YOU "OTTER" SEE THESE BONES

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Many zooarchaeological assemblages remain untouched for decades and may not be processed for many more decades due to complicating provenience practices and curation issues. This scenario is manifested in SFR-7, a site in the San Francisco Bay formerly believed to date from the Gold Rush era. This project uses Enhydra lutris *femurs to develop a metric system that examines the morphological changes caused by human predation. To do this, femurs from* Enhydra lutris *specimens collected within the last 50 years and available from the California Academy of Sciences, U.C. Berkeley's Museum of Vertebrate Zoology (MVZ), and UC Santa Cruz's Long Marine Lab (LML) were measured to determine if there are specific measurements indicative of a change in body size. Specimens complete with necropsy data provided information on body size, allowing for an initial estimation range for the body-size-to-limb ratio. Measurements were then taken from specimens dated to 2000-700 B.P. at U.C. Berkeley's Museum of Paleontology (MP) and from the historical archaeological site of SFR-7 as a case study to test the results gathered from current specimens, making sure to note any morphological differences.*

This project uses *Enhydra lutris* (sea otter) femurs to develop a metric system that examines the morphological changes caused by human predation. To accomplish this, data from sea otter femurs collected within the past 50 years from the California Academy of Science, UC Berkeley's MVZ, and UC Santa Cruz's LML (pending data) were measured. At these institutions, some of the sea otter osteological remains included necropsy reports indicating body weight, overall length, sex, and the condition in which the remains were found. This project is still in its preliminary stages of gathering information on the current sea otter population by searching for morphological differences evident in the limb elements as body mass changes. Once this information is collected and interpreted, we can then use it in case studies, for SFR-7 and in the MP collection (pending data).

The reason for focusing on limb morphological changes is because they are a proven indicator of load bearing when the diameters of limbs are examined (Wainwright et al. 1976), or of locomotive changes if there is a decrease in femoral length (Gingerich 2003). This is an ongoing project, so for the purposes of this paper femurs were the only skeletal element analyzed. This research hopes to find a relationship between femoral morphology and body size within present-day sea otters and apply those results to estimate the body size of precontact sea otters, to ultimately shed light on the effects of human predation on sea otters during the late 1800s, at the time of the maritime fur trade (Szpak et al. 2012).

ARCHAEOLOGICAL CONTEXT

SFR-7 is a site excavated in 1910 by Nels Nelson. Originally it was thought to date from the Gold Rush era, but from available records it has been found to be a prehistoric shell mound. This was confirmed after later finding human remains at the site and documentation of additional human remains. Unfortunately, due to poor provenience practices at the time of excavation, little information about the faunal remains is known.

METHODS

Materials

- Sea otter elements and information came from the California Academy of Science, LML, MVZ, and MP.
- Sea otter elements from SFR-7 were identified by comparing morphological features present in the MVZ collections of sea otters and river otters.
- Caliper (digital recommended).
- Charts (digital or paper).

Measurements Taken

This project uses the methods found in Naoko Egi's (2000) "Body Mass Estimates in Extinct Mammals from Limb Bone Dimensions: The Case of North American Hyaenodontids," and Angela von den Driesch's (1976) *Guide to the Measurement of Animal Bones from Archaeological Sites*, as a framework to deduce which measurements are most indicative of morphological differences.

- Long length (LL)
- Short length (SL)
- Diameter width (MP)
- Diameter depth (AP)
- Condyle width (Cw)
- Femoral head to greater trochanter (FH-GT)
- Lesser trochanter to 3rd trochanter (LT-3T)
- Femoral head depth [FHd]

Age Estimates

Because no definite ages can be given, age estimates were based on skeletal developmental features known in humans (Schaefer et al. 2009).

- Sacral fusion
- Fusion on the iliac crest of ox coxae
- Vertebral fusion
- Femoral epiphyseal fusion

Data Collecting Procedure

This procedure was developed to collect data from collections at the California Academy of Sciences, MVZ, and for SFR-7.

1. Setup Workspace
    a. A table clear of any obstructions was used to lay out the specimens and tools needed for recording data.
2. Recorded Before Measurements Were Taken
    a. Specimen number
    b. Sex - if available
    c. Approximate age range was recorded by looking at key epiphyseal fusions (Schaefer et al. 2009) and labeling as fused, late fusion, partial fusion, and unfused. Notes were recorded as

necessary; i.e., pathology, missing elements, etc. These are the criteria developed for our project's labeling purposes.

i. Epiphysis of Femur
    1. Unfused - Femoral head to neck and condylar fusion to the diaphysis of the femur is detached.
    2. Partial fusion - Fusion line at femoral head to neck and condylar fusion to the diaphysis is distinct and clear.
    3. Late fusion - Fusion line at femoral head to neck and condylar fusion to the diaphysis is less distinct but still present.
    4. Fused - No fusion line is present.

ii. Vertebral fusion
    1. Superior and inferior sides of the body of each vertebra
        a. Unfused - Superior and inferior epiphysis are detached.
        b. Partial fusion - Fusion line of superior and inferior aspects of body distinct is clear.
        c. Late fusion - Fusion line of superior and inferior aspects of body is less distinct but still present.
        d. Fused - No fusion line is present.
    2. Body to right and left arch fusion
        a. Unfused - Fusion of right and left arch to each other and to the body is not present.
        b. Partial fusion - Fusion line of right and left arch to each other and to the body is distinct and clear.
        c. Late fusion - Fusion line of right and left arch to each other and to the body is less distinct but still present.
        d. Fused - No fusion line is present.

iii. Ox coxae fusion
    1. Anterior portion of the iliac crest
        a. Unfused - Iliac crest epiphysis is detached.
        b. Partial fusion - Fusion line of the iliac crest is distinct and clear.
        c. Late fusion - Fusion line of the iliac crest is less distinct but still present.
        d. Fused - No fusion line is present.

iv. Sacrum fusion
    1. Are the four segments (specific to sea otters compared to the three sacral segments in river otters) completely fused?
        a. Unfused - All four sacral segments are separated.
        b. Partial fusion - Fusion line of four sacral segments is distinct and clear.
        c. Late fusion - Fusion line of four sacral segments is less distinct but still present.
        d. Fused - No fusion line is present.

3. Measurements
    1. Long length (LL). The right femur was held in the upright position with the anterior part facing the researcher. For the left femur, the posterior part faced the researcher. The most proximal point on the femoral head and the most distal part of the medial condyle were located, and the outside jaws of the caliper were placed at these points. The following

instructions were repeated for steps 2-8. One to two seconds were allotted for the caliper to stabilize before each measurement (mm) was recorded. Measurements were taken two additional times and then averaged.

