Assessing the Accuracy of Photogrammetry via an Unmanned Aircraft System (UAS) on Northern Elephant Seals (*Mirounga angustirostris*)

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Recent developments in unmanned aircraft systems (UAS) allow researchers to conduct aerial surveys more safely and at less cost than ever before. This study quantified the accuracy of morphometric measurements collected with an UAS. Photographs of northern elephant seals (*Mirounga angustirostris*) with empirically measured mass and size (n=14) were collected at Año Nuevo State Park during the 2017-breeding season from January to March. Photogrammetric measurements were collected and compared to direct mass and size measurements collected in the field. The accuracy of measurements collected from photographs varied between individuals, this variation was considered a result of environmental factors in the field and not an error in the process of analyzing photographs. A measurement of seals size was collected from the images and had a significant relationship with seal mass ($P<.001$ $R^2 = 0.773$ RMSE= 43kg). Mass estimation via an UAS was on average within 12% of the direct mass measurement, this level of accuracy is similar to other photogrammetric methods while causing less disturbance to study individuals. Overall as long as environmental factors in the field are accounted for morphometric measurements collected via UAS photogrammetry are accurate enough for the application of UAS as a research tool.

Introduction

Aerial surveys and photographs have historically been used to collect biological data from hard to study marine mammal species (Westlake *et al.* 1997, Bowen *et al.* 2007, Sweeney *et al.* 2014). Aerial surveys have historically been conducted using weather balloons and kites; more recently aerial surveys have been conducted using manned aircraft at high cost and potential risk to researchers (Watts *et al.* 2010, Torres *et al.* 2005). Recent developments in unmanned aircraft systems (UAS) provide a new method for collecting aerial photographs at a lower cost than ever before. UAS are small multi-propeller helicopters with onboard cameras controlled by an operator on the ground.

UASs are currently being utilized for marine mammal population surveys (Adame *et al.* 2017, Hodgson *et al.* 2013) . Such surveys are more accurate than land or boat surveys while causing only minimal disturbance to study animals (Adame *et al.* 2017). It has been demonstrated that photo identification of individual cetaceans is possible via UAS photographs (Durban *et al.* 2015). Researchers have also used morphometric features that are visible in UAS photographs to categorize California sea lions (*Zalophus californianus*) by sex and age class (Adame *et al.* 2017). Although results from UAS aerial surveys are encouraging the limits of UASs as research tools are poorly understood.

Photogrammetry is the science of collecting measurements from photographs. One study has used UAS photogrammetry to measure the morphometrics, as a proxy for body condition, of hump back whales *(Megaptera novaeangliae)* in northern Australia (Christiansen *et al.* 2016). Although they were able to collect a very large number of samples they were not able to validate the accuracy of their measurements.

Monitoring the body condition of marine mammals can be used to assess individual foraging success and as an indication of marine ecosystem productivity (Shero *et al.* 2014). Pinnipeds' morphometry can be collected directly in the field (Le Boeuf *et al.* 2000, Wheatley *et al.* 2006); however, taking these measurements can cause a large disturbances to other seals and create a potential risk to researchers (Costa *et al.* 1986). The high risk and large cost of collecting direct morphometric measurements have limited sample sizes to small subsets of study populations. To limit risk and increase sample sizes researchers have created and validated methods for estimating pinniped mass through photogrammetry (Haley *et al.* 1991, Ireland *et al.*

2006, Bell *et al.* 1997). While accurate these methods still require researchers to be on the ground near their study individuals.

The aim of this study was to determine the accuracy of morphometric data collected from aerial photographs taken by an UAS and to access the level of accuracy that mass could be estimated via UAS photogrammetry. Data was collected with a publicly available middle of market UAS, and photo analysis used open source software to enable others to use similar methodologies for as little cost as possible.

Methods

This study was conducted at Año Nuevo State Park, California (37.1188° N, 122.3066° W), during the 2017 breeding season from January to March. Aerial photographs were collected with a DJI Phantom Advanced III UAS with an on-board 12-megapixel camera. Altitude of each photograph was measured by the on-board GPS.

