Haul-out Behavioral Patterns and Photo-Identification of Pinnipeds in Narragansett Bay, Rhode Island: 2016-2017 Technical Report

NAVSEA WARFARE CENTERS NEWPORT

Prepared by

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Executive Summary

Harbor seal (*Phoca vitulina concolor*) distribution along the U.S. Atlantic coast has shifted in recent years, with an increased number of seals reported in southern New England. Narragansett Bay is an ecosystem with a substantial seasonal harbor seal presence and extensive commercial and recreational boating traffic, shoreline development pressure, and Navy activities. To better understand harbor seal haulout usage in this system we have been conducting regular, opportunistic observations of seal abundance, seal behavior, potential disturbance, and environmental conditions at a haulout site off Naval Station Newport, from 2010 - 2017.

Our study had two major components. We used *ExtractCompare*™ software to conduct a photo-identification effort and a baseline photographic capture-recapture estimate of the population of seals using the haulout. We also developed a "hurdle" modeling framework to relate haulout usage to environmental conditions at the haulout.

Our study shows varying amounts of site fidelity among the seals using this haulout. Some individuals were regularly observed throughout the season, while others were seen only sporadically or once. The total population using the haulout over the course of a season (November-April) was estimated at 240 animals, which is approximately one third of the 600+ animals known to be in the system. Our modeling approach shows strong relationships between haulout usage and environmental parameters such as temperature, wind speed and direction, tide level, and time of day. The model also shows a trend of increasing haulout usage during marginal weather conditions over the course of the study period.

Overall, this study improves our understanding of haulout usage and its relationship to environmental variables, which will allow for a more robust analysis of potential impacts of Navy activities in this area, and the potential impacts of changing environmental conditions (e.g., increases in sea level and temperature).

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Harbor seal (*Phoca vitulina*) *hauled out at a survey site in Narragansett Bay, RI.* Cover photo by Christopher Tompsett, Photo taken under National Marine Fisheries Service General Authorization #19826-00. VIRIN ID: 20171118-N-TF213-011.

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Acronyms and Abbreviations

AIC	Akaike's Information Criterion
ANCOVA	Analysis of Covariance
^{o}F	degrees Fahrenheit
ft	feet
KTS	nautical miles per hour (Knots)
NOAA	National Oceanic and Atmospheric Administration
Photo-ID	Photo-identification
SEM	Standard Error of the Mean
U.S.	United States

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1. Introduction and Background

The distribution of harbor seals (*Phoca vitulina concolor*) and gray seals (*Halichoerus grypus*) along the Atlantic coast of the United States (U.S.) appears to be shifting, and in recent years there has been an increased number of seals reported in southern New England and the mid-Atlantic region. This increase is perhaps an indication of localized population growth or redistribution of existing animals (Kenney 2014; Waring et al. 2014). The harbor seal is one of the most widely distributed seals, found in temperate to polar coastal waters of the northern hemisphere (Jefferson et al. 2011). Occasional sightings and strandings have been reported as far south as Florida and North Carolina for harbor and gray seals for many years (Waring et al. 2014), but more recently, small winter haulout sites have been discovered in the lower Chesapeake Bay, Virginia and near Oregon Inlet, North Carolina (Waring et al. 2014). Range expansion is a common occurrence when a population is growing rapidly, but it is important to understand how that population interacts with its environment, in order to understand how population changes may affect habitat utilization and the potential for anthropogenic impacts. This study focuses on harbor seals and continues previously funded efforts to monitor and assess seal usage of a haulout site near Naval Station Newport in Narragansett Bay, Rhode Island. This report presents an analysis of seal counts at the haulout and relates these counts to environmental parameters using a "hurdle" type model. In addition, we present a local population estimate and analysis of haulout fidelity using ExtractCompare™ photo-capture-recapture software.

An important aspect of seal physiology is the need to haul out. Harbor seals in the northeast U.S. haul out to breed and pup during the summer, but also must haul out during the winter to rest and thermoregulate, as their blubber layer is insufficiently thick to defend against colder water temperatures (Grellier et al. 1996; Terhune and Brillant 1996). Haulout sites vary but include intertidal and subtidal rock outcrops, sandbars, sandy beaches, and even peat banks in salt marshes (Burns 2008; Gilbert and Guldager 1998; Prescott 1982; Wilson 1978). When hauled out, seals are particularly vulnerable to anthropogenic noise and disturbance, and can easily be startled and "flush" back into the water by loud noise or close proximity to humans, boats, aircraft etc. Repeated flushing of haulouts can have numerous deleterious effects including reduced pupping success, behavior changes, and abandoning the haulout (Lelli and Harris 2001; Richardson et al. 2013; Terhune and Brillant 1996).

