Body Condition in Sea Otters (*Enhydra lutris)* due to Sea Urchin Rich Diets

Lauren Reid- Fish, Wildlife, and Conservation Biology
Email: lreid2@colostate.edu
Ava Spencer - Fish, Wildlife, and Conservation Biology
Email: avaspenc@colostate.edu
Beckett Olbrys - Fish, Wildlife, and Conservation Biology
Email: becketto@colostate.edu

Abstract

California sea otters (*Enhydra lutris nereis*) are a keystone species predominantly residing in the northern coastal regions of the United States, alongside the pacific shoreline. They play a key role in the reduction of sea urchins in environments where they are invasive and threaten the health of the ecosystem. Alongside historic extirpation, sea otter populations have declined in recent years due to climate change, disease, and human disturbance. This project will provide more insight into kelp forest food web systems that could help stabilize sea otter populations. As additional studies have suggested, marine systems lack a significant amount of literature in the field of animal diet, fat content, and resulting body condition. We hope to bridge the gap between this vast topic of interest, alongside the challenges and threats of invasive species like purple sea urchins (*Strongylocentrotus purpuratus*). Sea otters will be used as an indicator species by observing the effects of urchin populations in controlled versus uncontrolled areas. In sites where sea urchins are more pervasive, we predict that sea otter fat content will be negatively correlated, and overall health will decline. We assume these differences will be due to the lack of nutritional benefits of an artificial sea urchin rich diet.

Background

Sea Otters are apex predators and serve as ecosystem engineers, their presence "strongly influences the abundance and diversity of the other species within its kelp forest ecosystem, primarily by its effect on sea urchins that eat the kelp stipe and holdfast." (Jessup et al. 2004). Because of this they play a key part in keeping kelp forests ecosystems healthy. However, sea otters have faced many threats to their survival both from past and present anthropogenic influence. In the past sea otters were hunted for the maritime fur trade and became completely extirpated from the coasts of Washington in the early 20th century and at one point were thought to be extinct. However the small remaining population was able to grow (Jessup et al. 2004) and they were reintroduced to Washington in 1969 and 1970 (Laidre and Jameson 2006) facing another threat in the first half of the 20th century from fisheries that caught them as bycatch. Now regulations exist to limit fishing in the areas that sea otters inhabit, pushing it further out from the coast (Jessup et al. 2004).

Even with regulations such as this in place, sea otters still face other threats due to human influence. Sea otters serve as bioaccumulators, having both pollutants and infectious agents accumulate in their tissues throughout their lifetime without little to no opportunity to get rid of them (Murray 2015). They also possess small home ranges and do not migrate, meaning that maintaining the health of the ecosystem they thrive in is important to their survival. According to the article written by Jessup, et al. *Southern Sea Otter as a Sentinel of Marine Ecosystem Health,* "Sea otters eat approximately 25% of their body weight per day in shellfish and other benthic invertebrates." Their diet consists mostly of prey that are calorically rich, large and easy to capture like albolene, other bivalves and larger sea urchins in order to maintain their high metabolic rates (Laidre and Jameson 2006). These lower level filter feeders also contain pollutants that when eaten accumulate in the higher food levels and end up in high amounts in the apex predator, like the sea otter in this environment.

Purple sea urchins are oceanic grazers that inhabit shallow areas of the ocean worldwide (Pearse 2006). They range from Baja California, Mexico to Cook Inlet, Alaska. They are known for their quality to create sea urchin barrens, in which they overgraze the kelp forests they reside into a level of desert-like absence of biodiversity (Rogers-Bennet 2013). J. S. Esklöf's paper, *Sea urchin overgrazing of seagrasses: A review of current knowledge on causes, consequences and management,* reported that over the last four decades, the number of overgrazing events has increased. This made our analysis of some impacts of these events more important and meaningful. Removal of sea urchins in habitats where they are deemed dangerous has occurred and is a regular and successful management practice (Esklöf et al. 2008).

