Project title: Building an Eastern Pacific Marine One Health Coalition to Strengthen Capacity for Health Monitoring, Zoonotic Disease Surveillance, Response and Management in Marine Ecosystems

Description of entities:

Oregon Department of Fish and Wildlife (ODFW) Wildlife Health and Population Lab Program provides expertise, technical assistance, and training to staff and partners in addressing wildlife health issues, including wildlife disease surveillance, outbreak response, and human-wildlife conflict. The Marine Mammal program, part of the marine resource division, is tasked with research and management of marine mammals inhabiting the OR coastline in collaboration with government and tribal partners.

University of California, Los Angeles (UCLA) is dedicated to the creation, dissemination, preservation and application of knowledge for the betterment of our global society and prides itself on strong training, research, and extension programs that are active across the world. UCLA is a long-standing partner of ODFW, and other organizations in the Eastern Pacific, in researching the ecology of leptospirosis in the marine ecosystem, and brings expertise in disease ecology, wildlife capture, epidemiology and modeling.

Washington Department of Fish and Wildlife (WDFW) preserves, protects, and perpetuates the state's fish, wildlife, and ecosystems. WDFW's marine mammal research group is housed within the Wildlife Science Division. This team has conducted diverse research on marine mammals since the 1980s with the goal of providing the science needed to make evidence-based management decisions.

Statement of need:

Marine wildlife currently face numerous health threats, many of which are exacerbated by the impacts of climate change and other anthropogenic stressors on these same populations (Lettrich et al. 2019; NASEM 2017). In addition, almost 40% of the U.S population resides on or near the coast [1], intensifying anthropogenic stressors that negatively impact marine wildlife, as well as the health and livelihoods of local communities, including Tribal Nations, who are reliant on a healthy and productive marine ecosystem. Throughout the eastern Pacific marine ecosystem, marine animals are exposed to pathogens (e.g., *Leptospira* spp., Otarine herpesvirus-1, *Toxoplasma gondii*, sea star wasting disease) [2–7], biotoxins (e.g. domoic acid) [8–12], contaminants (e.g. Polychlorinated Biphenyls, persistent organic pollutants, DDT) [13–18], and heavy metals (e.g. mercury, lead, selenium) [16,19–24] which impact their health, and many of which are influenced by climate change and anthropogenic disturbance. In addition, there have been major, climate-driven shifts in forage communities, some of which have significantly impacted marine wildlife health and nutrition [25–33]. Impacts of these threats, including multifactorial exposures (e.g., pathogens and toxins), have been documented with associated negative effects on marine mammal behavior, diet, health, reproduction, and survival [14,26,34–37]. However such studies are rare and difficult to conduct for a number of reasons including, but not limited to the following: long-term datasets, required to assess changes in health, are rare and difficult to build as they require substantial investments in time, personnel and money; baseline data on what is 'normal' with regards to the presence of harmful compounds such as the frequency of a pathogen or level of a contaminant often do not exist; similarly 'normal' health reference ranges for marine mammals are generally unknown due to lack of samples or funding to support such work. Without these key data and long-term datasets, it is difficult to detect epidemics (e.g. an increase, often sudden, in the number of cases of a disease above what is normally expected in that population in that area), harmful contaminant or toxin levels, to assess disease (i.e. health measures that fall outside of the normal reference range), and to identify and characterize the impact of climate and anthropogenic stressors on marine health [36–39]. **Long-term studies of marine ecosystem health must be prioritized, before it is too late, as they can provide key insights into risks to human health**. Marine mammals are exposed to many of the same anthropogenic stressors as domestic animals and humans living in coastal communities, and are therefore important indicators for human and ecosystem health [36,40,41] and provide early warnings of ecosystem-level health threats[40].