Año Nuevo is the site of a long-term biologging program on northern elephant seals (*Mirounga angustirostris*). As part of a standard satellite tag deployment and recovery procedure individuals are chemically immobilized and morphometric and mass measurements are collected directly (Costa *et al.* 1986, Le Boeuf *et al.* 2000). Individuals for this study were selected from the biologged individuals based on weather conditions being suitable to a UAS flight. Each seal was photographed from four altitudes; 20 meters, 25 meters, 30 meters, and 35 meters.

Not all individuals could be photographed on the same day mass measurements were taken, in which case their mass was corrected using the average rate of mass loss for a lactating northern female elephant seal (7.5 ± 0.9 Kg a day)(Crocker *et al.* 2001).

Images were analyzed with the software ImageJ. To calculate the ratio of pixel to centimeter test images of a 2.4m stick were taken every 5m from 10m to 45m (Figure 1). These ratios were used to convert seal measurements in pixels from ImageJ into centimeters so these measurements could be compared to the direct measurements taken in the field.

Using as similar as possible methods to other researcher's standard-length and axillary width were measured for each seal (Image 1), axillary width was measured only in images captured on the day of direct measurement collection. To reduce the error associated with manual measurements each photograph was measured 5 times and averaged. UAS measurements were then compared to measurements collected directly in the field. A one direction ANOVA was run on a metric of measurement accuracy to see if any of the altitudes were significantly better than the rest for future measurements.

The polygon tool in ImageJ was used to outline the seals and the area within the outline (“seal footprint”) was used as a measure of seal body size, (Image 2). To limit variation between measurements seal footprint did not include the area of the flippers (Haley *et al.* 1991). Seal footprint was also measured 5 times and averaged.

An estimation of seal volume was generated from the seal footprint measurements and the standard-length measurements to account for the body condition of seals. For volume estimations seals were assumed to be perfect cylinders with a diameter equal to the average width of the seal.

Mathematically for volume estimation, seal footprint was divided by standard-length to give the average width of the seal. This average width was then divided by 2, squared, multiplied by π, and multiplied by the standard-length to give the volume of the estimated cylinder. The equation for this estimation is:

$$\left(\frac{\frac{seal\ footprint\ cm^2}{seal\ length\ cm}}{2}\right)^2 * \pi * (seal\ length) = est\ seal\ volume\ cm^3$$

Results

The accuracy of standard-length and axillary width measurements collected with an UAS varied between the different test altitudes (Table 1 and Table 2). A one directional ANOVA found no significant difference in the accuracy measurements taken at different altitudes ($P=.878$ & $P=.617$). The lack of significant difference in accuracy between altitudes might a result of the small sample size of this study ($n=14$).

Footprint Measurements

A linear regression between footprint measurements and direct mass of all seals showed a significant relationship at all test altitudes (Figure 2.) ($n=13$). The strongest linear relationship was from the images collected at an altitude of 35 meters ($P<.001$, R-squared= 0.773, RMSE= 43kg) (Figure 3.) these photographs were used for all future calculations. Using the regression equation from the seal footprint measurements taken from images captured at 35 meters mass was estimated with an average error of ± 12% of the directly measured mass.

Standard-Length x Axillary Width

A linear regression was run between seal mass and standard-length multiplied by axillary width for all possible seals (n=7). A significant linear relationship was found (P= 0.01702, R-squared= 0.7119, RMES= 34 kg) (Figure 3). Mass estimation from this regression was on average within ± 9% the directly measured mass.

Volume estimation

A linear regression between the estimated volume measurement and seal mass for all possible seals (n=11) showed a significant linear relationship (P<.001, R squared= .7671 RMSE= 44kg) (Figure 5). The volume regression equation estimated mass on average within ± 14% the of the directly measured seal mass.

Discussion

This project is one the first to collect and validate morphometric data with an UAS for any pinniped species. Many aspects of the data collection method for collecting data were created through trial and error in the field. Multiple environmental factors were found to have a detrimental effect on the accuracy of measurements collected with an UAS.