Harbor seals undertake an annual migration from summer breeding and pupping grounds in northern New England and maritime Canada to winter feeding grounds in southern New England and the Mid-Atlantic region in autumn and early winter. The reverse migration occurs before the pupping season, which takes place from mid-May through June (Barlas 1999; Jacobs and Terhune 2000; Rosenfeld et al. 1988; Whitman and Payne 1990).

1.1 Study Site

Narragansett Bay is a well-known winter feeding ground for harbor seals, occupied roughly from late September until early May (Raposa and Dapp 2009; Schroeder 2000). There are over 20 documented haulout sites within the bay, mostly on rock outcrops which are away from shore and exposed at low tide, although seals do occasionally come ashore on beaches (Raposa and Dapp 2009; Schroeder 2000). The number of haulout sites has increased in the last decade, concurrently with the general increase in the harbor seal population size throughout New England (Gilbert et al. 2005; Raposa and Dapp 2009). However, specific information on the population size and ecology of harbor seals in Narragansett Bay remains relatively sparse due to limited and sporadic volunteer monitoring efforts (Raposa and Dapp 2009). The haulout studied in this project is on a rock outcrop known as “The Sisters” located near Coddington Point on Naval Station Newport (Figure 1). This haulout has been studied by the Naval Undersea Warfare Center Division Newport since 2011 during winter months when harbor seals are present in the bay. While completely submerged at high tide, the rocks can provide space for more than 40 seals to haul out at low tide (Figure 2).

Figure 1. Location of the haulout study area on Naval Station Newport.

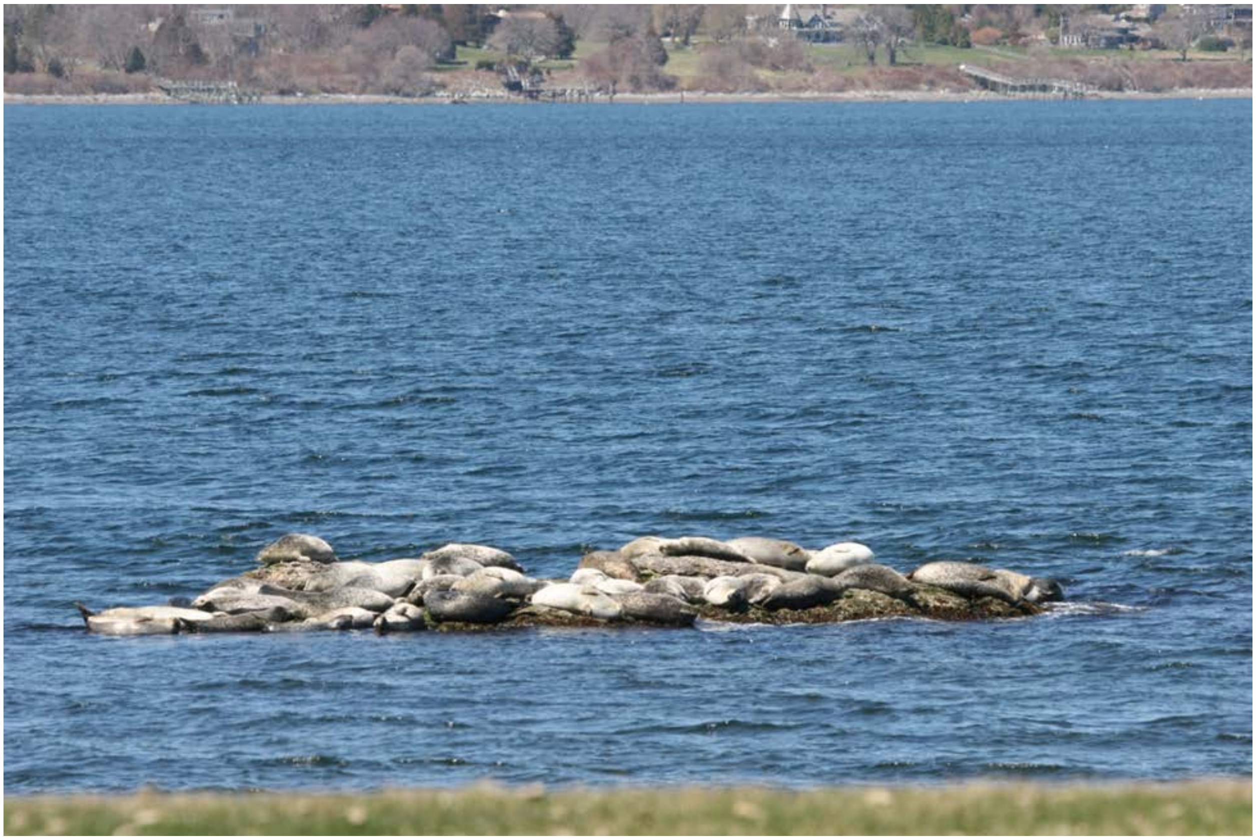

Figure 2. Photo showing Naval Station Newport haulout from typical photographic vantage point. Photos were taken adjacent to a jogging path which runs parallel to shore, approximately 500 feet from the haulout (Photo: T. Moll, photo taken under National Marine Fisheries Service General Authorization #19826-00).

