

Annual Progress Report
to
National Oceanic & Atmospheric Administration

NOAA Award# NA16OAR4320152

Reporting period: 10/1/16 – 6/30/17

Oregon State University

Cooperative Institute for Marine Resources Studies



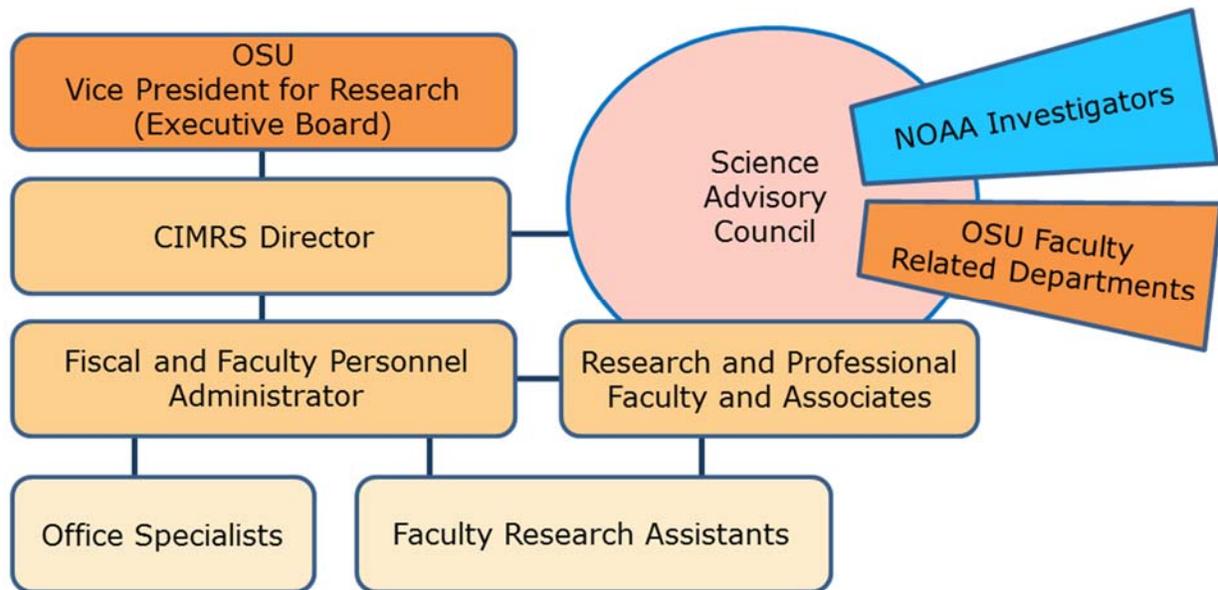
TABLE OF CONTENTS

TABLE OF CONTENTS	1
ORGANIZATION	3
2016/2017 EXECUTIVE BOARD	4
2016/2017 SCIENCE ADVISORY COUNCIL.....	4
RESEARCH AT CIMRS	5
RESEARCH PERSONNEL.....	6
2016-2017 PUBLICATIONS.....	6
ALL PEER-REVIEWED	6
TASK 1: ADMINISTRATION, EDUCATION, AND OUTREACH.....	7
ADMINISTRATIVE STAFF	7
INSTITUTE DIRECTOR ACTIVITIES.....	7
CIMRS EDUCATION.....	9
CIMRS GRADUATE STUDENTS SUPPORTED THROUGH JOINT PROJECTS	9
CIMRS UNDERGRADUATE STUDENTS PROJECTS.....	10
CIMRS OUTREACH ACTIVITIES.....	11
TASK 2	12
Theme: Marine Ecosystem and Habitat.....	12
Amendment 5: Indicators of Phenology in the northern California Current	12
Amendment 3: Climate and Habitat Effects on Productivity of Important Alaska Fisheries.....	18
Theme: Protection & Restoration of Marine Resources	20
Amendment 8: Atlantic Kemp’s Ridley age, growth dynamics, habitat use, and trophic ecology, with comparison to the Gulf of Mexico	20
Amendment 6: Stock Assessment Research Review of Pacific Hake	21
Amendment 12: A Novel Approach to Habitat Identification Using Detections of Acoustically Tagged Marine Species.....	22
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.....	23
Theme: Seafloor Processes.....	24

Amendment 7, 10, 13: Impacts of Submarine Volcanism and Hydrothermal Venting on the Global Ocean and Deep-Sea Ecosystems	24
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	32
TASK 3	34
Theme: Seafloor Reflectance Mapping	34
Amendment 1: Seafloor Reflectance Mapping for the U.S. Virgin Islands	34
Amendment 9: A Multidisciplinary, Integrative Approach to Valuing Ecosystem Services from Natural Infrastructure	39
Amendment 2: Towards Optimizing the Determination of Accurate Heights using GNS...	46
Amendment 4: Advancing the Analysis of Pacific Basin Coastal Flood Sensitivity under a Changing Climate	55

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.



2016/2017 EXECUTIVE BOARD

<p>Cynthia Sagers (Chair) Vice President for Research, Oregon State University</p>	<p>Shelby Walker Director, Oregon Sea Grant, Oregon State University</p>
<p>Roberta Merinelli Dean, College of Earth, Ocean & Atmospheric Sciences, Oregon State University</p>	<p>Jeff Napp Director, Resource Ecology and Fisheries Management Division, Alaska Fisheries Science Center, NOAA</p>
<p>Roy Haggerty Associate Vice-President of Research, Oregon State University</p>	<p>Sastry G. Pantula Dean, College of Science, Oregon State University</p>
<p>Dan Edge Dean, College of Agricultural Sciences, Oregon State University</p>	<p>Chris Sabine Director, Pacific Marine Environmental Laboratory, NOAA</p>
<p>Robert Cowen Director, Hatfield Marine Science Center, Oregon State University</p>	<p>Kevin Warner Director, Northwest Fisheries Science Center, NOAA</p>
<p>Merrick C. Haller Professor; Assoc. Head of Grad Affairs, School of Civil & Constr. Engineering, Oregon State University</p>	<p>Michael Banks (Ex Officio) Director, Cooperative Institute for Marine Resources Studies, Oregon State University</p>

2016/2017 SCIENCE ADVISORY COUNCIL

<p>David Noakes (Chair) Professor, Department of Fisheries and Wildlife, Oregon State University</p>	<p>Chris Parrish Associate Professor, College of Engineering Oregon State University</p>
<p>Jerri Bartholomew Professor, Department of Microbiology, Oregon State University</p>	<p>Clare Reimers Professor, College of Earth, Ocean, and Atmospheric Sciences, Oregon State University</p>
<p>William Chadwick Professor Sr. Res., Cooperative Institute for Marine Resources Studies, Oregon State University</p>	<p>Clifford Ryer Fisheries Biologist, Resource Assessment and Conservation Engineering Division, Alaska Fisheries Science Center, NOAA</p>
<p>Louise Copeman Asst. Prof., Sr Res., College of Earth, Oceans, and Atmospheric Sciences, Oregon State University</p>	<p>Paul Wade Research Biologist, National Marine Mammal Laboratory, Alaska Fisheries Science Center, NOAA</p>
<p>Kurt Fresh Estuarine and Ocean Ecology Program Manager, Fish Ecology Division, Northwest Fisheries Science Center, NOAA</p>	<p>George Waldbusser Assistant Professor, College of Earth, Oceans, and Atmospheric Sciences, Oregon State University</p>
<p>Sarah Henkel Asst. Professor Sr. Res., Department of Integrative Biology, Oregon State University</p>	<p>Laurie Weitkamp Research Fisheries Biologist, Conservation Biology Division, Northwest Fisheries Science Center, NOAA</p>

<p>Michelle McClure Director, Fishery Resource Analysis and Monitoring Division, Northwest Fisheries Science Center, NOAA</p>	<p>William Percy Professor Emeritus, College of Earth, Ocean, & Atmospheric Sciences, Oregon State University</p>
<p>Michael Banks (Ex Officio) Director, Cooperative Institute for Marine Resources Studies, Oregon State University</p>	

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 FY17, CIMRS researchers spent 108 days at sea. In addition, CIMRS researchers conducted six sampling days on the Newport Hydrographic Line.

RESEARCH PERSONNEL

The following table describes CIMRS research personnel in FY17

Position Category	# Staff	# B.S.	# M.S.	# Ph.D.
Research Scientist	4	--	--	4
Research Associates	1	--	--	1
Research Assistants	13	12	5	1
Total Support >50%	18	12	5	1
Research Scientist < 50%	1	1	1	1

2016-2017 PUBLICATIONS ALL PEER-REVIEWED

Institute Lead Author	NOAA Lead Author	Other Lead Author
5	2	16

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	0.2	No
Travel Specialist	0.25	No

INSTITUTE DIRECTOR ACTIVITIES

National Service

National Cooperative Institute Directors' Executive Committee:

- Retired from service to the executive committee, but engaged in discussions and letter preparation for budget protection made by current committee to House and Senate appropriators in DC in the week beginning May 22nd, 2017.
- National CI Directors meeting, Washington DC, March 1&2, 2017.
- Attended 50-year celebration of CIRES in Boulder, CO, May 17&18, 2017, and presented a poster:
Davie-Martin, C.L., K. Halsey, S.J. Giovannoni, J. de Gouw, & M.A. Banks
Exploring the VOC metabolome and its impacts on air and sea

University Service

- OSU Centers, Institutes and Programs meetings
- Convened meetings for CIMRS coordination and oversight:
 - CIMRS Seattle Labs and Director visits (Mar 20&21 2017)
 - CIMRS Executive Board, Corvallis, OR (11 May 2017)
 - CIMRS update with Bob Cowen, Director HMSC (various)
- 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 2016-17 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 – 06/30/2017	\$456,000
Banks	Oregon Department of Fish and Wildlife	Genetics Analysis of fall!run Chinook salmon in the Grays River, Washington.	03/22/2016 – 06/30/2017	\$49,926
Banks	Oregon Department of Fish and Wildlife	Genetics Analysis of Oregon Steelhead.	03/22/2016 – 06/30/2017	\$46,343
Banks	USDA	AMS - USDA Banks Gentes Pac Oysters	09/28/2015 – 09/27/2017	\$83,000
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	\$3,635,098

Grant and Journal Reviews:

CIMRS, African Journal of Marine Science, Gene, KAUST, MEPS, WA Sea Grant panel member, J Fish Biology, Endangered Species Review, Population Ecology

Publications:

MARINE FISHERIES GENETICS & CONSERVATION

*Papers by students or postdoctoral advisees, whom I offer first authorship as a matter of policy.

*Davis CD, JC Garza and MA Banks. 2017. Identification of multiple genetically distinct populations of Chinook salmon (*Oncorhynchus tshawytscha*) in a small coastal watershed. <https://link.springer.com/content/pdf/10.1007%2Fs10641-017-0616-z.pdf>

*Ottmann D, K Grorud-Colvert, NM Sard, BE Huntington, MA Banks, S Sponaugle. 2016. Long-term aggregation of larval fish siblings during dispersal along an open coast. *PNAS* 113(49):14067-14072

*Sard NM, DP Jacobson, MA Banks. 2016. Grandparentage assignments identify unexpected adfluvial life history contributes offspring to a reintroduced population. *Ecology and Evolution*. 6(19): 6773–6783

*Sard NM, KG O'Malley, DP Jacobson. M, Hogansen, MA Johnson, MA Banks. 2016. Genetic monitoring guides adaptive management of anamigratory fish reintroduction program. *Animal Conservation*. 19(6):570-577. <http://onlinelibrary.wiley.com/doi/10.1111/acv.12278/epdf>

In Review/revision:

*Hemstrom W, MA Banks, S Van deWetering. Causes and hatchery-based mitigation of hybridization between different steelhead salmon life-histories in the Siletz River, Oregon. CJFAS

*Davis CD, CW Epps, RL Flitcrof, MA Banks. Refining and defining riverscape genetics: how rivers influence population genetics structure. WIREs Water

Other Reviewed Scholarship:

Abdalati, W, T Ackerman, S Ackerman, D Anderson, MA Banks, U Bhatt, O Brown, B Cardinale, B Cornuelle, B Kirtman, C Kummerow, M Merrifield, F Miralles-Wilhelm, R Moorhead II, RA Pepler, S Pomponi, J Sarmiento. May 22nd Letter to Senate - support for FY 17 CI funding.

Abdalati, W, T Ackerman, S Ackerman, D Anderson, MA Banks, U Bhatt, O Brown, B Cardinale, B Cornuelle, B Kirtman, C Kummerow, M Merrifield, F Miralles-Wilhelm, R Moorhead II, RA Pepler, S Pomponi, J Sarmiento. May 22nd Letter to Congress - support for FY 17 CI funding.

