Annual Progress Report
to
National Oceanic & Atmospheric Administration

NOAA Award# NA11OAR4320091A

No-Cost Extension

Reporting period: 7/1/16 – 6/30/17

Oregon State University

Cooperative Institute for Marine Resources Studies

This progress report covers updates of the projects that were still active during the no-cost extension reporting period. They are identified by Amendment Number and Title. All other projects are considered complete with progress reported on July 30, 2016 as final reports.

TASK 2

(PROJECTS SUPPORT NOAA STRATEGIC PLAN GOAL OF HEALTHY OCEANS AND CLIMATE ADAPTATION AND MITIGATION)

Theme: Marine Ecosystem and Habitat

Amendment 74: Indicators of Phenology in the northern California Current
Funded: $81,392

OSU RESEARCH STAFF: *Jennifer Fisher,* Faculty Research Assistant; *Xiuning Du,* Research Associate
NOAA TECHNICAL LEAD: *Bill Peterson,* FE/NWFSC

PROJECT BACKGROUND: The classical view of productivity in the California Current holds that production in the California Current depends largely upon the length and strength of the coastal upwelling season. However, this paradigm has been challenged recently in two respects: first, production events in late winter and early spring are critical for successful recruitment of winter-spawning invertebrate and finfishes including many that are fished commercially, including pink shrimp, rockfish, and sablefish. In addition seabirds such as the common murre, Cassin's auklets and Rhinoceros auklets have life history strategies that include reproduction during the winter and early spring because downwelling and poleward transport enhances larval retention. Thus any process that disrupts the timing of winter/spring reproduction events may affect subsequent recruitment of the winter spawners.

Interannual variations in the species composition of zooplankton in the NCC in spring and summer sets the efficiency at which productivity is transferred to higher trophic levels. A better understanding of the magnitude and timing of winter production and of efficiency of energy transfer during spring and summer is needed because the NCC is a feeding ground for numerous migrant species which come to the NCC in spring to fatten-up. Species such as Pacific hake, sardines and anchovies migrate northward from the warm waters of the southern California Current; stocks of salmonids from the Columbia, Snake, Sacramento and coastal rivers migrate to the sea in spring. Other species travel thousands of miles from breeding grounds throughout the Pacific Basin to feed in shelf and slope waters off northern California, Oregon and Washington –extreme examples include sooty shearwaters from New Zealand, black-footed and Laysan albatross from Hawai'i, humpback whales from Peru and grey whales from Baja California.

Little work has been done on phenology in the marine environment due largely to the fact that most biological oceanographic sampling programs are not designed to look at this phenomenon (e.g., annual trawl surveys of fishes and quarterly surveys by CalCOFI clearly cannot capture any aspect of phenology). Biological observation programs that can or do produce phenological

data are very rare and for the California Current include the 20-year time series of plankton and krill observations along the Newport Line, 30 year time series of plankton and krill off Vancouver Island (Mackas et al. 2007) and long-term surveys of seabirds nesting at colonies on the Farallon Islands (for Cassin's Auklets),Yaquina Head (Newport) Oregon and Cape Flattery (for common murres), and Triangle Island BC (for Cassin's and Rhinoceros auklets).

PROJECT PROGRESS: During the time period of 2000-2016, winter phytoplankton bloom (defined as total Chl a concentration ≥ 1.5μg/l) timing, magnitude and duration were examined using in situ chlorophyll measurements at a mid-shelf station offshore Newport. Winter phytoplankton blooms commonly occur in February or March in the northern California current when clear skies and sunny weather appears for a few days. Weather conditions, e.g., light and photoperiods, seem to be the key limitation factors determine the presence/absence, timing and magnitude of the winter phytoplankton bloom. In most years, at least two sampling cruises were conducted in each month of February and March which makes the estimate of winter bloom timing relatively appropriate. Among the 17 years, 8 out of 14 years winter blooms started in February (5 years in mid-February), 4 years in March and 2 (year 2007 and 2015) in late January. No winter blooms were observed in 2006, 2010 and 2012. The peak of winter blooms (as total Chl a measurements) commonly fell in the range between 1.5-3μg/l, and in some years, 2005, 2003, 2002, 2008 and 2015, the bloom magnitude was very high, between 4-5μg/l, with the highest winter bloom level of 9μg/l in 2005. Duration of winter blooms is hard to be accurately estimated based on bimonthly data points. However, it seems that each year the winter bloom commonly lasted for about a month. The relatively constant occurrence of winter blooms every year, the small to moderate bloom magnitude and the about one-month duration are very important to support the winter growing season for some young stages of invertebrates (copepods and krill), winter spawned fish larvae and these close trophic links affect far into the later spring and summer growth and survival of older life stages of higher-trophic predators for an entire year. It seems that the winter bloom timing in February could maximize the prey-predator links for the most resulting in a more productive food chain in the NCC.

During 2009-2016, spring transition was significantly delayed in years of 2010 and 2012 but earlier in years of 2009, 2013 and 2016. The determination of spring transition dates based on physical conditions measured as Bakun upwelling index (CUI) and alongshore wind stress (CWS) was more consistent with phytoplankton and copepod biological spring transition dates for years 2012 and 2013. Phytoplankton spring transition dates were more in agreement with upwelling and wind stress determined spring transition than that by copepods (2011-2014, 2016). There was no spring transition of copepod communities in 2015-16. Phytoplankton spring transition dates (Julian day) are overall later than those determined from copepod community index although these two sets of spring transition are strongly correlated ($r^2 = 0.93$). Phytoplankton spring transition dates had stronger correlations with that determined by wind stress than by coastal upwelling index ($r^2 = 0.68$ vs. 0.43 excluding 2010).A negative but nonsignificant correlation was found between phytoplankton spring transition dates and the PDO index (both winter and spring) and this correlation became slightly stronger after removing the outlier year 2010 ($r^2 = -0.3$). That is to say, during a warm ocean year, phytoplankton spring transition starts earlier than that during a colder year. In contrast, it was a positive correlation (though not significant either) between the spring transition dates by copepod and that by the PDO. The opposite correlations with the PDO indicates the different mechanisms controlling the

community structure changes of phytoplankton and copepod, for example, higher temperature induces faster local growth winter-summer community changes of phytoplankton while transport of warm or cold water type of copepod species affiliated with differential water masses (warm or cold) determines the shift of copepod community structure in the coastal waters off Oregon.

Winter bloom peaks mostly occurred in March than in February (ratios of 7:4). Winter blooms in February seem to match with lower values of upwelling intensity (pUI, preconditioning of upwelling index) while blooms in March were associated with both low and high pUI. Winter blooms either in February or March were not specifically related to phase changes of the PDO values in winter (average from January to March). However, there was a significant and negative correlation between the PDO and winter pUI which indicates positive effects of the warm phase of the PDO on the occurrence of winter bloom in February. Spring bloom peaks occurred mostly in May than in April (10:3) which is expected because upwelling conditions usually become more stable in later spring season. The only three spring blooms in April (2005, 2006 and 2015) were associated with the warm phase of the PDO in winter although the warm PDO phase also related to the spring bloom peak in May, such as 2016 and 2004. The annual dates of spring transition (marking the start of the coastal upwelling season) were not associated with timing of the spring bloom peaks. Annual summer bloom peaks were observed either in July or August and that had no correlations with the intensity of summer upwelling. Only in 2009 and 2015, the peak of summer blooms occurred in June when upwelling intensity fell in the lower and higher end of the time series, respectively. It is also known that for both years there were EI Nino events began to develop in the equator during summer which affected local ecosystems through either atmospheric teleconnections or coastally trapped waves from changing coastal upwelling, water mass properties and nutrient supplies, and thus local plankton community structure and trophic correlations.

Winter production of phytoplankton was associated with weather conditions, sea temperature and winter upwelling events. Diatom cell abundance (log-transformed) showed the most significant positive correlation with local sea surface temperature while dinoflagellate was only weakly and positively correlated with temperature. Simple linear regression analysis also found positive and significant correlations of diatom abundance with basin-scale temperature indices, PDO and ONI, suggesting the basin-wide effects on local diatoms as well. Total Chl a and the larger fraction (>5μm) of Chl a concentrations were not significantly correlated with sea surface temperature. Winter upwelling intensity was positively correlated with the total Chl a concentration but strongly and negatively correlated with dinoflagellate cell abundance (log-transformed). Diatom production in winter is more sensitive to weather conditions, and that includes temperature, light irradiance, photoperiods and water column mixing (winter storm related) while the intensity of winter upwelling events is less determinant and the sufficiency of nutrient supply is rarely limited to diatom growth. The similarly positive correlation between diatom abundance and deeper water temperature indicates that temperature could be an indicative factor of diatom production in winter (but not effective for dinoflagellates and the phytoplankton biomass proxy Chl a concentration). The responses of dinoflagellates to temperature and upwelling intensity (which is under control of basin-scale drivers) indicate dinoflagellate production is less dependent on local growth and rather results from direct transport from either more offshore waters or from further south along the west coast. Therefore, the basin-wide ocean condition indices such as the PDO and ENSO seem to be more effective for

predicting dinoflagellate production in winter. The positive correlation between Chl a and upwelling intensity indicates the overall positive effects from upwelling on total local phytoplankton biomass for winter season when nano- and pico-sized phytoplankton were the most dominant contributors to total biomass. The analysis found that diatom production responded to temperature changes of the coastal ocean of the northern California Current where coastal physical environments are influenced from seasonally to decadally by local atmospheric conditions but also basin-scale current circulations in the North Pacific. Therefore, it appears to be normal to see the higher variability of diatom community composition and biomass than other types of phytoplankton under the highly dynamic and unpredictable coastal environments.

CONFERENCES:
Xiuning Du, William Peterson, Tracy Shaw, Jennifer Fisher and Jay Peterson. September 5-12, 2016. San Diego, CA. Winter phytoplankton blooms and trophic implications on copepod and krill biomass and egg production in the northern California Current (Poster presentation)

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. *J. Geographic Res*. (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 Lette*r. (Under revision)

Amendment 66: Coast-wide Genetic Stock Identification – Ecosystem Effects on Adult Chinook Salmon Distribution and Abundance

Funded: $133,460

OSU RESEARCH STAFF: *Michael Banks*, Director, CIMRS; *Jonathan Minch*, Faculty Research Assistant, Hatfield Marine Science Center
NOAA TECHNICAL LEAD: *Peter Lawson*, Conservation Biology, NWFSC

PROJECT BACKGROUND: Genetic Stock Identification (GSI) is a uniquely useful tool for salmon management because it enables identification of nearly all hatchery and natural origin fish sampled and results are available in a few days. This is in contrast to the traditional Coded Wire Tags, which provide data on about 5 percent of hatchery fish only. Ages of GSI-sampled fish are determined from scales. GSI in combination with fine-scale at-sea sampling allows determination of which stocks are present in the fishery with a high degree of certainty and to map dynamic stock-specific distributions. It is anticipated that 2400 tissue samples will be analyzed from

collections of Oregon Chinook salmon from three areas in August and September. Genetics labs from Alaska to California have created a database of genetic microsatellites from Pacific salmonids through a consortium called Genetic Analysis of Pacific Salmonids (GAPS).

