I. Project Title: Investigating the mechanism by which southern sea otters (*Enhydra lutris nereis*) facilitate the invasion of an exotic fouling bryozoan.

II. Abstract

Keystone species are important drivers in shaping community composition via trophic cascades. The role of southern sea otters in structuring near shore communities and promoting native diversity is well documented. However, trophic interactions are altered in communities comprised of invasive species. In the highly invaded Morro Bay estuary, the southern sea otter facilitates the invasion of *Watersipora subtorquata*, an invasive bryozoan. The mechanism by which this invasion is facilitated has not been fully explored. I propose to investigate the mechanism by which southern sea otters facilitate the invasion of *W. subtorquata*. Elucidating the mechanism has important implications for invasive species management and informing ecological theory. Preliminary evidence suggests that *Cancer* crabs break apart *W. subtorquata* colonies through non-consumptive foraging behavior. I hypothesize that Sea otter predation on *Cancer* crabs increases *W. subtorquata* abundance by releasing *W. subtorquata* from the disturbance caused by crab foraging behavior. I aim to quantify changes in *W. subtorquata* abundance in response to varying crab density, and to track sea otter foraging within Morro Bay.

III. Introduction

Keystone species are important drivers in shaping ecosystems and promoting community diversity (Paine 1966, Paine 1969). Through trophic cascades, top-down predation indirectly influences community composition in both terrestrial and marine environments (Terborgh 2015). The southern sea otter *(Enhydra lutris nereis)* is a widely studied keystone species known to control urchin populations and increase diversity in kelp forest ecosystems (Estes and Palmisano 1974). Additionally, the southern sea otter promotes growth of native sea grass in the estuarine environment of Elkhorn Slough by consuming crabs, and thereby releasing algal feeding mesograzers from crab predation (Hughes 2014). However, human influences on marine systems, such as introduction of invasive species, alter trophic interactions (Pace 1999; Kimbro et al. 2008).

In the highly invaded Morro Bay estuary, the southern sea otter facilitates the invasion of *Watersipora subtorquata*, an exotic encrusting colonial bryozoan found in marine fouling communities (Needles et al 2015). However, the mechanism(s) by which this invasion is facilitated are not fully explored. Needles et al. suggested sea otter predation on *Cancer* crabs as a potential mechanism of facilitation (2015). *Cancer* crabs comprise 43 percent of the sea otter diet in Elkhorn Slough, another estuary inhabited by sea otters (Hughes 2014). Evidence from a preliminary study suggests that *Cancer gracilis* crabs may decrease *W. subtorquata* abundance by breaking apart *W. subtorquata* while foraging for prey items living within the *W. subtorquata* colony (Aiken 2014). Therefore, removal of *Cancer* crabs may facilitate the invasion of *W. subtorquata*. I propose to focus on exploring sea otter predation on *Cancer* crabs as a potential mechanism for *W. subtorquata* facilitation.

Elucidating the mechanism by which sea otters facilitate the invasion of *W. subtorquata* is important from both a theoretical and management perspective. First, this study will enhance our understanding of ecological theory by examining how trophic cascades can influence species composition in highly invaded ecosystems. Secondly, it will provide an understanding of the mechanisms by which invasive species proliferate, which is critical for developing effective invasive species management strategies (Pace 1999, Keller et al. 2007).

IV. Objective(s)

1) We aim to determine if *Watersipora subtorquata* abundance changes in response to

varying *Cancer* crab densities.

2) To quantify changes in *W. subtorquata* abundance over time in response to natural crab densities in a system open to predation on *Cancer* crabs.
3) To determine the proportion of *Cancer* crabs in the sea otter diet in Morro Bay.
4) To determine and document if foraging sea otters are present at the study site.

V. Methodology

Field Experiment: Objectives 1 & 2

In order to assess the effect of *Cancer* crabs on *W. subtorquata* abundance, I will exclude predators and manipulate crab densities on 10 pier pilings at the North T-pier in Morro Bay, CA. Using wire mesh that is small enough to prevent crabs from leaving, and restrict access to sea otters and other predators, I will construct 3.0m x 0.34m cages. The cages will be assigned to one of the following treatments: low density of crabs (1 crab per cage), high density of crabs (4 crabs per cage), or no crabs (figure 1). One face of the piling will remain un-caged in order to quantify changes in *W. subtorquata* abundance in a system open to predation on crabs (figure 1). Within each treatment, I will deploy three, 0.3 m x 0.3 m roughened PVC settlement plates to encourage settlement of sessile invertebrate organisms, including *W. subtorquata* (Marshal et al. 2004). Pier pilings will be treated as blocks, so that all four treatments are represented on each piling. The direction that each treatment faces on the pier piling will be randomly assigned.