1.2 Project Goals

The overall goal of this project was to gain an understanding of seal movement and behavior, assess how environmental conditions may affect haulout usage, and develop a photo-identification (photo-ID) protocol. Monitoring the Naval Station Newport site has provided insight on trends in seasonal movements, site fidelity, and relative abundance. By establishing a record of seal presence and abundance, we have furthered our understanding of the general ecology of the population in Narragansett Bay. The relationship between seal presence and environmental parameters provides understanding of how the changing seal population may affect haulout usage under varied environmental conditions, and how changing weather and climate patterns may affect the population in the future. Finally, having pilot tested several software programs designed to photo match individual animals based on pelage patterns as part of previous efforts on this project (Moll et al. 2016), we utilized *ExtractCompare*™ software to produce a basic population estimate for "The Sisters" haulout on Naval Station Newport. Photo-capture-recapture analysis has been used successfully with other similar marine mammal species (Bolger 2012; Hiby et al. 2007; Paterson et al. 2013), but with only limited success on harbor seals (e.g. McCormack 2015). Photo-ID methods could eventually lead to a better understanding of the movement of these animals within and between haulout sites. Maintaining this type of long-term dataset enhances the Navy's ability to understand how this population may respond to changes in climate and other anthropogenic disturbances.

2. Methods

2.1 Field Observations

Following National Oceanic and Atmospheric Administration (NOAA) seal watching guidelines (NOAA 2015) and authorized under National Marine Fisheries Service General Authorization #19826-00, a series of systematic, land-based counts of all seal species was conducted from a walking path approximately 500 feet from the haulout (Figure 2). Counts were made approximately once per week during the daytime and at low tide, usually within one hour of peak low tide. The number of seals hauled out and observed in the water nearby was recorded three times at 10-minute intervals during each site visit throughout the season. Whenever possible, a second observer verified the count. For analysis purposes, we totaled the number of seals observed hauling out with the number observed in the water adjacent to the haulout (indicating very recent haulout usage) across each of these three surveys, and retained the maximum of these three totals. This is consistent with similar studies by Grellier et al. (1996) and Pauli and Terhune (1987). Therefore, unless otherwise specified, seal count data were interpreted as the maximum number of animals counted during the survey period.

Photographs of seals were collected between counts using a Canon EOS 7D Mark II camera with a zoom lens (Canon EF 100-400mm f/4.5-5.6L IS USM) or a prime lens (Canon EF 300mm f4 L IS), sometimes combined with a 2x tele-extender (Canon Extender EF 2x III) for photo-ID and a photo-capture-recapture study. Multiple photos of each seal were taken using different photographic angles (to the maximum extent feasible given the geography of the haulout), zoom and exposure combinations to maximize pelage visibility. The camera settings used are shown in Table 1 and the shot sequence and guidance are shown in Table 2. When taking sequences 2 through 6 the images were overlapped so entire animals would appear in at least one frame each. In the future, photographs could be used to develop a local catalog and database which can be compared to other regional catalogs.

Table 1. Custom Camera Settings.

Custom Mode	Base Mode	Shutter Speed	Exposure Compen-sation	Bracket-ing	White Balance	Metering	Drive	Auto-focus	ISO	Auto Lighting Optimizer
C1	Tv	1/1000	+ 1/3	+/- 2/3	Auto	spot	quiet	5 point	auto	High
C2	Tv	1/800	+ 1/3	+/- 2/3	cloudy	spot	slow	5 point	auto	High
C3	M	1/640	+ 1/3	+/- 2/3	Auto	spot	slow	5 point	auto	High

Table 2. Shot Sequence.

Series	Lens	Setting	Shot framing
1	100-400mm	C3	zoomed to ~200mm, 3 images of the entire haulout
2	100-400mm	C3	Zoomed in, 3 images in each of 5 locations, L-R
3	2x+100-400mm	C1	Zoomed in, 3 images in each of 5 locations, L-R
4	2x+100-400mm	C2	Zoomed in, 3 images in each of 5 locations, L-R
5	2x+300mm	C1	3 images in each of 5 locations, L-R
6	2x+300mm	C2	3 images in each of 5 locations, L-R

Observers also recorded weather and environmental conditions at the time of observation, as well as any potential disturbance, and how the animals reacted. Environmental data were supplemented with high resolution, historical meteorological and oceanographic data from the nearest NOAA weather station (# 8452660) located on a boat pier at the southern end of Coasters Harbor Island, Naval Station Newport (Figure 3). These data were downloaded from NOAA (https://tidesandcurrents.noaa.gov). Additional weather data (e.g., precipitation, visibility, cloud cover) were obtained from instruments located at Newport State Airport via Weather Underground (www.wunderground.com) and NOAA's National Centers for Environmental Information (www.ncddc.noaa.gov). A handful of missing NOAA weather station observations were replaced with analogous data from instruments located at the Narragansett Bay National Estuarine Research Reserve. Environmental data were used to investigate relationships between seal presence/abundance and environmental parameters, and to parameterize the hurdle model.