PROJECT PROGRESS: The work accomplished under the subaward to the Oregon Salmon Commission (OSC) for the period July 1, 2016 through June 30, 2017 included 1) fishermen charters, 2) fleet management, 3) port sampling, 4) tablets, 5) supplies and tags, and 6) database maintenance. The OSC entered into contracts with the fleet manager, fishermen, Oregon Department of Fish & Wildlife (ODFW), and Fish Trax Systems, Inc. (website maintenance) to perform the tasks for this project.

Tablets & Supplies: This year the fishermen were equipped with Samsung tablets rather than GPS units. The tablets have a built in application that recorded their GPS locations and logged any fish caught. The tablets were configured so that once turned on and the fisherman entered their vessel name, port of origin, and started the trip and deployed their gear, the tablet would record their trip location and all areas transited. When they landed a fish, the fisherman would press a button on the tablet to mark the location of the catch, enter other fish related information on the tablet, and then put a barcode on the fish. The tablets were developed so that they could be used in direct sunlight out on the deck of the vessel and easily charged overnight in the cabin. Supplies included the barcodes to be attached to each fish, as well as garment guns. In previous years, fishermen have used zipties to attach the barcode to the fish through the gills. This year we had the fishermen use garment guns to push a plastic piece directly through the gill plate. Fishermen found this to be an easy way to attach the barcode and could be done rather quickly.

Fishermen Charters: The fishermen were given Samsung tablets that have a mapping function to help enable them to fish. The application charts out the course the fisherman has taken and the fishermen log all fish caught barcoding each individual fish marking down the depth the fish was caught and if there was a presence of an adipose fin clip. Upon entering port, the fishermen would upload their data directly to the Pacific Fish Trax (PFX) website.

Fleet Management: The fleet manager coordinated with the Newport area fishermen through one-on-one training to prepare fishermen and give them their supplies for the sampling season. The fleet manager was in contact with the fishermen for fish count updates. At the end of each fishing trip, the fleet manager met with the fishermen to ensure that their information was properly transferred to the website, and to restock their supplies (barcode tags, envelopes, etc.).

Port Sampling: In 2016, one objective was to develop a dockside methodology for genetic sampling. In past years, fishermen have collected all genetic information onboard the vessel, by taking a fin clip for GSI (genetic stock identification) and scales for ageing. These were placed in an envelope for delivery to the lab by the fleet manager. During slow fishing times, this process is not hard for the fisherman to accomplish. But collecting the genetic information can become time consuming and interfere with fishing operations when catch rates are high. Also, this process only collects information for a limited number of vessels participating in the project during limited periods.

The OSC met with ODFW, two port samplers, and several buyers to discuss the project and get their confirmation to assist. Upon return to port, a fisherman would alert the port samplers telling them their arrival time and their buyer. The samplers would meet the fisherman at the buying station where they would sample 20 fish. If there were more than 20 fish, the samplers would not sample all fish, but a subsample. Port samplers would select the fish to measure, and then sample for GSI and scales following an established protocol to minimize sampling bias and maximize random selection of samples. Coded Wire Tags (CWT) were collected concurrently. Data was transmitted directly from the tablets to the PFX database. Samples were transferred to the lab for analysis, with results linked to individual fish using the barcode.

Database Maintenance: The PFX website has several portals for access by different groups. The public portal allows anyone to view aggregate data by time, regions, fish size, and river of origin. Individual fishermen data is available through a specific log-in allowing them to view their own fishing data. Continual operation of the site involves assuring functionality of all features, confirming that fishermen data is properly uploaded to the site, answering questions from fishermen about their tablets, and updating the software on the tablets as needed.

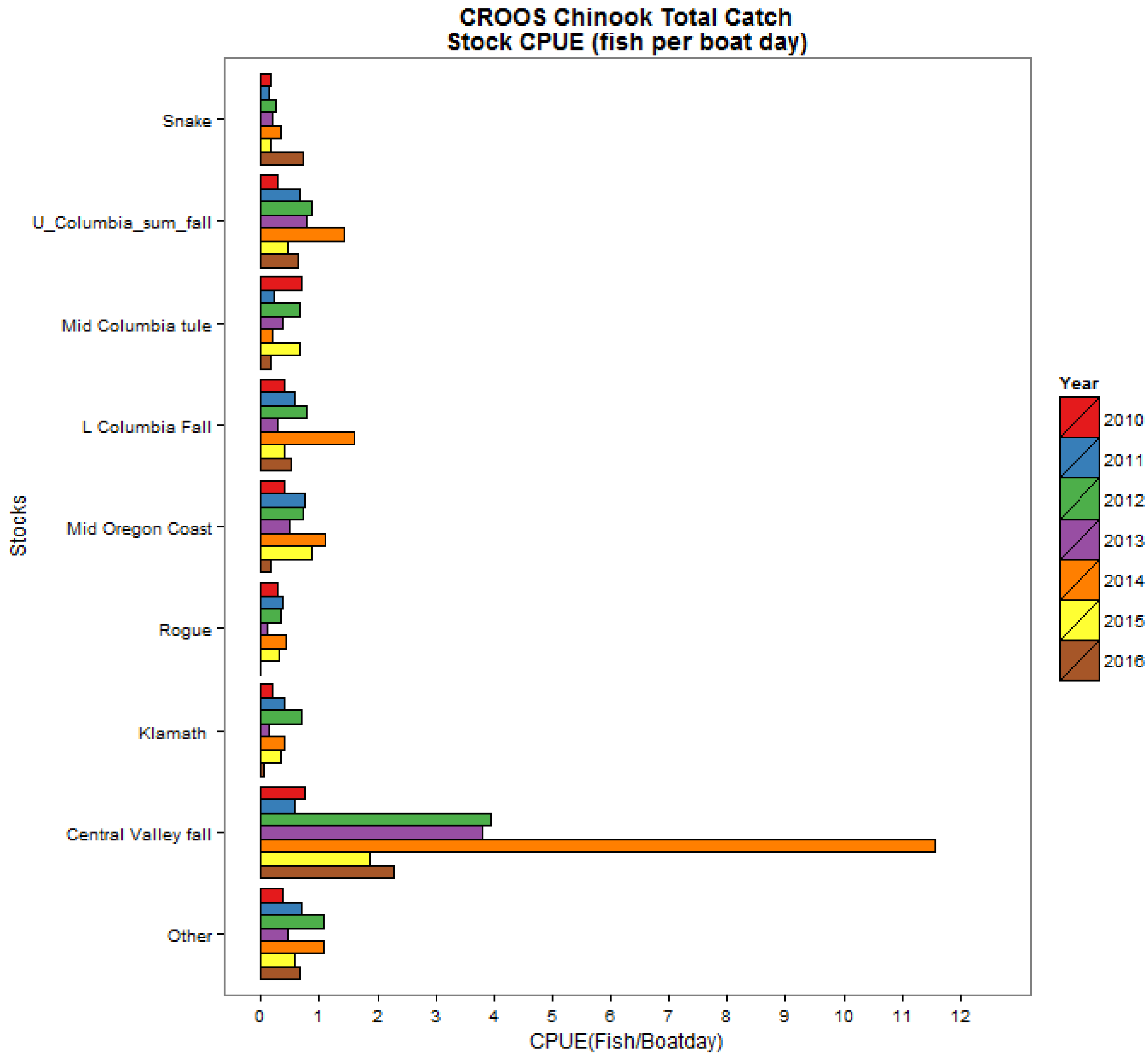
Sampling Results: 2016 was not a good fishing year for Chinook salmon in Oregon with few landed anywhere in the state. You will see on the attached chart that only 21 days were fished with 109 legal-sized fish sampled. The average fish caught per boat day (CPUE) was 5.21. The chart also shows the genetic break out of the fish sampled.

Project CROOS Yearly Historical Data

CROOS Sample Statistics

	2010	2011	2012	2013	2014	2015	2016
Number days fished	1209	565	928	318	71	176	21
Fish caught per boat day (CPUE)	3.55	3.74	8.70	6.53	16.02	5.72	5.21
Number legal-sized fish sampled	4046	3523	8301	2437	983	984	109

The table show the annual combined CPUEs for 2010, 2011, 2012 , 2013 , 2014 , 2015 and 2016. The bar graph shows CPUEs for 9 stock groups estimated from GSI sampling.



Amendment 64: Improving Ecosystem-based Fisheries Management and Integrated Ecosystem Assessments by Linking Long-term Climate Forcing and the Pelagic Nekton Community in the NCC

Funded: $25,040

OSU RESEARCH STAFF: *Lorenzo Ciannelli,* Professor, CEOAS; *Caren Barcelo*, GRA, CEOAS

NOAA TECHNICAL LEAD: *Ric Brodeur*, FE/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. 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.

Both fine-scale remotely sensed oceanographic data as well as forecasted climate change scenarios are being used to generate species distribution models for forage fish species (herring, mackerel and sardine) off the Oregon and Washington coasts. 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.

PROJECT PROGRESS: Our project aims to develop new indicators that will describe how the pelagic nekton communities in the NCC have responded to climatic forcing during the period 1998-2016, with the twin goals of providing critical ecosystem information for fisheries management and expanding the availability of indicators for Integrated Ecosystem Assessments put together by NOAA. Additionally, additional funds allocated the project were to continue providing updates to the CCIEA on the abundance time series for key forage species up to 2016 and to further ongoing diversity, community analysis as well as species distribution modeling.

In the past FY, 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. As a result of this workshop, 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*.

Amendment 59: Climate and Habitat Effects on Productivity of Important Alaska Fishery Species

Funded: $126,839

OSU RESEARCH STAFF: *Louise Copeman*, Asst. Professor, Sr. Res., CEOAS/CIMRS,
NOAA TECHNICAL LEAD: *Tom Hurst*, *Cliff Ryer, Ben Laurel*, RACE/AFSC

Effects of ocean acidification on Alaskan fishes

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

PROJECT PROGRESS: Research Technician, 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 Dr. Thomas Hurst (NOAA) to examine the effects of high CO_2 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 manuscript with Dr. Thomas Hurst at NOAA.

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 EFH 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 FMP 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: Along with Thomas Hurst (NOAA) and AFSC-NOAA technical staff, Jessica Andrade completed experiments describing the effects of temperature on the growth rates of four species of Alaskan flatfishes: Pacific halibut, yellowfin sole, Alaska place, 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 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 snow crab (*Chinoecetes opilio*) and Tanner crab (*Chonoecetes 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 EFH 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 FMP species. While focused on cold pool effects in the southeastern Bering Sea, this project will have utility for understand crab habitat in the greater Bering, Chukchi and Beaufort Seas as bottom temperatures rise.