This project will unite a multidisciplinary, cross-sectoral network of experts with the common goals of strengthening capacity for health monitoring, zoonotic disease surveillance, response and management in

marine ecosystems in the Eastern Pacific. In particular, we will establish a marine One Health coalition to address complex challenges that no one discipline or sector can tackle alone and to build critical long-term datasets on marine health and disease. The Eastern Pacific Marine One Health Coalition (EPMOHC) will be founded on a model that brings partners shared value and is solutions-based, transformative, sustainable, and scalable. Through the coalition, we will create opportunities to harness and mobilize expertise and resources and collectively unleash innovative approaches that will have direct bearing on the management of protected marine species and the health and livelihoods of coastal communities. Specifically, the coalition will provide a platform for identifying common goals; sharing knowledge and resources; developing a framework through which to share data, and build and integrate long-term datasets on marine mammal health and oceanographic conditions; sharing archived samples to reach common objectives around zoonotic surveillance, health monitoring and research; fostering research collaborations; and sharing analytical approaches to understand complex interactions driving infectious disease dynamics in the marine ecosystem.

We will demonstrate the value of this multidisciplinary and collaborative approach through building on a long-term collaboration investigating the pathogen dynamics of a zoonotic pathogen in marine mammals in the Eastern Pacific, and the impacts of climate and oceanographic factors on these dynamics. Leptospirosis, the disease caused by pathogenic species in the genus *Leptospira*, is endemic in the California sea lion (*Zalophus californianus*; CSL) population and causes yearly, seasonal outbreaks of varying magnitude[4]. It is infrequently diagnosed in humans in the U.S., but cases have been reported in humans and domestic animals along the California coast[42,43]. Infections or evidence of exposure have also been documented in several other marine mammal species that share habitat with CSL, including northern elephant seals (*Mirounga angustirostris*)[44], northern fur seals (*Callorhinus ursinus*) [45], pacific harbor seals (*Phoca vitulina*) [46], Steller sea lions (SSL; *Eumetopias jubatus*) [47], and sea otters (*Enhydra lutris*) [48].

From 2013-2017, the northeastern Pacific Ocean experienced anomalous conditions during which cyclical outbreaks of *Leptospira* in the CSL population ceased. This "fadeout period" was associated with poor growth and survival in CSL pups coinciding with decreased consumption of high quality forage among adult females and juveniles, and a shift in historic age- and sex-specific seasonal movement patterns [26,30,32]. In 2017, leptospirosis re-emerged in the CSL population as higher numbers of susceptible juvenile CSLs had the energy stores to migrate northward and mix with adult male CSLs and other marine wildlife [49]. Because of the long-term dataset that resulted from a large, multidisciplinary, collaborative effort, this unique pathogen fadeout event was detected, and connections from climate to pathogen fadeout were detected. Continued extension of this exceptional dataset will enable detection of future fadeout events and its drivers, as well as complex interactions between climate driven expansion of host ranges and new transmission opportunities between CSL and other susceptible host species, including vulnerable marine mammal species (e.g. Steller sea lions, sea otters), and coastal communities of the eastern Pacific. This case study also serves as a model example that can be scaled to other species and health threats.

Long-term studies such as this one along with increasing technical advancements in remote sensing, laboratory diagnostics, information systems, and data analytics are creating opportunities for more in-depth monitoring and research in marine environments[50]. With these advancements on-board, we are better able to disentangle the complex relationships between hosts, pathogens, and environmental drivers of pathogen dynamics and thereby improve our understanding of marine health threats and how to rapidly detect and mitigate them. Our coalition creates an opportunity to harness these tools and expertise to monitor for and preemptively address emerging and re-emerging pathogens, including high-priority zoonoses. The ability to assess and forecast risk in combination with rapid detection and response to health threats is essential for protecting vulnerable marine mammal populations as well as mitigating the risk of zoonotic spillover from marine mammals into domestic animal and human populations. These abilities depend on interjurisdictional collaborations and regional capacity for marine mammal disease surveillance, laboratory diagnostics, information management, data analytics, public education and outreach, and rapid response.

This proposed project will make important contributions to multiple USFWS objectives outlined in the notice of funding opportunity, including but not limited to: an evidence-based wildlife disease plan which considers disease surveillance; access to laboratory diagnostics; outbreak response; wildlife population management; data management; risk assessment and decision support; interjurisdictional network of practitioners; and communication plans. Without this award, wildlife managers and stewards of the marine ecosystem will continue to be in the dark with regards to shared health threats to marine mammals and coastal communities, including anthropogenic and climate change impacts on vulnerable marine species and their pathogens [36,38].