Practical Application Requirements

For accurate measurements by UAS, researchers need to control as many variables as possible in the field at the time of photograph collection. The first factor to account for is the light level at the time of photographs: UAS flights should be done during the middle of the day to limit the effect of shadowing within the images. The next factor researchers need to control for is to ensure that the altitude measurement is correct by launching the UAS from the same relative altitude as the target individual(s).

Some factors are not in the control of researchers but still need to be considered and accounted for when using an UAS for photogrammetry. The orientation of the seal in three-dimensional space can have a dramatic effect on the accuracy of any measurement from an UAS. For pinniped species that haul-out on level fast or pack ice this will not be an issue. For species that haul-out on land, researchers will need to consider whether the ground below the seals is level. Another factor researchers need to consider before attempting UAS photogrammetry is how difficult it is to isolate the seal from its background. Seals that haul out onto land can be difficult to distinguish from the land or rock they are on, this makes the image analysis much more challenging and more time-consuming. Different animal behaviors can also influence the accuracy of UAS measurements. Measurements in this study were affected by elephant seals close huddling behavior and overlapping individuals.

The optimal pinniped system for UAS photogrammetry would be where dark seals loosely congregate on, level, fast ice or pack ice. It should also be possible for UAS photogrammetry to be implemented with a high level of accuracy for cetacean research. Previous cetacean studies have accounted for the three-dimensional orientation of study individuals by their relative flatness on the ocean's surface (Christiansen *et al.* 2016).

Best measurement for mass estimation

The standard-length multiplied by width regression had the lowest RMSE at 34kg or 8.5% of the average mass of study individuals. This higher precision was most likely a result of having a smaller sample size than the footprint or volume regressions. To compare the accuracy between the different measurement techniques the different R^2 values were compared. The highest R^2 value was for the regression of footprint vs mass, indicating that the footprint measurements explained variation in mass better than the standard-length multiplied by axillary width or volume estimation.

Future researchers will be able to use the methods for collecting the footprint measurement and the regression equation:

$$Mass\ (kg) = 32.167492 + 0.027308(footprint\ cm^2)$$

to estimate the mass of northern elephant seals with an average error of 12% without causing any disturbance to the animals and for cheaper than ever before possible.

Being able to estimate mass with an average error of 12% is extremely useful for body condition studies on northern elephant seals because of their unique life history. Northern elephant seals go through a dramatic fasting period during breeding season where they lose an average of 35.8% ± 3.6% of their body mass over the 28-day lactation period (Crocker *et al.* 2001). Using the methods developed here researchers could remotely monitor the mass lots by adult females' seals during lactation. With a larger sample size, it might also be possible to monitor pup development throughout the lactation period.

Two individuals were tracked throughout the breeding season and photographed again 20 and 19 days after the first photograph, respectively. Using the volume estimation regression, the first individual lost an estimated 122 kg over 12 days a 25% reduction in total mass. The second individual lost an estimated 94 kg over 19 days or 18% reduction in total mass. Being able to document change over time from aerial photographs alone will allow researchers to monitor changes in body condition using a larger sample size than ever before possible.

Comparison to other methods

The high level of variation in accuracy of standard-length measurements in this study may call into question the accuracy of aerial photogrammetry in other studies where environmental factors cannot be accounted for. A previous study has used aerial photogrammetry via a fixed wing manned aircraft to compare standard-lengths of Stellar sea lions *(Eumetopias jubatus)* from the two distinct population segments (Sweeney *et al.* 2014). While this study accounted for any error statistically with a large sample size and assuming all location would have a similar amount of error future comparison of these photogrammetric measurements and measurements collected directly in the field may not be possible. Future aerial surveys need to make every effort to account for the flatness of the substrate that study individuals are located on and how body position is effecting measurements.