PROJECT PROGRESS: Dr. Copeman (OSU) and staff have completed the crab morphometric sampling as well as the lipid class and fatty acid analyses of 80 additional crabs during this study period. These crabs were collected on the NOAA-BASIS survey and 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.

PUBLICATIONS:

Hurst, T.P., B.J. Laurel, E. Hanneman, S.A. Haines, and M. Ottmar. 2017. Elevated CO_2 does not exacerbate nutritional stress in larvae of a Pacific flatfish. *Fisheries Oceanography*. 26:336-349. doi: 10.1111/fog12195

Copeman LA, B.J. Laurel, M. Spencer, A. Sremba. 2017. Temperature impacts on lipid allocation among gadid species at the Pacific Arctic–Boreal interface: a common garden laboratory approach. *Marine Ecology Progress Series* 566:183–198. DOI: 10.3354/meps12040

Laurel B.J., L.A. Copeman, M. Spencer, P. Iseri. 2017 Temperature-dependent growth as a function of size and age in juvenile Arctic cod (*Boreogadus saida*). *ICES J Mar Sci*. DOI: 10.1093/icesjms/fsx028

MEETING PRESENTATIONS:

Hurst, TP, Copeman LA, Meredith S, Haines SA, Daniels K Elevated CO_2 alters growth and behavior of first-feeding Pacific cod larvae. Symposium on Impacts of a changing environment on the dynamics of high latitude fish and fisheries. Anchorage, AK, May 2017.

Andrade JF, Hurst TP, Miller JA. Effects of elevated CO2 on the behavior of speckled sanddab (*Citharichthys stigmaeus*). Research Advances in Fisheries, Wildlife, and Ecology Symposium. Corvallis, OR, April 2017.

Copeman LA, Laurel BJ, Spencer M, Iseri P. Temperature impacts on the eggs and larvae of Alaskan gadids. Oral presentation, Alaska Marine Science Symposium, Anchorage, Alaska, January 21-26, 2017.

Koenker B, Copeman LA, Laurel BJ. The effect of temperature and food availability on the growth, condition and survival of larval gadids. Poster Presentation, Alaska Marine Science Symposium, Anchorage, Alaska, January 24-29, 2016.

Copeman LA, Hurst T, Haines S, Meredith S, Hubbard K The interactive effects of changes in CO_2 exposure and food quality on the growth and lipid composition of Pacific cod (*Gadus macrocephalus*) larvae. Poster presentation, ESSAS Open Science Meeting on Subarctic and Arctic Science, Tromso, Norway, June 10-15, 2017.

Copeman LA and Laurel BJ. 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. 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.

Amendment 55: Survey of Pelagic and Demersal Habitats

Funded: $45,873

OSU RESEARCH STAFF: *Jennifer Fisher*, Faculty Research Assistant, CIMRS
NOAA TECHNICAL LEAD: *Bill Peterson*, Fish Ecology, NWFSC

PROJECT BACKGROUND: This project aims to examine both the nearshore and the offshore habitats of fish and their food resources off the Oregon coast. CIMRS investigators continue to conduct a fishing vessel-based survey of YOY groundfishes along the NH-Line along with the plankton and physical oceanography sampling program. The project provides valuable information on the status of pelagic habitat relevant to early life history stages of many commercially and ecologically important species. Further, the project builds upon a long-term data set critical for detecting trends over time scales relevant to climate variability.
PROJECT PROGRESS: The project has continued 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 we sample 13 stations out to 85 nautical miles offshore, along the NH Line. At each station we 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. Our collaboration with the commercial fishing industry continues to be a positive relationship, with scientists and fisherman contributing knowledge and expertise to goals of the project.

Sample processing continues in all aspects of the project. All CTD data have been processed, quality controlled and uploaded to our MS Acsess database and posted on our Newportal Blog

(https://www.nwfsc.noaa.gov/news/blogs/display_blogentry.cfm?blogid=1.). All nutrient samples have been analyzed and entered in our database and approximately half of the chloroyll samples have been processed and entered. All zooplankton from NH-5, NH-25, and NH-65 have been enumerated and entered into our database. Work continues on the backlog of juvenile fish samples, with a successful processing event where 8 researchers and volunteers from PSMFC, ODFW, CIMRS, and OSU worked up over 1,100 frozen fish 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.

CONFERENCES:

Jennifer Fisher, Bill Peterson, Louise Copeman, Jessica Miller. The skinny about how the Blob and El Niño changed the hydrography, zooplankton, lipid, and fatty acid structure off Oregon. Eastern Pacific Oceans Conference, Timberline Lodge Oregon, Sept 21-23, 2016. (Oral Presentation)

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

Jennifer Fisher. Ecological indicators and ocean conditions in the Northern California Current. West Coast Regional NOAA Leads Newport OR Feb 8, 2017. (Oral presentation)

Amendment 50: Long-term Observations of Physical and Biological Oceanographic Conditions in Coastal Waters off Oregon: Hydrography and Zooplankton

Funded: $94,000

OSU RESEARCH STAFF: *Jennifer Fisher* Research Assistant, CIMRS
NOAA TECHNICAL LEAD: *Bill Peterson*, Fish Ecology, NWFSC

PROJECT BACKGROUND: This project which monitors ocean conditions and zooplankton communities continues to produce a combined northern California Current copepod anomaly index annually. In addition, copepod abundance anomalies are calculated on a seasonal basis (spring, summer, fall) for comparison to sablefish, whiting, rockfish and Chinook and Coho salmon time series of recruitment and survival. CIMRS investigators monitor ocean conditions off the coast of

Oregon sampling hydrography and plankton along the Newport Hydrographic Line (44.6°N) on a biweekly basis.

PROJECT PROGRESS: Ten research cruises along the Newport Hydrographic (NH) Line were conducted over the last year. 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 Stateand in to the Gulf of Alaska.

<u>Data products</u>

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

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

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

PUBLICATIONS:

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

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

Theme: Protection & Restoration of Marine Resources

Amendment 76: A Pilot Project toward Measuring Physiological Effects of Noise Exposure on Pacific Gray Whales (*Eschrichtius robustus*)
Funded: $74,999

OSU RESEARCH STAFF: *Joe Haxel*, Asst. Professor, Sr. Research, CEOAS; Leigh Torres, Asst. Prof., Sr. Res., Marine Mammal Institute
NOAA TECHNICAL LEAD: *Robert Dziak*, OERD/PMEL

PROJECT BACKGROUND: Long-term, deep ocean acoustic measurements from fixed hydrophone stations have documented a steady increase in low frequency ambient noise levels (10-12 dB) in the Northeast Pacific since the 1960s, primarily associated with increased commercial shipping traffic throughout the basin. In contrast, long-term trends in underwater noise levels within shallower waters of the continental shelf region remain largely unknown due to a lack of adequate time series measurements. These shallow water coastal areas may be more susceptible to rising levels of anthropogenic noise generated from expanding commercial activities and coastal development (e.g., fishing, marine renewable energy, tourism). The threat of rising anthropogenic noise levels in the oceans has raised concern for many marine species that rely on acoustic sensitivity for a variety of ecosystem functions including baleen whales (*Mysteceti*) whose functional range overlaps with low frequencies commonly generated by anthropogenic sources. The effects of long-term exposure to increasing ambient sound levels resulting from anthropogenic sources are not well known, and may not be easily recognized from

short-term observation of behavioral changes. Rather, chronic stress effects may potentially manifest as a physiological response within animals.

Using Pacific Coast Feeding Aggregation (PCFA) gray whales along the Oregon coast as our study species, CIMRS researchers will develop methods and collect data aimed at addressing the following questions:

1. Are whales exposed to significantly different anthropogenic and naturally influenced ambient noise environments depending on location and time?
2. Do individual GC hormone concentrations vary relative to individual, body condition, prey availability or habitat (location)?
3. Relative to samples collected in low-noise environments, do fecal samples from whales in noisy environments have higher GC concentrations, indicative of elevated stress? Furthermore is there an observed difference in GC concentrations between environments dominated by anthropogenic verses natural sound sources?
4. What is the time scale of recovery for fecal stress hormone concentrations to baseline levels after an increased noise event?

PROJECT PROGRESS: Data collection efforts were separated into an early (May-Jun) and late (Aug-Oct) field season (2016) in order to collect comparative data between early-season conditions when whales were likely to be malnourished and have higher stress levels due to the long migration and fast periods, relative to the late-season after significant feeding had occurred. Over the course of the field season efforts from May 23 – October 16, 2016 the project team spent 155 hours on the water over 27 sampling days, with 109 gray whale encounters, 53 fecal samples collected, 75 UAS flights and 40 hydrophone drifter deployments.

Analysis from the 2016 season data was used to inform the collection efforts for the 2017 season data currently underway.

Amendment 57: PNW Fishing Community Oral Histories: A Collaborative, Educational Project for Researchers, Students, and Community Members

Funded: $25,000

OSU RESEARCH STAFF: *Flaxen Conway*, Professor, Department of Fisheries and Wildlife
NOAA TECHNICAL LEAD: *Suzanne Russell*, NWFSC

PROJECT BACKGROUND: Oral histories are a methodology to collect previously undocumented and unique, in-depth information. Oral histories capture and preserve the heritage and culture of an individual, family, community of place, or a community of interest that spans over several places. Oral histories can identify key issues and concerns, identify and record an individual's or a community's inherent and observed knowledge, and inform the public, local community leaders and members, and management entities. In the first part of this project, one of the themes that emerged was the changing role of women. The previous student who worked on this project focused her MS research on this theme while conducting oral histories.

Another theme that emerged was the "graying of the fleet." This year, while gathering oral histories and seeing what additional themes arise, a student will focus their MS research on the intergenerational transfer of fishing family businesses and how this impacts the resilience of the fleet (thus the term "graying") and the coastal community in two ports in Oregon: Port Orford and Newport. Thus this project continues to be a collaborative process that engages students, faculty, agency researchers, and community partners thereby providing an educational experience to a broad range of project participants and community members.

PROJECT PROGRESS: The goal of this project is to identify and collect oral histories from coastal communities in Port Orford and Newport, Oregon, focusing but not limited to intergenerational fishing family businesses. The ability to collect and document oral histories before fishermen and other key community members retire or are no longer accessible is critical to preserving local knowledge and heritage. The oral histories will be obtained from various perspectives for the most complete representation of the culture and heritage. Efforts will be made to capture oral histories from fishermen, processors, wives/partners, suppliers, and possibly even state and federal fisheries managers. These stories about how the management of many fisheries in these communities is changing rapidly as a result of recent or forthcoming fisheries and environmental management efforts will become part of the Voices from the Fisheries.

- One student (Sarah Calhoun) worked on this project last summer (7/1/15 – 9/1/15). She gathered six oral history interviews.
- Two additional new students joined the project during the 2015-16 academic year and worked through the 2016-17 academic year:
  - Deanna Caracciolo, Marine Resources Management student, began interviewing Spring 2016 quarter--completed 23 interviews.
  - Courtney Flathers, Masters of Public Policy student, began interviewing Spring 2016 quarter-- completed 16 interviews.