2. Short length (SL). The right femur was held in the upright position with the posterior part facing the researcher. For the left femur, the anterior part faced the researcher. The most proximal point on the greater trochanter and the most distal part of the lateral condyle were located, and the outside jaws of the caliper were placed at these points.
3. Diameter width (MP). The right femur was held in the upright position with the anterior part facing the researcher. The most constricted part of the diaphysis was located, and the outside jaws of the caliper were placed at this point.
4. Diameter depth (AP). The researcher used fingers as a guide to place the caliper jaws at the anterior and posterior part of the same location where the MP was taken.
5. Condyle width (Cw). The femur was held in the upright position with the anterior part facing the researcher, and the condyles were in the superior position for both left and right femurs. The most lateral point of the lateral condyle and the most medial point of the medial condyle were located, and the outside jaws of the caliper were placed at these points.
6. Femoral head to greater trochanter (FH-GT). The femur was held in the upright position with the anterior part facing the researcher and the proximal end in the superior position. The most lateral point of the greater trochanter and the most medial point of the femoral head were located, and the outside jaws of the caliper were placed at these points.
7. Lesser trochanter to 3rd trochanter (LT-3T). The femur was held in the upright position with the anterior part facing the researcher. The most lateral point of the lesser trochanter and the most medial point of the 3rd trochanter were located, and the outside jaws of the caliper were placed at these points.
8. Femoral head depth (FHd). The femur was held with the superior portion facing the researcher, and the femoral head was in the superior position. The most anterior point and the most proximal point on the femoral head were located, and the jaws of the caliper were at these points.

2. Case Study - SFR-7
    0. Identifying femoral elements
        0. To distinguish from river otter, comparatives from the MVZ were compared with its collection of sea otters and river otters. There is a noticeably visible size difference between mature river and sea otter specimens.
        1. Measurements identical to those taken for sea otter were conducted on four MVZ specimens of river otter and four specimens of sea otter.
    1. Data collecting procedure
        0. Information that was available was recorded using the same procedure that was used in the California Academy of Sciences collection.
3. Statistical Analysis
    0. The statistical analysis used is based on the procedures found in Naoko Egi's (2000) paper, "Body Mass Estimates in Extinct Mammals from Limb Bone Dimensions: The Case of North American Hyaenodontids," using the reduced major axis (RMA) model. Data sets were separated by the different collections and by the type of measurements recorded. A regression line was produced for each data set. The data for the regressions were natural log-transformed species mean values.

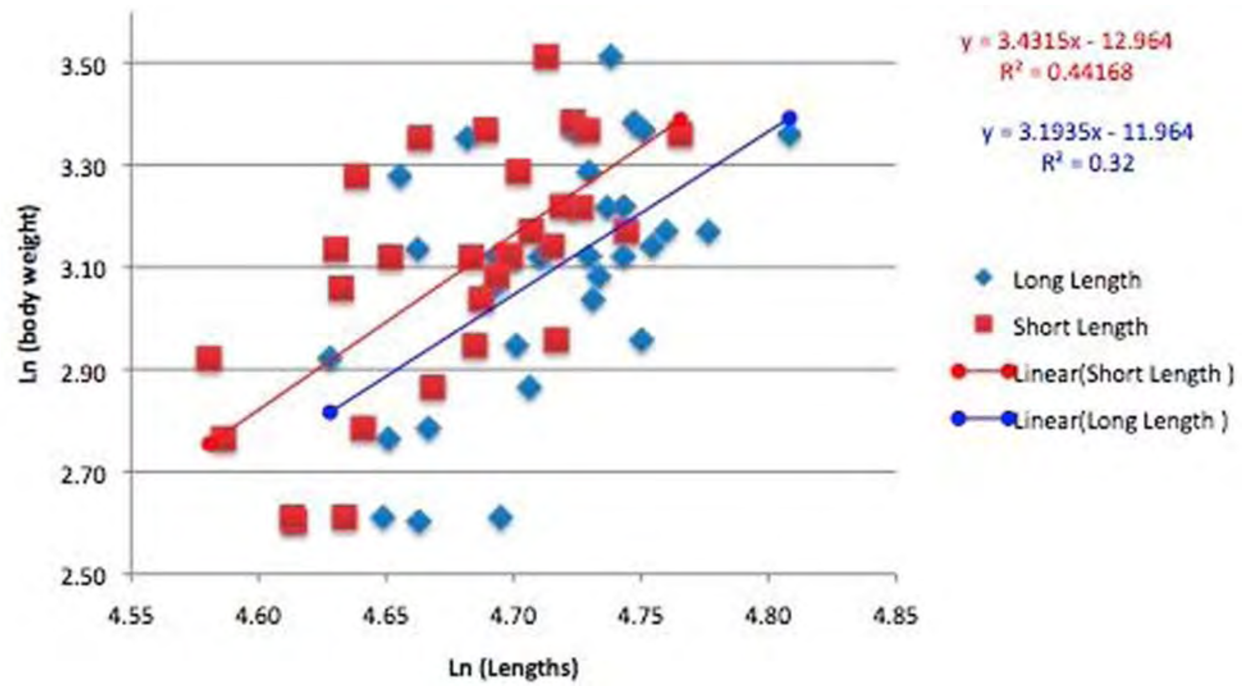

Figure 1. Relation of right femur length to body weight, California Academy of Sciences specimens.

DATA/RESULTS

California Academy of Science Results

Figure 1 shows the log-transformed relationship between right limb length averages and body weight averages. Regressions were calculated for each set of data. The r value for the short limb length shows a higher degree of confidence than the long length.

Figure 2 shows the log-transformed relationship between left limb length averages and body weight averages. Regressions were calculated for each set of data. The r value for the short limb length shows a higher degree of confidence than the long length.

Figure 3 shows the log-transformed relationship between right limb length averages and standard length averages. Regressions were calculated for each set of data. The r value for the short limb length shows a higher degree of confidence than the long length.

Figure 4 shows the log-transformed relationship between left limb length averages and standard length averages. Regressions were calculated for each set of data. The r value for the short limb length shows a higher degree of confidence than the long length.

Figure 5 shows the log-transformed relationship between right limb diameter MP/AP averages and body weight averages. Regressions were calculated for each set of data. The r value for the MP and AP show similar degree of confidence.