Figure 3. NOAA weather station located at Naval Station Newport.

2.2 Model Development Methods

In order to determine the weather, tidal, and atmospheric variables likely to influence seal haulout behavior, we undertook an extensive data exploration effort. We visualized relationships between each continuous environmental predictor and seal abundance via scatterplots, and quantified these relationships with linear regressions (using both first and second-order polynomials) and associated correlation scores, p-values, and goodness-of-fit measures (see example Figure 4D-F). We also visualized the relationship between each continuous environmental predictor and seal presence/absence via density plots of the predictor's distribution, conditioned on seal presence/absence (see example Figure 4A-C), and quantified these relationships with T-tests. We paid particular attention to the interaction between wind speed and wind direction vs. seal abundance, after exploratory analyses revealed strong winds from sheltered (southeast) aspects might have less of an effect than strong winds from exposed (northwest) aspects. Relationships between categorical predictors (i.e., raining/not raining, exposed/not exposed wind direction) and seal presence/absence and abundance were assessed via T-tests and contingency tables, as appropriate.

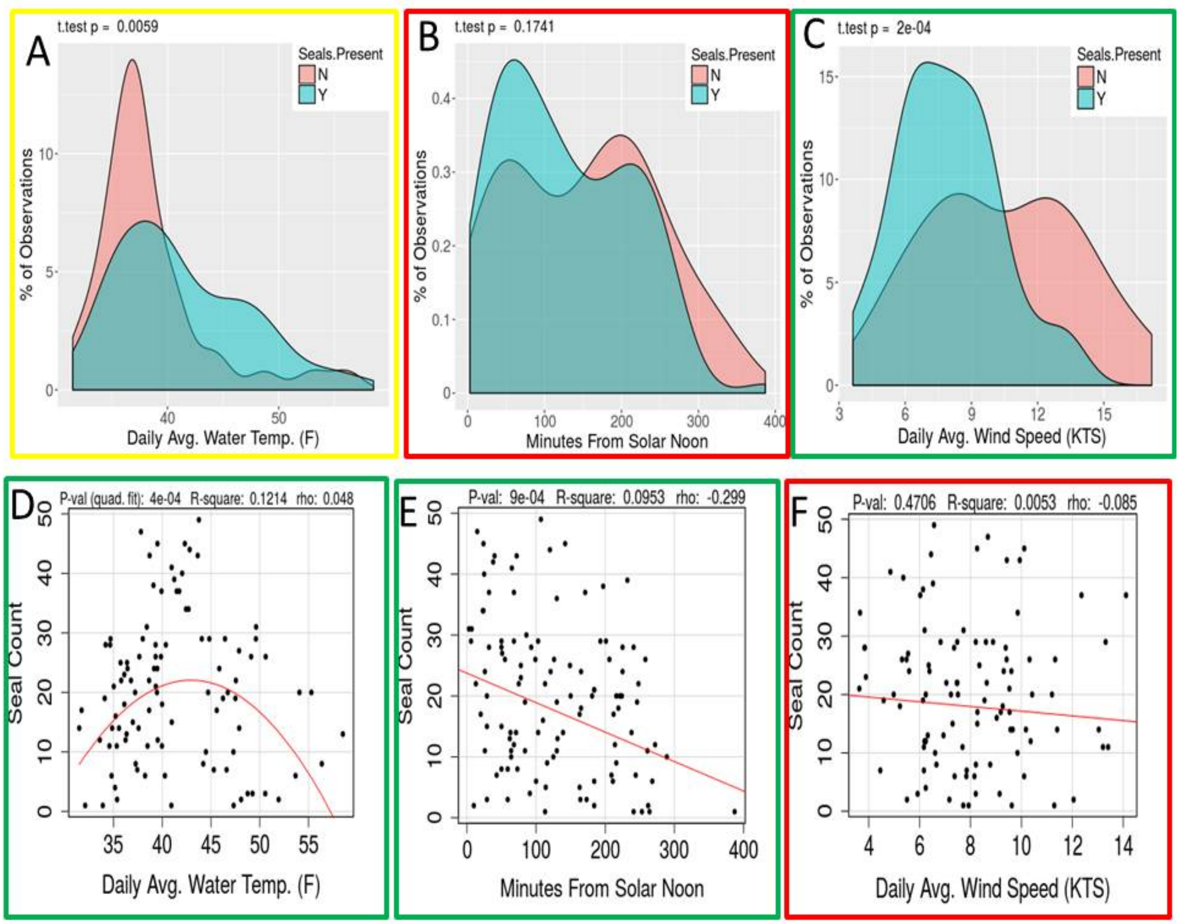

Figure 4. Comparison of distribution with seal presence vs. absence (A-C) and scatterplot of relationship to abundance (D-F) for three example parameters. Green borders indicate strong effect, yellow indicates significant effect but marginal model utility, and red indicates no effect. Quadratic relationships were only selected over linear when the p value for the quadratic term <0.05.

After reviewing the graphical outputs mentioned above, we selected our initial set of predictor variables based on the strength of and ecological basis for their relationship to seal haulout behavior. Parameters were also categorized according to the underlying phenomena they represented (e.g., temperature, wind, time of day), and to help reduce collinearity, we avoided including multiple parameters from a single category in the same model component. We then built a "hurdle model" using this initial set of predictors. This type of model allows separate environmental processes to govern both seal presence/absence and seal abundance. Hurdle models are also appropriate for dealing with high numbers of absences in count data, and are frequently applied in ecology (e.g., Lyashevska et al. 2016; Ver Hoef and Jansen 2007).