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

Banks, MA, CIMRS 2017 Executive Board meeting agenda and director overview

Administrative Tasks

Dr. Banks and the CIMRS Administrator were responsible for submission of 17 proposals under the new Institutional award during the period 10/1/16 – 6/30/17. CIMRS Administrator Jessica Waddell retired Oct 1, 2016, and new CIMRS Administrator, LeAnne Rutland, started on August 1, 2016. Ms. Waddell remains at CIMRS with an academic appointment to assist with the transition of CIMRS Administrator duties to Ms. Rutland.

CIMRS Education

CIMRS Graduate Students Supported through Joint Projects

A small number of graduate student projects are being supported with contributed grant funds from NOAA Fisheries and Oceans and Atmospheric Research.

M.S. Candidates

Samara Haver 2015-2017
 Project: Measuring Soundscapes in the Atlantic Ocean
 Major Professor: Holger Klinck
 NOAA Fisheries Rep: Bob Dziak, PMEL

Ph.D. Candidates

OSU College of Earth, Ocean, and Atmospheric Sciences

Caren Barceló 2009-2017
 Project: Community dynamics of marine fish assemblages in northern neritic and pelagic environments
 Major Professor: Lorenzo Ciannelli
 NOAA Fisheries Rep: Ric Brodeur, NWFSC

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, Holger Klinck
 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, Holger Klinck

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 2016, Gabriella Kalbach, California State University of Monterey Bay, visited for a summer internship with Dr. Joe Haxel for a project: “Glider derived ambient noise levels along the continental shelf break of the Pacific Northwest”

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. Two new blogs have been created by CIMRS investigators this year: www.blogs.oregonstate.edu/acoustics/ and [Newportal: A gateway to oceanographic information from the Newport Line and beyond](#)

CIMRS research efforts 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. "Patterns from Sound" 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. "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 depth, 3-D sculptures of crab larvae, and microscopes showing actual larvae. "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. Local television station KGW interviewed Jennifer Fisher about the Newport Hydrographic Line in June 2016.

TASK 2

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

Theme: Marine Ecosystem and Habitat

Amendment 5: Indicators of Phenology in the northern California Current

Funded: \$264,855

OSU RESEARCH STAFF: Michael Banks, Director CIMRS; Jennifer Fisher, Faculty Research Assistant; Xiuning Du, Research Associate

NOAA TECHNICAL LEAD: Bill Peterson, 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 are 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 will be 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, 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.

Progress Report: The project continues its successful collection of hydrography, zooplankton, ichthyoplankton, and juvenile fishes in the Northern California Current ecosystem. One quarterly cruise was completed on board the commercial fishing vessel F/V Michelle Ann, as well as three cruises of opportunity on the R/V Shimada in October 2016, Feb 2017 and May 2017. During each cruise researchers sample 13 stations out to 85 nautical miles offshore, along the NH Line. At each station researchers collect hydrographic data; water samples for nutrients, chlorophyll-a concentration, and phytoplankton species abundance and composition; 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. Oregon State University collaboration with the commercial fishing industry continues to be a positive, with scientists and fishermen contributing knowledge and expertise to goals of the project.

Sample processing continues in all aspects of the project. All CTD data has 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 the database and approximately half of the chloroyll samples have been processed and entered into the database. All zooplankton from NH-5, NH-25, and NH-65 have been enumerated and entered into the database. Work continues on the backlog of juvenile fish samples, with a successful processing event where over 1,100 frozen fish samples were analyzed in February 2017.

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

Presentations:

The Ocean Ecology Meeting Newport OR Jan 25, 2017. Jennifer Fisher; The skinny about how the Blob and El Niño changed the hydrography, zooplankton, lipid, and fatty acid structure off Oregon

The West Coast Regional NOAA Leads Newport OR Feb 8, 2017. **Jennifer Fisher**; Ecological indicators and ocean conditions in the Northern California Current.

Publications:

Peterson, WT, **Fisher, JL, Du, X**, Risien, C, Peterson, J, Shaw, CT, & Strub, T. Hydrography, plankton and krill during the Blob (2013-14) and El Niño (2015-16): biological indicators of the unusual nature of source waters found over the continental shelf of the northern California Current. *In Revision JGR*

Auth, Toby D., **Elizabeth A. Daly**, Richard D. Brodeur, and **Jennifer L. Fisher**, Phenological and distributional shifts in the ichthyoplankton assemblage of the northern California Current during the 2015-16 marine warming phenomenon. Submitted to *Global Change Biology*

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

Project Background: OSU researchers will 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 will be summarized into ecosystem indicators of ocean conditions. These indicators include basin-scale and regional physical properties, and local biological indices (e.g., copepod biomass anomalies). All indices will be 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.

Project Progress: Nine research cruises were conducted aboard the R/V Elakha. Seven stations from 1 to 46 km from shore were sampled during each cruise. Additionally, three research cruises were conducted aboard the R/V Bell Shimada in Oct 2016, Feb 2017, and May 2017. 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 await analysis with environmental variables. Presently, all of the hydrographic, chlorophyll and nutrient samples have been processed and uploaded into a database, and the zooplankton and phytoplankton have been enumerated for all dates from two of the seven stations along the NH line. 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 20 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 creating 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 2016-17, this warm water still exists and the biomass of the cold water lipid rich copepods reached the lowest we've observed in the 20 year time series. The warm ocean conditions in 2014 - 2016 also contributed to a prolonged bloom of the diatom *Pseudo-nitzschia* (PN). Blooms of this species have occurred in every year of our 16-year time series but PN were particularly dominant and persistent from 2014 through 2016. The toxic PN blooms off Newport in 2015 were the most prolonged (late-April through October 2015) and among the most toxic blooms observed. This bloom was also spatially extensive, from southern California to Washington State and in to the Gulf of Alaska.

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 was 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 Ocean Ecology Meeting Newport OR Jan 25, 2017. **Jennifer Fisher**; The skinny about how the Blob and El Niño changed the hydrography, zooplankton, lipid, and fatty acid structure off Oregon

The West Coast Regional NOAA Leads Newport OR Feb 8, 2017. **Jennifer Fisher**; Ecological indicators and ocean conditions in the Northern California Current.

Publications:

Du, Xiuning, William Peterson, **Jennifer Fisher**, Matt Hunter, and Jay Peterson. "Initiation and development of a toxic and persistent Pseudo-nitzschia bloom off the Oregon coast in spring/summer 2015." *PloS one* 11, no. 10 (2016): e0163977.

McClatchie S, Goericke R, Leising A, Anderson C, and **others** (2016) State of the California Current 2015-16: Comparisons with the 1997-1998 El Niño. Calif Coop Ocean Fish Investig Rep 57:1-57

Peterson, WT, **Fisher, JL**, **Du, X**, Risien, C, Peterson, J, Shaw, CT, & Strub, T Hydrography, plankton and krill during the Blob (2013-14) and El Niño (2015-16): biological indicators of the unusual nature of source waters found over the continental shelf of the northern California Current. *In Revision JGR*

Auth, Toby D., **Elizabeth A. Daly**, Richard D. Brodeur, and **Jennifer L. Fisher** Phenological and distributional shifts in the ichthyoplankton assemblage of the northern California Current during the 2015-16 marine warming phenomenon. *Submitted to Global Change Biology*

Yi Chao, John D. Farrara, Eric Bjorkstedt, Fei Chai, Francisco Chavez, Daniel Rudnick, Wendy Enright, **Jennifer L. Fisher**, Bill T. Peterson, Gregory F. Welch, Curtiss O. Davis, Richard C. Dugdale, Frances P. Wilkerson, Hongchun Zhang, Yinglong Zhang, Eli Ateljevich. The origins of the anomalous warming in the California coastal ocean and San Francisco Bay during 2014-2016. *Submitted to JGR*

Transport indices of ecosystem structure in the NCC

Project Background: Large-scale transport holds a central place in the energetics of the food web, stemming from the apparent role of basin-scale dynamics in controlling the source waters and the copepod communities that feed into the NCC. Local transport also affects cross-shelf and alongshore structure, and connectivity in copepod communities and how they change over time. Therefore, information on transport at smaller scales is needed both to address outstanding questions of how well zooplankton-based indicators for the NHL represent the broader NCC, and to enhance our understanding and predictability of latitudinal variability in recruitment to salmon and other fishery stocks.

OSU researchers will (1) develop local-scale indices of transport derived from ocean circulation models (ROMS) for the California Current that integrate evolving ocean responses to basin-scale and local-scale forcing, (2) quantify local- and regional-scale response of alongshore- and cross-

shelf transport of shelf waters to basin-scale variability associated with the PDO, El Niño, and the North Pacific Gyre Oscillation, (3) evaluate the utility of local-scale transport indices as predictors of copepod community structure, and (4) compare the timing (and lag) of copepod indicator species at two locations (NHL and THL) to infer whether alongshore transport and/or local production are driving those variations.

Progress Report: To date (June 2017), environmental fields have been extracted from the ROMS model for the Newport Oregon and Trinidad California regions from 1999-2012, and alongshore transport indices have been generated. Analysis is ongoing, but initial results suggest strong seasonal patterns in alongshore transport and copepod community structure at both locations. OSU researchers are analyzing the connectivity between the two locations and correlating the transport indices to basin scale and local processes.

Indicators of phenology in the NCC

Project Background: Changing ocean conditions often trigger changes in seasonal peaks of migrations and production and possible latitudinal shifts in species distributions. Using existing physical and biological data from the NHL to OSU researchers will (1) investigate processes associated with the timing (phenology) of the onset of biological production in winter, (2) compare the physical and biological dates of spring and fall transition and (3) investigate possible shifts in the seasonal peaks in the abundance of the dominant copepod species in summer.

Progress Report: Dr. Du focused on the characterizing and analyzing the winter phytoplankton bloom, biological spring transition, seasonal shifts of phytoplankton blooms, and local upwelling and climate indices such as the Pacific Decadal Oscillation (PDO) and El Niño–Southern Oscillation (ENSO) relationships with phytoplankton production.

Publications:

Miller, J. A., Peterson, W. T., Copeman, L. A., **Du, X.**, Morgan, C. A., Litz, M. N. C. Temporal variation in the biochemical ecology of lower trophic levels in the Northern California Current. *Progress in Oceanography*. 2017. (Accepted)

Peterson, W. T., **J. Fisher, X. Du**, C. Risien, J. Peterson, T. Shaw, and T. Strub. 2017. Hydrography, plankton and krill during the Blob (2013-14) and El Niño (2015-16): biological indicators of the unusual nature of sources waters found over the continental shelf of the northern California Current. *Journal of Geographic Research*. (Accepted after minor revisions)

Du, X. and Peterson, W. T. 2017. Phytoplankton community structure in 2011-2013 compared to the extratropical warming event of 2014-2015. *Geographic Research Letter*. (Under revision)

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

Funded: \$87,156

OSU RESEARCH STAFF: Louise Copeman, Assistant Professor, Senior Researcher
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 CO₂ 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: While a graduate student, Jessica Andrade, completed analyses related to the impact of ocean acidification on the forage behavior of juvenile speckled sanddab, an experimental model flatfish species. Currently, Jessica Andrade is expanding her work on juvenile sanddab to test the same behavioral parameters in walleye pollock. She is running a number of experiments with NOAA collaborators to examine the effects of high CO₂ on the behavior of juvenile walleye pollock.

Dr. Louise Copeman (CIMRS & CEOAS, OSU) has continued to work on statistically examining the interactive effects of food quality and ocean acidification on larval Pacific cod. She has finished statistical analyses and is working on the preparation of a co-authored manuscript with her NOAA collaborator.

Optimal thermal habitats of Alaskan fishes

Project Background: The degree to which fish species respond to changing temperatures depends on their thermal preferenda i.e., the temperature at which physiological processes are optimal. These physiological processes include a suite of cellular activities (e.g., biochemical homeostasis, energy conversion efficiency, muscle performance, etc.) but are manifested collectively in terms of growth and condition of the animal (Amara et al. 2007). The thermal habitats for yellowfin sole (*Limanda aspera*) and Alaska plaice (*Pleuronectes quadrituberculatus*) have not been described. A document combining Essential Fish Habitat information for crabs, gadids and flatfish would provide readily accessible habitat information for regions where bottom temperatures are available, as well as a framework and repository for additional Fishery Management Plan species. While focused on cold pool effects in the southeastern Bering Sea, this project will have utility for understand flatfish habitat in the greater Bering, Chukchi and Beaufort Seas as bottom temperatures rise.

Project Progress: Graduate Student and technician, Jessica Andrade completed experiments describing the effects of temperature on the growth rates of four species of Alaskan flatfishes: Pacific halibut, yellowfin sole, Alaska plaice, and longhead dab. Each of the experiments had 3 to 5 temperature treatments and measurements of growth were taken over 7 to 6 weeks.