Figure 6 shows the log-transformed relationship between left limb diameter AP/MP averages and body weight averages. Regressions were calculated for each set of data. The r value for the MP shows a greater degree of confidence than the AP.

Figure 7 shows the log-transformed relationship between right limb diameter MP/AP averages and standard length averages. Regressions were calculated for each set of data. The r value for the depth shows a greater degree of confidence, but neither r values are high enough to show any substantial results.

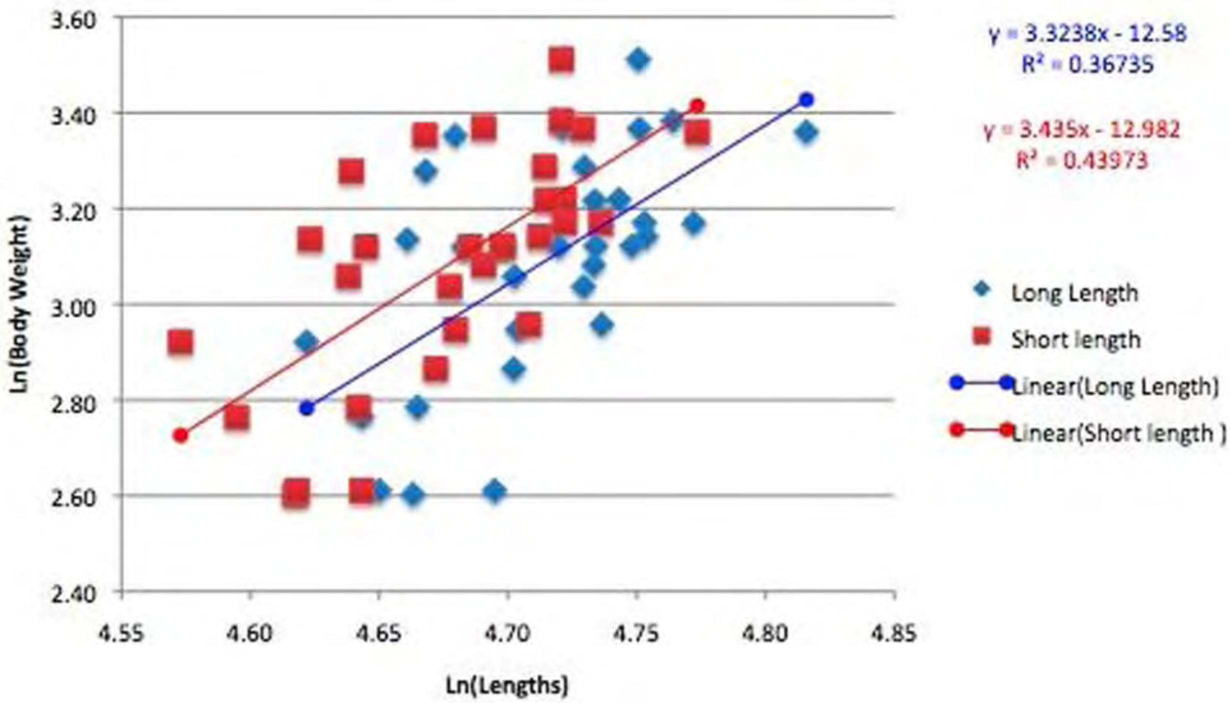

Figure 2. Relation of left femur length to body weight, California Academy of Sciences specimens.

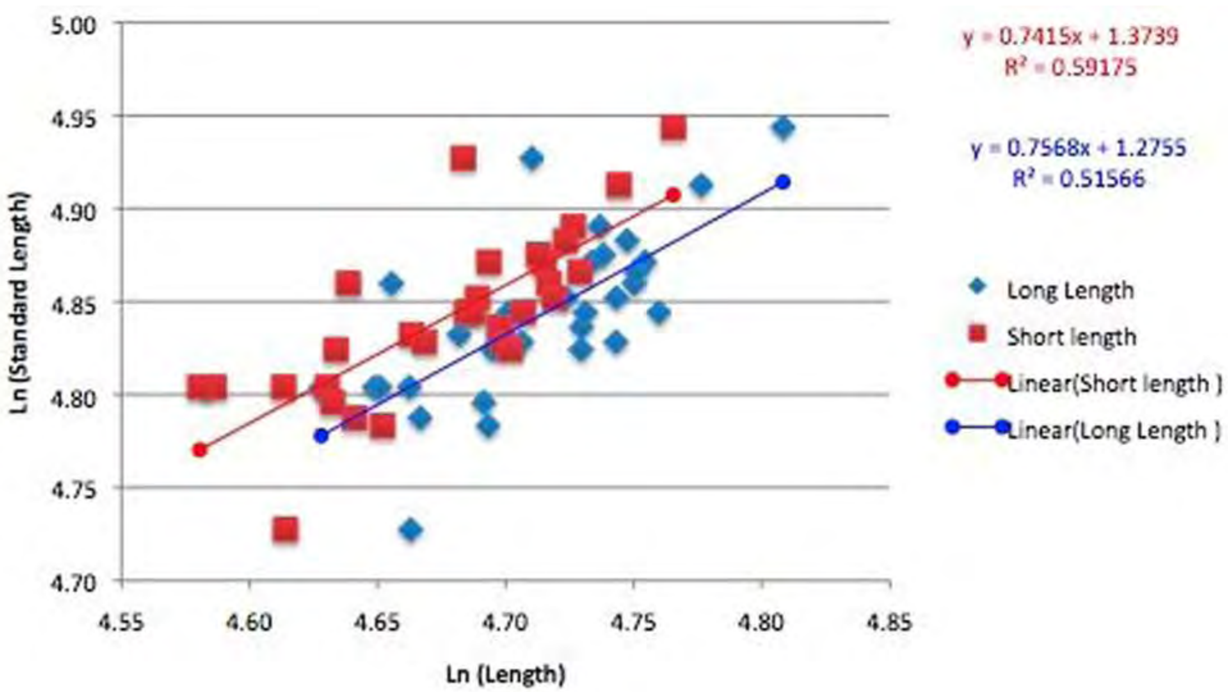

Figure 3. Relation of right femur length to standard length, California Academy of Sciences specimens.

