and coordinate systems
Each GNSS adopts its own reference system and frame in the ECEF coordinates system. GPS uses World Geodetic System-84 (WGS-84) reference system. GLONASS reference frame is Parametery Zemli (PZ) - 90.11. Galileo and BeiDou use the terrestrial reference frame (GTRF) and China Geodetic Coordinate System 2000 (CGCS2000), respectively. In developing routines for creating the database, WGS84 was selected as a reference for four constellations. Moreover, the time reference systems of GNSS constellations were also transformed to the GPS time (GPST) to put all system in consistent time system.

Computation of satellite positions in consistent reference system

To store the satellite positioning the database, two groups of routines have been developed. Since GPS, Galileo and BeiDou broadcast navigation data are in the same format with the same observation interval, the first group of routines have been developed to calculate the satellite position of those constellations in the common reference time and frame. Unlike those three constellations, GLONASS doesn't use close analytical formula for determine its satellites orbits, being necessary to apply a numerical integration technique. To determine the GLONASS satellite position at a given time, it is required to solve for six orbital differential equations that are published in the GLONASS ICD. We used the forth-order Runge-Kutta method which was suggested by the GLONASS ICD. The second groups of routines contain RKM method as well as GLONASS time and reference frame conversion into the reference time and coordinate scale.

Tropospheric delay computation

Another component in the database is the tropospheric delay. The troposphere is the layer of the atmosphere from the surface of the earth up to 40 km. It can be separated into dry and wet components. The dry component consists of dry gas molecules and represents about 90% of the total tropospheric error, while the wet component consists of the water molecules and represents about 10% of the total tropospheric error. The signal delay from the dry component can be modeled with high accuracy, but the one from the wet component is relatively difficult to model due to the irregular variation of the water molecules over time. Once the signal delays are modeled in zenith direction, they should be projected along the ray path between a satellite and a receiver. This projection is done using a mapping function with respect to the elevation angle of the satellite (Hofmann-Wellenhof et al. 2008). Tropospheric delay is usually expressed as a product of a zenith delay and a mapping function. A number of pre-established models allow us to estimate the ZHD and ZWD empirically such as the Hopfield model, Saastamoinen model, UNB3 model, MOPS model, David et al. model, etc. Among them, the Saastamoinen model is the most widely used. The tropospheric path delay calculation routines have been developed based on Saastamoinen model to calculate the zenith hydrostatic delay (ZHD) and zenith wet delay (ZWD). For the mapping functions, the Global Mapping Function (GMF), Vienna Mapping Function (VMF), and Neill Mapping Function have been implemented.

Preprocessing:

Cycle slip (CS) is a sudden jump in the carrier phase observable. A CS can be caused by the failure of a receiver, signal interruption, low signal-to-noise ratio, or high receiver dynamics. They must be detected and corrected using the positioning process before the carrier phase (Dai 2012). Some of the conventional approaches to handle cycle-slips are following:

- ✓ Detection: Detect CS by observing signals epoch by-epoch (since a CS is a random event).
- ✓ Determination: Quantify the amplitude of the detected CS.
- ✓ Validation: Validate the corrected CS.
- ✓ Removal: Subtract the CS after the values are fixed and pass the validation.

A few available strategies of the cycle slip detection and repair were reviewed and summarized in the literature review report. One of the common approaches is to form the linear combinations of multi-frequency GNSS observations or parameters to mitigate the effects of other parameters, such as geometric terms or ionospheric errors. In the geometry free linear combination approach, multiple carrier phase measurements are combined to remove the geometry terms such as the geometrical range between a satellite and a receiver, clock biases, and all non-dispersive effects of carrier phase observations. In multi-frequency GNSS, various geometry-free combinations can be made and accordingly, more than one CS detection methods can be applied.

The preliminary results show that the two detection criteria simultaneously reduces the amount of undetectable CS groups. Using two proper geometry-free combinations, the CS were significantly reduced. As of July 2018, the geometry free cycle slip detection algorithm for GPS-only was implemented. By the end of the project in the FY2018, the extension of GF combination model for other constellations will be performed. In addition, another routine will be develop to test the Melbourne-Wubbena (MW) technique, which is another widely used CS algorithm. This detector uses the Melbourne-Wubbena combination using dual frequency carrier phase and code measurements. This combination has two significant advantages by involving a larger wavelength with a reduced noise. The larger wavelength increases the spacing between two candidate integer ambiguities, which makes the detection easier.