Optimal Thermal Habitats of Alaskan crabs

Project Background: The degree to which crab species respond to changing temperatures depends on their thermal preferences, i.e., the temperature at which physiological processes are optimal. These physiological processes include a suite of cellular activities (e.g., biochemical homeostasis, energy conversion efficiency, muscle performance, etc.) but are manifested collectively in terms of growth and condition of the animal (Amara et al. 2007). The thermal habitats for snow crab (*Chionoecetes opilio*) and Tanner crab (*Chionoecetes bairdi*) have not been fully described nor have they been consolidated into a single reference for the purposes of science and management. A document combining Essential Fish Habitat information for crabs, gadids and flatfish would provide readily accessible habitat information for regions where bottom temperatures are available, as well as a framework and repository for additional Fishery Management Plan species. While focused on cold pool effects in the southeastern Bering Sea, this project will have utility for understanding crab habitat in the greater Bering, Chukchi and Beaufort Seas as bottom temperatures rise.

Project Progress: Dr. Copeman (OSU) and staff have completed crab morphometric sampling as well as the lipid class and fatty acid analyses of 80 additional crabs collected on the NOAA-BASIS survey. These analyses will be used to examine the effect of variability in temperature and food quality on the condition of both juvenile tanner and snow crabs from the Bering Sea. Dr. Louise Copeman and Dr. Cliff Ryer (NOAA) are currently collaborating on the final stages of manuscript preparation over the spring of 2017.

Deliverables:

Presentations:

Copeman LA, Hurst T, Haines S, Meredith S, Hubbard K (2017). The interactive effects of changes in CO₂ exposure and food quality on the growth and lipid composition of Pacific cod (*Gadus macrocephalus*) larvae. **Poster presentation**, ESSAS Open Science Meeting on Subarctic and Arctic Science, Tromso, Norway, June 10-15, 2017.

Copeman LA and Laurel BJ (2017). The interaction of temperature and diet quality in determining the condition of juvenile saffron cod (*Eleginus gracilis*) and Arctic cod (*Boreogadus saida*): results from combined laboratory and field based approaches. **Oral presentation**, ESSAS Open Science Meeting on Subarctic and Arctic Science, Tromso, Norway, June 10-15, 2017.

Laurel BJ, **Copeman LA**, Koenker B (2017). Temperature sensitivity of Arctic and Sub-Arctic gadids to match-mismatch scenarios. **Oral presentation**, ESSAS Open Science Meeting on Subarctic and Arctic Science, Tromso, Norway, June 10-15, 2017.

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: \$72,333

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 ($\delta^{13}\text{C}$ as an indicator of foraging location and $\delta^{15}\text{N}$ 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: Laboratory analyses is ongoing for this project. Bone samples were shipped to M. Ramirez in April 2017. In May 2017, OSU researchers began developing the sampling plan for laboratory analyses, which will begin in June and run through September 2017. Laboratory analyses began in June 2017. Multiple methods will be investigated in parallel to characterize the biogeochemical composition of bone tissue. Bone dust will be collected using a micromill and analyzed for stable nitrogen and lead isotope ratios to reconstruct diet and habitat use. Stable nitrogen isotope data will be use to estimate diet composition for each turtle, whereas stable lead isotope data will be used to identify alternative habitat use throughout life. Graduate Student Matthew Ramirez, will also use laser ablation-inductively coupled plasma-mass spectrometry to collect additional elemental ratio within each bone, which will be used to investigate alternative

habitat use among turtles. Laboratory analyses will span summer term. Data analysis will be ongoing and extend into fall term 2017.

Presentations:

The International Symposium on Sea Turtle Biology and Conservation, held in Las Vegas, NV, April 16-20, 2017 **S. Heppell** and **M. Ramirez** presented results of ongoing research in **two oral presentations** and a **poster presentation**. The symposium attracted approximately 1000 attendees.

Amendment 6: Stock Assessment Research Review of Pacific Hake

Funded: \$19,028

OSU RESEARCH STAFF: David Sampson, Professor, Fisheries and Wildlife

NOAA TECHNICAL LEAD: Sheryl Robinson, WC Region

Project Background: Dr. David Sampson will conduct a review of the new assessment of stock status and potential yield for the 2017 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.

Project Progress: Dr. Sampson's primary activity for this project was participation in a three-day meeting of the SRG held at the Morris J. Wosk Centre for Dialogue in Vancouver, British Columbia, Canada on 14-16 February 2017. Additional activities included preparing for the meeting by reading the draft 2017 stock assessment document, contributing text to the SRG's report to the Joint Management Committee, and subsequently finalizing the SRG report by email correspondence.

The 2017 assessment for the coastal Pacific hake stock and related analyses had been conducted during the summer and fall of 2016 and early winter 2017 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), two Canadian stock assessment biologists from the Pacific Biological Station, Fisheries and Oceans Canada (Chris Grandin and Andrew Edwards), and a consulting academic from Simon Fraser University (Sean Cox). The assessment was more or less an update of the 2016 assessment, with the addition of one more year of landings and age-composition data for the commercial fishery and a reanalysis of the 1995 biomass estimate from the acoustic survey, which had not been included in the major revision of the survey biomass series conducted for the 2016 assessment. No acoustic survey was conducted during 2016. Although there were no changes to the fundamental structure of the estock assessment model, which includes time-varying selectivity for the fishery, the JTC loosened the constraint on the annual deviations in fishery selectivity to provide a mechanism for

controlling an otherwise extremely large estimate of the 2014 year-class. This seemingly innocuous change to the model was the focus of much discussion during the review.

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

Funded: \$147,941

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: Funds were awarded for this project late in the reporting period. As of June 2017, the custom engineered underwater glider components with acoustic receivers and Conductivity Temperature Depth (CTD) sensor have been purchased.

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: \$10,000

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 of catch per unit effort 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 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. we 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: 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.

Publications:

Barceló C., Ciannelli L., Brodeur R. Pelagic marine refugia and climatically sensitive areas in an eastern boundary current upwelling system. Accepted in *Global Change Biology*.

Theme: Seafloor Processes

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

Funded: \$1,220,495

OSU RESEARCH STAFF: William Chadwick, Professor, Senior Research, CIMRS; Holger Klinck, Assistant Professor, Sr. Res., 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; Leigh Evans, Lauren Roche, Faculty Research Assistants, CIMRS; Samara Haver Graduate Student

NOAA TECHNICAL LEAD: John Lupton, Bob Embley, Bob Dziak, Carol Stepien, Chris Sabine, 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 CO₂ 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 FY17 with a focus on Axial Seamount in the NE Pacific, the Cascadia continental margin, and the Mariana back-arc spreading center in the western Pacific.

Professor William Chadwick published two papers this year presenting results from the 2015 eruption at Axial Seamount, with the help of Senior Faculty Research Assistant Andra Bobbitt and Senior Faculty Research Assistant Susan Merle. One paper (Chadwick et al., in GRL) described the lava flows that erupted in 2015 from multibeam sonar re-surveys, autonomous underwater vehicle (AUV) bathymetry, and remotely operated vehicle (ROV) dive observations and sampling. This was the first historical eruption on Axial's north rift zone, and the locations of eruptive fissures reveal the structures that connect the summit caldera to the north rift for the first time. The composition of 2015 lavas sampled during ROV dives is the most mafic (MgO>8%) erupted in over 600 years at Axial Seamount. This is consistent with a significant increase in the magma supply rate since the 2011 eruption detected by the deformation measurements and a decrease in the magma residence time between eruptions. The lava compositions also show a general progression of decreasing MgO with distance along the rift zone, consistent with it having tapped a zoned magma body. Mapping of the location, extent, and thickness of the new lava flows allows correlation with both the seismicity and the unusual explosion-like signals that were detected on the north rift zone. ROV visual observations located explosion pits on the new flows that suggest a mechanism to explain the unusual impulsive seismic signals. The calculated volume of the new lava flows can be compared with the volume of co-eruption deformation measured during the event.

The second paper (Nooner and Chadwick, in Science) presented geodetic inflation/deflation data recorded between the 2011 and 2015 eruptions that allowed the latter to be forecast with much greater precision than was previously possible. The 2015 eruption was forecast 7 months in

advance to occur sometime within 2015, based on the long-term pattern of ground deformation, a remarkable success with implications for other volcano forecasting efforts around the world. The deformation measurements show that the rate of inflation was 4 times higher after the 2011 eruption, implying a major increase in the magma supply rate that dramatically decreased the eruption recurrence interval. The co-eruption deflation rate was much higher initially and much longer in duration than observed in 2011, which can be related to both the character of the eruption seismicity and the location on the north rift zone. The increased number of monitoring instruments due to the cabled observatory allows for more complex modeling of the ground deformation than was previously possible and allows new comparisons to the magma reservoir imaged by multichannel seismic results.

In June 2016, Senior Faculty Research Assistant Susan Merle participated in a research cruise along the Cascadia continental margin, offshore Oregon, Washington, and northern California conducted on the Ocean Exploration Trust Inc. ship E/V Nautilus. Merle used the latest midwater sonar technology on the expedition to map out methane bubble streams. In addition, dives with a remotely operated vehicle at selected sites to sample the methane bubbles. The results from this expedition were extraordinary - more than 900 new methane sources were discovered in water depths from 105 to 2045 m, more than four times the number previously known. This large number of seeps from this limited survey indicates that a substantial revision of the methane flux is needed and that cold seeps and the extensive carbonate hard grounds associated with them are an important ecosystem that needs to be factored into future management decisions concerning essential fish habitat. One exciting discovery was finding an exposure of methane hydrate and gas bubbles streaming out of the seafloor in Astoria canyon at a depth of 850 m. The hydrate, a mixed water/methane ice phase, is present over extensive areas of continental margins, but has only rarely been observed exposed at the seafloor along the Cascadia margin.

Another major research expedition took place from November 29 to December 20, 2016 in the Mariana region on R/V Falkor (operated by the Schmidt Ocean Institute). Professor Chadwick and Senior Faculty Research Assistant Andra Bobbitt participated and Chadwick was co-chief scientist. The cruise staged out of Guam and focused on a 600-km long section of the Mariana back-arc spreading center that was previously virtually unexplored. The cruise built on results from another exploration cruise the year before. ROV dives were used to characterize the geology, chemistry, biology, and microbiology at the new hydrothermal sites, confirming that the chemosynthetic ecosystems along the Mariana Back-arc are distinct from those along the adjacent Mariana Arc. This has important implications for the management of the Mariana Trench Marine National Monument, which NOAA co-manages. The cruise was highlighted on this web site: <https://schmidtocean.org/cruise/searching-life-mariana-back-arc/>

Research results were presented at 2016 Fall Meeting of the American Geophysical Union (AGU) in San Francisco, the 2016 Annual Meeting of the Geological Society of America in Denver, the Seismological Society of America Annual Meeting in Denver, the AGU Chapman Conference on Submarine Volcanism in Hobart, Tasmania, and the 2016 Goldschmidt Conference, Yokohama, Japan.