Both students completed their research projects and successfully defended in June 2017; papers available via OSU Scholars Archive.

MEETING PRESENTATIONS:
Caracciolo and Flathers both presented oral presentations at the 2017 Annual Meeting of the Society for Applied Anthropology, Santa Fe, NM (Spring 2017).

Theme: Seafloor Processes

Amendment 65, 71, 73: Impacts of Submarine Volcanism and Hydrothermal Venting on the Global Ocean and Deep-Sea Ecosystem

Funded: $1,677,879

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; *Andra Bobbitt*, *Susan Merle*, Senior

Faculty Research Assistants, CIMRS; *Leigh Evans, Matt Fowler,* Faculty Research Assistants, CIMRS; *Samara Haver* Graduate Student

NOAA TECHNICAL LEAD: *John Lupton, Bob Embley, Chris Sabine,* PMEL

Volcanic and Hydrothermal Event Detection in the Northeast Pacific

PROJECT BACKGROUND: The efficient propagation of sound in the oceans highlights the beneficial use of underwater acoustics for studies involving geophysical seafloor processes, assessing the health of marine ecosystems, marine mammal and fish behavior, and climatic processes near the Polar Regions. Project analysis of hydroacoustic recordings from fixed and mobile platforms provides information on submarine volcanic events, long-term ambient noise levels, marine mammal vocalizations, signals radiated by sea ice and glacial decomposition, as well as anthropogenic contributions to regional soundscapes all in support of NOAA's Goal for Healthy Ocean and Ecosystems.

PROJECT PROGRESS: CRUISES: Assistant Professor Joseph Haxel leads acoustic data collection and analysis efforts on a project focused toward quantifying physiological and behavioral impacts on gray whales from noise level variations off the Oregon coast. He also led design, development and operations for a shallow water acoustic experiment off the northern Oregon coast with final hydrophone recoveries in October 2016. He presented research on acoustic signals and environmental correlates recorded in the Ross Sea at the Fall AGU 2016 meeting in San Francisco, CA. H. Matsumoto also attended the Fall AGU 2016 meeting in San Francisco, CA presenting research on iceberg related noise level variations observed with moored hydrophones in the eastern equatorial Pacific. Faculty Research Assistant A. Turpin assisted H. Matsumoto in engineering development and assembly of hydrophone instruments for both fixed and mobile platforms. Faculty Research Assistant L. Roche completed training for mooring operations, shipping and logistics, and hydrophone assembly and testing.

CRUISES:

L. Roche**,** January 2017 – March 2017, *R/V* Araon, expedition to the Ross Sea, Antarctica supporting the recovery/ re-deployment and new deployments of Acoustics Program hydrophone mooring arrays for research of ice dynamic processes.

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.

Caplan-Auerbach, J., R.P. Dziak, **J. Haxel**, D.R. Bohnenstiehl, and C. Garcia. 2017. Explosive processes during the 2015 eruption of Axial Seamount, as recorded by seafloor hydrophones. *Geochem. Geophys. Geosyst.*, 18, doi: 10.1002/2016GC006734, Published online.

Dziak, R.P., **J.H. Haxel, H. Matsumoto, T.-K. Lau, S. Heimlich, S. Nieukirk, D.K. Mellinger**, J. Osse, C. Meinig, N. Delich, and S. Stalin. 2017. Ambient sound at Challenger Deep, Mariana Trench. *Oceanography*, 30(2), doi: 10.5670/oceanog.2017.240, Published online.

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.

Nieukirk, S.L., S. Fregosi, D.K. Mellinger, and H. Klinck. 2016. A complex baleen whale call recorded in the Mariana Trench Marine National Monument. *J. Acoust. Soc. Am.*, 140(3), EL274, doi: 10.1121/1.4962377.

Schnur, S.R., W.W. Chadwick, Jr., R.W. Embley, V.L. Ferrini, C.E.J. de Ronde, K.V. Cashman, N. Deardorff, S.G. Merle, R.P. Dziak, **J. Haxel**, and **H. Matsumoto**. 2017. A decade of volcanic construction and destruction at the summit of NW-Rota-1 Seamount: 2004–2014. *J. Geophys. Res.*, 122(3): 1558–1584, doi: 10.1002/2016JB013742.

Research on the Near- and Far-field Physical and Chemical Impacts and Consequences to Ocean Ecosystems Caused by Submarine Volcanoes and Hydrothermal Venting

and

Interpreting Digital Seafloor Bathymetry and Imagery, From Ship-based sonar, Deep-Towed Sidescan, Optical Sensors, Submersible and Remotely Controlled Vehicles

PROJECT BACKGROUND: CIMRS researchers study and document interactions between submarine volcanic events, hydrothermal systems, and chemosynthetic ecosystems. Time-series studies are focused at Axial Seamount, the most active submarine volcano in the NE Pacific. Axial is an excellent long-term study site because it has a continuous and high magma supply, volcanic eruptions are relatively frequent (every 4-13 years), and it is the only site in the world where a repeatable (and apparently predictable) cycle of inflation and deflation has been documented at a submarine volcano. The seamount is now a node on the Cabled Array component of the National Science Foundation’s Ocean Observatories Initiative (OOI), which transmits real-time data from instruments on the seafloor to shore, and this is opening up new research opportunities. For example, CIMRS researchers collaborated with NOAA/PMEL Engineers to design and build bottom-pressure/tilt instruments that were installed on the OOI cabled observatory. In April 2015, those instruments detected the start of an eruption at Axial

Seamount that had been previously forecast, based on the long-term inflation/deflation time-series.

Another focus of CIMRS research is exploration of submarine volcanoes and hydrothermal vent ecosystems in the subduction zones of the western Pacific, in both arc and back-arc settings. Part of this research is the use of repeated sonar mapping for detecting depth changes on the seafloor due to volcanic eruptions. These depth changes can be either positive (due to the addition of erupted material) or negative (due to collapses or landslides on unstable slopes). Documenting and quantifying these changes enables the calculation of eruption volumes and rates, yields opportunities to explore the interaction between constructive and destructive events at submarine volcanoes, and gives insight into the processes of how volcanoes grow underwater.

Another avenue of research is investigating the fate and consequences of hydrothermal emissions into the global ocean. A powerful tool in this research is the Helium Isotope Lab located in Newport, Oregon. Helium-3 is an isotope that is produced in the earth's mantle and because it is inert and conservative, it is an unambiguous tracer of hydrothermal discharge. Thus, helium-3 can help identify vent sites in unexplored areas as well as track hydrothermal emissions across entire ocean basins.

These projects contribute to the NOAA mission of science, service, and stewardship through the Healthy Ocean Goal of sustaining marine habitats and biodiversity within healthy and productive ecosystems. CIMRS research also supports OAR's main science goal of gaining a holistic understanding and making useful predictions of future states of the Earth-Ocean system. Likewise, CIMRS research falls under 3 of the 5 PMEL research themes: Marine Ecosystem Research, Ocean and Coastal Processes Research, and Research Innovation.

PROJECT PROGRESS: 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. Meeting presentations with CIMRS co-authors are listed below.

MEETING PRESENTATIONS:

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. 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 2017, 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, 12-16 December 2016, San Francisco, cA.

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**. New hydrothermal vents discovered along the Mariana back-arc spreading center. Abstract presented at 2016 Goldschmidt Conference, 26 June-1 July 2016, Yokohama, Japan.

Caplan-Auerbach, J., R. P. Dziak, D. R. Bohnenstiehl, and **W. W. Chadwick Jr.** 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 2017, 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. 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 December 2016, San Francisco, CA.

Chadwick, W. W., Jr. Volcanic Geodesy: from Mount St. Helens to Axial Seamount. Abstract presented at 2016 Annual GSA Meeting, 25-28 September. 2016, Denver, CO. 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, 12-16 December 2016, San Francisco, CA.

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, 12-16 December 2016, San Francisco, CA.

Embley, R. W., and **W. W. Chadwick Jr.** Submarine Volcanism along the Mariana Frontal Arc. Abstract presented at the AGU Chapman Conference on Submarine Volcanism, 30 January-3 February 2017, Hobart, Tasmania.

Fine, I. V., R. E. Thomson, **W. W. Chadwick, Jr.**, E. E. Davis, and C. G. Fox. Statistical features of deep-ocean tsunamis based on 30 years of bottom pressure observations in the northeast Pacific. Abstract NH41A-1771 presented at 2016 AGU Fall Meeting, 12-16 December 2016, San Francisco, CA.

Haney, M., G. Tepp, J. Lyons, D. Bohnenstiehl, **W. W. Chadwick, Jr., S. G. Merle**, R. P. Dziak, D. Fee, and C. K. Searcy. Hydroacoustic observations of recent submarine eruptions

at Ahyi and Bogoslof volcanoes. Abstract presented at the Seismological Society of America Annual Meeting, 18-20 April 2017, Denver, Colorado

M.D. Hannington, and N. Augustin. 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 2017, 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, 12-16 December 2016, San Francisco, CA.

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**. New hydrothermal vents discovered along the Mariana back-arc spreading center. Abstract presented at 2016 Goldschmidt Conference, 26 June-1 July 2016, Yokohama, Japan.

Caplan-Auerbach, J., R. P. Dziak, D. R. Bohnenstiehl, and **W. W. Chadwick Jr.** 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 2017, 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. 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, 12-16 December 2016, San Francisco, CA.

Chadwick, W. W., Jr. Volcanic Geodesy: from Mount St. Helens to Axial Seamount. Abstract presented at 2016 Annual GSA Meeting, 25-28 September 2016, Denver, CO.

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, 12-16 December 2016, San Francisco, CA.

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, 12-16 December 2016, San Francisco, CA.

Embley, R. W., and **W. W. Chadwick Jr.** Submarine Volcanism along the Mariana Frontal Arc. Abstract presented at the AGU Chapman Conference on Submarine Volcanism, 30 January-3 February 2017, Hobart, Tasmania.

Fine, I. V., R. E. Thomson, **W. W. Chadwick, Jr.**, E. E. Davis, and C. G. Fox. 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, 12-16 December 2016, San Francisco, CA.

Haney, M., G. Tepp, J. Lyons, D. Bohnenstiehl, **W. W. Chadwick, Jr., S. G. Merle**, R. P. Dziak, D. Fee, and C. K. Searcy. Hydroacoustic observations of recent submarine eruptions at Ahyi and Bogoslof volcanoes. Abstract presented at the Seismological Society of America Annual Meeting, 18-20 April 2017, 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, 12-16 December 2016, San Francisco, CA.

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, 12-16 December 2016, San Francisco, CA.

Paduan, J. B., **W. W. Chadwick, Jr.**, D. A. Clague, M. Le Saout, D. W. Caress, H. Thomas, and D. R. Yoerger. High-resolution AUV mapping of the 2015 flows at Axial Seamount, Juan de Fuca Ridge. Abstract OS41C-1990 presented at 2016 AGU Fall Meeting, 12-16 December 2016, San Francisco, CA.