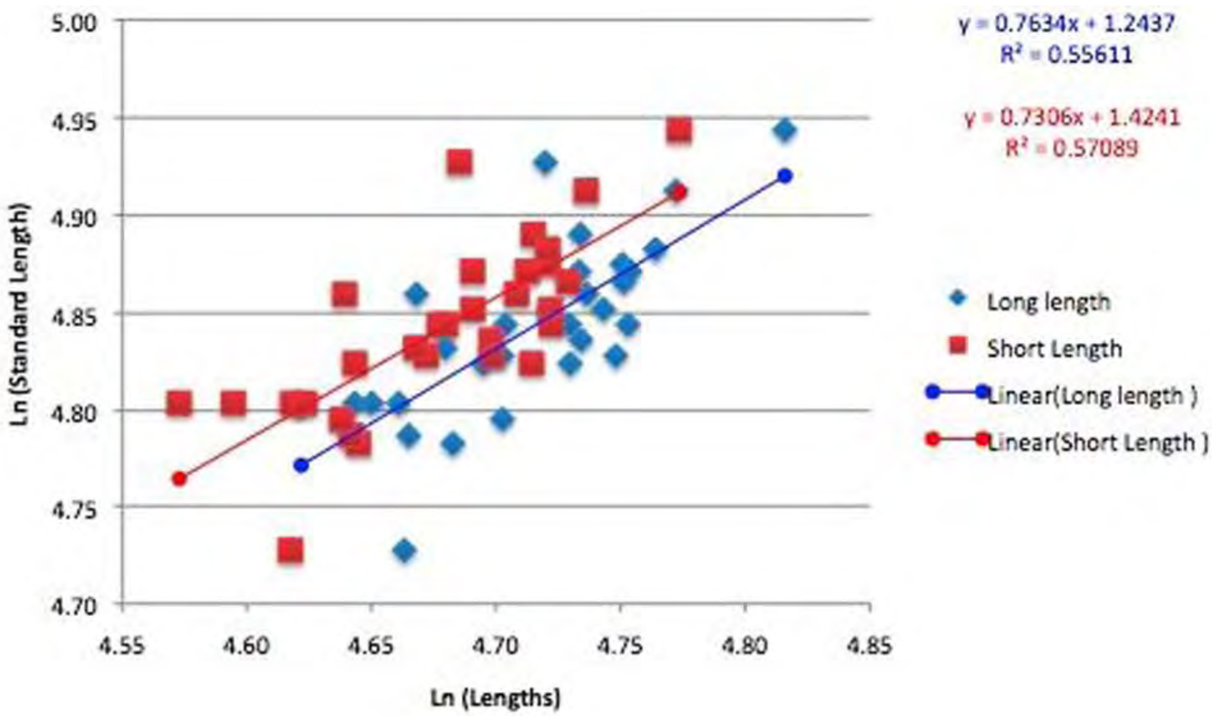

Figure 4. Relation of left femur length to standard length, California Academy of Sciences specimens.

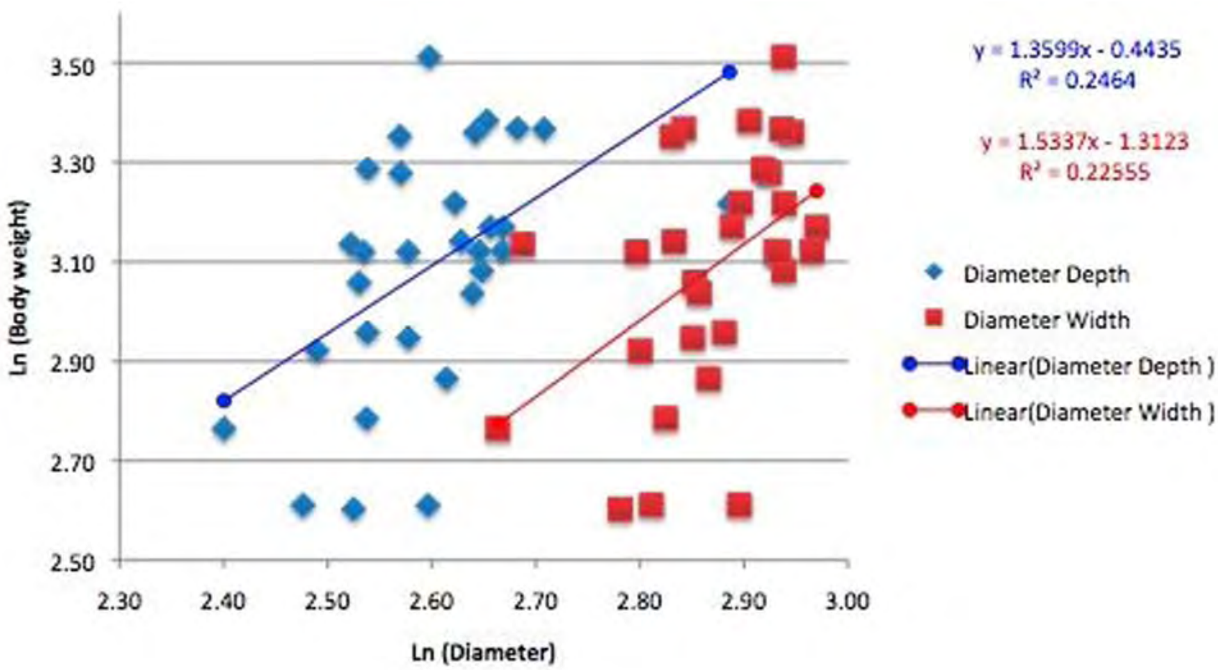

Figure 5. Relation of right femur diameter to body weight, California Academy of Sciences specimens.