Project objectives:

The overarching goal of this project, during this period of intense anthropogenic pressures and climate perturbations, is to **enhance capacities for marine mammal health and disease monitoring, research and management in the Eastern Pacific** through leveraging multidisciplinary efforts and broad-scale collaborations. In particular, we focus on zoonoses that could affect the viability of marine populations, as well as the health and livelihoods of humans and their pets living in coastal communities; and strengthening regional capacities for coordinated disease surveillance, early detection, information management, and disease forecasting. We will accomplish this via the following five Objectives.

Objective 1. ODFW and UCLA primary and co-investigators (PI and CIs) **will strengthen existing networks by establishing a scaleable Eastern Pacific Marine One Health Coalition (EPMOHC) consisting of relevant stakeholders by January 2023 to identify and address key issues in marine mammal health.** This coalition will build on and strengthen existing collaborations among universities, organizations, and government agencies working on marine mammals, and aims to harness expertise; facilitate knowledge sharing; and strengthen coordinated, sustainable marine mammal research, surveillance, health monitoring and management efforts across organizations and jurisdictions. Establishment of this coalition will enable construction of the long-term, spatially extensive datasets necessary to identify emerging zoonoses and other infectious disease threats, and to address critical questions regarding climate and anthropogenic impacts on marine mammal health and infectious disease dynamics. The Specific Activities (SA) achieved under this objective and their timing are as follows:

SA 1.1 In the first 3 months PI and CIs will engage stakeholders from agencies, universities, tribal nations, and non-profit organizations involved in response, research, management, and infectious disease surveillance (including zoonoses) of marine mammals from the Eastern Pacific coastal zone (see Appendix 3 for detailed list of stakeholders).

SA 1.2 Between months 3 and 6, through stakeholder engagement and an online survey, the PI and CIs will identify the key needs and priorities around infectious disease surveillance, response, population management, data sharing and management, sample collection and biobanking, and research to be discussed at a EPMOHC workshop (to be held by month 6). The team will also identify funding opportunities and priorities to be discussed at the workshop.

SA 1.3 PI and CIs will draft a Memorandum of Understanding (MOU) for EPMOHC which outlines a data and sample sharing approach for participants. This may involve a tiered approach where certain groups have access to different levels of data (e.g. stranding network participants vs. university researchers vs. general public), and will ensure protection of intellectual property and appropriate citation and acknowledgement among collaborators. The MOU will be reviewed and discussed during the initial EPMOHC workshop with interested stakeholders signing on by the end of the project.

SA 1.4 PI and CIs will conduct two 3-day workshops at Portland State University (PSU, Portland, OR) in the first and last six months of the 24 month project. Roughly 60 stakeholders engaged in SA1.1 will participate in these workshops to collectively achieve the following aims:

A. Present 2-3 case studies highlighting marine health monitoring and research efforts in the Eastern Pacific that illustrate how an established coalition can strengthen existing capacities for detecting

outbreaks, conducting disease surveillance and identifying key drivers of disease in the marine ecosystem (e.g. climate impacts on leptospirosis in CSLs, sea star wasting disease, protozoal pathogens in sea otters and pinnipeds).

B. Using survey results as a template, discuss existing needs and gaps in knowledge, protocols , data and sample sharing, analytic approaches and resources (e.g. diagnostic laboratories, biobanking, data repository) to address critical needs across the coalition.

C. Prioritize gaps and address the top 5 through small working groups focused on a single need or gap. In year 1, these teams will compile and present current knowledge, data, and resources regarding their topic, and in year 2 will present a draft action plan.

D. Harness and share expertise and resources on:
   a. Disease surveillance strategies that will improve partners' capacities to monitor for and rapidly detect and characterize unusual health events, identify and characterize health impacts of disease and zoonotic disease risk, and inform stranding response and marine mammal wildlife disease management plans.
   b. Field techniques, sample collection, processing, and biobanking (Obj 3 & 4); information management (Obj 2); and effective methods for community engagement and outreach.

E. Discuss opportunities and approaches for integrating key data streams (e.g. marine mammal stranding and disease surveillance, oceanographic conditions, fisheries data) into analyses for assessing climate change impacts on Eastern Pacific marine ecosystem health (see Obj 5).