The level of accuracy of photogrammetric mass estimation with an UAS is similar to other photogrammetric methods that use only one measurement to estimate mass. Bull northern elephant seals mass has been estimated with a high level of accuracy (± 14%, $R^2 = 0.923$) by measuring the side area of stationary individuals (Haley *et al.* 1991) . A slightly more accurate (95% CI: 6.36% $R^2 = .862$) estimation of mass was created for southern elephant seal (*Mirounga leonina*) by including all age classes in the estimation model (Bell *et al.* 1997). By creating specific hardware to standardize the photo capture process researchers were able to generate an arcuate (95% CI: 19.8% $R^2 = 0.788$) method for estimating the mass of Weddell seals (*Leptonychotes weddellii)* for a larger sample size then previous studies (Ireland *et al.* 2006). UAS measurements have a similar accuracy to these methods while being cheaper to implement and requiring a smaller research effort in the field.

Currently the most accurate method for mass estimation via photogrammetry was developed using multiple photographs and three-dimensional modeling software to estimate the volume of study individuals (Bruyn *et al.* 2009). This method has been implemented with very high levels of accuracy for estimating the mass of both marine and terrestrial mammals (Postma *et al.* 2013, Postma *et al.* 2015). While these methods are more accurate than mass estimation via an UAS they require more time and effort by research in the field as well as more expensive photo analysis software. Future developments in UAS technology and image processing power may allow researchers to estimate the volume and mass of hauled out pinnipeds with extreme accuracy using the Bruyn *et al.* method.

Conclusion

Overall, the level of accuracy of photogrammetric measurements collected with an unmanned aircraft system is high enough for the application of UASs for ecological research. While environmental factors can limit the accuracy of measurements, if these environmental factors are accounted for, the variation in accuracy is minimal. Being able estimate mass with an UAS with similar accuracy to other photogrammetric methods will allow future researchers to collect body condition data from dramatically larger samples than ever before for lower cost and with no risk to researchers or disturbance to study individuals.

Acknowledgements

This project would not have been possible without the help of many different people involved in the elephant seal research at Año Nuevo, specifically Dr. Patrick Robinson, Rachel Holser, and Garrett Fielding. Funding for this project was acquired through the University of California Santa Cruz Norris Center student project award and the UCSC Packard ocean sciences endowment.

All research was coordinated with through UC natural reserve research and was conducted under Dr. Daniel P. Costa elephant seal permit NMFS #191081, in accordance with the University of California Santa Cruz Animal Care and Use Committee, and in agreement with Año Nuevo State Park.

Image 1

An aerial photograph taken with and UAS of a female northern elephant seal, standard-length (1) and axillary width (2) measurements were collected. Measurements were taken five times and an average was used for all future calculations.

Image 2

An aerial photograph taken with an UAS of a female northern elephant seal. Seals were outlined with the polygon tool in ImageJ and the area within the outline was used as a proxy of seal size. Seals were outlined five times and an average of the five was used as the seal footprint measurement for all future calculations.