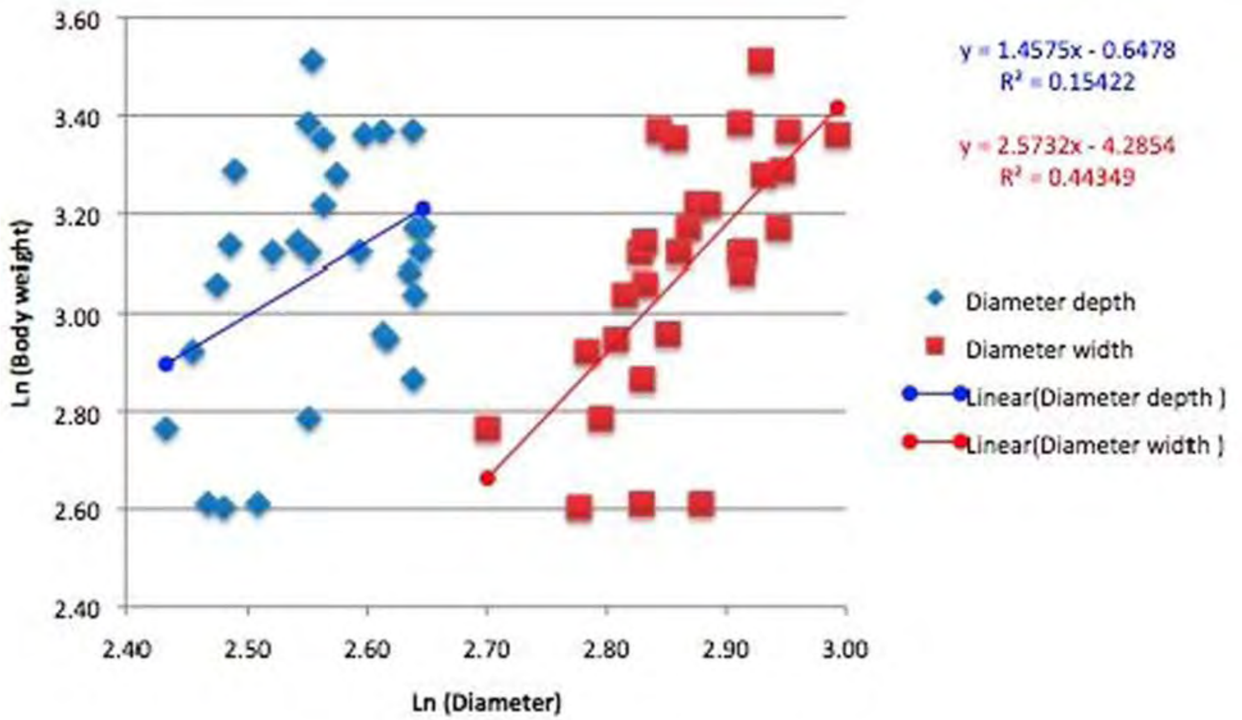

Figure 6. Relation of left femur diameter to body weight, California Academy of Sciences specimens.

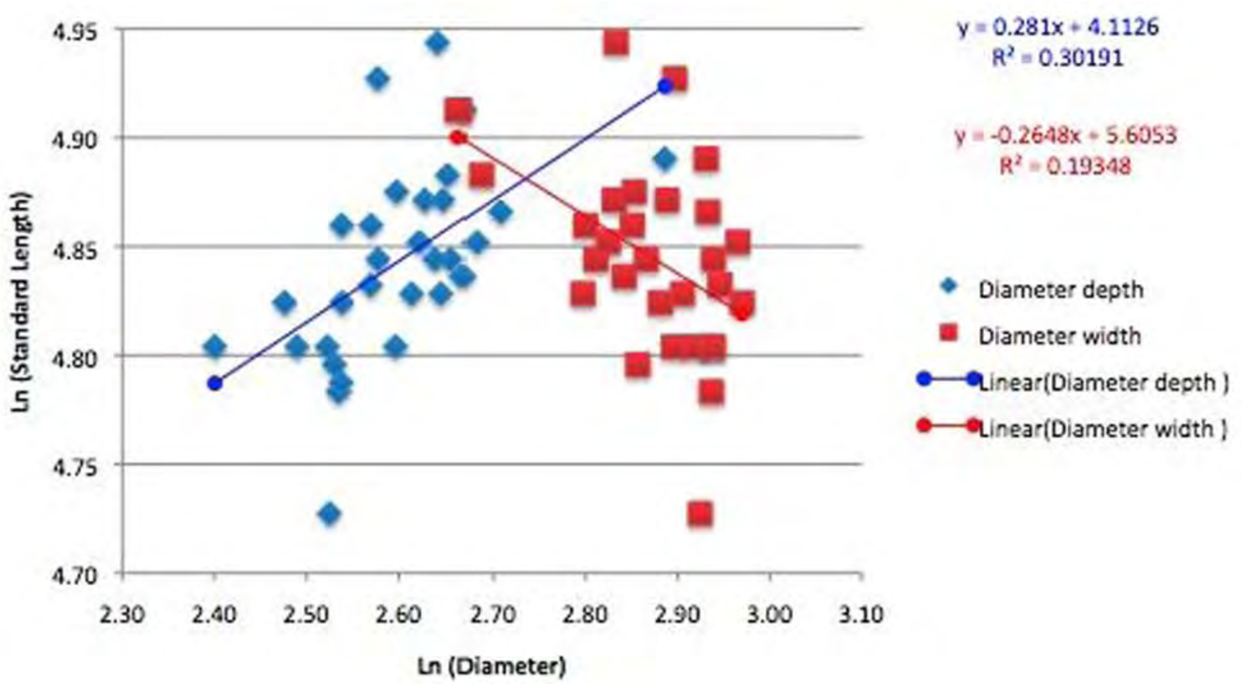

Figure 7. Relation of right femur diameter to standard length, California Academy of Sciences specimens.