Presentation:

- Anderson, M.O., **W.W. Chadwick Jr.**, **S.G. Merle**, J.A. Resing, E.T. Baker, S.L. Walker, M.D. Hannington, and N. Augustin, 2017, Relationship between tectonism, volcanism, and hydrothermal venting along the Mariana back-arc spreading center between 12.7°N and 18.3°N, abstract presented at the AGU Chapman Conference on Submarine Volcanism, 31 January-3 February, Hobart, Tasmania.
- Baker, E.T., S. L. Walker, J. Resing, **W. Chadwick**, **S. G Merle** and Melissa O Anderson, Hydrothermal Plume Surveys of the Mariana Backarc (12.7°-18.3°N) by Surface-Ship and AUV Find an Unexpectedly High Spatial Frequency of Vent Sites, 2016 AGU Fall Meeting
- Baumberger, T., J. E. Lupton, J. A. Resing, **W. W. Chadwick, Jr.**, D. A. Butterfield, E. T. Baker, S. L. Walker, and **S. G. Merle** (2016), New hydrothermal vents discovered along the Mariana back-arc spreading center. Abstract presented at 2016 Goldschmidt Conference, Yokohama, Japan, 26 June-1 July.
- Caplan-Auerbach, J., R. P. Dziak, D. R. Bohnenstiehl, and **W. W. Chadwick Jr.** (2017), Submarine Eruption Dynamics, Revealed by Hydroacoustic Data at NW Rota-1, West Mata, and Axial Volcanoes. Abstract presented at the AGU Chapman Conference on Submarine Volcanism, 30 January-3 February, Hobart, Tasmania.
- Caress, D. W., D. A. Clague, J. B. Paduan, H. J. Thomas, **W. W. Chadwick, Jr.**, S. L. Nooner, and D. R. Yoerger (2016), Vertical deformation of the Axial Seamount summit from repeated 1-m scale bathymetry surveys using AUVs. Abstract OS41C-1991 presented at 2016 Fall Meeting, AGU, San Francisco, Calif., 12-16 Dec.
- Chadwick, W. W., Jr.** (2016), Volcanic Geodesy: from Mount St. Helens to Axial Seamount. Abstract presented at 2016 Annual GSA Meeting, Denver, CO, 25-28 September., GSA Abstracts with Programs.
- Dziak, R. P., H. Matsumoto, **S.G. Merle**, R. W. Embley, Passive acoustics records of two vigorous bubble-plume methane seeps on the Oregon continental margin, 2016 AGU Fall Meeting
- Embley, R. W., **S. G. Merle**, N. Raineault, T. Baumberger, S. Seabrook, H. P. Johnson, A. M. Trehu, J. E. Lupton, A. R. Thurber, M. Torres, S. R. Hammond, E. Solomon, and M. Salmi, Numerous Bubble Plumes Mapped and New Seeps Characterized on the Cascadia Margin, 2016 AGU Fall Meeting
- Embley, R. W., and **W. W. Chadwick Jr.** (2017), Submarine Volcanism along the Mariana Frontal Arc. Abstract presented at the AGU Chapman Conference on Submarine Volcanism, 30 January-3 February, Hobart, Tasmania.
- Fine, I. V., R. E. Thomson, **W. W. Chadwick, Jr.**, E. E. Davis, and C. G. Fox (2016), Statistical features of deep-ocean tsunamis based on 30 years of bottom pressure observations in the northeast Pacific. Abstract NH41A-1771 presented at 2016 Fall Meeting, AGU, San Francisco, Calif., 12-16 Dec.

- Haney, M., G. Tepp, J. Lyons, D. Bohnenstiehl, **W. W. Chadwick, Jr., S. G. Merle**, R. P. Dziak, D. Fee, and C. K. Searcy (2017), Hydroacoustic observations of recent submarine eruptions at Ahyi and Bogoslof volcanoes. Abstract presented at the Seismological Society of America Annual Meeting, 18-20 April, Denver, Colorado
- Kane, R., N. Raineault, R. Embley, **S. Merle**, P. Girguis, O. Irish, M. Lubetkin, C. German, L. Levin, M. Cormier, C. Caldow, R. Freedman, E/V Nautilus Mapping and ROV Dives Reveal Hundreds of Vents along the West Coast of the United States, 2016 AGU Fall Meeting
- Merle, S. G.**, R. W. Embley, N. Raineault, H. P. Johnson, E. Sampaga, T. Baumberger, T. K. Lau, Water column methane bubble stream data analysis and visualization from a survey of the U.S. Cascadia continental margin, 2016 AGU Fall Meeting
- Paduan, J. B., **W. W. Chadwick, Jr.**, D. A. Clague, M. Le Saout, D. W. Caress, H. Thomas, and D. R. Yoerger (2016), High-resolution AUV mapping of the 2015 flows at Axial Seamount, Juan de Fuca Ridge. Abstract OS41C-1990 presented at 2016 Fall Meeting, AGU, San Francisco, Calif., 12-16 Dec.
- Paduan, J. B., D. A. Clague, **W. W. Chadwick Jr.**, D. W. Caress, B. M. Dreyer, M. Le Saout, and H. J. Thomas (2017), Examination of the Axial 2011 and 2015 lava flows from high-resolution AUV bathymetry and ROV dives. Abstract presented at the AGU Chapman Conference on Submarine Volcanism, 30 January-3 February, Hobart, Tasmania.
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Chadwick, W., J. Paduan, D. Clague, B. Dreyer, **S. Merle**, **A. Bobbitt**, D. Caress, B. Philip, D. Kelley, and S. Nooner (2016), Interpreted outlines of the 2015 lava flows and eruptive fissures at Axial Seamount, Juan de Fuca Ridge (investigator William Chadwick). Integrated Earth Data Applications (IEDA). doi: <http://dx.doi.org/10.1594/IEDA/323598>.

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Resing, J.A., **W.W. Chadwick Jr.**, S.L. Walker, **S.G. Merle**, E.T. Baker, and C.L. Kaiser (2016): Raw Near-Bottom CTD and Magnetometer Data (ASCII format) from the Izu-Bonin-Mariana Volcanic Arc acquired by AUV Sentry during the Falkor expedition FK151121 (2015). Integrated Earth Data Applications (IEDA), doi: 10.1594/IEDA/323566, Published data set.

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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: 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 long-term ocean bottom hydrophone (OBH) data set at Axial Seamount that includes in-situ measurements from two seafloor eruptive episodes. J. Haxel also contributes effort toward processing and analysis of Ross Sea, Antarctica hydrophone array recordings for ice generated signals.

Assistant Professor Haru Matsumoto continues technological development on a hydrophone winch system with an in water test in Puget Sound, WA in early October 2016. The winch can be deployed under sea ice cover and remain submerged for extended time periods. When the surface is clear, the winch unreels a buoy with satellite telemetry to the sea surface and transmits diagnostic data back to shore. The winch system will undergo an ocean test in July 2017 off Newport, OR for one week and then be shipped out for a year-long deployment in the Arctic in September 2017. Additionally, H. Matsumoto continues development of a near real time acoustic detection and monitoring system using a surface buoy connected through an acoustic modem link to sensor packages on the seafloor. This system is being developed for coastal application at the Northwest National Marine Renewable Energy Center's South Energy Test Site off Newport, Oregon. The new RAOS II 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.

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 San Diego, CA in February 2017 aimed at Ishmael software use and applications for marine mammal studies.
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, and ambient noise studies from recordings in Challenger Deep, Marianas Trench.

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 prepared a manuscript that introduces 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, assists in the organization and logistical operations of the NRS hydrophone network, Ross Sea hydrophone arrays, and other key hydrophone related projects. She completed a sea safety survival training course at OSU's Hatfield Marine Science Center Ship Operations in April 2017.

Publications:

Balcazar, N.E., H. Klinck, **S.L. Nieukirk, D.K. Mellinger**, K. Klinck, R.P. Dziak, and T.L. Rogers (2017): Using calls as an indicator for Antarctic blue whale distribution and occurrence across the southwest Pacific and southeast Indian oceans. *Mar. Mamm. Sci.*, 33(1), 172–186, doi: 10.1111/mms.12373.

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Haver, S.M., H. Klinck, **S.L. Nieukirk, H. Matsumoto**, R.P. Dziak, and J.L. Miksis-Olds (2017): The not-so-silent world: Measuring Arctic, equatorial, and Antarctic soundscapes in the Atlantic Ocean. *Deep-Sea Res. I*, 122, 95–104, doi: 10.1016/j.dsr.2017.03.002.

Küsel, E.T., T. Munoz, M. Siderius, **D.K. Mellinger, and S. Heimlich** (2017): Marine mammal tracks from two-hydrophone acoustic recordings made with a glider. *Ocean Sci.*, 13, 273–288, doi: 10.5194/os-13-273-2017

Küsel, E.T., M. Siderius, and **D.K. Mellinger** (2016): Single-sensor, cue-counting population density estimation: Average probability of detection of broadband clicks. *J. Acoust. Soc. Am.*, 140(3), 1894–1903, doi: 10.1121/1.4962753.

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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 Leonardardi, 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 sent 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: With the protocols now under control following the initial 2015 curation efforts in the OSU Marine and Geology Repository (OSU-MGR) for the ROV rocks collected

with the R/V Okeanos Explorer, we have been processing the incoming rocks from the 2016 and 2017 seasons in fast order.

Once the rocks arrive at the OSU-MGR, Dr. Anthony Koppers, with assistance from his research assistant Dr. Kevin Konrad, verify that all samples were received in accordance with the documentation and database. Then the samples are boxed, labeled with QR codes and IGSN numbers, photographed, and bagged. Next 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 double-polished thin sections. When the polished thin sections are returned, they are photographed in plain polarized light and cross polarized light, and described for their petrology (e.g. mineral contents, alteration, volcanic features, vesicles). All samples have been curated, packaged and are now made available online for 2016. The researchers are currently working on the first expeditions from 2017. Leg 1702 samples are being cut and bagged; Legs 1703 and 1704 are at the OSU-MGR waiting to be processed. We expect Leg 1702 to be finished and available online by the end of September 2017; Legs 1703-1704 likely will follow shortly after and will be available online by the end of October 2017. The final batch of rocks is expected to arrive at the OSU-MGR in the Fall of 2017. These rocks will be online in the early part of 2018.

All data, metadata and imagery has been entered into the OSU-MGR database and presented online.

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.

TASK 3

Theme: Seafloor Reflectance Mapping

Amendment 1: Seafloor Reflectance Mapping for the U.S. Virgin Islands

Funded: \$24,998

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: A key project objective during the current reporting period was the generation of seafloor relative reflectance mosaics for the full St. Thomas - St. John project site flown with the EAARL-B. The input to the procedures include peak amplitude (“intensity”) values extracted from the portions of the return waveforms corresponding to the seafloor return. The main steps in the workflow (Wilson, 2017) include: noise removal, depth correction, incidence angle correction, iteration, histogram normalization, gridding, and quality assurance. A relative reflectance mosaic, generated from over 84 million data points and covering ~120 km², was delivered to NOAA CCMA Biogeography Branch on April 3, 2017. Subsets of the relative reflectance mosaic, indicating prominent bedforms and a range of benthic habitat types, are shown in the screenshots in Fig. 1.

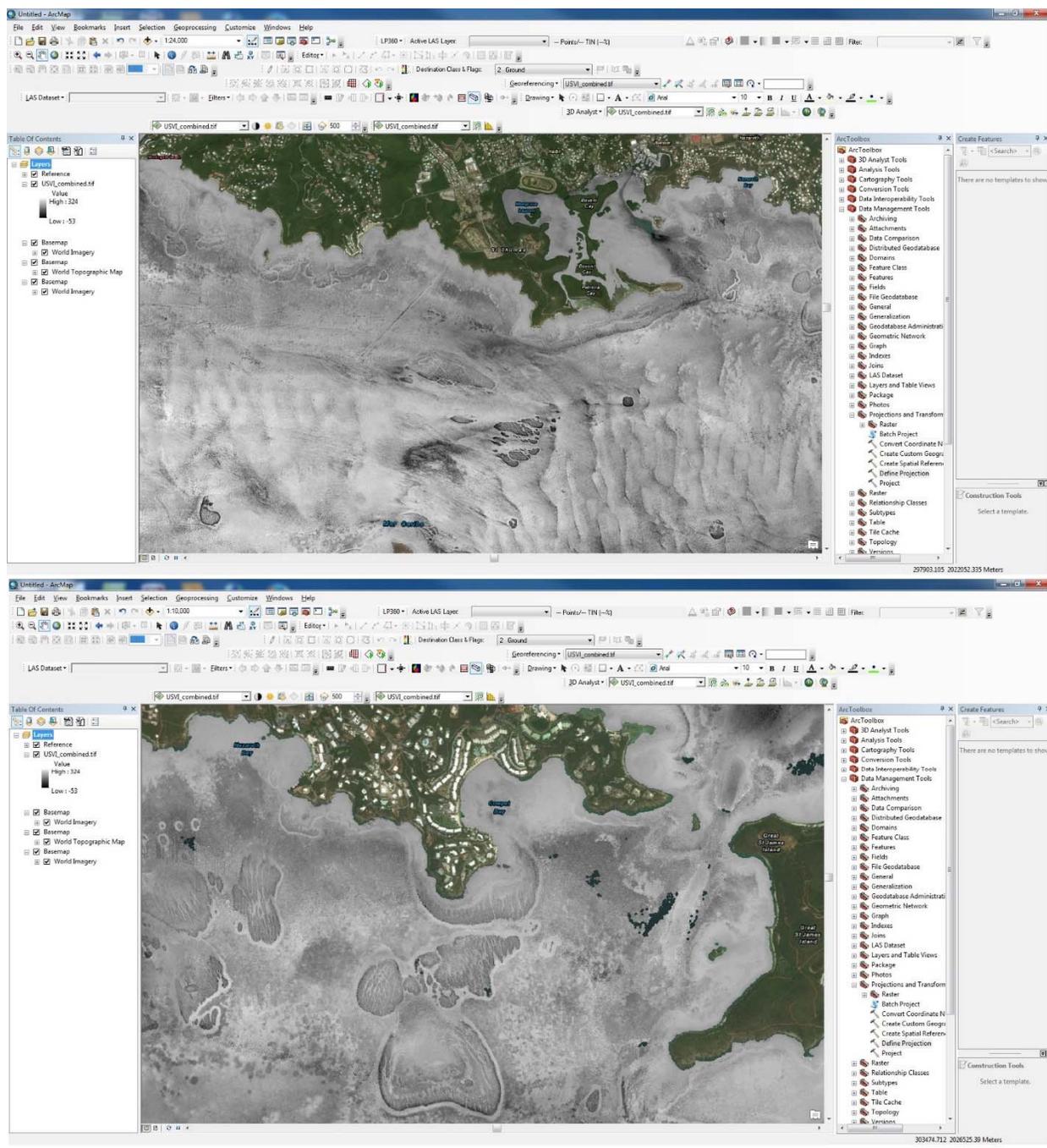


Figure 1: Screenshots of St. Thomas relative reflectance mosaic showing bedforms and a variety of benthic habitat types.