Paduan, J. B., D. A. Clague, **W. W. Chadwick Jr.**, D. W. Caress, B. M. Dreyer, M. Le Saout, and H. J. Thomas. 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 2017, Hobart, Tasmania.

Resing, J.A., **William Chadwick**, Edward T Baker, David A Butterfield, Tamara Baumberger, Nathaniel J. Buck, Sharon L Walker, and **Susan G Merle**, Hydrothermal exploration of the Mariana Back Arc Basin: Chemical Characterization, 2016 AGU Fall Meeting, 12-16 December 2016, San Francisco, CA.

Seabrook, S., A.R, Thurber, T. Baumberger, R.W. Embley, **S.G. Merle**, N. Raineault, Examining the diversity and distribution of microbial communities from newly discovered methane seeps along the Cascadia Margin, 2016 AGU Fall Meeting, 12-16 December 2016, San Francisco, CA.

Stern, R.J., Maryjo N Brounce, **William Chadwick**, Patricia B Fryer, Deborah Glickson, and **Susan G Merle**, NOAA Deepwater Exploration of the Marianas 2016: Volcanic arc and Backarc Basin, 2016 AGU Fall Meeting, 12-16 December 2016, San Francisco, CA.

Tepp, G., M. M. Haney, J. J. Lyons, R. P. Dziak, D. R. Bohnenstiehl, **W. W. Chadwick Jr.**, and K. Unglert. Automatic Detection and Classification of Submarine Volcano Signals. Abstract presented at the AGU Chapman Conference on Submarine Volcanism, 30 January-3 February 2017, Hobart, Tasmania.

Walker, S.L., E. T Baker, Joseph Resing, **William Chadwick, Susan G Merle**, and Carl L Kaiser, High resolution mapping of hydrothermal plumes in the Mariana back-arc relate seafloor sources to above-bottom plumes, 2016 AGU Fall Meeting, 12-16 December 2016, San Francisco, CA.

PUBLICATIONS:

Anderson, M. O., **W. W. Chadwick, Jr.**, M. D. Hannington, **S. G. Merle**, J. A. Resing, E. T. Baker, D. A. Butterfield, S. L. Walker, and N. Augustin. 2017. Geological interpretation of volcanism and segmentation of the Mariana back-arc spreading center between 12.7°N and 18.3°N. *Geochem. Geophys. Geosyst.*, (in press)

Chadwick, W. W., Jr., B. P. Paduan, D. A. Clague, B. M. Dreyer, **S. G. Merle, A. M. Bobbitt**, D. W. Caress, B. Philip, D. S. Kelley, and S. L. Nooner. 2016. Voluminous eruption from a zoned magma body after an increase in supply rate at Axial Seamount, *Geophys. Res. Lett.*, 43: 12,063–012,070, doi:10.1002/2016GL071327.

Nooner, S. L., and **W. W. Chadwick, Jr.** 2016. Inflation-predictable behavior and co-eruption deformation at Axial Seamount. *Science*, 354(6318): 1399-1403, doi:10.1126/science.aah4666.

Schnur, S. R., **W. W. Chadwick, Jr.**, R. W. Embley, V. L. Ferrini, C. E. J. De Ronde, K. V. Cashman, N. Deardorff, R. P. Dziak, J. H. Haxel, and H. Matsumoto. 2017. A decade of volcanic construction and destruction at the summit of NW Rota-1 seamount: 2004–2014. *J. Geophys. Res.*, 122: doi:10.1002/2016JB013742.

DATA SETS PUBLISHED:

Bobbitt, A., Butterfield, D., **Chadwick, W.**, 2017, Falkor 2016 Cruise Report, Mariana Back-arc, FK161129.

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.

Chadwick, W. W., Jr., and S. G. Merle (2016), Processed EM122 Swath Bathymetry Grids (NetCDF:GMT format) derived from ship-based Multibeam Sonar Data from the Izu-Bonin-Mariana Arc: Mariana: NW_Rota-1 Volcano to Esmeralda Seamount (20m grid) and Esmeralda to SW of Guam (40m grid) acquired during the Kilo Moana expedition KM1005 (2010). Integrated Earth Data Applications (IEDA). http://dx.doi.org/10.1594/IEDA/317112

Merle, S., Resing, J., **Chadwick, W.**, 2016, Falkor 2015 Cruise Report, Hydrothermal Hunt on the Mariana Back-arc, FK151121.

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.

Walker, S.L., E.T. Baker, J.A. Resing, **W.W. Chadwick Jr., S.G. Merle**, and C.L. Kaiser (2016): Raw Near-Bottom MAPR Data 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/323567, Published data set.

Amendment 72: Curation of ROV-collected rock samples in the OSU Marine Geology Repository for the 2015 CAPSTONE Expeditions using R/V Okeanos Explorer

Funded Amount: $40,866

OSU RESEARCH STAFF: *Anthony Koppers* Professor, Geophysics, CEOAS
NOAA TECHNICAL LEAD: *Alan Leonardi*, OER

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. 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 70 rock samples were collected during the 2015 CAPSTONE legs. These rock samples will be sent to the OSU-MGR for curation, sample description and will be made available for sampling to the wider national and international research community for carrying out further science projects.

PROJECT PROGRESS: In the beginning, there was significant delay in funding of this project, which was to start 1 February 2016. Initial progress has been slow as funding to OSU did not arrive until May 2016 and the rock samples didn't arrive until 17 May 2016 in the OSU Marine and Geology Repository (OSU-MGR).

Once the rocks arrived at the OSU-MGR, Dr. Anthony Koppers with assistance from his research assistant Dr. Kevin Konrad worked to verify that all samples were received in accordance with the documentation and database. Samples were boxed, labeled with QR codes and IGSN numbers, photographed, and bagged. Samples were then 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 were cut from the working halves and sent out for the making of double-polished thin sections. Upon their return, the thin sections were photographed in plain polarized light and cross polarized light, and then described for their petrology (e.g., mineral contents, alteration, volcanic features, vesicles). All samples have been curated, packaged and are now made available for 2015.

All data, metadata and imagery were entered into the OSU-MGR database and presented online. Below is shown a list of representative URL's at which to find examples of these contents made available. **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-ex1504/	Expedition page for the collection of the 1504 Capstone Expedition to the Papahānaumokuākea Marine National Monument and the Johnston Atoll region of the Pacific (map interface)
http://osu-mgr.org/noaa-ex1504l2-table/	Expedition page for the collection of the EX1504L2 or Leg 2 of the Papahānaumokuākea Marine National Monument expedition (table interface)
http://osu-mgr.org/request-samples/	Home page with instructions for making sample requests to the OSU-MGR

Theme: Marine Bioacoustics

Amendment 54: Advanced Methods for Passive Acoustic Detection, Classification, and Localization of Marine Mammals

Funded: $109,163

OSU RESEARCH STAFF: *David Mellinger*, Professor, Senior Research, CIMRS; *Sara Heimlich*, *Curtis Lending*, Faculty Research Assistants CIMRS

NOAA TECHNICAL LEAD: *Jonathan Klay*, Computing and Network Services, PMEL

PROJECT BACKGROUND: For effective long-term passive acoustic monitoring of today's large data sets, automated algorithms must provide the ability to detect and classify marine mammal vocalizations and ultimately, in some cases, provide data for estimating the population density of the species present. In recent years, researchers have developed a number of algorithms for detecting calls and classifying them to species or species group (such as beaked whales). Algorithms must be robust in real ocean environments where non-Gaussian and non-stationary noise sources, especially vocalizations from similar species, pose significant challenges. In this project, improved methods for detection, classification, and localization of many types of marine mammal sounds are being developed by CIMRS researchers using a two-pronged approach: developing improved DCL algorithms, and developing standardized interfaces and software.

PROJECT PROGRESS:

Detection/classification algorithms: tonal sounds. A whistle clustering manuscript was revised with a new classification section showing that shape-related whistle features carry species-specific information useful for species identification. The revised paper on this subject is currently in review.

Improvements were made to the *Silbido* whistle detector that improved the precision rate from 76.0% to 89.7% with a corresponding penalty in recall of only 0.1%, representing a 57% decrease in false positives generated by the detector with trivial impact on correct detections. A manuscript detailing these results is underway. Also, as part of the *Silbido* effort to reduce false positives, we constructed a visualization and debugging utility that lets one examine how the algorithm is working and provided a level of abstraction to better understand where the algorithm was making mistakes and let us examine how proposed changes would affect performance. Having this type of abstraction was a critical component to recognizing that there were problems due to noise regime changes and that the whistle graphs associated with false positive detections had certain characteristics that we could exploit.

Detection/classification algorithms: odontocete clicks. An article (Roch et al., 2015) was published describing current work with subaward collaborators from San Diego State University on the impact of equipment and site differences on odontocete species identification through features derived from echolocation clicks. The article demonstrates that there are significant

performance impacts on species classification when training data are recorded with instruments of a specific type or at a specific location and tested under non-matching conditions. This has significant impact on any Naval monitoring scheme that uses features from broadband echolocation clicks. We were also able to demonstrate that simple noise estimates can be used to reduce this penalty significantly. Further research in this area has the potential to further mitigate for train/test mismatch.

One of the most important things learned over the last year is that when one moves to working with very large datasets that have not been hand-curated to extract sections with data from relevant target species, performance degrades quickly. Analysis of the 2015 DCLDE development data led us to recognize that sporadic false positives from echolocation click detectors can wreak havoc on performance and we subsequently developed filtering rules that remove low frequency sporadic clicks as well as methods of identifying and removing instrument self-noise. Work with Kullback-Leibler distances between encounters enabled us to inspect characteristics of specific encounters to better determine what problems exist, and we are continuing work on this productive path.

Software: The architecture for writing detection, classification, and localization modules has been completed and communication between Ishmael and PAMGUARD and a test module has been established. The architecture provides a translation library for each DCL platform supported that marshals data into a format that can be shared with other processes. Modules run as separate programs that share a limited region of memory with the DCL platform. This allows modules written on platforms that require separate processes (e.g., Matlab, R) to be gracefully handled. Users designing classification modules will configure the DCL platform to send data to their module and make calls to a standard interface library. Results are sent back to the DCL platform in a similar manner. The plug-in architecture has been successfully demonstrated in Ishmael with a detector in MATLAB. The architecture now supports multiple languages, and work continues to refine the interface to make it as easy to use as possible.

PUBLICATIONS:

Frasier, K.E., E.E. Henderson, H.R. Bassett, and M.A. Roch. (2016) Automated identification and clustering of subunits within delphinid vocalizations. *Mar. Mamm. Sci.* 32(3):911-930.

Mellinger, D.K., M.A. Roch, E.-M. Nosal, and **H. Klinck.** 2016. Signal processing, In: **Listening in the Ocean,** W. Au and M. Lammers (Eds.), Springer-Verlag, New York, pp. 359-409.