Kelp forests are a unique vegetative component of ocean systems that provide many abiotic and biotic resources for many marine species. Diversity includes fish, bivalves, crabs, sea urchins, algae, sea otters and other marine mammals (Steneck et al 2003). Off the coast of California, kelp forests scatter along the pacific in large, clumped sections. There, they protect coastlines from extreme weather events like El Niño, contribute to overall global primary production, and serve as a natural sink through carbon fixation (Jackson and Winant 1983, Steneck et al. 2003). California has proved to be an example of a successful system with limited kelp deforestation, though globally the issue has escalated (Steneck et al. 2003). This "healthy" site is helpful in this study as it reduces the confounding effects of reduced health from degraded, nutritionally-lacking environments. We can focus on the value of the species present beyond those factors.

As mentioned prior, kelp forests have historically been impacted by increased herbivory through sea urchins and predator removal (Steneck et al. 2002). Through this unnatural trophic system, the overall marine community structure has shifted. As trophic levels in this marine system are highly interconnected, when large populations of urchins rise, overgrazing of macroalgae becomes inevitable, creating a cascading effect and reducing overall species diversity in a bottom-up approach (Nichols et al. 2015). Though other factors likely influence the community structure, sea otters' relationship to their prey represent a significant role in the system that cannot be ignored (Carter et al. 2007). Previous studies have noted that effects of sea otters on systems may be overstated, however, the literature lacks sufficient material on how this relates back to overall healthy individuals (Carter et al. 2007)

Food quality is a major part of this study. The major emphasis came from Tinker et. al's paper *Sea otter population collapse in southwest alaska: assessing ecological covariates, consequences, and causal factors.* Along with many other useful insights this paper provided, it contained a table of sea otter prey mean energy density measured in kilocalories per gram. Invasive purple sea urchins (*Strongylocentrotus purpuratus*) provide .39 kcal/g, while unidentified bivalves provide .65 kcal/g. This gave us the basis for our experiment in testing the physical effects of the main diet on sea otters. While other nutritional factors could affect the body condition of otters, the mean energy density of prey can impact how much an otter has to hunt. Predicted changes in hunting time can negatively impact the health of otters. In habitats overrun by urchins, otters may be overall less healthy due to the amount of time spent foraging and the quality of the food (Tinker et al. 2021).

The main response variable in our study is the health of otters, as quantified by body condition. The use of body condition (log mass/log length) as a response variable was used in K.L. Laidre's paper, *Patterns of growth and body condition in sea otters from the Aluetian archipelago before and after the recent population decline*. Calculating and using body condition in this way allows for the effect of diet to be shown, with otters having better diets having a larger body condition value. In this study, as well as our study, body condition is separated by male and female sea otters and compared within groups. It is particularly important to focus on the difference within sex because body condition varies greatly due to biology. Male can be up to two times the length and weight of females (SOURCE). Although female body condition likely fluctuates throughout their reproductive cycle, we intend to control for the reproductive stage throughout this study. As noted in the literature, this creates a more accurate representation of the population (Laidre et al. 2006).

Justification

Sea otters serve as keystone species in kelp forests, controlling prey species that feed on the giant kelp that serves as a backbone to the ecosystem. Currently many kelp forests are becoming overrun by invasive sea urchins, the purple sea urchin (*Strongylocentrotus purpuratus*) posing the largest threat as they are found in low tidal areas and inhabit the floors of kelp forest ecosystems. In the past, these numbers were controlled by higher numbers of predation, with sea otters (*Enhydra lutris*) playing a key role in this. Due to past anthropogenic influence lowering predator population rates, sea urchins have increased immensely in numbers, starting to take over entire ecosystems. Now there are many areas along the coast of california called sea urchin barrens where the areas are void of any kelp or seaweed. It is known that removing predators from ecosystems has drastic impacts on the health of the ecosystem as a whole, creating shifts in trophic levels and food supply, but it also has cascading effects that are not often thought about.Our focus is to see how this shift in lower trophic levels impacts sea otter health in that area.