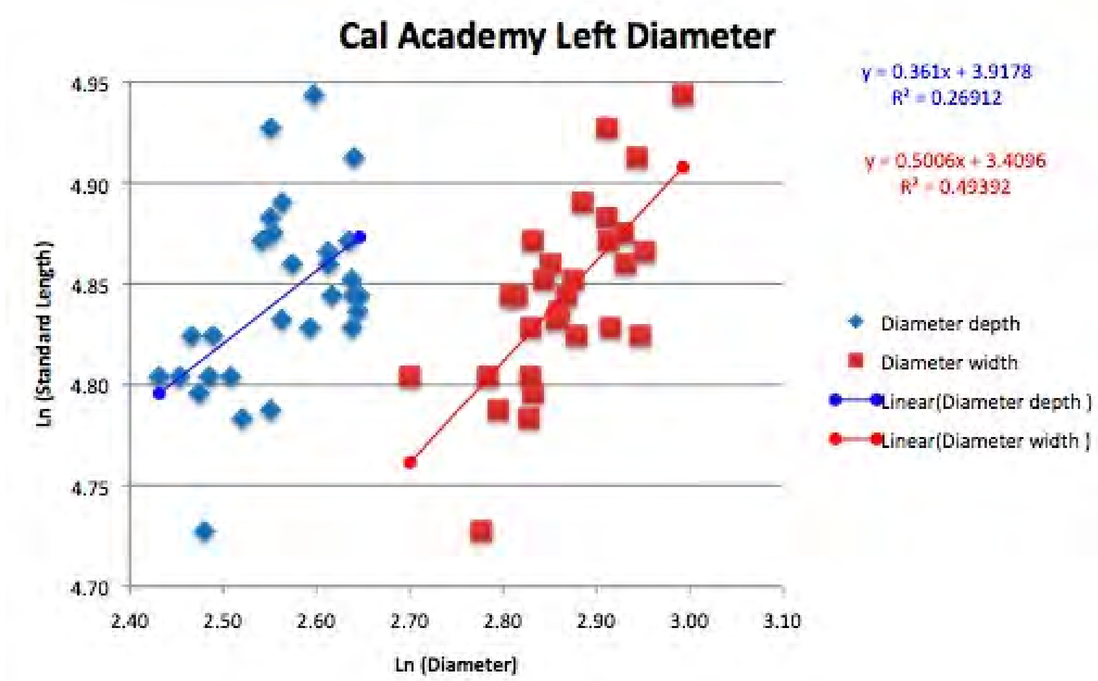

Figure 8. Relation of left femur diameter to standard length, California Academy of Sciences specimens.

Figure 8 shows the log-transformed relationship between left limb diameter MP/AP averages and standard length averages. Regressions were calculated for each set of data. The r value for the MP shows a greater degree of confidence than the AP.

Figure 9 shows the log-transformed relationship between articular surface averages and body weight averages. Regressions were calculated for each set of data. The r values did not show any substantial results.

Figure 10 shows the log-transformed relationship between articular surface averages and standard length averages. Regressions were calculated for each set of data. The r values for the FH-GT and the Cw showed more significance than FHd and the LT-TT measurements.

MVZ Data

The MVZ collection was used to confirm that the specimens found in the SFR-7 archaeological site were indeed sea otter and not river otter. Only eight specimens were measured. Tables 1-3 show the average lengths, diameters, and articular points of four river otter specimens and four sea otter specimens from the MVZ. It is evident that the river otters are significantly smaller than the sea otters.

SFR-7 Data

Table 4 shows the femoral lengths and diameter measurements of specimens from the SFR-7 site. Table 5 shows the articular measurements of specimens from the SFR-7 site.

Comparative Analysis

Table 6 compares the overall average lengths of all specimens from California Academy of Sciences and those found at the SFR-7 site. Analyzing length size alone, it is evident that the specimens from SFR-7 are longer than specimens from the Academy. The average long length of the Academy collection is about the same as the average short length of the SFR-7 site.

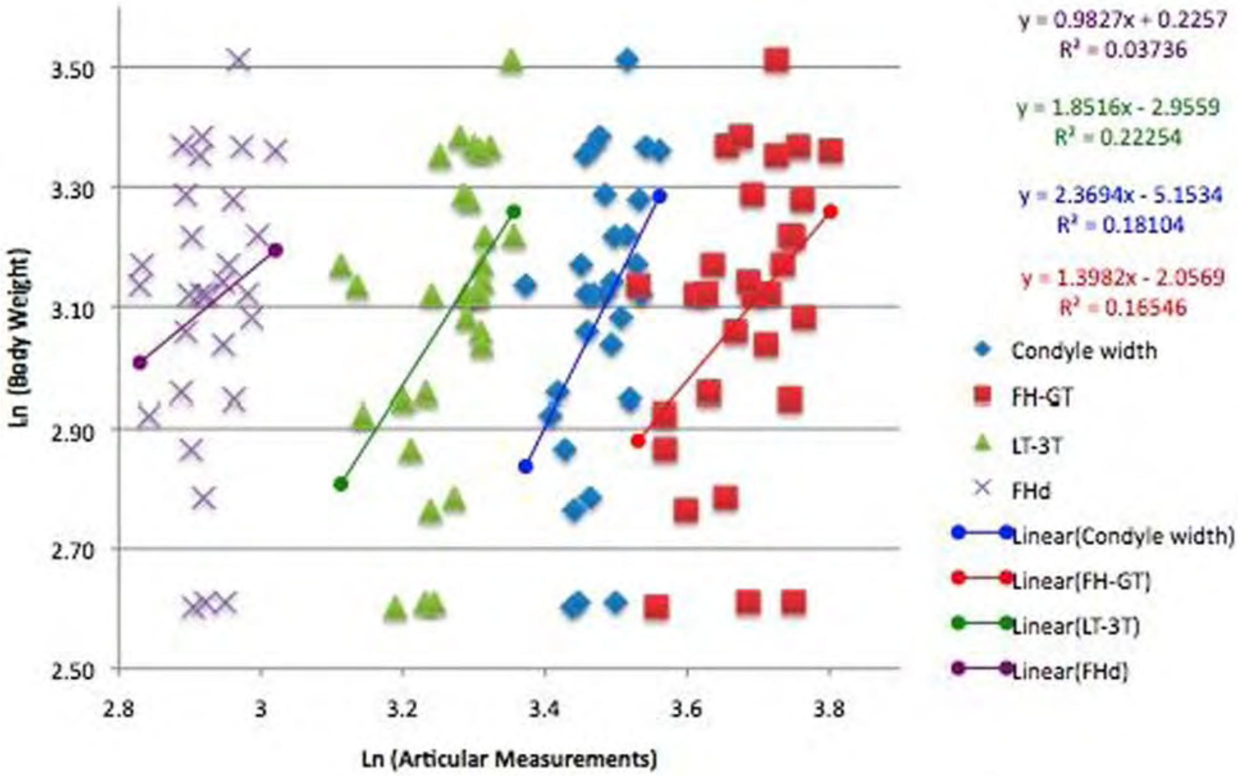

Figure 9. Relation of right articular measurements to body weight, California Academy of Sciences specimens.