F. Identify funding opportunities to meet goals (e.g. research, surveillance, stranding, response, population management, information management, sample archiving) and form working groups with interested coalition members to develop grant proposals between Year 1 and 2 workshops for submission at the end of Year 2. Funding opportunities for continued support of the coalition and its workshops will also be sought, such as that received by Dr. Drew Harvell, an engaged stakeholder who has provided a letter of support (Appendix 4; e.g. National Science Foundation Marine Disease Research Coordination Network).

Stakeholders will be reconvened for workshop 2 during which working groups from workshop 1 will discuss their progress on their aims, and a similar process of prioritization and small working group formation will occur to continue to address the stakeholder-identified needs of the coalition. PI and CIs will present updates on progress and results related to Objs 2-5.

Objective 1 Deliverables:

1. An EPMOHC with formalized partnerships through MOUs (by month 24).
2. Coalition needs and knowledge gaps prioritized highest to lowest (months 6 & 24).
3. 4-5 working groups established to address key gaps in need/knowledge (by month 6).
4. 2-3 drafted grant proposals to advance the goals of the coalition stakeholders (by month 24).

Objective 2. Develop a conceptual model for integration of Eastern Pacific data on marine mammal health monitoring, zoonotic disease surveillance, and research into an existing marine mammal information system (Health MAP) by September 2024. The Marine Mammal Health Monitoring and Analysis Platform (Health MAP), a collaborative effort between the U.S. Marine Mammal Commission, NOAA, National Marine Mammal Foundation, and TMMC (in support of the Marine Mammal Health and Stranding Response Program), is a nationally centralized system that aggregates, curates, and provides online access to marine mammal health data in near real-time. The system was developed with the goals of facilitating early detection of potential health threats, applying an ecosystem-based approach for situational awareness and risk forecasting, and serving as a decision support tool for resource managers. The data - collected through stranding events, health assessments, and research - can enhance visualization of potential unusual morbidity and mortality events (UMEs) and be analyzed in relation to other data, including oceanic conditions, such as sea surface temperature (SST), salinity, and primary

productivity. Once fully deployed, Health MAP will be linked to the Wildlife Health Information Sharing Partnership - event reporting system (WHISPers). We will work with the Health MAP team on a conceptual model for integration of Eastern Pacific marine mammal data into the Health MAP system through the following Specific Activities:

SA 2.1 Engage with the Health MAP Executive Committee and technical team and members of EPMOHC to assess needs and priorities for marine mammal data and information management.

SA 2.2 Develop a conceptual model for a specimen-information repository to allow researchers and network partners to deposit and exchange metadata on samples collected during disease surveillance activities, research projects, and investigations of morbidity and mortality events to facilitate specimen exchange and collaboration. Investigators will engage the Health MAP team to explore opportunities for managing these data in Health MAP.

SA 2.3 Engage with the Health MAP technical team and members of EPMOHC on the approach and process for sharing data with WHISPers.

Objective 2 deliverables:

1. Report of marine mammal information management needs and priorities to EPMOHC (Sept 2024).
2. Conceptual model for a specimen-information repository in Health MAP by Sept 2024.

Objective 3. PI and CIs will strengthen the case study of *Leptospira* in the marine ecosystem by engaging key EPMOHC members to extend the long-term dataset on *Leptospira* infection and exposure in CSL, and begin a similar dataset in SSL, through diagnostic testing, every 3 to 6 months, of archived and prospectively collected samples from Oregon and Washington. This study will expand to include *Leptospira* in Steller sea lions (SSL), and possibly sea otters (SO), as the populations of these vulnerable species expand, and contact with potentially *Leptospira* infected CSL increases. Additional health or disease assessments using archived and prospectively collected CSL, SSL and SO samples will be prioritized by EPMOHC in the first workshop. Funds from this proposal will go towards conducting the highest priority analyses and additional funds will be sought by working groups from the workshop to cover other prioritized analyses. UCLA has been collaborating with ODFW, NOAA AFSC, and TMMC as well as other organizations, universities, and agencies for over a decade. These multidisciplinary cross-sectoral collaborations have resulted in a long-term dataset, unprecedented in disease ecology, which integrates data on sea lion health and disease, demography and movement. Through analyses which leverage publically available data on oceanographic and climate variables, we have used this unique, long-term dataset to gain a better understanding of *Leptospira* dynamics in the marine ecosystem, identify key oceanographic factors that influence these dynamics, and build a sample archive that has been, and can continue to be, used to address critical questions regarding sea lion health and disease, and the climatic and anthropogenic factors impacting them [35,49,51–54]. By extending these rare, long-term datasets and sample archives, we can continue to use this case study to disentangle the complex links between climate impacts on marine mammal health and infectious disease dynamics during this current period of intense climate variability and increasingly frequent marine heat waves [32,33,55–57]. Marine mammals have been identified as sentinels for ocean and human health [27,38,40], and, CSL are critical indicators of California Current ecosystem and coastal ocean health based on long-term studies of CSL health and links to ecosystem changes [27–29,54,58,59]. The CSL population is robust and thus also an excellent sentinel for sympatric threatened and endangered species which are more difficult to monitor and for which large data sets might not yet exist. Together with coalition partners we will be able to leverage new skills towards identifying, investigating and understanding threats to other species of marine wildlife and enhance our understanding of the relationships between their health and human health in coastal communities. This will be accomplished through the following Specific Activities:

SA 3.1 Conduct prospective sampling of CSL for *Leptospira* surveillance (SA 3.3), renal health assessment (SA 2.4), and sample archiving for additional high priority disease surveillance and health

assessment activities as identified during the EPMOHC workshop. At a minimum, blood and urine will be collected from all animals. But additional samples, as identified by EPMOHC, may also be collected (e.g. vibrissae for stable isotope diet analyses, nasal and rectal swabs for SARS-CoV-2 and influenza A surveillance, tissues for toxins, hormones and contaminants).

A. Each year, between the months of September and May, ODFW/WDFW/IDFW will collect samples from an estimated 60 CSL and 40 SSL under Section 120f of the Marine Mammal Protection Act, which authorizes the states of Washington, Oregon and Idaho to lethally remove CSL and SSL at Bonneville Dam and Willamette Falls that are feeding on ESA-listed salmon and steelhead in the Columbia River Basin.
B. In August 2022 and 2023 UCLA and ODFW will lead one week field expeditions in Astoria, OR, where, since 2012, they have successfully conducted fieldwork to sample an estimated 30 CSL/year. Most Bonneville Dam and Willamette Falls sampling occurs in the spring months, hence sampling in August ensures adequate sampling during the fall months.
C. During the 2 year grant, samples will collected and shared for *Leptospira* diagnostics from up to 50 CSL and SSL handled by OR and WA stranding and rehabilitation organizations (e.g. SR^3, Northern Oregon/Southern Washington Marine Mammal Stranding Program, Oregon Marine Mammal Stranding Network - see LOS in Appendix 4). If possible, samples from sea otters will also be shared. Access to associated demographic data will also be provided.

Results from analyses of CSL samples from Bonneville Dam and Willamette Falls will provide key data on *Leptospira* dynamics in the PNW during the spring months, samples from Astoria, OR will provide data from the fall months, and samples from CSL stranded along the OR and WA coast will provide critical data on when and where CSL with clinical leptospirosis strand. Data from the stranded CSL will fill a key gap in our knowledge of *Leptospira* dynamics in CSL in the eastern Pacific as all stranded CSL data to date are from CA, and this will be the first time that stranded CSL from OR and WA are systematically sampled and tested for exposure and infection with *Leptospira*. This will also be the first systematic *Leptospira* surveillance of SSL.

Funding will be sought to scale-up this approach by including sample collection and diagnostic testing of archived and prospectively collected samples from throughout the Eastern Pacific, and to include additional species (e.g. northern elephant seals, pacific harbor seals, northern fur seals, sea otters) to understand *Leptospira* and other disease dynamics in the marine ecosystem.

SA 3.2 PI and CIs will select, for *Leptospira* diagnostics and serum chemistry (SA 3.3), archived samples from 50 CSL and SSL collected by ODFW/WDFW/IDFW between 2020-2022. Combined with SA 3.1 A & B, diagnostic results from these samples will extend the long-term dataset on *Leptospira* infection and exposure in CSL in OR and WA from 8 to 12 years and will increase our ability to detect long-term trends and climatic and anthropogenic drivers.