Table 3. All predictor variables considered for the hurdle model divided by category (dark grey). After initial screening via plots and bivariate tests of association, a reduced list of predictors was presented to the model, which then used automatic stepwise procedures to arrive at the final set (highlighted in light grey). Correlations are Spearman rank against abundance data only (0's removed). Bold = abundance parameter, *italics* = presence/absence parameter.

Parameter	Correlation	Significant?
Time of Day-Type Parameters		
Minutes Until/Since Solar Noon	**-0.24**	**√**
Minutes Until/Since Sunrise	-0.02	
Sun Altitude	0.30	√
Water Level-Type Parameters		
Water Level at Nearest Low Tide	-0.23	√
Minutes Before/After Neareast Low Tide	-0.27	√
Water Level	**-0.25**	**√**
Temperature-Type Parameters		
Air Temp.	0.30	√
Water Temp.	**0.22**	**√**
Air - Water Temp. Difference	0.27	√
Daily Avg. Air Temp.	0.34	√
Daily Maximum Air Temp. (Airport)	0.31	√
Daily Mean Air Temp. (Airport)	0.32	√
Daily Minimum Air Temp. (Airport)	*0.29*	√
Daily Avg. Water Temp.	0.24	√
Daily Avg. Air-Water Temp. Difference	0.32	√
Wind-Type Parameters		
Wind Direction	0.00	
Wind Gust (5 sec. avg.)	***-0.40***	**√**
Wind Speed (2 min. avg.)	-0.35	√
Daily Avg. Wind Speed	-0.29	√
Daily Max Wind Gust (5 sec. avg.)	-0.23	√
Daily Max Wind Speed (2 min. avg.)	-0.19	√
Daily Avg. Wind Gust (5 sec. avg.)	-0.34	√
Binned Wind Direction (Exposed vs. Protected)	**NA**	NA
Daily Avg Wind Speed (2 min. avg.)	-0.30	√
Atmospheric-Type Parameters		
Cloud Cover %	0.09	
Daily Mean Visibility	0.00	
Barometric Pressure	0.26	√
Daily Total Precipitation	-0.02	
Rainfall Exceeding 0.25 inches (Y/N)	NA	NA
Wind/Temperature Indices		
Wind Chill Temp.	0.37	√
Gust Wind Chill Temp.	**0.37**	**√**
Gust Wind Chill - Water Temp. Difference	0.39	√
Beaufort Sea State	-0.49	√

We then applied a model simplification procedure to increase interpretability and generalizability. The procedure iteratively assesses variables and removes ones that do not improve the fit enough to warrant the additional complexity they add. This tradeoff between fit and complexity is formalized by Akaike's Information Criterion (AIC). We retained the model with the lowest AIC. We then validated this final model by looking for unusual patterns in residuals and assessing overall fit. Finally, we used the model to predict seal abundance under a set of standardized environmental conditions. By holding these conditions constant and varying the year, we were able to remove variation in counts due to environmental conditions and examine the annual haulout population trend on its own. We assessed the uncertainty in this trend estimate via bootstrapping. For more information regarding the modeling process, Appendix A provides annotated R code describing the entire modeling process in detail.