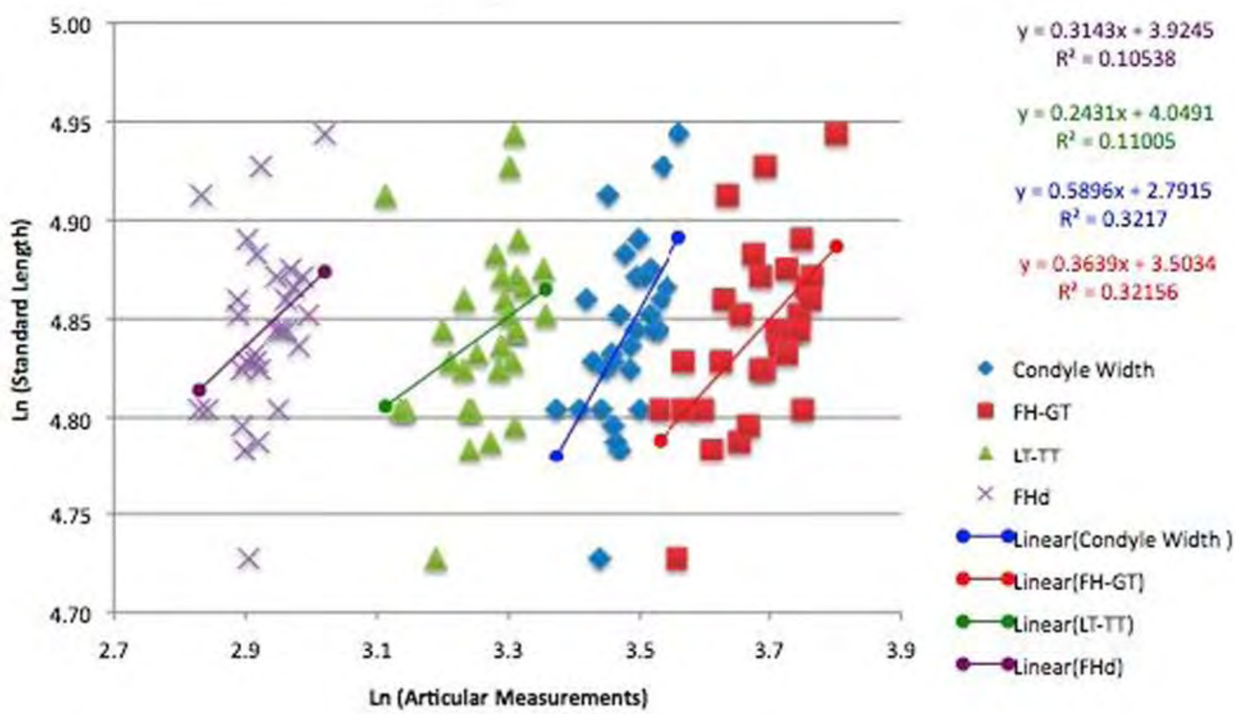

Figure 10. Relation of right articular measurements to standard length, California Academy of Sciences specimens.

Table 1. Right femoral lengths and diameters for MVZ specimens.

Catalog Number	Sex	Long Length		Short Length		Diameter Depth (AP)		Diameter Width (MP)	
		Average	ln(length)	Average	ln(length)	Average	ln(depth)	Average	ln(width)
River Otter									
29243	female	75.11	4.319	72.81	4.288	7.41	2.002	8.93	2.190
46661	female	76.40	4.336	73.54	4.298	7.45	2.008	9.75	2.277
24779	male	78.15	4.359	75.32	4.322	7.69	2.039	9.83	2.285
21413	male	79.92	4.381	78.80	4.354	7.73	2.045	9.56	2.258
Sea Otter									
116611	female	107.20	4.675	103.45	4.639	13.73	2.620	17.20	2.845
163330	male	104.68	4.651	101.28	4.618	13.84	2.627	16.44	2.800
135831	male	102.14	4.626	95.94	4.564	11.32	2.427	14.82	2.696
116213	female	101.13	4.616	94.12	4.545	11.22	2.418	15.35	2.731

Table 2. Left femoral lengths and diameters for MVZ specimens.

Catalog Number	Sex	Long Length		Short Length		Diameter Depth (AP)		Diameter Width (MP)	
		Average	ln(length)	Average	ln(length)	Average	ln(depth)	Average	ln(width)
River Otter									
29243	female	74.52	4.311	72.20	4.279	7.64	2.033	9.29	2.229
46661	female	76.49	4.337	73.92	4.303	7.65	2.035	9.81	2.283
24779	male	78.17	4.359	75.47	4.324	7.66	2.036	9.52	2.253
21413	male	79.72	4.378	77.72	4.353	7.91	2.069	9.55	2.257
Sea Otter									
116611	female	107.88	4.681	105.10	4.655	13.97	2.637	16.65	2.813
163330	male	--	--	--	--	--	--	--	--
135831	male	101.80	4.623	96.81	4.573	11.22	2.418	15.09	2.714
116213	female	101.69	4.622	93.88	4.542	11.65	2.455	15.30	2.728

Table 3. Right articular measurements for MVZ specimens.

Catalog Number	Sex	FH-Gt		LT-3T		Cw		FHd	
		Average	ln(length)	Average	ln(length)	Average	ln(depth)	Average	ln(width)
River Otter									
29243	female	21.16	3.052	16.69	2.617	22.71	3.123	11.18	2.414
46661	female	22.33	3.106	15.24	2.724	23.77	3.168	11.85	2.473
24779	male	23.02	3.137	15.00	2.708	24.74	3.209	12.35	2.514
21413	male	22.45	3.111	14.90	2.701	23.28	3.148	12.09	2.492
Sea Otter									
116611	female	38.89	3.661	27.18	3.302	33.44	3.510	19.16	2.953
163330	male	40.61	3.704	36.83	3.290	35.82	3.579	19.51	2.971
135831	male	37.31	3.619	23.62	3.162	32.97	3.496	17.80	2.879
116213	female	35.80	3.578	24.17	3.185	31.54	3.451	17.49	2.862

Table 4. Femoral lengths and diameters for SFR-7 specimens.

Catalog Number	Long Length		Short Length		Diameter Depth (AP)		Diameter Width (MP)	
	Average	ln(length)	Average	ln(length)	Average	ln(depth)	Average	ln(width)
1-16685ee	--	--	105.38	4.658	12.22	2.503	17.69	2.873
1-16685ee	115.40	4.748	106.78	4.671	12.27	2.507	16.68	2.814
1-16685L	--	--	116.49	4.758	13.37	2.593	16.68	2.814
1-16685n	115.43	4.749	105.51	4.659	12.22	2.503	17.18	2.844
1-16685o	126.53	4.841	--	--	13.33	2.590	20.91	3.040
1-16685p	--	--	113.54	4.732	14.25	2.657	16.70	2.816
1-16685r	--	--	--	--	11.92	2.478	15.48	2.739
1-16685s	120.12	4.788	113.14	4.729	12.45	2.522	17.74	2.876
1-16685t	121.27	4.798	115.49	4.749	14.45	2.671	19.84	2.988
1-16685u	--	--	--	--	14.44	2.670	18.32	2.908
1-16685v	--	--	--	--	13.86	2.629	15.59	2.746
1-16685w	--	--	--	--	12.55	2.530	16.87	2.825
1-16686a	124.14		117.27	4.765	11.10	2.407	19.84	2.988
1-16685cf	--	--	--	--	13.84	2.627	14.94	2.704

Table 5. Right articular measurements for SFR-7 specimens.