Health of mammals in ocean ecosystems based on food intake is not a highly studied area and could be very important information to help inform regulation and management decisions in areas where these species occur. In order to keep kelp forests thriving it is important to maintain the populations of predators that inhabit these areas. Sea otters are highly charismatic species that have strong social interactions and creative lifestyles, drawing in large amounts of tourism and funding. The prolonged protection of this species relies on the protection of current populations and in order to do so we need to be aware of how the changing environment around them affects their ability to live, grow, and reproduce. These live history traits all rely heavily on both the quality and quantity of the diet that is consumed. Protecting a balance in this diet could also help to protect populations from other threats that could impact them due to poor health such as disease and natural disaster events by helping to increase resilience. These are the reasons why this project could help to improve individual species health and overall ecosystem health for many years to come.

One of the main ideas of our study was to test the effects of food quantity vs food quality and the impacts it can have on the health of otters, with using body condition as an indicator. Food quality is an understudied area in aquatic mammals but as food webs change and trophic cascades occur it is important now more than ever to study the effects these changes can have on top predators. If the amount of food consumed remains the same but the quality starts to lower it can have many implications on the health of important keystone species such as the sea otter.

Objectives

Through our research we hope to find how uncontrolled areas with high numbers of purple sea urchins (*Strongylocentrotus purpuratus*) will shift the quality of diet for sea otters (*Enhydra lutris nereis*) and cause declines in their health. We will have two independent binary categorical variables, sex (male vs. female) and site location (controll vs treatment). The control sites will be areas with a high density of sea urchins that remain unmodified by humans and the treatment sites will have a low density of sea urchins that are controlled by human efforts to keep the population under control. Our response variable will be sea otter body condition, which will be used to estimate the general health of the populations of sea otters and will be measured by taking the log of the mass and dividing it by the log of the length. More invasive techniques such as blood draw, stomach pumping or scat analysis could be used to further assess the health of the populations. We will compare the two data sets between areas of high sea urchin control and those without sea urchin control and split the data by sex. Because we are expecting the purple sea urchins to lower the overall body condition of the otters, we will be using a two-way ANOVA to produce our final results. We hope to find how human management of kelp forest ecosystems influences the health of sea otters and the implications it can have on future management decisions. If otters remain healthier in areas that are managed by humans their numbers could potentially grow, in turn helping to improve the overall ecosystem health and potentially reduce the amount of human control needed to maintain kelp forests. If diet plays a large role in sea otter health this could also be useful for captivity management informing decisions on what to feed the otters to help them be maintained at healthy weights and activity levels.