TASK 3

Theme: Seafloor Processes

Amendment 67: Towards Optimizing the Determination of Accurate Heights Using GNS

Funded: $150,444

OSU RESEARCH STAFF: *Dan Gillins, Assoc. Professor, Civil/Constr. Eng.*
NOAA TECHNICAL LEAD: *Mark Armstrong, NGS/NOS*

Funded: $150,444

PROJECT BACKGROUND: In 1997, NOAA's National Geodetic Survey (NGS) published *NOAA Technical Memorandum NOS NGS-58*, "Guidelines for Establishing GPS-derived Ellipsoid Heights" (Zilkoski et al., 1997). These guidelines served a critical need in providing procedures that enable accurate ellipsoid heights on marks to be determined with GNSS. Accurate ellipsoid heights are an essential component of using GNSS (combined with a high-resolution hybrid geoid model) to determine accurate orthometric heights as an alternative to more expensive differential leveling surveys (NGS et al., 1998). However, recent research, as well as the experience of the broad community of surveyors, indicates that advances in GNSS technology, as well as the latest real-time GNSS techniques, may enable substantial efficiency gains in achieving accuracy requirements for GNSS-derived ellipsoid heights, as compared with what was achievable nearly 20 years ago. There is particular interest in the possibility of easing the requirements for multiple, long-duration static post-processed GPS observations, as required in NGS-58. For example, NGS-58 requires three 5-hr static GPS observations on several marks in order to determine ellipsoid heights with an accuracy less than 2 cm at 95% confidence.

The purpose of this research is to investigate a variety of GNSS data acquisition and post-processing procedures that have been developed since 1997 which can be used to more quickly determine ellipsoid heights on marks. The data acquisition procedures and post-processing software under investigation in this study include: 1) static GPS observations post-processed in Trimble Business Center, commercial baseline processing software; 2) static GPS observations post-processed in OPUS-Projects, web-based software released by NGS in 2013; 3) real-time kinematic GPS and GPS+GLONASS observations using correctors from a single base station in a real-time network; 4) real-time GPS and GPS+GLONASS observations using full network correctors from a real-time network. Some of the GNSS data evaluated in this study were collected during an NGS survey study in South Carolina (Gustin, Cothern & Tucker, Inc. 2013; Dennis 2014). Additional GNSS data were collected on 18 passive marks in Oregon by the project team at Oregon State in the fall of 2014.

After evaluating the various procedures and software, the ultimate goal for the project team is to write procedures for how to efficiently determine ellipsoid heights using the latest GNSS hardware and software. The written procedures will recommend techniques for collecting the data in the field, using real-time observations when and where appropriate, and post-processing static observations in OPUS-Projects. They will specify techniques (e.g., the number and duration of GNSS sessions) in order to achieve a particular accuracy in ellipsoid height.

PROJECT PROGRESS: The overarching goal of the first portion of the project was to investigate methods for efficient determination of accurate ellipsoid heights on marks (2 cm or better accuracy at the 95% confidence level, referenced to the NSRS), leveraging real-time GNSS. Specific project tasks aimed at achieving this objective include: 1) determining optimal observation durations, 2) investigating the effects on including GLONASS observations, 3) comparing single-base RTK (sRTK) and network RTK (nRTK) solutions, and 4) evaluating the effects of baseline length. In the nRTK analysis, both Virtual Reference Stations (VRS) and Master-Auxiliary Concept (MAC) methods were considered.

Analysis was performed using survey data collected on 20 passive marks in South Carolina and 18 passive marks in Oregon using various settings. The South Carolina data were collected by Gustin, Cothern & Tucker, Inc. (GCT) Engineering and NGS in 2013 in Aiken, Lexington, Richland counties, while the Oregon GNSS data were acquired by OSU Geomatics in 2014 and 2016, and included real-time observations using the Oregon Real-time GPS Network (ORGN). Some of the important findings from assessing the results of this analysis (Fig. 1) include:

1. For both nRTK and sRTK, both horizontal and vertical accuracy do not change significantly after 180 to 300 seconds
2. GLONASS helps achieve more fixed solutions at longer baseline lengths for sRTK
3. GLONASS significantly improved the performance for the sRTK solutions, but only slightly improved the accuracy of the nRTK solutions

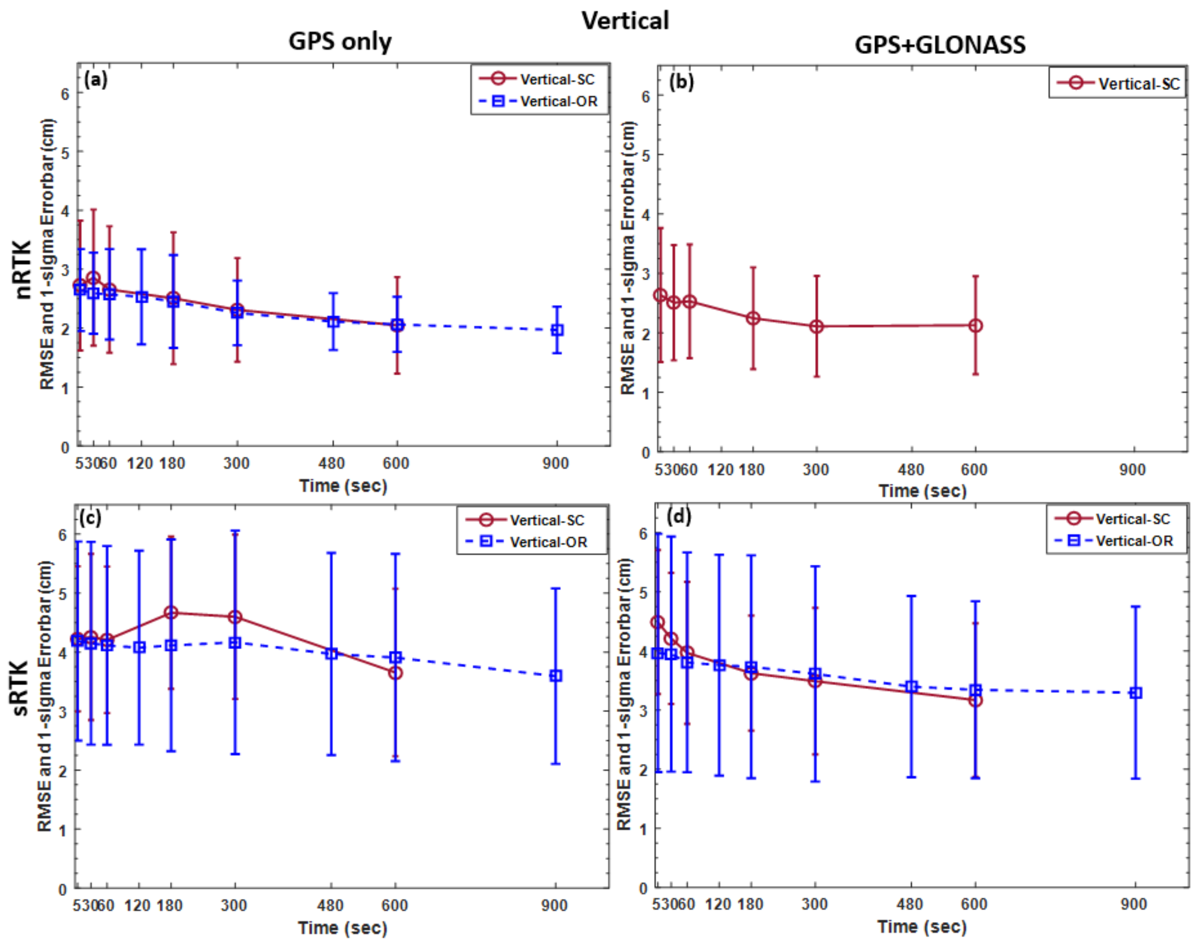


Figure 1. Vertical root mean square error (VRMSE) versus observation duration for (a) nRTK GPS-only, (b) nRTK GPS+GLONASS, (c) sRTK GPS-only, and (d) sRTK GPS+GLONASS observations.

The results and conclusions from the portion of the study are described in detail in Volume 1 of the final project report, entitled "Towards Optimizing the Determination of Accurate Heights using GNSS, Volume 1: Use of Real-Time Kinematic GNSS Survey Data for Establishing Geodetic Control," which was delivered to NGS on March 15, 2017. The results were also presented to NGS in a brownbag seminar in Silver Spring, Maryland, on March 16, 2017.

The hybrid network adjustment investigated in this study utilized the workflow depicted graphically in Fig. 2. In this workflow, baselines are processed in PAGES, and sessions are combined into a survey network and adjusted. The conceptual design of the hybrid network is illustrated in Fig. 3. In total, 30 hybrid networks were developed using 30 different samples of RTK data (10 from Oregon and 20 from South Carolina).