2.3 Photo-Identification Methods

Previous work on this project (Moll et al. 2016) identified *ExtractCompare*™ as the software option with the highest potential to serve as an aide to manual matching and improve our ability to recognize repeated visitors to the haulout. Using a subset of cropped seal photos to build a testing catalog, we devised a protocol to assess the impact of known confounding variables such as obstruction, glare, and image quality on the false negative and false positive identification rates across a range of similarity score thresholds (see Bendik et al., (2013)). We used this analysis to assess the minimum level of photo quality which could be successfully matched using the software, providing as much sensitivity as possible to minimize false negatives, while maintaining a low false positive rate. We devised a simple grading scale to score images from 1 (poor) to 5 (excellent) based on sharpness, pelage visibility, and lack of obstruction. We determined that the software had reasonably high probability of matching an image as long as the score was 3 or higher, and therefore established this as the cutoff for photo analysis. Adopting more stringent standards for photo quality did not seem warranted, as confirmed by a lack of significantly higher match rates for higher image scores (Table 4).

Table 4. Comparison of image quality for matched and unmatched images. The software was slightly, but not significantly, better at matching higher quality images (χ^2 = 4.66, p = 0.15, n=159).

Photo Quality	Mediocre (3)	Good (4)	Excellent (5)	Totals
Matched	40	33	14	87
Not Matched	43	21	8	72

We also assessed the ability of the software to successfully match different body aspects (e.g., flank, head, abdomen, neck, etc.). After careful review, we settled on using abdomen extracts only for the population estimation portion of the study. Abdomen extracts provided the best resolution and rate of successful matching, without having to address the lack of bilateral pelage similarity associated with using flank, head or neck extracts. For example, the left flank of a seal can't be matched to the right flank of the same seal, unless one can simultaneously capture both sides of the same seal on the same day and link the two images, which was not possible from our photographic vantage point.

ExtractCompare™ uses a droplet extraction pattern-matching algorithm, paired with a 3-D wireframe surface model to identify the most likely matches for a given photo (Figure 5). The process of fitting the wireframe is user-driven. First, the user selects pre-defined points on the body of seal (e.g., nose, left flipper, right flipper). Then, the user traces the outline of the seal against the photo background.

Portions of the seal that are obscured by rocks or other seals can be blanked out, so that they do not introduce errors into the pelage matching process. The software then fits the 3D wireframe, attempting to minimize the distance between the user-defined points and those same reference points on the wireframe. It then "extracts" the body region of interest, standardizes contrast across the extracted image, and identifies spot patterns for future comparison. Thus, *ExtractCompare*™ has a relatively robust adjustment for differences in contrast, angle, and body position, which allows improved matching of seals at different aspects. This software also includes a built-in database, which allows tracking of repeat encounters. In combination, these enhancements dramatically reduce the false negative rate compared to the Wild-ID software previously used by this project (Moll et al. 2016) and enhance our ability to track repeat matches. However, this software is also significantly more complex and time consuming than Wild-ID, and while the algorithm has been demonstrated repeatedly and successfully on gray seals (Hiby et al. 2007; Paterson et al. 2013), previous usage with harbor seals has met with mixed results. Harbor seals generally have less distinctive pelage patterns, and are therefore more challenging to match. This problem would likely exist regardless of software choice. Because *ExtractCompare*™ uses an internal database, it is not necessary to organize and pre-crop images before loading. Furthermore, *ExtractCompare*™ does allow for multiple aspect angles and even multiple seals to be extracted from each image. Therefore, we simply selected the best available image of each seal abdomen for extraction.