Point positioning:

GNSS positioning is based on a trilateration method that determines an unknown position from multiple range measurements of GNSS data.GNSS data consists of a carrier phase observable and a modulated code observable (also called as pseudorange) for each frequency that they are affected by various error sources which must be either eliminated or mitigated (Hofmann-Wallenhof et al., 2001; Park et al., 2016). The GNSS errors which are generated from satellites, receivers, atmosphere, Earth surface, etc., can be independently parameterized in the adjustment computation for processing or minimized as being treated as noise. In any case, the increased redundancy decreases the positioning errors in Least Squares Solution (LESS). This supports the claim that the multi-GNSS improves the positioning performance by adding more observations. We used the Gauss-Markov Model (GMM) for the LESS. In LESS, the precision of the observation plays a critical role that is also shown in (Park et al.,2017). Since the signal strengths, robustness, noise levels, etc., of GPS, GLONASS, Galileo, and BeiDou are different, the variance-covariance matrix should be reasonably determined. During this project, the rule of thumb precision of each GNSS signal was investigated and implemented for the positioning algorithm.

The LESS can be determined by either a batch process by accumulating multiple epochs' observations, or a sequential process that can be adapted for the dynamics of users. The batch processing has a potential drawback associated with the computational load for a large network solution or with high sampling rate observations. However, this process is considered to be robust without the additional back-substitution (or back smoothing). Filtering implementations such as a sequential adjustment are usually more efficient than the batch adjustment implementations. On the other hand, the filtering (sequential adjustment) implementations require a backward smoothing for the parameters that are not retained from epoch to epoch. Furthermore, filter/sequential approaches can also model variations in the states of the parameters between observation epochs with appropriate stochastic processes that also update parameter variances from epoch to epoch. During this project, the sequential processing method was chosen to be implemented in the program in order to show the positioning error in a time

series. The solution from point positioning observation equation will provide us two types of parameters (station position and receiver clock offset). By July 2018, the development of the sequential least square solution has been completed for GPS observations, and will be extended for full-constellation processing capability. The positioning results are then validated by the true coordinates of NGS CORS sites.

Summary and final remarks:

At the beginning of the project, an in-depth literature review has been conducted, which provided a clear outline for understanding the currently available techniques and algorithms as well as identifying the research gaps. The literature review summarized and thoroughly analyzed by subtopics within GNSS positioning. The literature review included the papers discussing biases for both phase and range measurements, as collected from multi-GNSS receivers (Håkansson et al., 2016). It will be also captured the basic ideas of the CS detection and repair for multi-GNSS carrier phase data. Although Galileo and BeiDou are not fully operational yet, many companies, institutions, and government organizations in the world have been developing multi-GNSS support software for preparing the new era of GNSS. Understanding the currently available state of the art GNSS positioning tools was critical in taking a step forward. Therefore, reliable open source routines have been collected and reviewed during this project.
This project also focuses on developing the basic point positioning tool. After the pre-processing for multi constellation GNSS data, the PP for each type of GNSS and also multi-GNSS will be tested and compared. The advanced error corrections from error modeling must be considered for PPP, which can be carried out in the future based on the outcome of this project. As a project outcome, by October 2018 basic point positioning routines for four GNSS constellations (GPS, GLONASS, Galileo, and BeiDou) will be implemented and a case study with the developed PP routine will be documented. These basic point positioning programs will be written in the C++ computer language and include both pseudorange and carrier phase data. Qt has been used for developing graphical user interfaces (GUIs) and multi-platform applications that run on all major desktop platforms and most mobile or embedded platforms. Qt supports various compilers, including the GCC C++ compiler which has been used for developing the PP tool. The PPP tool will be implemented in the future project staring in October 2018

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Amendment 4, 27: Advancing the Analysis of Pacific Basin Coastal Flood Sensitivity under a Changing Climate

Funded: $404,298

OSU RESEARCH STAFF: *Peter Ruggiero, Professor, College of Earth, Ocean, & Atmospheric Sciences*
NOAA TECHNICAL LEAD: *John Marra, NOS*

Project Background: The primary goal of this work is to advance the practical application of statistical and other analytical techniques that can be used to assess the vulnerability of built and natural environments to the impacts of coastal flooding in a changing climate. Formulation of innovative approaches to coastal flood sensitivity analysis and the creation of proof-of-concept products will add to the set of tools that federal agency policy and decision-makers, as well as

the broader community, use to identify vulnerable assets, assess impacts, and determine appropriate adaptive responses to coastal flooding, sea-level rise, and associated phenomena. This ongoing work is leading to an improved understanding of potential impacts of climate change and climate variability, including extreme events, on resources of relevance in the Pacific Island region and beyond. The work is focusing on 4 project sites including:

- Site 1 – Southern California (Naval Base Coronado – NBC).
- Site 2 – Republic of Marshall Islands (US Army Garrison Kwajalein Atoll– USAKA).
- Site 3 – Hawaii (Marine Corps Base Hawaii -MCBH).
- Site 4 – Guam (Naval Base Guam –NBG).