SA 3.3 PI and CIs will organize quarterly sample shipments for diagnostic analyses. Serum samples will be sent to the Oregon State University Veterinary Diagnostic Laboratory for microscopic agglutination testing (MAT) for anti-*Leptospira* antibodies to assess exposure and for serum chemistry analysis to assess general renal health. Urine will be sent to the Colorado State University Diagnostic Laboratory for PCR to detect *Leptospira* DNA, and culture media inoculated with aseptically collected urine or kidney will be sent to Michigan State University Diagnostic Laboratory to attempt *Leptospira* isolation. Both PCR and culture detect current, active *Leptospira* infections (kidney and urine), as well as leptospire shedding (urine), a proxy for transmission risk. Culture and isolation are required to identify the infecting *Leptospira* serovar and strain necessary for characterizing transmission linkages between host species.

SA 3.4 In months 12 and 18, PI and CIs will coordinate selection and shipment of 90 samples for urine protein creatinine ratios to be conducted at IDEXX, and urinalysis and renal histopathology to be conducted at TMMC. These diagnostics are to characterize renal disease and function to identify health

impacts of historic or current *Leptospira* infection in CSL that are more subtle than those detected via serum chemistry analyses, as well as health impacts of other conditions impacting kidneys (e.g. urogenital carcinoma, renal amyloidosis, domoic acid toxicity).

SA 3.5 During the first stakeholder workshop, stakeholders will determine which additional surveillance and/or health assessments will be conducted using archived and prospectively collected CSL samples using the available 'unassigned' diagnostic funds included in the budget. Samples will be selected and sent quarterly for the chosen analyses.

Objective 2 Deliverables:

1. Summary of *Leptospira* and renal diagnostic results for samples from SA 3.1 and 3.2 in a surveillance report (Sept 2024).
2. Draft of a peer-reviewed publication of the surveillance efforts (Sept 2024).

Objective 4. Comparatively evaluate the diagnostic potential of WITNESS Lepto, SNAP Lepto, and MAT for detection of *Leptospira*-specific antibodies in 40 banked CSL serum samples with known MAT titers of varying magnitude by Sept 2024. The SNAP Lepto and WITNESS Lepto tests are rapid, point-of-care diagnostics used in domestic dogs that, if validated in CSL, would enable rapid confirmation of *Leptospira* in suspect leptospirosis cases. In addition, because the WITNESS Lepto test detects IgM, the first antibody class to increase post-infection, it may be more sensitive during the acute stages of infection as compared to the MAT and SNAP Lepto test. The relative performance of these novel diagnostic tests and MAT (the gold standard) will be assessed through the following Specific Activities:

SA 4.1. Test aliquots of archived frozen CSL sera, with known *Leptospira*-specific antibody levels, by MAT, SNAP Lepto test, and WITNESS Lepto test. We will analyze serum samples from a total of 60 unique CSL with known *Leptospira* antibody titers that fall within one of the following four groups: no detectable titer (< 1:100), low (1:100 - 1:1600), medium (1:3200 - 1:51200), and high ($\geq$ 1: 102000) titer. These groups were chosen based on prior work showing their association with the probability that these titers indicate a current vs. historic infection [60,61]. Fifteen unique CSL serum samples per group will provide 80% power to detect a difference between a kappa value of 0.61 (substantial agreement) and a kappa statistic of 0 (no agreement) under the null hypothesis for each titer level. MAT will be conducted at the Oregon State University Veterinary Diagnostic Laboratory and the SNAP and WITNESS Lepto testing will occur at TMMC where the CSL sera are archived (see LOS in Appendix 4).

SA 4.2. Results of the SNAP Lepto test and WITNESS Lepto test will be compared with each other and evaluated against the MAT as the gold standard across the four titer levels through estimations of SN and SP and test agreement statistics (e.g. Cohen's kappa statistic).