Catalog Number	FH-Gt		LT-3T		Cw		FHd	
	Average	ln(length)	Average	ln(length)	Average	ln(depth)	Average	ln(width)
1-16685	37.95	3.636	24.37	3.193	31.82	3.460	19.87	2.989
1-16685ee	--	--	28.24	3.341	33.16	3.501	--	--
1-16685l	--	--	27.84	3.327	34.81	3.550	--	--
1-16685n	42.12	3.741	26.34	3.271	32.65	3.486	19.43	2.967
1-16685o	--	--	27.70	3.322	--	--	19.85	2.988
1-16685p	--	--	29.56	3.386	34.78	3.549	--	--
1-16685r	--	--	26.10	3.262	--	--	18.43	2.914
1-16685s	44.60	3.798	27.98	3.332	35.56	3.571	--	--
1-16685t	43.44	3.771	28.43	3.348	33.31	3.506	19.53	2.972
1-16685v	--	--	26.79	3.288	31.04	3.435	--	--
1-16685w	41.77	3.732	26.15	3.264	--	--	19.31	2.960
1-16685x	--	--	--	--	31.94	3.464	--	--
1-16686a	43.00	3.761	25.46	3.237	25.15	3.225	20.13	3.002
1-16685cf	--	--	--	--	34.28	3.535	--	--
1-16685ch	--	--	--	--	31.82	3.460	--	--
1-16685u	43.68	3.777	28.29	3.342	--	--	19.29	2.960

Table 6. Comparison of lengths of California Academy of Sciences and SFR-7 specimens.

	California Academy of Sciences				SFR-7	
	Right Femurs		Left Femurs		Right Femurs	
Measurement	LL	SL	LL	SL	LL	SL
Average Length of all Specimens	111.56	107.70	111.63	107.77	120.47	111.70

DISCUSSION / CONCLUSION

The findings thus far have yielded results that show moderate to low relationship between body weight/standard length to the measurements collected. The r values of the data seen in Figures 1-4 indicate moderate to no degree of confidence in the equations for both limb length to body weight, and limb length to standard length relationships. Although results for diameter MP/AP to body weight/standard lengths ratios in Figures 5-8 show little to no degree of confidence, a higher degree of confidence was found when measuring the MP ratios instead of AP ratios in both body weight and standard length relationships. Articular measurements (Figures 9-10) yielded little to no degree of confidence regardless of whether or not they were compared to standard length or body weight. When compared to body weight, FHd and the LT-3T measurements had a higher degree of confidence. When compared to standard length, Cw and FH-GT relationships were stronger.

The procedure developed to collect measurements of length and articular surfaces has its flaws and calls for future improvements. Whether measurements are conducted by a single person or by two individuals, they are susceptible to error because of the difficulty of repeatedly placing the caliper in the same orientation at the same morphometric point. To compensate, three measurements were recorded at the same morphometric point to produce an average. In the future, instead of a caliper, perhaps the use of an osteometric board may be more suitable to collect consistent length measurements (Setiawan et al. 2004). In conducting AP and MP measurements, it was difficult to maintain consistency when transferring between the two. The negative regression line found in Figure 7 shows inconsistencies with the other regression lines in Figures 5-8. Further research to develop a more efficient method to collect diameter measurements is necessary. Articular measurements were found to be the most difficult to record with consistency, due to the challenge of maintaining proper alignment. This concern should be considered when interpreting the generated data.

After having examined specimens with known sex from the California Academy of Sciences, there appears to be a difference in the overall robusticity and length between females and males (Table 4). This difference in sexual dimorphism was also noted by Broughton (1999). For this portion of the project, the MVZ collection was used to confirm that the specimens in SFR-7 are indeed sea otter and not river otter. As this project progresses, the MVZ collection will be used to conduct similar statistical analysis as were done with the Academy collection. Unfortunately, there were not enough female specimens with complete necropsy information from either the Academy or MVZ to attempt to generate sexual dimorphic data. Lack of necropsy data for specimens lowered the number of specimens to be used for statistical analysis. In addition to the lack of necropsy data, juvenile individuals were also omitted because of the difficulty in conducting measurements with unstable epiphyseal fusions.

Table 6 simplifies the length data collected by averaging the femoral LL and SL of all 29 adult specimens from the California Academy of Sciences and specimens from SFR-7. The LL and SL measurements in SFR-7 appear to be larger than for the current populations of sea otters. This change in length is indicative of a possible increase in time spent in an aquatic environment (Gingerich 2003).

FUTURE WORK

The data presented here are preliminary results. For future work on this project, additional measurements need to be collected from other institutions in the area such as the LML and the Marine Mammal Center. More data will increase the likelihood of gaining insight into the sexual dimorphic differences in sea otters as well as contributing to the information of total pooled samples. For a better understanding of sea otter development, their life history in California needs to be understood. Exploring the possibility of an aquatic environmental preference is something that will be further researched at a later time. A trip to the Regatta Storage Facility is necessary to analyze the rest of the SFR-7 site to collect more femoral data and information on the site. Regarding the statistical analysis, here we use the RMA model to interpret our data based off of Egi's (2000) body mass estimates. Later we will look at other models such as the least-squares model (Smith 1994) to see what the results yield. This project hopes to build upon these data and find better techniques to continue the goal of developing an improved method of collecting measurements to ultimately develop a reliable metric system that examines the morphological changes caused by human predation.

ACKNOWLEDGEMENTS

I would like to say thank you to Dr. Jun Sunseri for his support and guidance through this project; Jillian Swift, Shelby Medina, Shannon Pfeiffer, Gloria Keng, Ed De Haro, Danielle Holman, Abbey White, and Di Hu for the support and discussions regarding the progress and future of this project; Natalia Viavicencillo for assistance in collecting and interpreting the data; Antonio Yip Wlassowsky for insightful advice; Maureen Flannery, the Ornithology and Mammalogy Collection Manager at California Academy of Sciences and Christopher J Conroy, the Mammal Collection Manager at UC Berkeley MVZ, for access to their sea otter specimen collections; and Laramie Mariah Martinez for comments on earlier drafts of this paper. Finally, thank you to Cristelita Bejar Guillen, Herbert Guillen Sr., and Vivian Lei for their endless support

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