Some of the corrections were particularly challenging to develop, due to the unique design characteristics of the EAARL and EAARL-B, such as the scan pattern that passes nearly through nadir on each scan line. Additional challenges specific to the St. Thomas - St. John project site included the exceptionally large data volumes, the temporal span of the project (numerous flight days) and the changing environmental conditions (water clarity, sun angle, cloud cover, wind and wave conditions, etc.) during the acquisition. These challenges were overcome by refining and

enhancing the data-driven correction procedures developed by the OSU researchers in earlier work, as well as by incorporating new processing procedures (Wilson, 2017).

The second focus of the OSU researchers in the current reporting period was the development of tools and procedures for generating corrected waveform feature grids (raster data sets) for the Flat Cays project site to facilitate enhanced benthic habitat mapping and biological assessments. The key insight underlying this portion of the collaborative research project is that the shapes of the return lidar waveforms—in particular the subsets of the digitized waveforms corresponding to the bottom return—can contain information on seafloor composition and cover type. For example, relatively flat, featureless regions of the seafloor typically result in compact, unimodal, relatively symmetric return waveforms, while the presence of coral or seagrass can affect the waveform shape in a number of ways, such as stretching, skewing, attenuating, or introducing multiple peaks into the bottom return. By computing a number of simple, shape-based metrics computed from the return waveform (Parrish et al., 2014), such as area under the curve (numerical integral), peak amplitude (calibrated intensity), asymmetry (skewness) and width (standard deviation), it may be possible to obtain enhanced information about seafloor composition and perhaps to predict indicators of coral health. Flat Cays provides an ideal test location for this investigation, due to its high species richness, range of seafloor characteristics, and dense EAARL-B data coverage from the 2014 flights. The OSU researcher and NOAA collaborators conducted fieldwork (diving and underwater video acquisition) at this site in summer 2016 for use in future project phases.

The process used by the OSU researchers to generate the waveform feature grids started with software for computing the full set of features from the return waveforms. The algorithms were originally developed by Dr. Parrish in earlier work (Parrish et al., 2014) and implemented in ALPS by David Nagle of USGS. After running this software on the Flat Cays data, noise removal was performed using a random consensus filter, followed by normalization and artifact removal. Final waveform feature grids generated through this process were delivered to NOAA CCMA on January 18, 2017 (Figure 2). Details of the procedures used to generate these final data products are contained in Wilson (2017), the M.S. thesis of OSU Graduate Research Assistant, Nick Wilson, who was supported under this CIRMS project.

The next steps will include using the data products generated in this work to update the benthic habitat maps of the project site. The full suite of waveform feature grids generated for the Flat Cays site will be evaluated for their usefulness in biological assessments. For example, these waveform features may prove useful in assessing species richness, canopy cover, coral health, and other parameters of interest to scientists studying USVI coral reef ecosystems. Additionally, the OSU researcher are collaborating with the CCMA Biogeography Branch on a related project involving bathymetric mapping from unmanned aircraft systems (UAS).

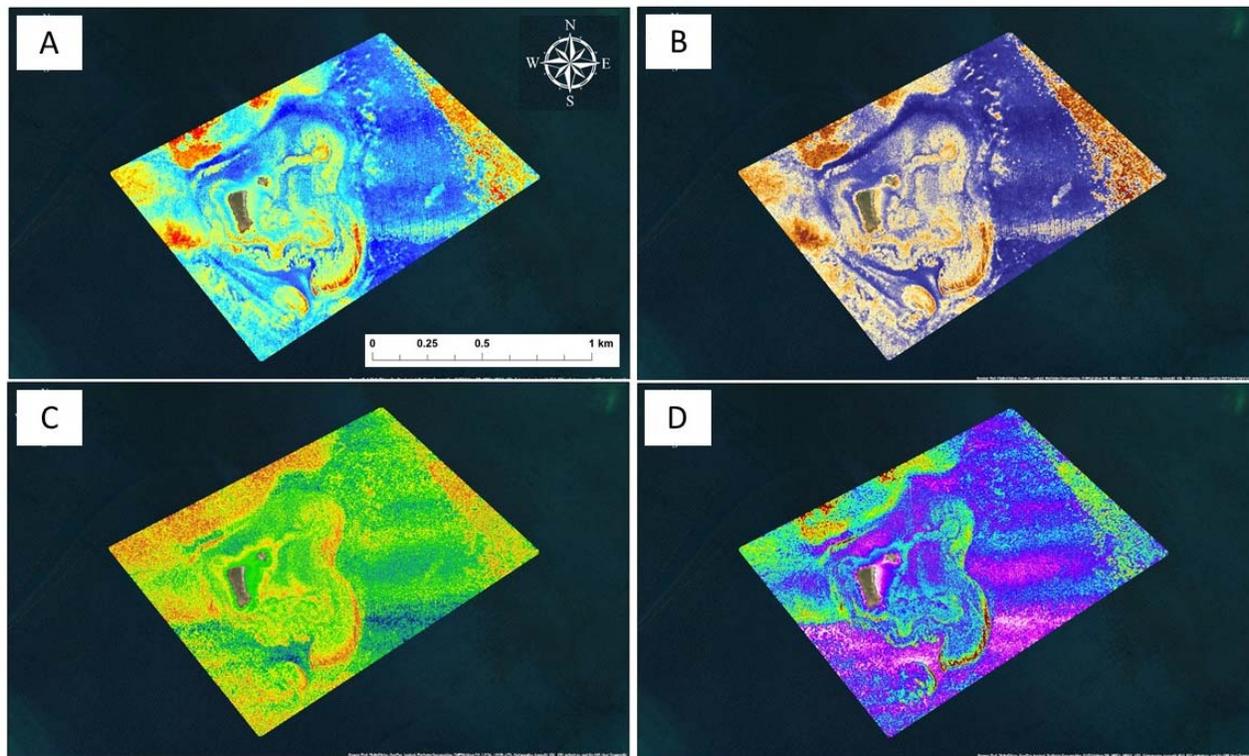


Figure 2: Gridded waveform features for Flay Cays project site. A) peak amplitude (calibrated intensity) of bottom return; B) area under the curve (numerical integral) of bottom return; C) asymmetry (skewness) of bottom return, and D) spread (standard deviation) of bottom return.

Presentations:

Dr Parrish attended and presented at the 17th Annual Coastal Mapping & Charting Workshop of the Joint Airborne Lidar Bathymetry Technical Center of Expertise (JALBTCX) in Silver Spring, Maryland.

In July 2016, Dr. Parrish delivered a OneNOAA Science Seminar, which included an overview of this project and preliminary results.

Publications:

Costa, B., T. Battista, **C. Parrish**, and N. Wilson, 2016. Evaluating the Utility of EAARL-B Lidar Waveforms for Mapping Coral Reef Habitats. The 17th Annual Coastal Mapping & Charting Workshop of the Joint Airborne Lidar Bathymetry Technical Center of Expertise (JALBTCX), 19-21 July, Silver Spring, Maryland.

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Parrish, C.E., J.N. Rogers, and B.R. Calder, 2014. Assessment of Waveform Shape Features for Lidar Uncertainty Modeling in a Coastal Salt Marsh Environment. *Geoscience and Remote Sensing Letters*, Vol. 11, No. 2, pp. 569-573.

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Parrish, C.E., J.A. Dijkstra, J.P.M. O’Neil-Dunne, L. McKenna, and S. Pe’eri, 2016. Post-Sandy Benthic Habitat Mapping Using New Topobathymetric Lidar Technology and Object-Based Image Classification. *Journal of Coastal Research*, SI 76, pp. 200-208.

Parrish, C.E., N. Forfinski, and N. Wilson, 2016. Advances in Seafloor Mapping with New Spaceborne and Airborne Lidar Systems. The 17th Annual Coastal Mapping & Charting Workshop of the Joint Airborne Lidar Bathymetry Technical Center of Expertise (JALBTCX), 19-21 July, Silver Spring, Maryland.

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Wright, C.W., C. Kranenburg, T.A. Battista, and **C. Parrish**, 2016. Depth Calibration and Validation of the Experimental Advanced Airborne Research LiDAR, EAARL-B. *Journal of Coastal Research*, SI 76, pp. 4-17.

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

Funded: \$477,619

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: The research supported by this grant advances the multidisciplinary science of ecosystem services. Our focus is on natural infrastructure, which we define broadly as a physical stock (i.e., durable physical quantities) 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 planned 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, we will measure 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. We will then develop optimal investment plans for each infrastructure type. Our study area encompasses the coast and estuaries of Oregon. In order to analyze approaches that maximize the TEV of a natural infrastructure investment, required information includes how the investment is 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 will 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 will address these two challenges by joining state-of-the-art non-market valuation methods with empirical ecological and engineering-economic models of natural infrastructure investment. The resulting models will yield generalizable methodological insights that will extend the frontier of ecosystem service science.

Methodologically our economics work is separated into three 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 develop an extensive choice experiment survey to estimate WTP for ecosystem service benefits that accrue as public goods benefits to a wide variety of coastal and non-coastal residents. In **Track III**, we develop a natural infrastructure dynamic investment model (NIDIM) to analyze how natural infrastructure placement can maximize the net present value of ecosystem services.

Progress Report: The second annual Advisory Board meeting was held in Newport, Oregon on April 14th, 2017. This was a full day meeting that included research presentations and updates, breakout sessions, and discussions on stakeholder engagement. Since the meeting, several board members have reached out to discuss outreach opportunities with coastal stakeholders in Oregon, a potential for a pilot project for dune management in Tillamook County, and development of a research project that would directly inform operations of a state agency. These topics are discussed further in the “Project Outcomes” section below.

The progress made since the beginning of this reporting period (October 2016) is highlighted below by detailing the contributions of each team member.

Environmental economist 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. Dundas has organized team meetings, planned the advisory board meeting, developed a project website, participated in outreach related to grant activities (e.g. 5th Oregon Coast Economic Summit and the Oregon Ocean Science Trust Summit) and contributed to a majority of the research meetings/discussions related to this

project. Dundas is also the coordinating economist for both the Coastal Protection and Coastal Land Use Pathways where he has led housing market and spatial data collection efforts. Dundas and co-PI Lewis are currently finishing the first of multiple housing market analyses of the effects of coastal protection features on shoreline property values. These Track I modeling efforts are providing values of willingness to pay for coastal protection from both grey (i.e. rip-rap revetments) and natural (i.e. dunes) infrastructure while also differentiating values for “chronic” (i.e. sea-level rise) and “acute” (i.e. tsunami inundation) coastal risks. Dundas and graduate student Jason Beasley have developed an empirical model of coastal landowners’ investment in grey infrastructure and preliminary results are currently being evaluated. Results from the efforts described above will be integrated into 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 Beasley have continued scoping the potential for urban natural infrastructure as a vertical evacuation option for tsunami inundation in Seaside, Oregon. Preliminary work at integrating evacuation, transportation, and economic models is currently ongoing with results expected in 2018. Dundas has 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 also beginning development of a third survey instrument designed to elicit preferences for different types of coastline management from both coastal and non-coastal households (Track II).

Environmental economist David Lewis (Professor, Department of Applied Economics) is the coordinating economist for the Estuary Pathway of research and has collaborated with other team members and NOAA economist and Board member Lew to develop a choice experiment survey on restoring Oregon Coast Coho salmon through estuarine conservation (Track II). The survey has been placed through multiple focus groups and has been widely vetted by economists, and environmental scientists and managers familiar with Oregon Coast coho. The survey will form the foundation for placing non-market values on estuary conservation actions that generate public goods. Lewis has led the experimental design for the survey and it is being placed in the field in summer of 2017 to a random sample of Pacific Northwest residents. Lewis and co-PI Hacker have recruited fisheries ecologist Mark Scheurell from NOAA to help develop a new data-driven biological model that links habitat investments such as salt marsh restoration to populations of Oregon Coast Coho. Preliminary data has been collected for the Coho biological model and preliminary estimation will commence in summer of 2017, led by Scheurell and graduate student Caitlin Magel. Lewis and graduate student Cassie Finer 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, and preliminary results are expected by late summer 2017. Lewis has also collaborated with PI Dundas on the Coastal Protection pathway and has been working with other team members to develop preliminary results for a hedonic analysis of the effects of alternative shoreline grey infrastructure on shoreline property markets, and an empirical model of coastal landowners’ investment in grey infrastructure.