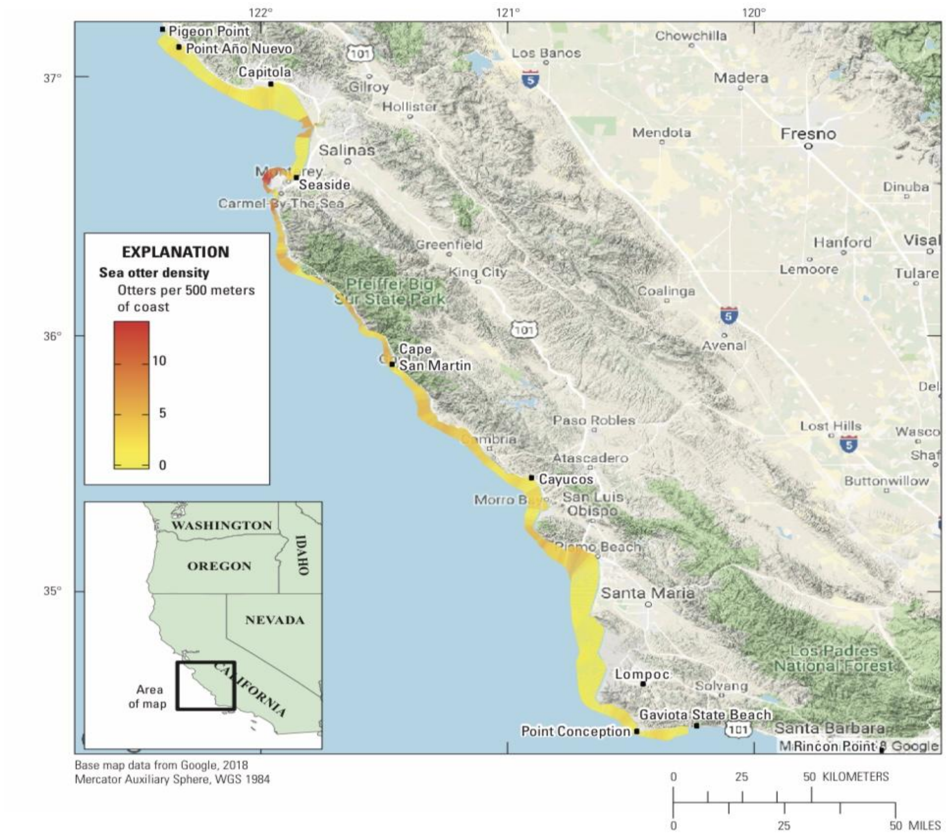
Approach

Study Animals

The animals that we will be focusing on for this study will be southern sea otters (*Enhydra lutris nereis*) and purple sea urchins (*Strongylocentrotus purpuratus*), both of which inhabit the kelp forest ecosystems off the coast of California. We chose to focus on purple sea urchins (*Strongylocentrotus purpuratus*) as they have become extremely invasive in California's kelp forest ecosystems and are causing bottom up trophic cascades by removing necessary habitat and ecosystem services that had been provided by the large kelp that used to dominate these areas. Sea otters (*Enhydra lutris nereis*) were chosen as they are a keystone species of this ecosystem and play an important role in the removal of the sea urchins that pose a threat to kelp abundance. They can also be used as an indicator of ecosystem health and can play an important role in management decisions for these areas.

Study Area

For our study area we will be sampling from 8 study sites along the coast of California, 4 of which will be our control sites where sea urchin populations are not managed by human influence, and 4 of which will be our treatment sites where urchins are removed to help maintain a lower population numbers. To differentiate between these two sites we will be using percent cover of sea urchins with >60% representing sea urchin barrens (control) and <60% representing kelp forest ecosystems (treatment). We will be sampling 6 otters at each site, 3 of which will be males and 3 will be females. To avoid overlap in the individuals that we are sampling the study sites will be distributed throughout the current range of sea otters in California, from Santa Cruz to Santa Barbara. The sites that will be focused on will be the areas with high sea otter density laid out by U.S. Geological Survey published in 2019 on sea otter census results. Hot spots for high sea otter density were found mainly in Monterey Bay, at Pismo Beach, and along the coast of Pfeiffer Big Sur State Park (Hatfield et al. 2019). In choosing areas with higher amounts of otters we aim to reduce or impact on the populations by avoiding creating disturbance to small populations.



Photograph 1: Sea otter density in their native range along the coast of California from the US Geological Survey report *California Sea Otter (Enhydra lutris nereis) Census Results, Spring 2019.*

Experimental design

Our experiment was designed using two independent variables, sex and location. Location was determined to be categorical, choosing to study areas of sea urchin barrens and areas containing healthy kelp forest ecosystems. The healthy kelp forest ecosystems were chosen as a model ecosystem in which sea otters would normally inhabit and thrive in, and the sea urchin barrens represent a depleted habitat that otters would be less likely to reside in and or contain smaller population numbers as the carrying capacity of these areas would be significantly lower. Otters were split between sexes as well due to an expected difference in body size and body condition between sexes, with females remaining smaller after reaching maturity than males who tend to be larger. Our experiment was designed with minimal variables in mind to focus on the importance of diet quality and the implications it can have to sea otter health. With our design we are assuming the otters in both ecosystems are getting the substantial amount of food needed to survive and live healthy lifestyles. Due to this, we are removing quantity of food supplies as a factor and focusing solely on the quality of the diet they are consuming in order to be able to fully assess the effects this shift in food supply can have.

Field and Lab Methods

Field data collection and observation will be crucial for future statistical analysis in this study. Over the span of one field summer and with the help of a professional fisherman to locate potential areas with sea otters, we will spend 14 days collecting data for a sample size of n = 48. Females will be controlled for based on their reproductive stage. As mentioned, sites will be chosen by percent cover of sea urchins. Preliminary assessments on suitable control and treatment sites will be taken six-months prior to data collection events, so field days can focus on the main objectives of this study. It will be necessary to ensure that both sites have reliable sea otter populations, as well as stable sea urchin densities. For this reason, before body condition is subsequently measured, a second measurement of percent urchin cover will be required.