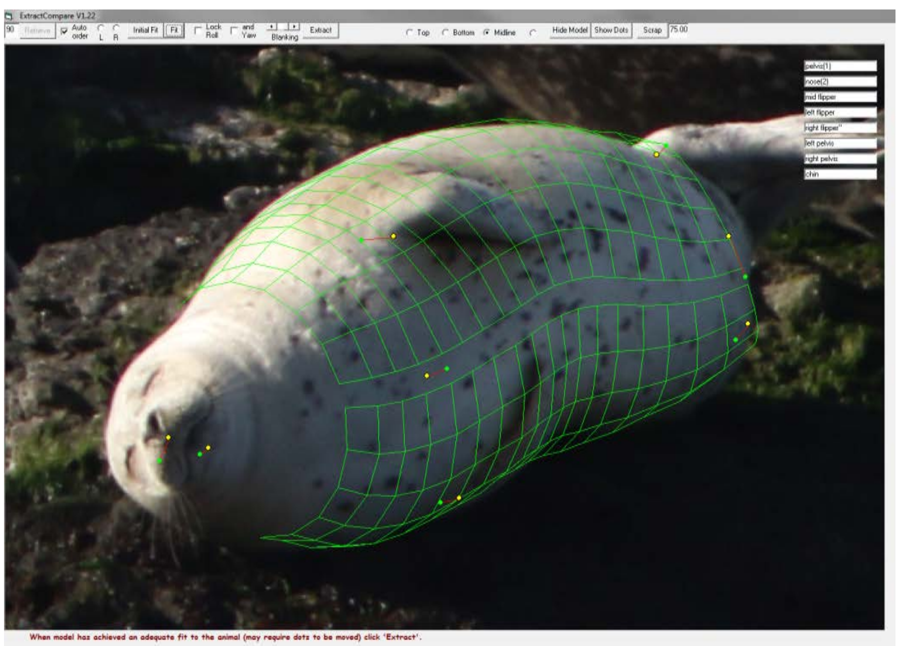

Figure 5. Extracting pelage patterns from a harbor seal abdomen using *ExtractCompare*™. The wire frame analysis compensates for differences in rotation and aspect between images.

3. Results

3.1 Haulout Counts: 2016/2017 Field Season

The seal season in Narragansett Bay is typically from fall through early spring. All counts represent a minimum number of seals because the west side of the haulout site is obscured from view. Observations were made weekly beginning in October, and ending two weeks after the last seal is observed, though for the purposes of this analysis, only the time period between the first and last observation is considered. The first seal observation of the 2016–2017 season was on November 1, 2016, which is similar to the previous year (11/5/2015), but slightly earlier than other years prior (Moll et al. 2016; Vars and Moll 2011). Animals were anecdotally observed elsewhere in Narragansett Bay during the week prior to the first observation of the 2016–2017 season. The last seal of the season was observed on April 27th, which is slightly earlier than previous years (at least one observance in May was documented in 2015 and 2016) although monitoring continued for several weeks afterward. Approximately 622 seals were observed during 30 survey days. Seals were observed on 28 of 30 (93%) days, with a nonzero minimum count of one and maximum count of 45. On days when seals were observed, the average number of animals sighted was 22+/- 2.6 (standard error of the mean [SEM]) (Figure 7). No gray seals were positively identified during the season. Over the course of the season, one partial flush was observed, potentially associated with a helicopter overflight of the haulout. The peak number of seals per observation was in late March and early April, with counts exceeding 35 animals per day for a roughly 2-3 week period, which is roughly similar to previous years' observations (Figure 6).

These numbers are similar to the number of animals observed per observation in 2015/2016, where seals were recorded in approximately 90% of observations, and the average number of animals present on days when animals were observed was about 22. However, this represents a substantial increase relative to the long term average. Since monitoring this haulout began in 2010, 2,267 seals have been observed during 159 survey days. Over the course of the study, seals were observed on approximately 72% of observation days (discounting monitoring before the arrival of the first observed seal or after last seal observed in a season), with an overall average of 19.7 +/- 1.6 (SEM) seals per day on days when seals were observed. The most frequent individual value in the dataset is zero, though when seals are present, 11-20 seals is the most frequent observation. Observations above 40 animals are relatively rare in the dataset, with four of the six 41+ observations occurring during the 2016-2017 field season (Table 5).