Natural resource economist David Kling (Assistant Professor, Department of Applied Economics) worked in collaboration with the PI Dundas and co-PI Lewis to implement the economic research component of the project. Kling is serving as the economist coordinator for the project's Dune Landscape pathway. Working with PI Dundas and co-PIs Hacker and Ruggiero, and graduate student Tu Nguyen, Kling was the primary author of a nonmarket valuation survey focusing on natural infrastructure and ecosystem services provided by Pacific Northwest coastal dunes and sandy beaches (Track II). Kling participated in focus-group testing of the draft survey instrument in November 2016 (in Sacramento) and February 2017 (in Portland, OR). He also began work on development of a dynamic ecological-economic model of coastal dune capital management (Track III). In addition, with PI Dundas and co-PI Cox, and graduate student Jason Beasley, he collaborated on preliminary work on a model for valuing expected tsunami risk benefits provided by green infrastructure. In the 2017-2018 project period, Kling will coordinate revision to the survey instrument, with the goal of deploying it to a random sample of the public in mid-to-late 2017. Kling will also coordinate development of modeling tools for support and planning of natural infrastructure management, with primary application to coastal dunes and sandy beaches.

Coastal Geomorphologist Peter Ruggiero (Associate Professor, College of Earth Ocean and Atmospheric Sciences) continued to work with the rest of the team to develop and refine the Dune Landscape pathway. Ruggiero hired Civil and Construction Engineering PhD student Paige Hovenga to help provide research and logistical support for this pathway. 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 is serving as the starting point for one of the three primary research tracks in the Dune Landscape Pathway – *stylized optimization of dune shape for various ecosystem services*. Ruggiero's group is also making progress on the development of a 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). To improve our understanding and work towards a predictive capability for beach/dune recovery processes, we have developed a beta version of the modeling tool Windsurf, which couples separate open-source numerical models for subtidal morphodynamics related to waves and currents (XBeach; Roelvink et al., 2009), subaerial morphodynamics related to wind shear and vegetation (Coastal Dune Model; Durán and Moore, 2013), and multi-fraction Aeolian sediment transport (AeoLiS; Hoonhout and de Vries, 2016). Presently, Windsurf consists of each of these three numerical models run in series, with information exchanged between the models at user defined time steps through a Matlab-based coupler. Under this framework both accretive and erosive conditions can be simulated, allowing coastal evolution to be explored on a wide range of time scales (hours to years). Furthermore, a front-end graphical user interface, the Coastal Recovery from Storms Tool (CReST), enables pre-processing capabilities to implement numerous coastal management strategies including beach and dune restoration, grass planting or removal, and coastal protection structures (e.g., sand fences) to be simulated within the modeling framework. This modeling framework may ultimately inform the empirical approach being developed by the Dune Landscape Pathway.

Coastal ecologist, Dr. Sally Hacker (Professor, Department of Integrative Biology), has worked with the research team to provide information on the ecosystem function and services portion of the overall project. She has focused on the ecological aspects of the Estuary and Dune Landscape pathways. 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 helping to develop drafts of the willingness to pay choice experiment surveys that are underway. 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.

Dr. Hacker has recruited two graduate students (Caitlin Magel and Katya Jay) to help provide research and logistical support for each of the pathways. In the Estuary pathway, Caitlin Magel is working with Dr. Mark Scheuerell at the National Marine Fisheries Service (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. She is collecting 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). She will start running analyses over the summer 2017. For the dune pathway, Dr. Hacker's graduate student Katya Jay is working with Dr. Peter Ruggiero's graduate student, Paige 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.

Geomatics Engineer Chris Parrish and his students are currently working to assemble coastal geospatial data, including topographic and bathymetric LIDAR, multispectral imagery, tidally-referenced shoreline, existing habitat maps, and land cover maps. Work performed by the Geospatial Group in this reporting period has focused on providing geospatial information and products supporting the Coastal Protection Pathway and the Dune Landscape Pathway. Two databases have been generated in support of the Coastal Protection Pathway, and several maps were produced to support the work being done under the Dune Habitat Pathway. In collaboration with OPRD and Board member Callahan, we have also conducted research on use of light detection and ranging (LIDAR) data for identification and analysis of shore protection structures along the Oregon Coast. This work, which ties into the Coastal Protection Pathway, will also be the focus of the M.S. thesis of supported graduate student, Laura Barreiro Fernández.

The two databases comprised numerous attributes associated with parcels extending the length of the Oregon coast: one including 1,282 parcels and the other including 9,536 parcels (referred to as the Goal 18 parcels, hereafter G18P). The parcel attributes include: presence/absence of shoreline protection structures (SPS) in front of the parcel, presence/absence of beach, cliff or ramp in the parcel, short term and long term erosion rates in parcels and distances from building's centroids to existing SPS, potential SPS shoreward of the parcel, NOAA CUSP shoreline (shoreline officially adopted by OPRD), cliffs of varying heights (< 5 m to > 35 m), beach and ramps, and features of interest (e.g., lighthouses, sea stacks). The extraction of building centroids was carried out using LIDAR data collected in 2009 by DOGAMI. The

automatic detection of structures proved to be accurate, with a high rate of success (Fig. 1). The potential SPS locations were identified using a semi-automatic approach that also used the DOGAMI LIDAR dataset as input. Digital Elevation Models (DEM) were created for the adjacent zone of the shoreline along the Oregon Coast, and contours were derived. Next, the contours corresponding to the elevations of potential SPS were visually selected. Using this procedure for each zone of the coast, a line feature layer was obtained without the need for manually delineation, saving time and reducing subjectivity in the process.

The two research projects conducted by the Geospatial Group helped to define the best approach for LIDAR data processing and analysis to support project needs. An analysis of two software packages (LP360 and LAsTools) was performed to assess their performance in building footprint auto-extraction, with quantitative and qualitative accuracy assessments performed on the outputs. The conclusions led us to determine the best approach and software for detecting buildings and delineating their footprints. A semi-automatic method was designed for mapping

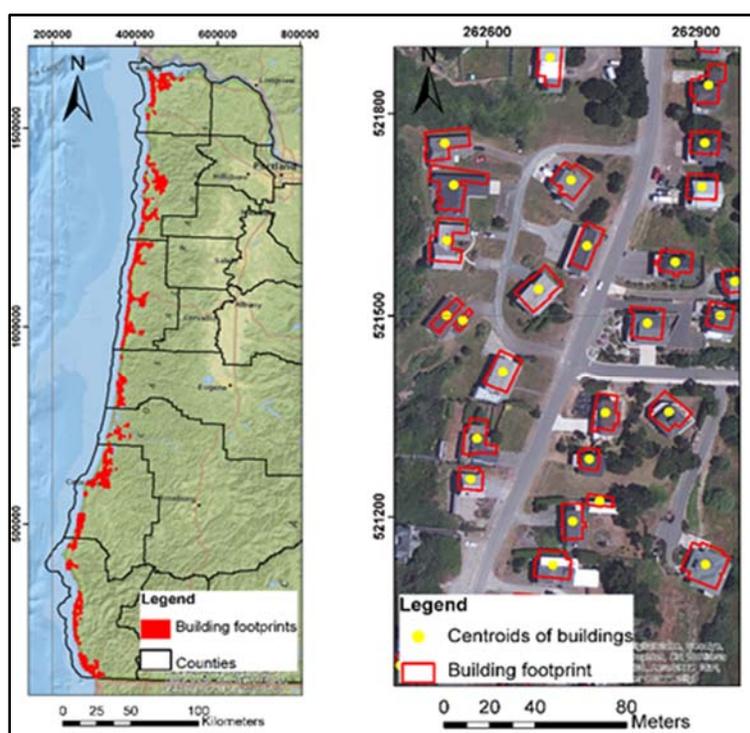


Figure 1. Automatic detection of the buildings: a) full extent, and b) detailed view of riprap structures using LIDAR data. The input data consisted of features layers derived from elevation and intensity information provided by LIDAR sensor (e.g., slope, aspect, curvature, etc.). The study area was located in Gleneden Beach, in Lincoln City, where there are significant riprap structures backed by bluff. A supervised, object-based image analysis (OBIA) classification was performed, and results showed a 92% success rate in mapping riprap (Fig. 2).



Fig 2. Mapping of riprap structures with LIDAR data. Light blue polygon shows the riprap classification.

The method appears highly promising for obtaining physical characteristics of these structures (e.g., elevation, width, slope, length, etc.), information that is valuable to the Coastal Protection Pathway and to OPRD. This work will be extended in the thesis research of team member, Laura Barreiro Fernández. The overall focus of this ongoing work is monitoring Shoreline Protective Structures (SPS) on the Oregon coast using remote sensing. The types of structures being analyzed include riprap, seawalls and dynamic revetments, and the remote sensing technologies being utilized include LIDAR and aerial imagery collected with conventional airplanes and unmanned aircraft systems (UAS). The research will define a methodology to be used by OPRD, the responsible agency for SPS management in Oregon. To date, relatively little work has been done on monitoring these types of SPS via remote sensing, so the results of this work are anticipated to be a valuable outcome of this portion of the project.

Coastal engineer Daniel Cox has worked with PI Dundas, co-PI Kling and graduate student Jason 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 an area to explore a model for valuing expected tsunami risk benefits provided by green infrastructure.

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.

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.

Ruggiero P., S.D. Hacker, E. Seabloom, and P. Zarnetske. In Press. 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 xxx-xxx in Moore, L., B. Murray. Barrier Dynamics and the Impacts of Climate Change on Barrier Evolution, Springer.

Presentations:

Dundas, S.J., S.D. Hacker, D. Kling, D.J. Lewis, P. Ruggiero. NOAA NCCOS Advisory Board Meeting. April 2017. Hatfield Marine Science Center, Newport, OR.

Biel, R., **S.D. Hacker, P. Ruggiero.** December 2016. Analysis of beachgrass ecomorphodynamics and foredune morphology along Pacific Northwest coastal dunes using a Bayesian network. American Geophysical Union meeting, San Francisco, CA.

Biel, R., **S.D. Hacker, P. Ruggiero.** 2016. Predicting coastal sand dune morphology and coastal hazard exposure in the U.S. Pacific Northwest using a Bayesian network. 101th Ecological Society of America, Fort Lauderdale, FL.

Dundas, S.J., D.J. Lewis. June 2017. Housing market response to a coastal protection option: Evidence from the Oregon Coast. Association of Environmental and Resource Economists (AERE) Annual Meeting, Pittsburgh PA.

Dundas, S.J. D.J Lewis. February 2017. Estimating Values of Coastal Protection from Chronic and Acute Risks. W-3133 Annual Meeting, Carlsbad, CA.

Ruggiero, P., December 2016. Beach and dune building processes: Linking Nearshore to Backshore and Events to Decades, American Geophysical Union Fall Meeting, San Francisco, CA.

Ruggiero, P. December 2016. Beach and dune building processes, CEOAS G&G Fall Seminar Series, Corvallis, OR.

Amendment 2: Towards Optimizing the Determination of Accurate Heights using GNS

Funded: \$50,049

OSU RESEARCH STAFF: Daniel Gillins, Professor-resigned Oct. 2016; Jihye Park, Asst. Professor, Civil & Construction Engineering-current
NOAA TECHNICAL LEAD: Mark Armstrong, NOS

Project Background: Over the past two fiscal years in collaboration with National Geodetic 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 major tasks to be carried out during the FY2017 are categorized into roughly three steps: 1) GNSS data processing for GNSS projects in NGSIDB using the OPUS-projects, 2) Analyzing the processing results, and 3) Generating the surveying guidelines. Currently, the data processing and the analysis of the results are ongoing. In this report, the workflow and the accomplished OPUS-Projects processing results are summarized.

1) The selection of NGSIDB projects with best-case scenario

To verify the expected positioning performance, the GNSS surveying projects should be sorted based on the various criteria such as field surveying condition, CORS network data availability, etc. For this task, we applied an initial filter for various factors which might affect the accuracy of the surveying results. We started selecting the GNSS project with the best case scenarios by defining a filter with the following criteria:

- Surveying plan and occupation: The projects with less than 5 marks, that were performed prior to 2010, or contained less than 2-hr of data were filtered out.
- The network stability: For the network stability, the velocities of the surveying area were considered in the long-term analysis. This verification was done based on the published velocity of the nearby CORS stations.

From the filtering criteria, 15 over 30 projects were identified as the candidates of the best scenario which is shown in Table 1.