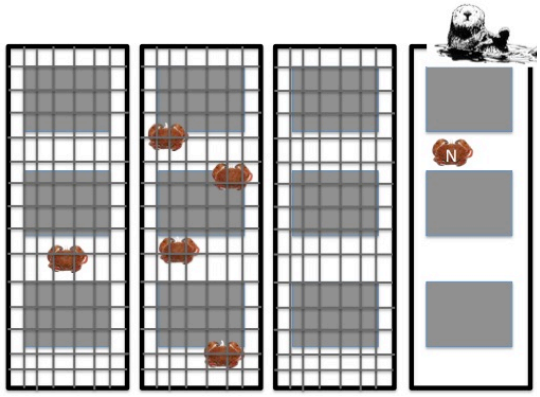

Figure 1. Treatments 1-4 of field experiment displayed left to right. Sea otters and other predators are excluded from treatments 1-3. Sea otters and other predators are allowed access to treatment 4.
Treatment 1: Low crab density;
Treatment 2: High crab density;
Treatment 3: No crabs;
Treatment 4: Natural crab density, represented as "N".

We will use *Cancer antennarius* for the cage exclusion experiments because it is both prevalent in the sea otter diet (Unpublished Data, Elkhorn Slough Sea Otter Monitoring Study), and relatively abundant on pilings at the Morro Bay T-pier (Unpublished Preliminary Crab Surveys). High and low crab density levels were determined relative to the naturally occurring crab density on the pier pilings in Morro Bay and reported low and high crab densities on artificial substrate in Goleta, CA. A total of 50 *Cancer antennarius* crabs will be collected using crab traps and SCUBA.

I will lead a team of scientific SCUBA divers to conduct surveys on *W. subtorquata* abundance and crab density, and to clean cages bi-weekly for 8 months. Percent cover of all sessile organisms covering each panel will be measured bi-weekly using a 0.3m x 0.3m quadrat. The percent change in *W. subtorquata* cover will be calculated to quantify changes in *W. subtorquata* abundance in response to the different treatments. Crab density will be measured bi-weekly on the panels open to crab predation (treatment 4). We will quantify the density and size of *C. antennarius* and other crab species present in the treatment area with predator access. Cages will be scrubbed clean bi-weekly to avoid build up of fouling organisms. If there is crab mortality in the low or high density crab treatments, we will replace crabs to maintain constant densities.

Field Observation: Objectives 3 & 4

We will use land based high power spotting scopes to collect sea otter foraging data once per week. Sea otters surface before consuming their prey items, so prey identification to the species level can be made from shore (Tinker et al. 2008). Following data collection, I will determine the proportion of *Cancer* crabs in the sea otter diet in Morro Bay. I will continue to collaborate with Dr. Tim Tinker at the University of California Santa Cruz, who is an expert in sea otter foraging, and the Monterey Bay Aquarium Sea Otter Research and Conservation department to train undergraduates on sea otter foraging data collection techniques.

In order to determine if foraging sea otters are present at the Morro Bay North T-pier, we will position 3 cameras with a wide-angle lens on the pier. An image will be captured every 20 seconds. The cameras will have an external battery that can easily be changed and will be enclosed in a waterproof housing to enable long term observation of the occurrence of southern sea otters at the study site.

VI. Timeline

May 2016-June 2016: Train undergraduate researchers on sea otter data collection methods, collect *Cancer antennarius* crabs, build cages, purchase any additional field gear needed.
June 2016-July 2016: Deploy settlement plates, cages, and cameras; begin field experiment; begin collecting sea otter foraging data; measure percent cover of sessile organisms on all panels; measure crab density on treatment 4; clean cages.
July 2016-February 2017: Continue the following: check cameras weekly, collect sea otter foraging data weekly, measure percent cover of sessile organisms on all panels bi-weekly, measure crab density on treatment 4 bi-weekly, and clean cages bi-weekly, replace crabs if mortality occurs. Prepare poster for presentation at Western Society of Naturalists Conference (October 2016).
March 2017-April 2017: Analyze results, remove all field gear from study site, create and present talk at 8th Annual Diver's Education Conference
April 2017-May 2017: Create poster and interactive game for Cal Poly Pier Spring Open House, begin writing thesis, create interpretive sign and post at the Morro Bay North T-pier.

VII. Final Products and Dissemination

I plan to communicate my findings in order to advance knowledge within marine biology and within our local community by presenting at the Western Society of Naturalists (WSN) Conference and at local workshops and events. I will present at the 8th Annual Diver Education Workshop in San Luis Obispo, and will create a poster and interactive trophic cascade activity to engage with all ages at the Cal Poly Pier Open House. I will also create an interpretive sign at the field site educating the public about current research on food-web dynamics in the highly invaded Morro Bay estuary.

VIII. Budget Justification

A total of $2,497.00 is needed for travel, research supplies, and printing to facilitate dissemination of my research. I have allocated $2,177 for research equipment, which I will use to purchase waterproof diving paper ($62), cameras for otter observation ($770), a wetsuit for cold water diving ($750), PVC panels for the field experiment ($275), and two tripods for sea otter foraging data collection ($320). I am asking for $200 to cover costs of local travel to and from my field site in Morro Bay, and $120 for printing costs associated with creating posters for the WSN conference, Cal Poly Pier open house, and interpretive signs.