Objective 4 Deliverables:

1. Draft of a peer-reviewed publication of the diagnostic test evaluation results (Sept 2024).

Objective 5. By December 2023, UCLA will update the current modeling framework to forecast *Leptospira* outbreak magnitude in CSL and create an online public platform to assess *Leptospira* outbreak magnitude. Using the current modeling framework [54] and long-term data from collaborators on leptospirosis (TMMC) and CSL demography (AFSC MML), as well as freely available SST, spring transition and upwelling data from NOAA (www.ndbc.noaa.gov, www.pfeg.noaa.gov) we can predict seasonal *Leptospira* outbreak magnitude in CSL 3-4 months in advance. The current model version is unable to fully incorporate and quantify all uncertainty surrounding parameter estimates and forecasting, due to its maximum likelihood framework. This offers an opportunity for model improvement, with tangible benefits for predicting outbreak magnitude. We will implement these improvements and make forecasts readily available to stakeholders through the following Specific Activities:

SA 5.1 By May 2023, convert the existing modeling framework to an improved Bayesian modeling framework that allows for improved assessment of model and parameter uncertainty. The result will be a

model that includes quantification of the strength of the correlations between outbreak size and the input variables (environmental conditions, leptospirosis strandings, CSL demography), the proportion of variance in outbreak size that can be explained by the models, and quantification of how well the model is able to forecast future outbreaks. Current forecasting can be done with reasonably high accuracy up to 3-4 months in advance, and to a lesser degree up to 6 months ahead. Improvements to the modeling framework may extend this time window, and at a minimum will provide better quantification of forecasting uncertainty.

SA 5.2 By June 2023, update the leptospirosis strandings, CSL demography and environmental condition datasets. The updated model from SA 5.1 will be used to make predictions for the fall 2023 *Leptospira* outbreak in CSL. The process will be repeated in June 2024.

SA 5.3 By December 2023, create an online, user-friendly public platform to query model forecasts using a Shiny App (e.g. an interactive web app programmed in R). This will provide stranding networks and rehabilitation centers predictions of *Leptospira* outbreak magnitude in CSL, giving them several months to prepare for large outbreaks.

While this modeling framework is specific to *Leptospira* in CSL, the approach can be applied to any host-pathogen system for which sufficient data are available. This approach will be presented and discussed during the stakeholder meetings and working groups can be formed to investigate opportunities to apply a similar approach to other systems.

Objective 5 deliverables:

1. Updated model framework for forecasting *Leptospira* outbreak magnitude 3-6 months in advance.
2. Freely accessible Shiny App for use by relevant stakeholders to predict *Leptospira* outbreak magnitude in CSL and prepare accordingly.

OVERALL GRANT TIMELINE: 24 months

Obj 1: Establish the EPMOHC **by Jan 2023.**

Obj 2: Develop a conceptual model for integration of Eastern Pacific data on marine mammal health monitoring, zoonotic disease surveillance, and research into an existing marine mammal information system (Health MAP) **by Sept 2024**.

Obj 3: Launch EPMOHC activities through an active marine mammal disease surveillance and health monitoring program in CSL and SSL **by Mar 2023.**

Obj 4: Comparatively evaluate the diagnostic potential of WITNESS Lepto, SNAP Lepto, and MAT for detection of Leptospira-specific antibodies **by Sept 2023.**

Obj 5: Create an online public platform to forecast *Leptospira* outbreak magnitude in CSL **by Dec 2023**.

Environmental compliance: All activities for this project will be conducted in environmental compliance with institutional regulations and policies. Bonneville and Willamette Falls sea lion removal activities are authorized under National Marine Fisheries Service (NMFS) Marine Mammal Protection Act §109(h), §120, and §120f. Marine mammal part use and field sampling will occur under UCLA's permits which will be renewed (Appendix 5 for current authorization and permit No. 21422).

Commitment to Diversity, Equity, Inclusion, and Environmental Justice: ODFW, UCLA, the PI and CIs of this proposal are committed to Diversity, Equity, Inclusion and Environmental Justice. ODFW has an acive committee and UCLA has a mission statement (https://equity.ucla.edu/our-mission) indicating their commitments, and the PI and CIs are in line with their institutions. In addition, they dedicated to including Tribal Nations in meeting the goals of this proposal as they are critical stakeholders and partners.

Key project personnel:

ODFW: Julia Burco (DVM, MPVM, PhD) is a wildlife veterinarian and epidemiologist for ODFW and courtesy faculty at Oregon State University. Her expertise in wildlife health spans 17 years, with the past 12 as

the field veterinarian for the state of Oregon leading wildlife outbreak investigations, captures and field training. She has extensive experience with live and dead marine mammal handling and sample collections. As project PI, Dr. Burco will oversee all aspects of the grant, will participate in regular meetings with the project team, oversee and conduct field work at Bonneville Dam and Willamette Falls, and assist with organizing and conducting wild-caught sea lion field sampling in Astoria, OR. She will also assist with organizing and running the stakeholder meetings, analyzing data, preparing and submitting peer-reviewed manuscripts, and presenting findings at national and international meetings. **Michael Brown** is the acting ODFW marine program lead and helps coordinate marine mammal surveillance and trapping activities. He has worked with the state marine mammal programs in OR and WA for the last 17 years.