Table 1. Initial filter applied to verify the best case of the project

Criteria	Projects Removed	Number of filtered projects	Number of remaining projects
Prior to year 2010	GPS1404	1	29
No. of marks < 5	FAAAF, GPS2859, GPS2876, GPS2978, and GPS2991	6	24
Duration < 2 hours	FAA2G2, FAABRD, GPS2870, GPS2888, GPS2898, and GPS2984	12	18
Horizontal velocities > 7 cm/year	GPS2933, GPS2939, and GPS3045	15	15

Figure 1 shows the locations of the selected 15 projects. Most projects include the eastern and midwest regions of the United States, and there are relatively less number of projects in western and central regions.

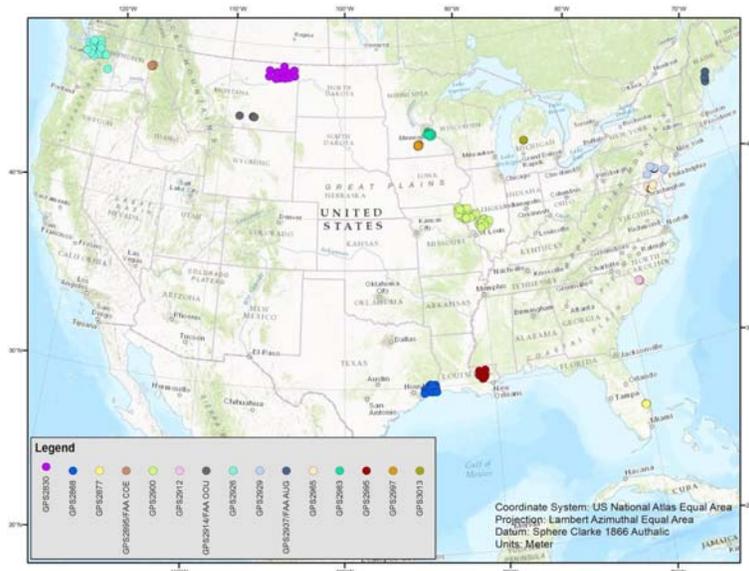


Figure 1. The location of the selected projects after applying initial filter. Furthermore, the atmospheric effects were examined. GNSS signals are affected by the atmospheric conditions. Specially, the ionosphere is one of the major error sources in relative GNSS positioning where the free electrons in the ionosphere generate the phase advances and group delays of radio signals. The Space Weather Prediction Center (SWPC) monitors planetary K-index (Kp) that indicates global geomagnetic activity which dynamically increases the Total Electron Content (TEC) and causes difficulties in GNSS data processing. Figure 2 shows the example of the Kp issued by the NOAA SWPC. The Kp

with the range of 0-3 is labeled as the low ionosphere activity, the K_p larger than 4 regards to high ionosphere activity, and the K_p equal to 4 indicates the moderate ionosphere activity. In order to summarize the atmospheric effects for the remaining 15 projects, the percentage of days which contained the K_p larger than 4 was computed and is provided in Table 2 whose information was considered in the analysis of the processing results using the OPUS-Projects.

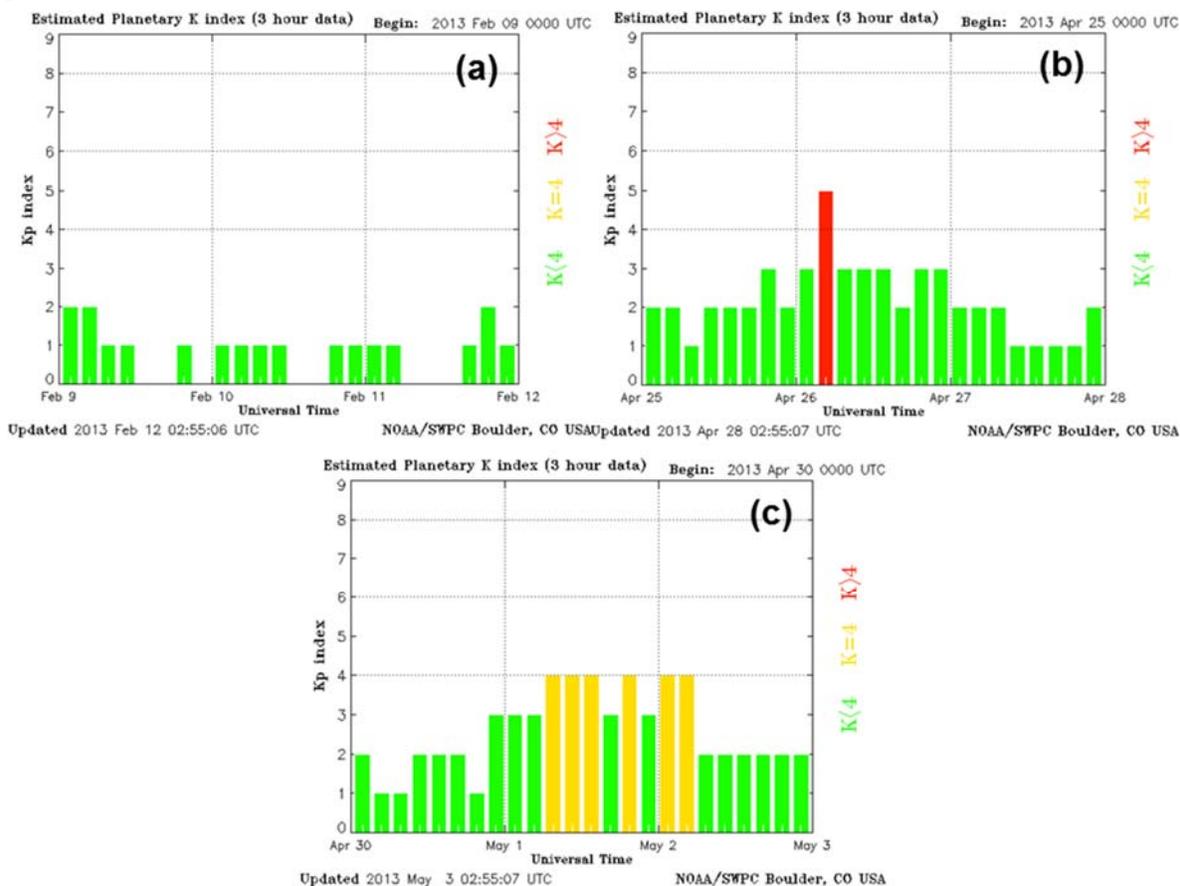


Figure 2. Example of the planetary K_p published by SWPC: (a) Low ionosphere activity ($K_p < 4$), (b) High ionosphere activity ($K_p > 4$), and (c) Moderate ionosphere activity ($K_p = 4$)

Table 2. Summary of the space weather activity for projects which passed the initial filter

Project ID	Num. survey days	% of survey days $K_p > 4$
GPS2914/FAAOOU	2	0
GPS2937/FAAAUG	2	0
GPS2895/FAACOE	2	0
GPS2830	10	10
GPS2868	9	0
GPS2877	3	33
GPS2900	12	0

GPS2912	2	0
GPS2926	22	5
GPS2929	3	0
GPS2965	4	25
GPS2983	4	0
GPS2995	14	0
GPS2997	2	0
GPS3013	11	0

2) *Data processing using the OPUS-Projects*

The multi-GNSS constellations and the multi-frequency carrier phase data have been available, which offers the opportunities for precise and reliable positioning, navigation, and timing services. Since the existing NGS GPS surveying guideline was published almost 20 years ago, as well as the current modern GNSS in-operation, preparing a realistic updated/renewed guideline is demanding for national surveying to meet the accuracy requirements. To collect realistic evidence for publishing the new guideline, various cases in the GNSS surveying project were analyzed using the OPUS-Projects. For the network-based GNSS static session processing using the OPUS-Projects, Armstrong et al. (2015) recommended the central hub network design with the following components:

- Hub station: One CORS site within approximately 100 km of the project area
- Distant station: At least one CORS site that is more than 1,000 km away from the hub for the improvement of the tropospheric delay modeling
- Control stations: The nearby CORS sites for controlling the network within the distance of about 300 km from the project marks
- Baselines: The baselines should connect all surveying marks and the CORS sites to the hub

Figure 3 illustrates the recommended hub network design.

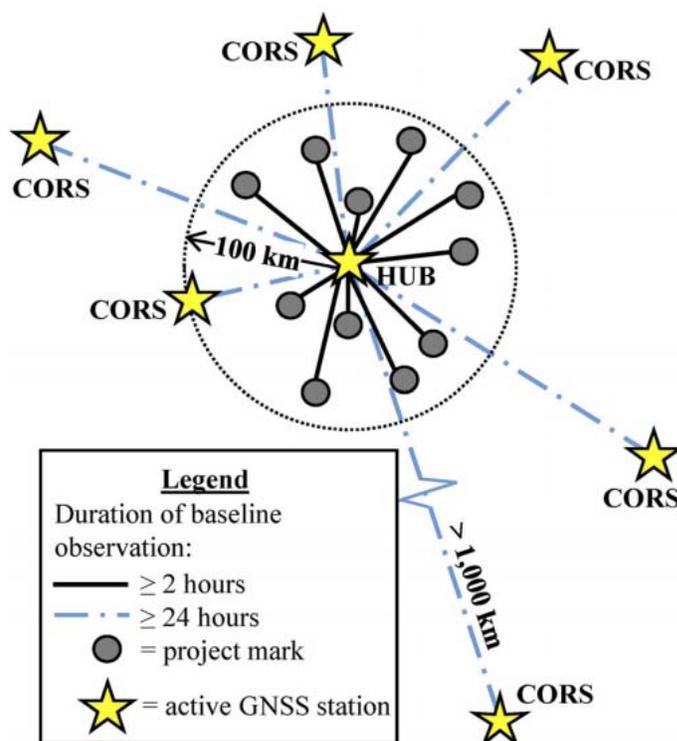


Figure 3. Hub network design recommended for the OPUS-Projects (Gillins and Eddy, 2016)

To select the reliable CORS sites, a list of CORS candidates for a hub network was created for each project based on the above-mentioned hub network design. Then, the time series plots of positioning errors (referred to as simply “time series plot”) at each CORS candidate were checked in order to validate the stability of the station. From the CORS candidates, the hub, the control, and distant stations were determined for every project. It should be noted that the future work should include more direct strategy for CORS candidates selection, for instance, by scoring (or ranking) the CORS candidates. Figure 4 shows an example of the short-term time series plots with their standard deviations, from which the stability and consistency of CORS candidates can be verified. There are various CORS conditions as shown in the time series plots in Figure 4. If a CORS is unavailable or there is some facility change, it would be marked as unstable site and excluded from the list of candidates. Table 3 provides an example of CORS selection for Project ID: GPS2912. The selected CORS sites are highlighted in yellow.