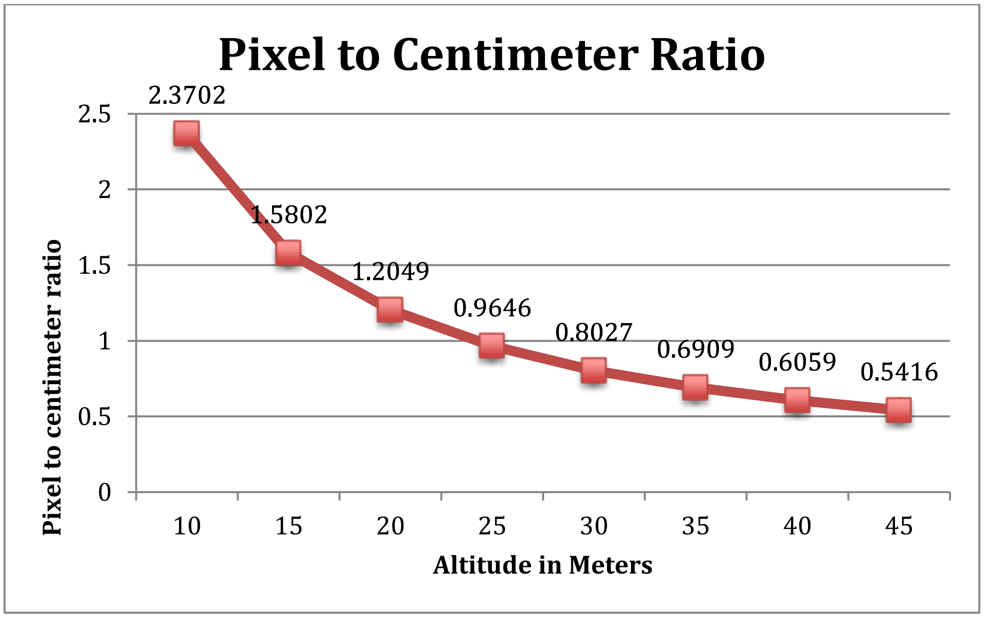


Figure 1.

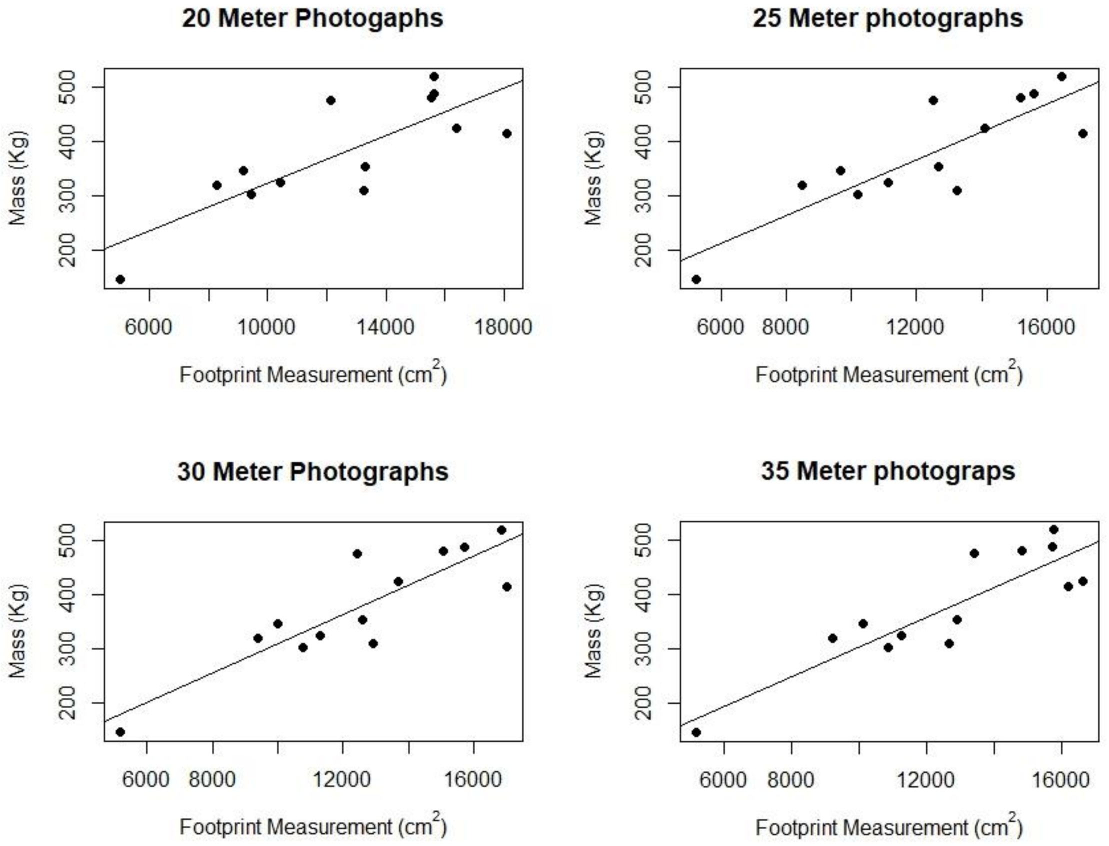
The ratio of pixel size to centimeter. This logarithmic decrease means that variation in relative altitude from environmental factors will have a smaller effect on analyses for photos taken at higher altitude.