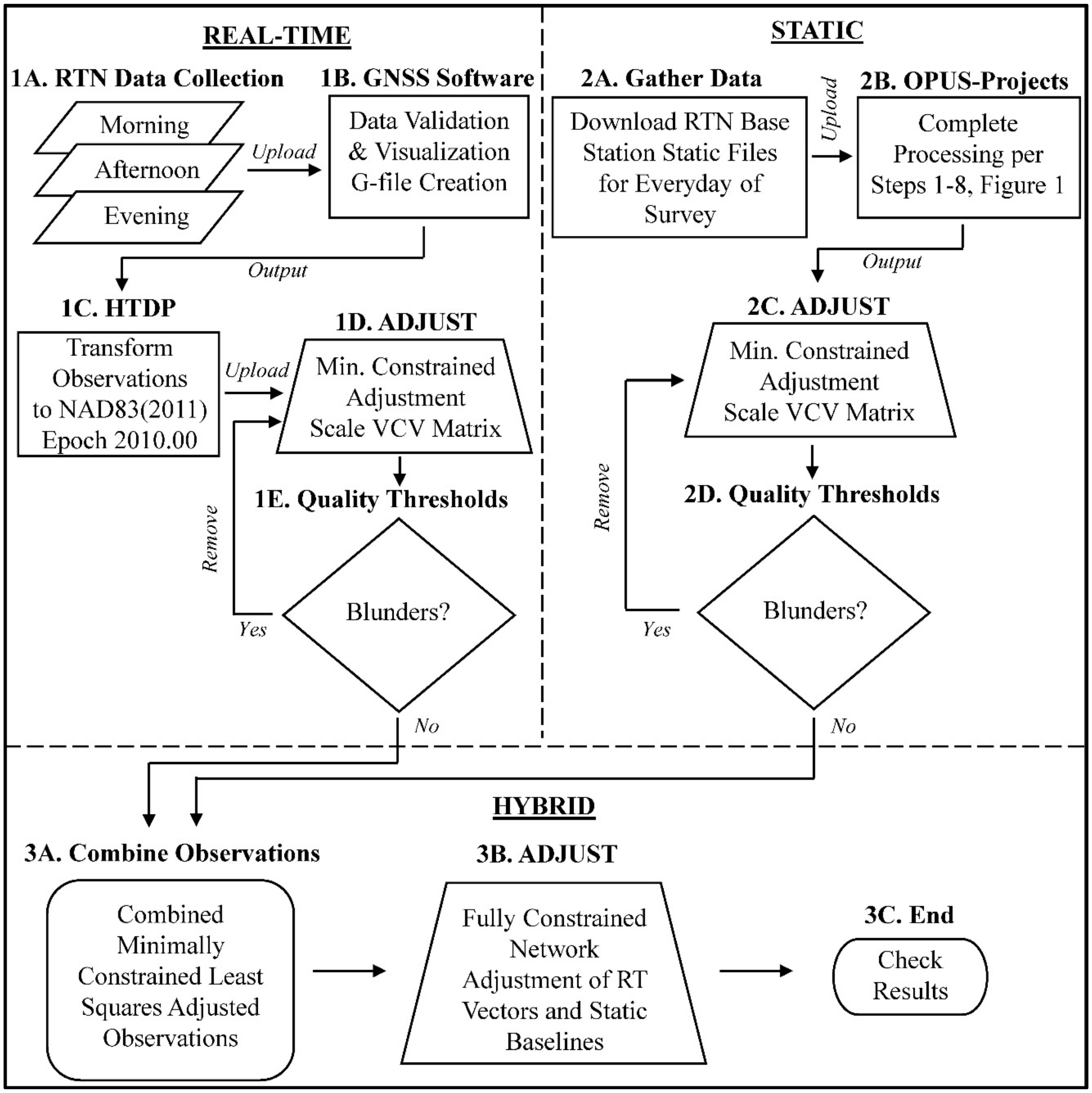


Figure 2. Flowchart for hybrid network adjustment.

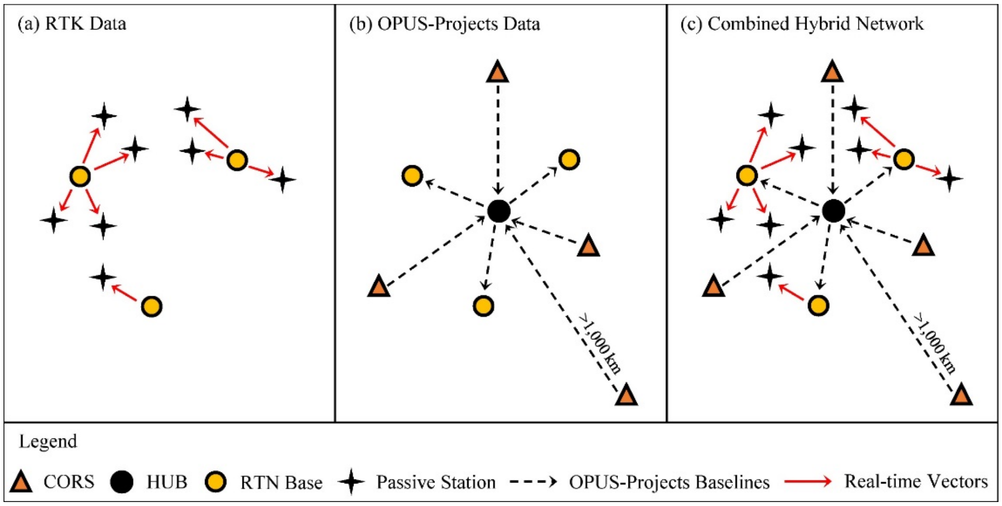
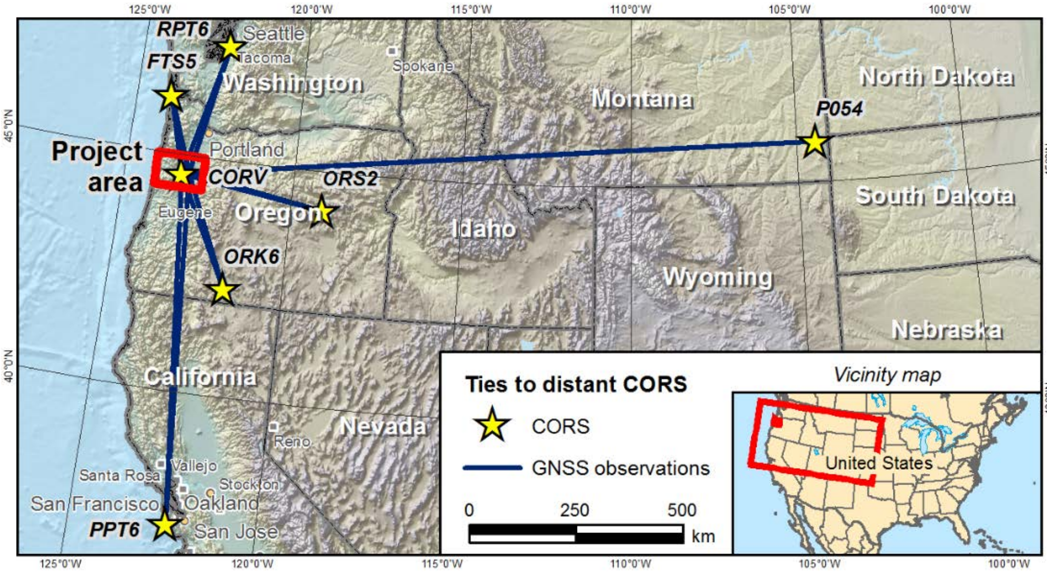


Figure 3. Hybrid network conceptual design.

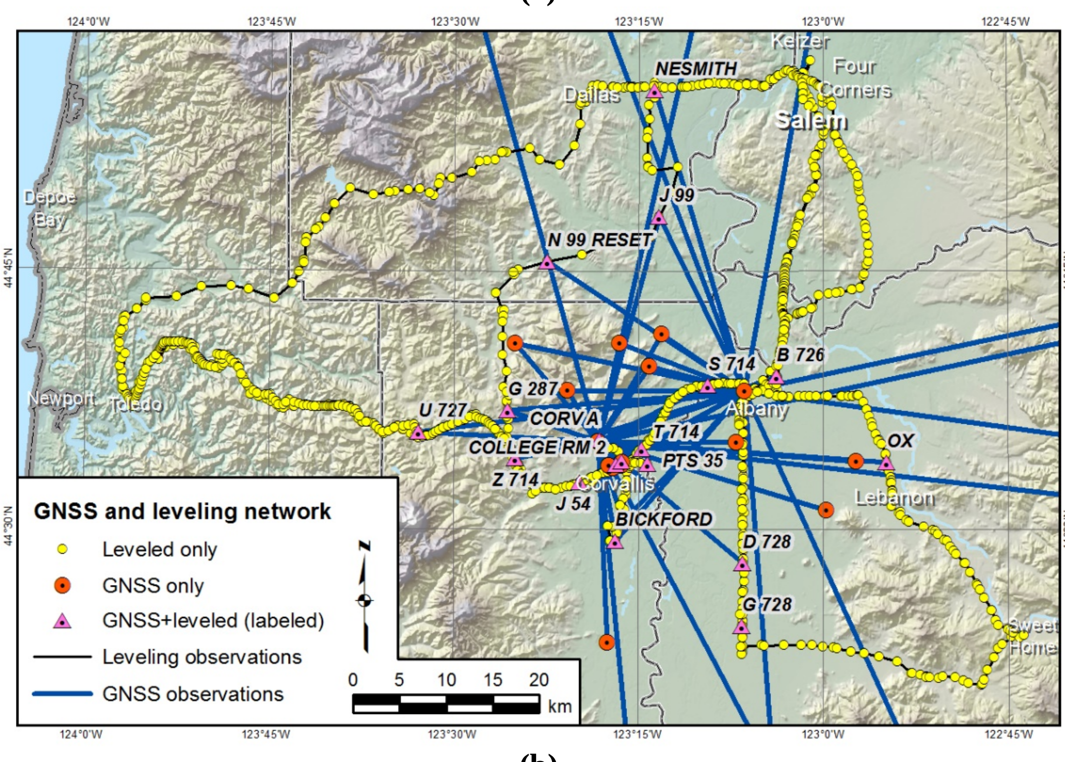
Significant findings from this portion of the project include:

1. Hybrid networks can increase the efficiency of height modernization surveys by including both RTK and static observations
2. It is important to scale variance-covariance (VCV) matrices to estimate realistic variances when combining data from different baseline processors
3. Appropriate Network RTK settings and up to date firmware versions are critical
4. The RTN must be configured to provide baselines to physical base stations
5. Formal error propagation network accuracies (95% confidence) were:
    a. Ellipsoid Height: 0.6 - 3.6 cm
    b. Horizontal: 0.3 - 1.7 cm
6. Comparisons against a static-only network (>30 hr data) yielded:
    a. VRMS: 1.3 - 2.2 cm
    b. HRMS: 0.6 - 1.0 cm

The second portion of the project has focused on the integration of differential leveling and GNSS. A specific objective was to develop methods and guidelines for integrating leveling and GNSS observations with a geoid model in a survey network adjustment. A key project task involved development of a 3D geodetic model for combining the reduced GNSS and leveling observations. This model includes variance component estimation of the leveling and GNSS observations, as well as empirical testing of relative geoid height error models in order to develop a realistic stochastic model for the combined 3D geodetic least squares adjustment.
In development of the model, the 2014 GNSS survey in western Oregon was studied in detail. Historic first- and second-order leveling observations in the vicinity of the 2014 GNSS survey were downloaded from the NGS Integrated Database and were converted from differences in geopotential numbers to differences in ellipsoid height. Fig. 4 displays a map of the study area.



(a)



(b)

Figure 4. (a) Overview map showing GNSS vector ties to six distant CORS, and (b) project area map of GNSS and leveling networks in Willamette Valley, Oregon, USA.

The results of minimally constrained (MC) and fully constrained (FC) network adjustments, including number of observations (*N*) in network, up residuals (*V*), and the standard deviation of unit weight (σ_0) are shown in Table 1 and illustrated graphically in Fig. 5:

Table 1. Summary of minimally and fully constrained network adjustments.