During the additional field days, weight and length of each individual sea otter will be measured to determine body condition. To capture these values, tools including calipers, rulers, and scales will be factored into the total budget (see Table 2). A licensed wildlife veterinarian will also be on site to provide anesthesia while the field technicians and masters students are taking measurements. This is to reduce the stress of the animal and to minimize danger for wildlife technicians and graduate assistants. While under anesthesia, the wildlife veterinarian will also take additional vitals to ensure the health of the sea otters are maintained, especially as they are protected species. After releasing, team members will remain on site to ensure effects of anesthesia have effectively worn off and no undue harm comes to our study subjects.

When data collection is completed, a small fraction of time spent in the lab analyzing this data will be necessary. There, field technicians will record weight and length measurements into an Excel spreadsheet and resulting .csv file. From those values the log of mass and length will be calculated to generate our resulting data sheet (see Table 1).

Statistical Analysis

Our statistical analysis was performed in R using the base packages, the emmeans package and the ggplot 2 package. Our test was a two-way anova function using the lm() and anova() functions within base R. The output was then also put into the emmeans() function to assess the possible covariates and factors contributing to the effects of treatment and sex on body condition.

Table 1: Field data sheet (first 10 rows)

Individual	Location	Sex	Weight	Length	Body Condition
1	Control	M			
2	Control	M			
3	Control	M			
4	Control	M			
5	Control	M			
6	Control	M			
7	Control	M			
8	Control	M			
9	Control	M			
10	Control	M			

In our R analysis, we used the tidyverse, emmeans and basic R packages to develop, analyze and visualize our data. To generate both control and treatment results, the rnorm function was used, shown in figure 4. These numbers were then put into a data frame to match the field data sheet. The lm() function was then used to run a linear model with the variable body condition as the x, and the variables sex and location as y. The result was then run through the anova() function to give us the two-way anova test results. These results were then presented graphically using the ggplot() function from the tidyverse package.

```
BodyMass <- c((rnorm(12, 28.1, sd = 0.47)), rnorm(12, 20.1, sd = 0.47), rnorm(12, 21.4, 0.14), rnorm(12, 15.7, 0.14))
BodyLength <- c(rnorm(12,118.7, sd = 2.67),rnorm(12,108.7, sd = 2.67), rnorm(12, 110.03, sd = 2.4), rnorm(12, 100.03,
sd = 2.4))
BodyCondition <- (log(BodyMass)/log(BodyLength))
```

Figure 4: Code used to generate the numeric variables in our experiment.

```
Otters <- lm(data = DataNew, DataNew$BodyCondition ~ DataNew$Sex * DataNew$Location)
anova(Otters)
emmeans(Otters, pairwise ~ Sex*Location)
ggplot(DataNew, aes(x = Sex, y = BodyCondition, fill = Location))+
  geom_boxplot()+
  theme_dark()
```

Figure 5: Figure shows R code used to perform statistical analysis as well as check for assumptions and create a box plot.

Results

48 sea otters were sampled in total with 12 male controls, 12 female controls, 12 male treatments and 12 female treatments. Figure one shows a box plot of the data. It is apparent that the difference between the means of groups by location

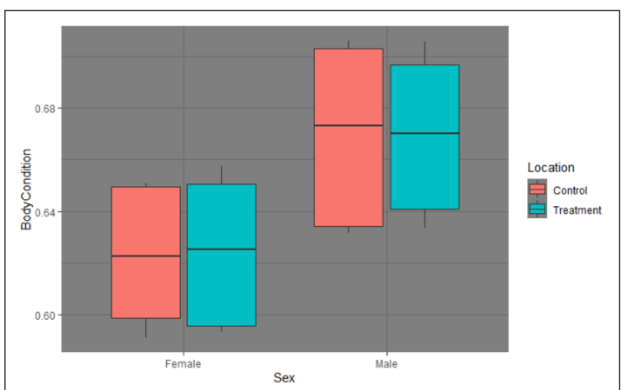


Figure 1: Boxplot showing the relationship between Body condition, sex and location.

is insignificant. The means of both groups (Male and Female) are remarkably similar from the treatment to control. The total averages and standard deviations of the data is shown in Figure three.