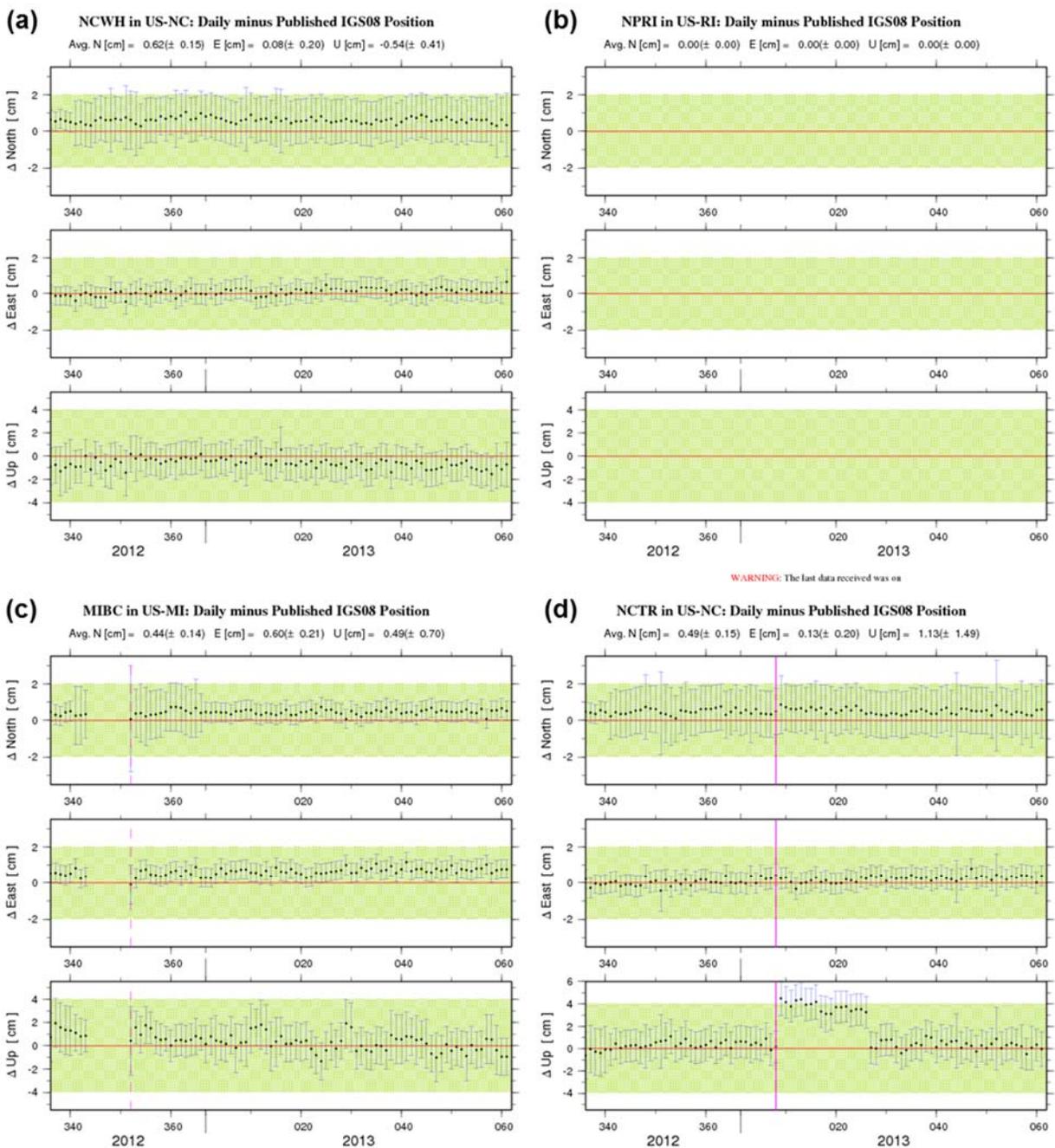


Figure 4. The time-series plots for CORS candidates: (a) Good condition, (b) Data unavailability, (c) Receiver and firmware change (pink dashed line), and (d) Antenna, radome, elevation, and cable change (pink solid line)

Table 3. Candidate stations for CORS selection (Project ID: GPS2912); the selected CORS are highlighted in yellow.

Type	CORS	uN	uE	uh	sN	sE	sh	2DRMS	3DRMS	Note	
HUB	<100km	NCWH	0.62	0.08	-0.54	0.15	0.2	0.41	0.67	0.96	
HUB	<100km	NCLU	0.73	0.06	0.41	0.17	0.17	0.53	0.77	1.02	
Control	<300km	SCWT	0.73	-0.11	0.52	0.15	0.18	0.44	0.77	1.03	
Control	<300km	NCJV	0.56	0.11	0.29	0.16	0.41	0.46	0.72	0.90	
Control	<300km	NCSF	0.63	0.15	0.12	0.11	0.16	0.51	0.68	0.86	
Control	<300km	NCTR	0.49	0.13	1.13	0.15	0.2	1.49	0.57	1.95	antenna, radome, elevation, cable change
Control	<300km	COLA	0.07	0.17	1.76	0.16	0.19	0.51	0.31	1.86	
Control	<300km	NCPO	0.09	-0.19	0.08	0.14	0.17	0.56	0.30	0.64	data unavailable during the first surveying day (014.2013)
Control	<300km	NCGO	0.55	0.19	0.24	0.16	0.18	0.48	0.63	0.83	
Control	<300km	NCKN	0.57	0.08	-0.15	0.17	0.15	0.5	0.62	0.81	
Distant	~1000km	ZME1	0.64	0.05	-0.02	0.2	0.22	0.75	0.71	1.03	
Distant	~1000km	ILUC	0.88	0.09	1.84	0.4	0.38	1.38	1.04	2.53	
Distant	~1000km	NYRM	0.47	0.33	0.27	0.16	0.23	0.59	0.64	0.91	
Distant	~1000km	NPRI	-	-	-	-	-	-	-	-	data unavailable
Distant	~1000km	MIBC	0.44	0.6	0.49	0.14	0.21	0.7	0.79	1.16	receiver, firmware change

Based on the CORS selection, the hub network for each project was designed and processed by the OPUS-Projects. After the session processing, the network adjustment was performed in order to determine the geodetic coordinates (latitude, longitude, and ellipsoid heights) with respect to NAD83 at epoch 2010. Currently, the processing for 14 projects is completed that includes the total of 300 baselines. The histograms in Figure 5 shows the baseline lengths, positioning RMS, and the ambiguity fixing rate of the sessions. From Figure 5(a), it can be found that about 60% of the baselines were shorter than 100 km. Figure 5(b) shows that the RMS follows a normal distribution with the mean of about 1.5 cm. In addition, it was confirmed that about 90 % of baselines fixed the integer ambiguity with 90% and higher success rate. Based on the statistics shown in Figure 5, it can be claimed that all the 14 projects were processed with an high level of accuracy.

Additionally, another experiment for 10 projects was conducted to validate the impact of distant CORS sites on the positioning results. For this experiment, the processing for each project was repeated by excluding the distant CORS sites in the hub network. As shown in Table 4, both scenarios show the similar level of RMS and fixing rate in overall, which demonstrates the

distant CORS sites do not have significant impact.

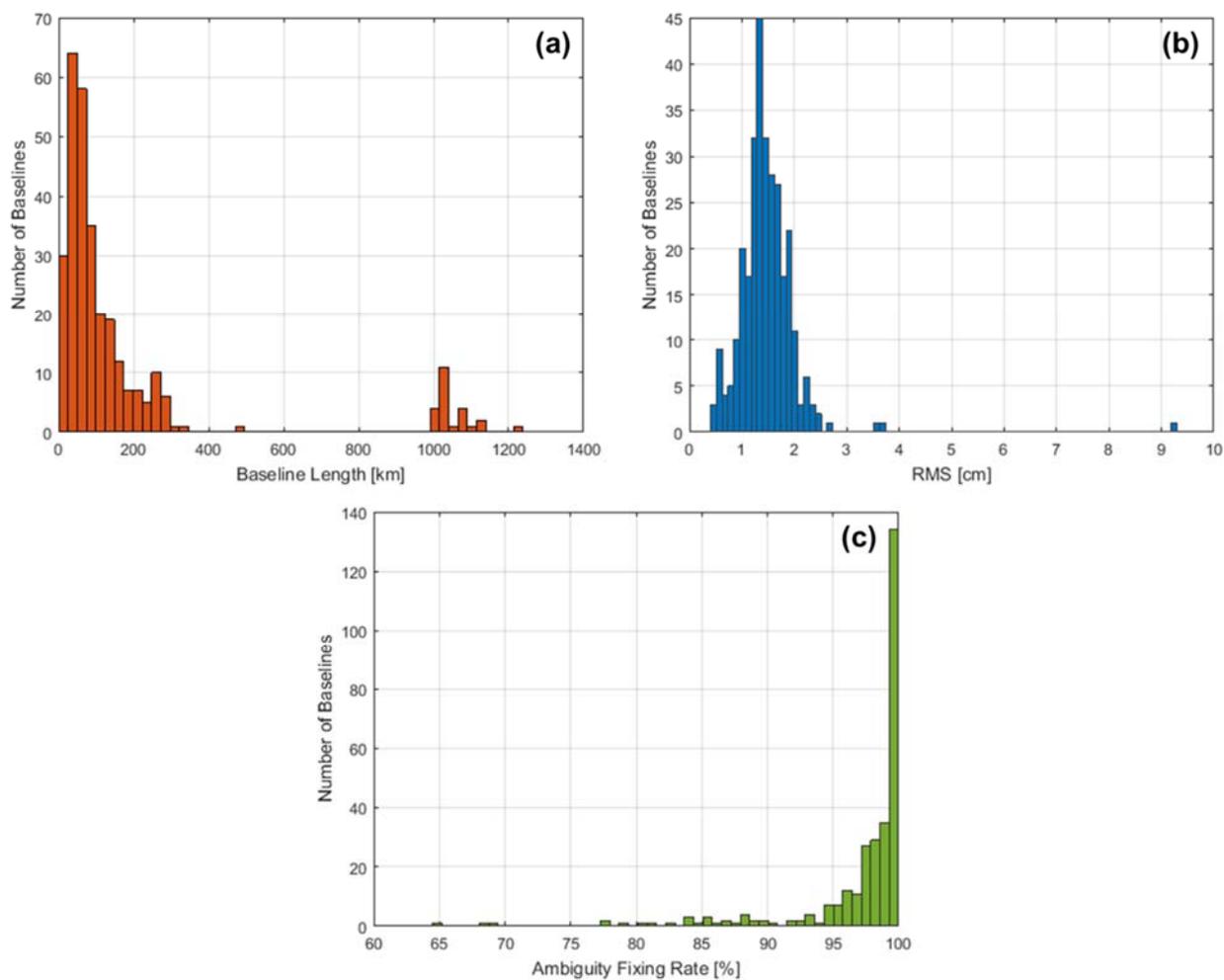


Figure 5. The histograms of baseline length, RMS and ambiguity fixing rate.

Table 4. The absolute discrepancy of positioning error on the surveying benchmarks by the original hub network design and the hub network without a distant CORS

	NAD_83(2011)			IGS08		
	East [mm]	North [mm]	Up [mm]	East [mm]	North [mm]	Up [mm]
Max	4.029	8.366	52.864	5.016	7.698	52.864
Mean	0.924	2.241	3.233	0.957	2.301	3.211
Min	0.000	0.000	0.000	0.000	0.000	0.000
RMS	1.233	3.016	6.394	1.274	3.139	6.394
Std.	0.819	2.027	5.539	0.844	2.143	5.552

Summary and Conclusion:

Prior to documenting the new guideline for the network-based GNSS positioning using the OPUS-Projects, the following steps were conducted:

1. 30 GNSS surveying projects in NGSIDB were analyzed and 15 best scenario cases were identified based on the filtering criteria characterized by 1) containing more than 5 static marks, 2) covering data time-interval longer than 2-hr 3) having low coordinate velocity.
2. The ionospheric condition of the surveying period was identified for each project. The ionospheric activity was evaluated based on the Kp index.
3. The session processing using the OPUS-Projects was performed. The hub network was formulated based on the recommended hub network design by Armstrong et al. (2015). A hub was determined from the CORS within approximately 100 km of the project area containing both the statically observed marks and the CORS sites. The nearby CORS sites (within 300 km of the project area) were applied to control the reference frame, and the distant CORS sites (approximately 1000 km away from the project area) were employed for the purpose of tropospheric delay modeling.
4. A scheme for the selection of reliable CORS sites was developed as follows:
 - a. A list of CORS candidates for the hub network of each project was created based on the hub network design recommendation.
 - b. Then, the time series plots for each CORS positioning error were checked in order to validate the stability of the station.
 - c. From the CORS candidates, the hub and the control stations were determined.

Up to now, 14 projects out of 30 projects were processed that include 300 baselines. About 60% of the baselines have a length of less than 100 km, the RMS of the positioning result represents a normal distribution with a mean of approximately 1.5 cm. In the case of ambiguity fixing rate, 90% of the baselines have a rate of higher than 90%. In addition, the examination of the distant CORS sites in the central hub network revealed that the scenarios with/without the distant CORS sites have a discrepancy of millimeter level, and thus, they do not affect the positioning significantly. However, the impact of the distant CORS must be further investigated, so the rest of the processing during this research project will follow the currently available recommendation of the network design, which involves the distant CORS.

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

Funded: \$201,831

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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. The proposed work will lead 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 will focus on 4 project sites, locations to be determined in consultation with the full project team and the program managers.

Project Progress: The research team has completed exploratory analysis of the satellite altimetry datasets to provide coastal information of the extreme climate sea level is being carried out. Assembled tide gauge data and developed time-dependent GEV statistical model to assess wave signals in tide gauge. Dr. Ruggiero and the research team completed identification of the study sites, initiated data assembly, and are developing the hybrid climate emulator to be use at the study sites. During the spring of 2017, Dr. Ruggiero and collaborators began setup of hybrid climate emulator for two sites (Kwajalein/ROI and San Diego/Coronado).

Publications:

K., **Ruggiero, P.** and Stockdon, H.F., 2017. The relative contribution of waves, tides, and non-tidal residuals to extreme total water levels on US West Coast sandy beaches. *Geophysical Research Letters*, DOI: 10.1002/2016GL071020.

Rueda, A., Vitousek, S., Camus, P., Tomas, A., Epejo, A., Losada, I.J., Barnard, P., Erikson, L., **Ruggiero, P.**, Reguero, B.G., Mendez, F.J., in revision. Global classification of coastal flooding climates. Submitted to *Scientific Reports*