UCLA: Katherine Prager (DVM, PhD) is a UCLA disease ecologist and wildlife veterinarian with 24 years of field experience studying disease in wildlife populations, including statistical analyses of empirical clinical, diagnostic and field data, 4 years of experience working as a clinical veterinarian in small animal practice, and substantial experience studying *Leptospira* dynamics - 12 years in CSL and in the marine ecosystem, and 11 years in island foxes and spotted skunks. She has been collaborating with many of the EPMOHC stakeholders - e.g. ODFW, WDFW, TMMC, SR^3, NOAA NMFS National and Regional Stranding Coordinators, NOAA ASFC MML, NOAA MMHSRP, Oregon and Washington Stranding Network Coordinators - in some cases for over a decade. Dr. Prager will oversee the UCLA subcontract; participate in regular meetings with the project team; assist with Bonneville Dam sample collection 1 week/year; work with Drs Burco and Kelly to organize and conduct wild-caught sea lion field sampling in Astoria, OR; assist with organization and implementation of the stakeholder workshops. She will lead efforts in study design, data analysis and peer-reviewed manuscript prep for work describing the sea lion-*Leptospira* work, and will assist with Obj 4 work. **James Lloyd-Smith** (PhD) is a quantitative ecologist and modeler with 21 years of experience studying zoonotic and wildlife disease dynamics, with emphasis on pathogen emergence across species and ecosystem boundaries and the impacts of environmental change. He has studied *Leptospira* in CSL and other island and coastal species since 2005, and with Dr. Prager has led ~$5M in federally funded transdisciplinary research on this system. **Benny Borremans** (PhD) is a disease ecologist with 13 years of experience conducting empirical and theoretical research in the field, including designing and conducting field studies, and performing statistical analyses, machine learning, mathematical modeling, and spatial statistics. Dr. Borremans has led the construction of a statistical model to make short-term predictions of *Leptospira* outbreak dynamics in CSL. **Terra Kelly** (PhD, DVM, Dipl. ACZM) is a wildlife veterinarian, epidemiologist, and the Director of EpiEcos with 20 years of experience working in wildlife population health and over 15 years of experience conducting applied epidemiologic research. Over the past decade, she has partnered on multiple projects aimed at strengthening capacities for wildlife disease surveillance, including approaches for early detection of emerging threats, including development of the Wildlife Morbidity and Mortality Event Alert System, a surveillance tool for early and enhanced detection of wildlife health events. Dr. Kelly will participate in regular meetings with the project team, assist with conducting field sampling in Astoria, OR; organizing and conducting the workshops; finalizing the study design, analyzing the data, and preparing the manuscripts describing the *Leptospira* work; conducting the analyses for assessing the performance of the *Leptospira* spp. diagnostic tests.; and assist the database manager on the conceptual model for integrating datasets.

WDFW: Casey Clark (PhD, M.S.) is the Lead Marine Mammal Researcher in the Wildlife Program. Dr. Clark will assist with field sampling at Bonneville Dam and with conducting the stakeholder workshops.

Project locations: PI Julia Burco and ODFW administrative staff will oversee all aspects of the grant, including financial aspects and associated subcontracts. The workshops will be held at PSU in Portland, OR. Fieldwork and disease surveillance will occur in Astoria and Willamette Falls, OR, and Bonneville Dam, WA. UCLA/TMMC will conduct diagnostic test evaluation (Obj 4) at TMMC. UCLA and ODFW will analyze data.

Description of stakeholder coordination or involvement: We will actively engage stakeholders (see stakeholder list and LOS in Appendix 4) throughout the entire project from the early planning stages through to implementation of activities, including, but not limited to, building on existing networks through establishing the EPMOHC, assessing needs and addressing common priorities of coalition partners, fostering new collaborations among stakeholders for marine health monitoring and research and facilitating opportunities to seek and obtain funding for collaborative research.