Using an two-way anova test with sex and location as independent variables and body condition as dependent, we produced three p-values. Figure two shows the r generated analysis of variance table, showing results, of which only one was significant, that being that there is a relationship between body condition and sex. This p-value was 4.042*10-6, which was under the 0.05 threshold for statistical confidence. This means we have statistical evidence to say that there is a relationship between sex and body condition, but not enough to say there is a relationship between location or sex:location and body condition. This leads to the scientific assumption that there is no relationship between body condition and diet.

```
Analysis of Variance Table

Response: DataNew$BodyCondition
                              Df   Sum Sq   Mean Sq F value    Pr(>F)
DataNew$Sex                    1 0.024163 0.0241633 27.6878 4.042e-06
DataNew$Location               1 0.000052 0.0000519  0.0594    0.8085
DataNew$Sex:DataNew$Location   1 0.000122 0.0001217  0.1395    0.7106
Residuals                     44 0.038399 0.0008727
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Figure 2: Output of ANOVA function in R, showing the p-values for all three variables (Sex, Location and Sex:Location)

Sex	Location	Mean of B.C.	S.D. of B.C.
Male	Control	0.7006593	0.004543204
Male	Treatment	0.6430954	0.01835397
Female	Control	0.6491507	0.004262062
Female	Treatment	0.6013489	0.01522622

Figure 3: Table showing the mean and standard deviations of all four treatment groups.

Based on the very small p-value generated for this study, it is difficult to say that there is definitive evidence for the presence of our predicted relationships. This is likely due to the fundamental issue of using the logarithmic scale to determine body condition. Since logarithms fundamentally generate smaller, powered values, the ability to detect significance is highly limited. For more conclusive results, future studies should use alternative methods to measure body condition. In particular, if body fat percentage can be obtained through non-lethal methods, this could be a highly more accurate measure of overall sea otter health.

```
Otters <- lm(data = DataNew, DataNew$BodyCondition ~ DataNew$Sex * DataNew$Location)
anova(Otters)
emmeans(Otters, pairwise ~ Sex*Location)
ggplot(DataNew, aes(x = Sex, y = BodyCondition, fill = Location))+
  geom_boxplot()+
  theme_dark()
```

Figure 5: Figure shows R code used to perform statistical analysis as well as check for assumptions and create a box plot.

Table 2: Budget

Personnel		
Professional Fisherman Salary	$1,000/day for 2 weeks (14 days)	$14,000
Professional Fisherman Fringe	20% of total	$2,800
Wildlife Veterinarian Salary	$1,000/day for 2 weeks (14 days)	$14,000
Wildlife Veterinarian Fringe	20% of total	$2,800
Field Technician Salary	$15/hr for 32 hrs/week for 12 weeks	$5,760
Field Technician Fringe	20% of total	$1,152
Graduate Research Assistant I Salary	$2,500 stipend for 12 months	$30,000
Graduate Research Assistant I Fringe	20% of total	$6,000
Graduate Research Assistant II Salary	$2,500 stipend for 12 months	$30,000
Graduate Research Assistant II Fringe	20% of total	$6,000
Total		**$112,512**
Travel		
Rental Car and Gas	$220/day for 2 weeks (14 days)	$3,080
Field Accommodations	$300/night for 2 weeks (14 days)	$4,200
Per diem	$50 per day for 2 weeks (14 days) for 3 people	$2,100
Total		**$9,380**
Materials/Supplies		
Scale	$400/scale	$400
Folding Ruler	$25/ruler, 2 needed	$50
6" Caliper	$50/caliper, 2 needed	$100
Total		**$550**
Equipment		
Included in fisherman and veterinarian per diem cost		
Total		

Total Direct Cost		**$122,442**
Indirect Cost	50% of total	**$61,221**
Total Actual Cost		**$183,663**

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