Project Progress: Coastal flooding is the result of nonlinear interactions between multiple environmental forcings (oceanographic, meteorological, hydrological) acting at varying spatial (local to global) and temporal scales (hours to centuries). The impact of wave-driven processes on coastal flooding in particular is noted. To better understand and more accurately predict coastal flood exposure the individual contribution of the complete range of processes resulting in compound TWL events (not just the SWL) must be accounted for. This is a complex and non-linear problem and typically, a lack of sufficient data (multivariate time series of the relevant variables) suggests that a range of different methods (e.g., dynamic downscaling, data analysis, and statistical models) must be combined in order to be able to provide robust estimates of coastal flood magnitude, frequency, and duration. The problem becomes even more difficult if a particular area of interest is affected by both extratropical storms and tropical cyclones. It is further compounded when rainfall, and its link to elevation of the groundwater table must be accounted for.

To address this problem, we have developed and begun to apply the **T**ime-varying **E**mulator for **S**hort- and **L**ong-term **A**nalysis of coastal **flood**ing (TESLA-flood). The innovative methodology is a hybrid statistical and process-based downscaling approach, capable of simulating thousands of years of a representative climate to produce potential combinations of contributing TWL variables not necessarily seen in the historical record. Data mining techniques are then used to identify representative combinations of forcing conditions to serve as design points for input into process-based hydrodynamic models.

Each process contributing to TWLs is a consequence of different climatic processes, which are simulated in the TESLA through an auto-logistic regression accounting for interannual variability of the El Niño Southern Oscillation (ENSO), seasonality, intra-seasonal propagation of the Madden-Julien Oscillation (MJO), and daily variability of local sea level pressure fields (SLP). The large-scale climate is controlled by an annual weather type (AWT) capturing the time-varying longitudinal distribution of sea surface temperature (SST) along the Pacific equator

during a given year. A daily weather type (DWT) is constructed from the SLPs producing waves and storm surge impacting the study sites. The resulting statistical emulator relates variability in ocean heat content and atmospheric phenomena (SST, MJO, and SLPs) to distributions of monthly sea level anomalies, non-tidal residuals, and ocean wave parameters.

Integrated Delft3D-FLOW, Delft3D-WAVE, and Xbeach model grids are used to downscale select offshore conditions to local TWLs at the coastline. Specific input conditions to dynamically simulate are chosen using a maximum dissimilarity algorithm (MDA) of all joint oceanic and atmospheric conditions derived in the statistical emulator. The MDA identifies representative forcing conditions for the entire multi-dimensional parameter space such that a Gaussian process regression is able to interpolate the selected dynamic results into a continuous time series of hypothetical TWLs.

The dynamic portion of the emulator is currently being demonstrated in San Diego, USA where the Coastal Storm Modeling System (CoSMoS) is utilized to simulate TWLs in the vicinity of the Coronado Naval Base. TWL return levels are being defined for the present climate with additional insight regarding conditional dependencies on the state of ENSO. Weather patterns with the greatest potential for flooding are also being determined using flood thresholds relevant to the naval base's particular needs. Future changes in the probability of occurrence in any weather pattern will be identified using CMIP5 global climate model SLP predictions. The methodology captures nonlinearities within both the climate and the additive processes causing coastal flooding, providing return level events with constrained confidence intervals to assist DOD managers developing policies for the future use of facilities prone to climate change.

Presentations:

Fernando J. Mendez, **Peter Ruggiero**, John J. Marra, Ana Rueda, **Dylan Anderson**, Jose A.A. Antolinez, Laura Cagigal, Katherine A. Serafin, Mathew Widlansky, Ayesha Genz, Patrick Barnard, Li Erikson, William Sweet, Curt Storlazzi, Melisa Menendez, Mark Merrifield, Janet Becker, Jayantha Obeysekera (2018) Towards TESLA-flood: a Time-varying Emulator for Short- and Long-term Analysis of coastal flooding, Third international conference on Advances in Extreme Value Analysis and Application to Natural Hazard (EVAN), 5 to 7 September 2017, Southampton, UK.

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Dylan Anderson, Peter Ruggiero, Fernando J. Mendez, Ana Rueda, Jose A.A. Antolinez, Laura Cagigal, Curt Storlazzi, Patrick Barnard, 2018. **T**ime-varying **E**mulator for **S**hort- and **L**ong-term **A**nalysis of coastal flooding: **TESLA**-flood, Ocean Sciences 2018, Portland, OR.