Adjustment	$N_{leveling}$	N_{GNSS}	$V_{leveling}$ (cm)	V_{GNSS} (up) (cm)	σ_0
MC, leveling only	1256	--	-0.8 to 0.8	--	0.998
MC, GNSS only	--	359	--	-3.2 to 2.7	1.000
MC, GNSS+leveling	1256	359	-2.4 to 1.2	-4.8 to 4.4	1.110
MC, GNSS+leveling*	1255	358	-1.0 to 1.1	-2.7 to 2.7	1.006
FC, leveling only	1256	--	-0.9 to 1.1	--	1.037
FC, GNSS-only	--	359	--	-3.2 to 2.7	1.013
FC, GNSS+leveling	1255	358	-0.9 to 1.1	-2.7 to 2.7	1.017

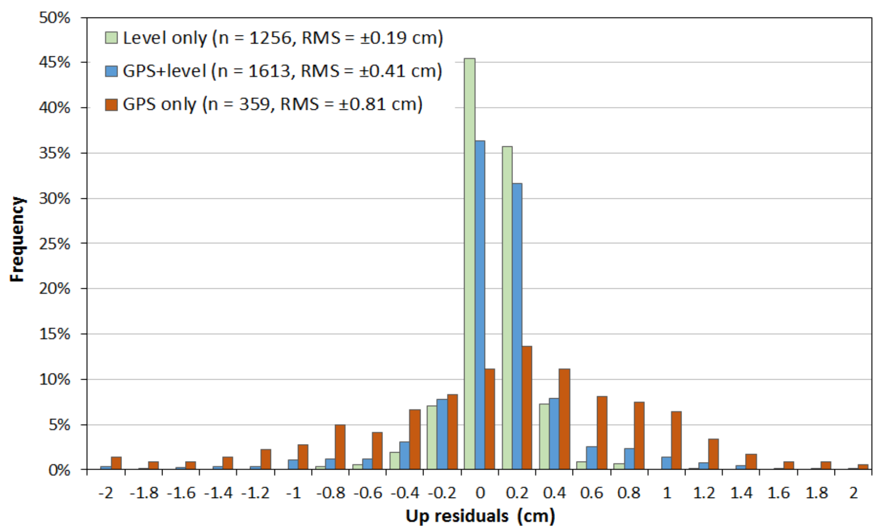


Figure 5. Up residuals for GNSS, leveling, and combined fully constrained adjustments.

In addition, an experiment for determining orthometric heights from the GNSS data, a geoid model, and leveling observations was conducted. During the project, we adopted a combined adjustment approach suggested by Kotsakic et al. (1999) that creates the correction surface model (CSM) to compensate the error of the simple equation, which linearly defines the relationship between ellipsoidal height, geoid height, and orthometric height. To validate the suggested approach, we estimated the orthometric heights using the CSM for the test area in Oregon, then compared the output with the published orthometric height. For this experiment, the NGS geoid models, GEOID12B and xGEOID16B were applied. Table 2 shows the experimental results by using the two geoid models. It should be noted that the GEOID12B yielded superior results, due to the nature of this geoid model that was generated by geometric measurements, while xGEOID16B was generated by gravity measurement. Both results show that the CSM works in terms of accuracy at the centimeter level.

Table 2. *Discrepancy between the published orthometric heights and the estimated orthometric heights using the CSM method with xGEOID16B and GEOID12B, respectively*

	xGEOID16B [cm]	GEOID12B [cm]
Average	5.551	2.484
Maximum	15.159	12.743
Minimum	1.086	0.186
Standard Deviation	3.308	3.310
RMS	6.412	4.060

PRESENTATIONS:

The project team has given a total of four presentations on this research project over the past year: two at international conferences, one at a state surveyor's conference in Virginia, and one to NOAA personnel at NGS headquarters. These are summarized below:

(1) ION GNSS+ 2016 conference in Portland, Oregon, September 16, 2016
(2) Virginia Association of Surveyors Annual Convention, Herndon, Virginia, January 28, 2017
(3) NOAA's Silver Spring Metro Campus (SSMC) Building 3, Silver Spring, Maryland, March 16, 2017.
(4) 2017 FIG Working Week in Helsinki, Finland, June 1, 2017.

PUBLICATIONS:

Allahyari, M. 2016. Accuracy evaluation of real-time GNSS survey observations. M.S. thesis, Department of Civil and Construction Engineering, Oregon State Univ., Corvallis, Oregon.

Gillins, D.T., and Dennis M.L. 2017. Inclusion of leveling with GNSS observations in a single, 3-D geodetic survey network adjustment. *Proc. FIG Working Week 2017*, Helsinki, Finland, 18 pp.

Gillins, D., and Eddy, M. 2015. An Evaluation of NGS-58 and OPUS-Projects: Methods for determining accurate ellipsoidal heights with GPS", Report. NOAA's National Geodetic Survey: Silver Spring, MD, USA.

Gillins, D., and Eddy, M. 2016. Comparison of GPS height modernization surveys using OPUS-Projects and following NGS-58 guidelines. *J. Surv. Eng.*, 143(1): 05016007.

Gillins, D.T., Dennis, M.L., Weaver, M.L., Olsen, M., and Parrish, C. 2016. Hybrid static plus real-time GNSS survey networks: An efficient approach for height modernization surveys. ION GNSS+ 2016, 12-16 Sept, Portland, Oregon.

Gillins, D.T., Olsen, M.J., Allahyari, M., Weaver, B., and Dennis, M.L. 2017. Towards optimizing the determination of accurate heights using GNSS, Volume 1: Use of real-time kinematic GNSS survey data for establishing geodetic control. Report. NOAA's National Geodetic Survey: Silver Spring, MD, USA.

Jamieson, M. 2017. Comparative analysis of online static GNSS post-processing services. Honors Baccalaureate of Science thesis, Department of Civil and Construction Engineering, Oregon State Univ., Corvallis, Oregon.

Weaver, B. 2017. Hybrid survey networks: Combining real-time and static GNSS observations for optimizing height modernization. M.S. thesis, Department of Civil and Construction Engineering, Oregon State Univ., Corvallis, Oregon.

Amendment 69: A Multidisciplinary, Integrative Approach to Valuing Ecosystem Services from Natural Infrastructure

Funded: $444,743

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

NOAA TECHNICAL LEAD: *Felix Martinez*, NCCOS

PROJECT BACKGROUND: This research advances the multidisciplinary science of coastal 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. We anticipate that our resulting models will yield generalizable methodological insights that will extend the frontier of ecosystem service science.

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

We are investigating four distinct systems on the Oregon coast that serve as applied pathways for our work. The project pathways are: 1) quantifying protection from different land features and types of risk in the coastal system subject to wave action (Coastal Protection Pathway); 2) resilience, native species conservation, and the non-consumptive value of dune habitat (Dune Habitat Pathway); 3) restoring coastal wetlands and the resulting implications for anadromous fish, water quality, and blue carbon in estuarine systems (Estuary Pathway); and 4) how to allocate land use to facilitate tsunami evacuation (Coastal Land Use Pathway).

PROJECT PROGRESS: Our second annual Advisory Board meeting was held in Newport, Oregon on April 14th, 2017. Participants included Advisory Board members: Felix Martinez (NOAA NCCOS), Shelby Walker (Oregon Sea Grant), Dan Lew (NOAA Alaska Fisheries Science Center), Jarod Norton (U.S. Army Corps of Engineers), Brady Callahan (Oregon Parks and Recreation (OPRD), Jonathan Allen (Oregon Department of Geology and Mineral Industries (DOGAMI)), W. Aaron Jenkins (Oregon Department of Fish and Wildlife (ODFW)), Patty Snow (Oregon Department of Land Conservation and Development (DLCD)), David Yamamoto (Tillamook County (OR) Commissioner), Casey Denehy (Surfrider Foundation), and Cam Parry (Wild Rivers Coast Alliance); CIMRS director Michael Banks; Oregon State University (OSU) faculty and project PIs: Steven Dundas, Sally Hacker, David Kling, David Lewis, Christopher Parrish, and Peter Ruggiero; OSU faulty research assistant Laurie Houston; and OSU graduate students Jason Beasley, Cassie Finer, Tu Nguyen, Paige Hovenga, Katya Jay, Caitlin Magel, and Laura Barreiro-Fernandez.

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 on-going 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 Atmospherics 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.

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 gathering data 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, my 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

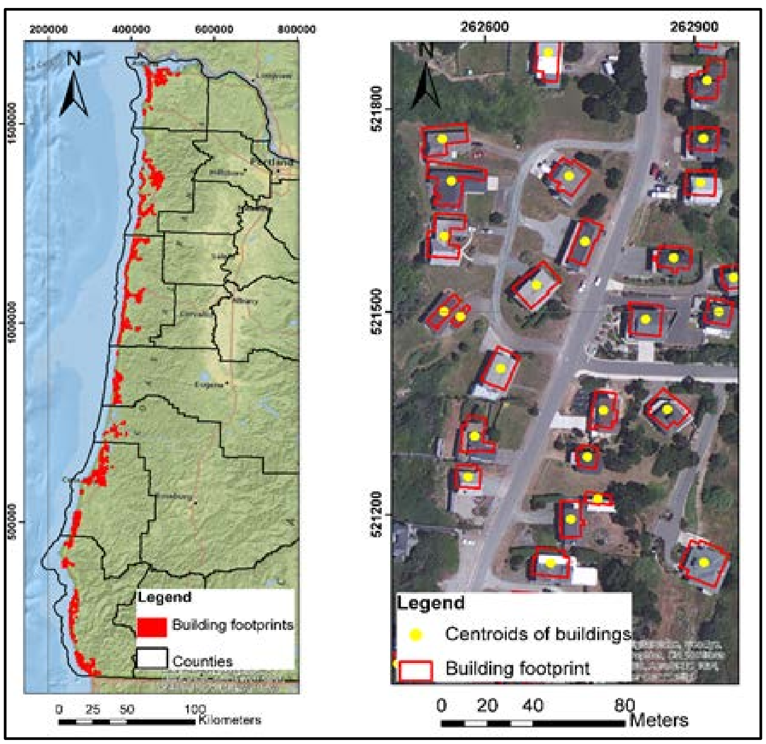


Figure 1. Automatic detection of the buildings: a) full extent, and b) detailed view.

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).

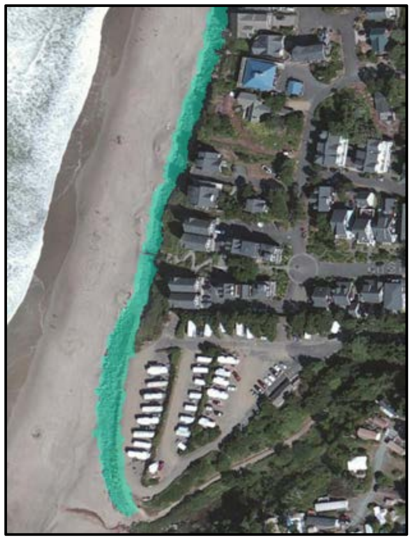


Fig 2. Mapping of riprap structures with LIDAR data. Light blue polygon shows the riprap classification.

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.

MEETING 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. .

Ruggiero, P., "Morphodynamics of Prograding Beaches", Hatfield Marine Science Center Seminar Series, Newport, OR, July, 2016.

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.

PROJECT OUTCOMES

Although the primary research is still developing, we see clear potential for the anticipated results of our research program associated with this project to lead to changes in the knowledge or actions of stakeholders and policymakers. Some examples are described below.

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

- Co-PI Parrish and graduate student Fernandez are coordinating with OPRD and board member Callahan on a remote sensing tool and data generating process that has potential to improve OPRD’s ability to manage coastal structures.