Table 1. The error in centimeters of standard-length measurements collected from the UAS photographs compared to the measurements collected directly in the field. The altitude with the lowest Root mean square error was 25 meters (RMSE= 19.461 cm), measurements from the 35 meter altitude photographs had a similar accuracy (RMSE= 19.833). A RMSE of 19.461 means that on average standard-length measurement collected with the UAS was off from those collected directly in the field by ±7.1%.

Altitude	20 Meters	25 Meters	30 Meters	35 Meter
Seal ID				
T269	51	44	40	39
4209	-11	-10	-13	3
9678	26	20	19	29
6118	-13	-3	-7	-13
U400	32	30	43	26
A278	16	8	13	25
5950	36	33	31	33
6871	4	-2	-1	1
6767	30	20	23	15
Y1481	-6	-4	-5	-3
U20	-8	-8	-9	-7
7430	60	51	50	44

Table 2. The error in centimeters of axillary width measurements collected from the UAS photographs compared to the measurements collected directly in the field. The most accurate measurements were from photos taken at 35 meters (RMSE = 4.125 cm). A RMSE of 4.125cm means that on average measuring axillary width with an UAS was off by ±6.0% from the measurements collected directly in the field.

Altitude	20 Meters	25 Meter	30 Meter	35 Meter
Seal ID				
T269	3	0	1	-2
4209	-22	-15	-10	-9
6118	-18	-2	-4	-4
A278	-12	-12	-15	-9
5950	1	-1	-3	-4
6767	-1	-3	-3	-2
Y1481	-3	-3	-2	0
U20	2	2	2	3



20 Meter Photogaphs

25 Meter photographs

30 Meter Photographs

35 Meter photograps

Figure 2.

Linear regression of footprint area and direct mass measurement had a significant relationship at all altitudes, the regression with the highest R² value was the 35 meter photographs (R² = .773). all future calculations were done using the 35 meter photographs.

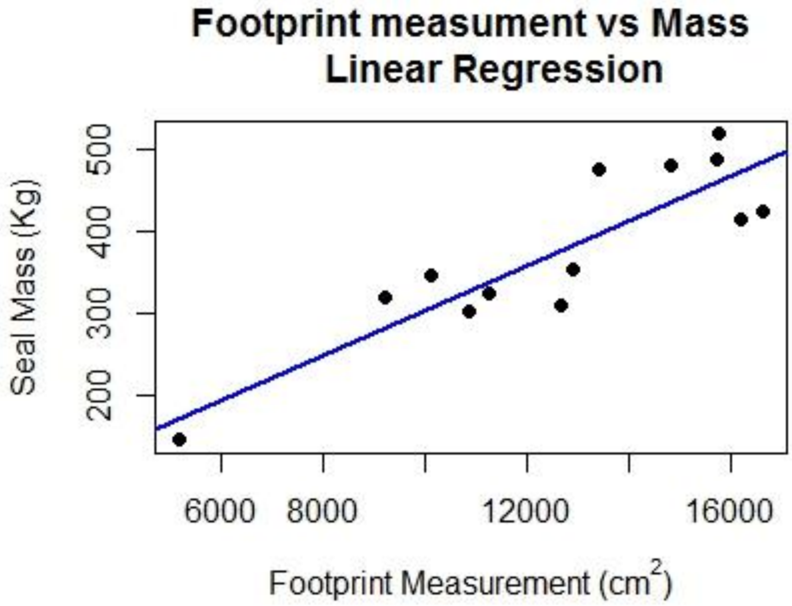


Figure 3.

A linear regression between seal outline and seal mass found a significant relationship. The equation of the regression line is $Mass = 32.167492 + \left(.027308 * (footprint)\right)$ (P <.001 R^2 0.773 RMSE= 43kg). Mass estimation with this method was on average within 12% of the directly measured mass.