Publications:

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APPENDIX

Annual Report for Non-Cooperative Institute NOAA Awards Administered by CIMRS

Award: NA16NMF4390149 - Enhancing the Capabilities of the Oregon Marine Mammal Stranding Network (Bi-Annual Report)

Summary of Expenditures AWARD NUMBER: NA16NMF4390149 Enhancing the Capabilities of the Oregon Marine Mammal Stranding Network							
Expenditures per category for period September 1, 2017 through February 28, 2018							
Category	Federal Share				Non-Federal (match)		
	Budgeted Expenses	Balance as of 09/01/2017	Expenditures for period	Balance as of 02/28/2018	Budgeted Expenses	Expenditures to date	Balance
Personnel							
PI - Bruce Mate	0.00	0.00			1,917.00	0.00	1,917.00
CoPI; Jim Rice, Stranding Network Coord	45,160.00	38,046.85	21,553.95	16,492.90	9,032.00	4,572.00	4,460.00
Student Worker Salary	0.00	0.00	0.00	0.00			
Fringe Benefits							
PI - Bruce Mate	0.00	0.00	0.00	0.00	805.00	0.00	805.00
CoPI; Jim Rice, Stranding Network Coord	23,032.00	19,218.78	11,519.99	7,698.79	4,606.00	2,442.00	2,164.00
Student Worker OPE	0.00	0.00	0.00	0.00			
Services and Supplies							
Diagnostic/ Rehabilitation expenses	3,500.00	3,223.40	6,187.38	-2,963.98			
Expendable Supplies	1600.00	1,310.13	141.51	1,168.62			
Fuel Mileage & Vehicle Maintenance	3,150.00	2,228.88	2,527.99	-299.11			
Cell and Data Ohone	1400.00	1,297.87	817.67	480.20			
Volunteer Time	0.00	0.00	0.00	0.00	2,199.00	1,099.00	1,100.00
Travel	1500.00	1,318.25	929.92	388.33			
Equipment	0.00	0.00	0.00	0.00			
Indirect Charges (F&A Cost/Admin Fees)	20,629.00	17,327.56	11,356.49	5,971.07	16,662.00	3,869.90	12,792.10
Totals	$99,971.00	$83,971.72	$55,034.90	$28,936.82	$35,221.00	$11,982.90	$23,238.10

Award: NA17NMF4390077 - Enhancing the Capabilities of the Oregon Marine Mammal Stranding Network (Bi-Annual Report)

Summary of Expenditures AWARD NUMBER: NA17NMF4390077 Enhancing the Capabilities of the Oregon Marine Mammal Stranding Network							
Expenditures per category for period September 1, 2017 through February 28, 2018							
Category	Federal Share				Non-Federal (match)		
	Budgeted Expenses	Balance as of 09/01/2017	Expenditures for period	Balance as of 02/28/2018	Budgeted Expenses	Expenditures to date	Balance
Personnel							
PI - Bruce Mate	0.00	0.00	0.00	0.00	1,974.00	0.00	1,974.00
CoPI; Jim Rice, Stranding Network Coord	43,513.00	0.00	0.00	0.00	8,456.00	0.00	8,456.00
Student Worker Salary	0.00	0.00	0.00	0.00			
Fringe Benefits			0.00				
PI - Bruce Mate	0.00	0.00	0.00	0.00	809.00	0.00	809.00
CoPI; Jim Rice, Stranding Network Coord	23,062.00	0.00	0.00	0.00	4,482.00	0.00	4,482.00
Student Worker OPE	0.00	0.00	0.00	0.00			
			0.00				
Services and Supplies			0.00				
Diagnostic/ Rehabilitation expenses	5,500.00	0.00	0.00	0.00	0.00	0.00	0.00
Expendable Supplies	1500.00	0.00	0.00	0.00	0.00	0.00	0.00
Fuel Mileage & Vehicle Maintenance	3,350.00	0.00	0.00	0.00	0.00	0.00	0.00
Cell and Data Phone	1400.00	0.00	0.00	0.00	0.00	0.00	0.00
Volunteer Time	0.00	0.00	0.00	0.00	2,275.00	0.00	2,275.00
Travel	1000.00	0.00	0.00	0.00	0.00	0.00	0.00
			0.00				
Equipment	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			0.00				
Indirect Charges (F&A Cost/Admin Fees)	20,625.00	0.00	0.00	0.00	16,658.00	0.00	16,658.00
Totals	$99,950.00	$0.00	$0.00	$0.00	$34,654.00	$0.00	$34,654.00