Warren J. Baker Endowment
for Excellence in Project-Based Learning
Robert D. Koob Endowment *for Student Success*

PROPOSAL BUDGET

Student Applicant(s): Maggie Jenkins	
Faculty Advisor: Dr. Dean Wendt, Dr. Lisa Needles	
Project Title: Investigating the mechanism by which southern sea otters (*Enhydra lutris nereis*) facilitate the invasion of an exotic fouling bryozoan	**Requested Endowment Funding**
Travel *subtotal*	**$200.00**
Travel: In-state	**$200.00**
Travel: Out-of-state	**$**
Travel: International	**$**
Operating Expenses *subtotal*	**$ 2,297.00**
Non-computer Supplies & Materials	**$2,177.00**
Computer Supplies & Materials	**$**
Software/Software Licenses	**$**
Printing/Duplication	**$120.00**
Postage/Shipping	**$**
Registration	**$**
Membership Dues & Subscriptions	**$**
Multimedia Services	**$**
Advertising	**$**
Journal Publication Costs	**$**
Contractual Services *subtotal*	**$0.00**
Contracted Services	**$**
Equipment Rental/Lease Agreements	**$**
Service/Maintenance Agreements	**$**
TOTAL	**$2,497.00**

CAL POLY
SAN LUIS OBISPO

Biological Sciences Department
College of Science and Mathematics
Tel 805-756-2896

April 20, 2016

To Whom It May Concern:

It is my sincere pleasure to write in support of Margaret Jenkins (Maggie) in her application for the Baker Koob Endowment. Maggie is a first year graduate student at California Polytechnic State University (Cal Poly) and is co-advised by myself and Dr. Lisa Needles. I have been extremely impressed with both Maggie and her proposed project.

Maggie is a bright, focused, hardworking individual that has well-defined goals for her master's thesis and for her future career. She came to Cal Poly with the expressed intention of focusing her research on the impact of keystone predators (particularly sea otters) on species invasions, a topic in line with current research in our lab. We have a recent journal article that demonstrates that sea stars and sea otters (two well-known keystone predators) facilitate the invasion of the non-native bryozoan *Watersipora subtorquata* via trophic cascades. However, the mechanistic processes underlying this facilitation have not fully been explored. Maggie was interested in following up on the unexplored mechanisms driving this trophic cascade and has developed a thesis project that combines experimental manipulation and sea otter foraging surveys to do so.

Her master's thesis will directly assess whether sea otter foraging on crabs increases *Watersipora subtorquatata* abundance. She has thought extensively about the experimental design and has incorporated; 1) caging studies on pier pilings in Morro Bay to isolate the effect of crabs on *W. subtorquata* abundance and, 2) surveys of sea otter foraging in Morro Bay to determine the impact of otter foraging on crab populations, and thus their potential impact to invaded communities. Maggie is well equipped to do both pieces of her study. She already has extensive experience in collecting data on sea otter foraging through an internship at the Monterey Bay Aquarium (MBA), and she recently completed a scientific dive course that will allow her to conduct her underwater field caging experiments.

Maggie's thesis has important implications to the fields of ecology and invasion biology as little is known about the indirect effects of keystone predators in ecosystems that are highly invaded. Her thesis will also have important management implications as the restoration of top predators is a conservation priority that may, in some instances, have the unintended and unforeseen consequence of promoting invasion. Moreover, the foraging data collected for her thesis will also be utilized in a comparative study to assess differences in prey consumption between Elkhorn Slough and Morro Bay sea otter populations.

Importantly, Maggie's project will increase the research opportunities for undergraduates at Cal Poly while also promoting collaborations with two other institutions; the University of California Santa Cruz (UCSC) and the Monterey Bay Aquarium. Both the foraging data and the caging experiments will provide opportunity for undergraduate students to; get involved in research projects, gain scientific diving and field data collection experience, and collaborate with individuals from the MBA and UCSC. Maggie has already begun training undergraduate students for each of these aspects of her study. She has already set up several trainings for six undergraduate students both in Morro Bay and at the Elkhorn Slough National Estuarine Research Reserve.

CAL POLY
SAN LUIS OBISPO

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Maggie has access to facilities and much of the equipment needed for her project. The majority of her work will be done in the field at Morro Bay. Some of the necessary equipment (spotting scopes, cage materials, and SCUBA equipment) has already been purchased. With funding, Maggie intends to purchase other necessary equipment to initiate the core of her thesis work (e.g., settlement plates, spotting scope tripods). Dr. Needles and I have both been in frequent communication with Maggie regarding the design and execution of her project and it is progressing nicely. We will continue to meet to provide feedback on experimental design, and data collection and analysis.

In summary, I have nothing but the highest regard for Maggie and her ability to successfully execute her research project. Her project will also help advance the fields of invasion biology and ecology. A Baker Koob Endowment would enable Maggie to purchase field equipment needed to begin her thesis project and continue mentoring undergraduate researchers.

Sincerely,

Dr. Dean E. Wendt
dwendt@calpoly