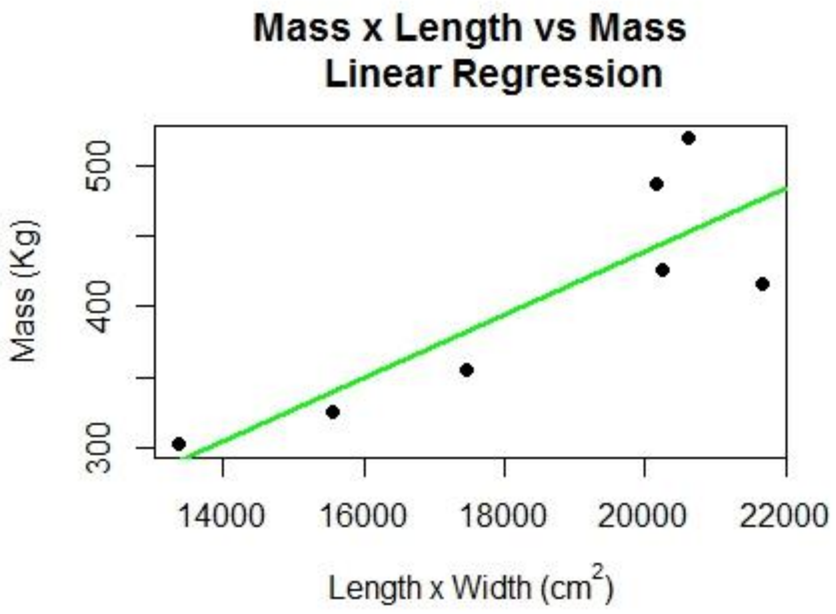


Figure 4.

A linear regression between seal mass and standard-length multiplied by axillary width. The regression equation is $Mass = -7.24409 + \left(.02232 * (length * width)\right)$ (P= 0.01702 R^2 = 0.7119 RMSE= 34kg). Mass estimation with this method was on average within 9% of the directly measured mass.

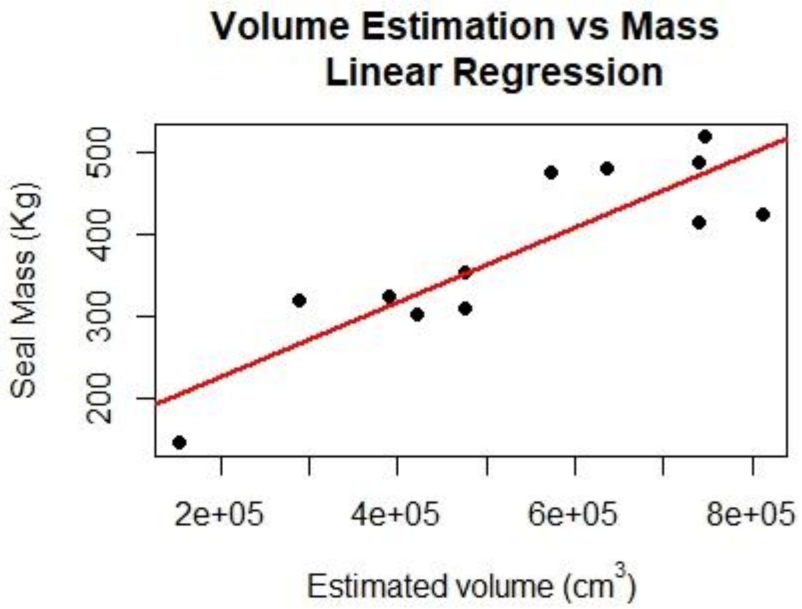


Figure 5

An estimation of seal mass was generated from the equations:

$$\left(\frac{\frac{seal\ footprint\ cm^2}{seal\ length\ cm}}{2}\right)^2 * \pi * (seal\ length) = est\ seal\ volume\ cm^3$$

A linear regression between estimated seal volume and true seal mass found a significant linear relationship, the regression equation was $Mass = 135.1 + (0.0004556 * esti.volume)$ (P<.001 R^2= .7671). Mass estimation with this method was on average within 14% of the directly measured mass.

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