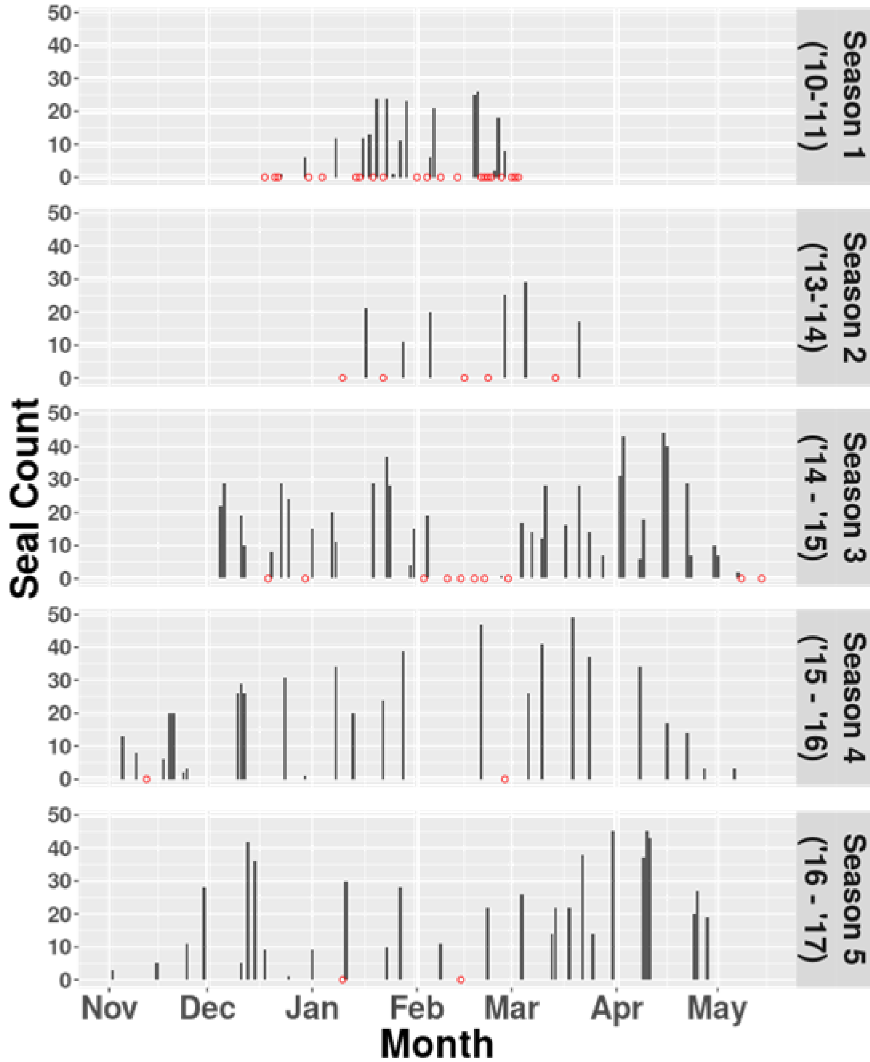

Figure 6. Seasonal haulout usage during the study period. Dates with a seal count of zero represented by red circles.

Table 5. Frequency distribution of observed seal count during the entire study period (2010-2017).

# Seals	Frequency (%)
0	26
1-10	20
11-20	21
21-30	20
31-40	7
41+	6

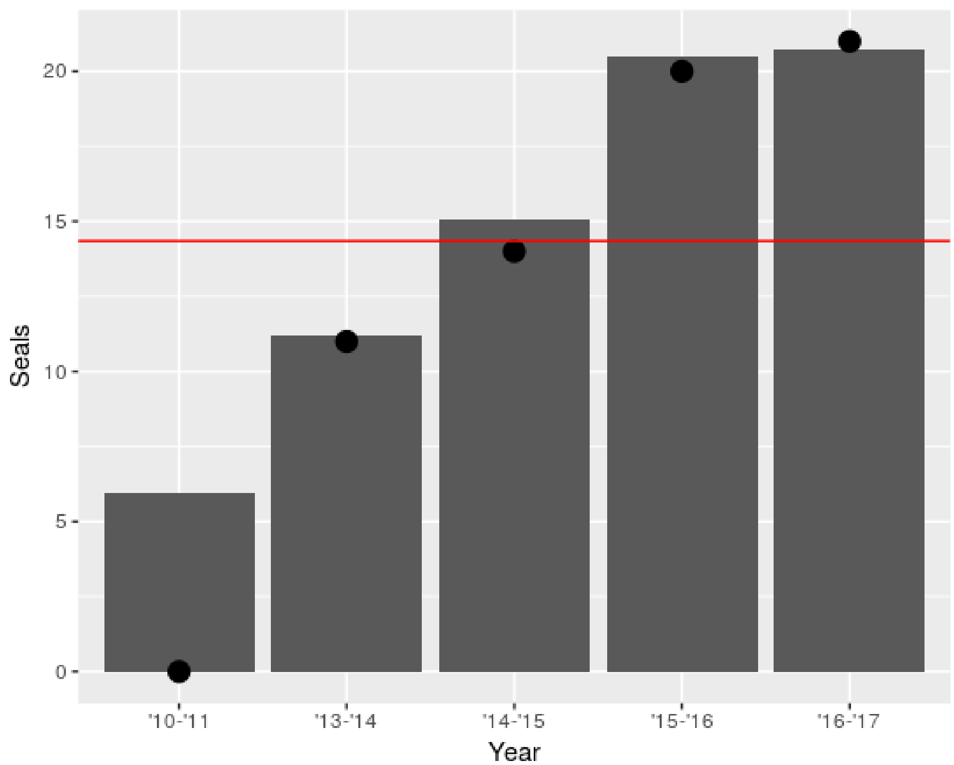

Figure 7. Mean (bar) and median (dot) seals observed in each sampling season (including zeroes). The red line indicates the survey wide mean for all observations (including zeroes).

3.2 Model Results

The final model was able to predict seal haulout count as a function of environmental variables with a good degree of accuracy ($R^2 = 0.57$). Unexplained variation as described by patterns in the residuals was generally random, indicating appropriate specification of relationships and error terms. However, the model systematically predicts low (1-15) but non-zero counts for observations where the number of seals is known to be zero. In general the model under-predicts high counts and over-predicts low counts, although the overall fit is reasonable (Figure 8).

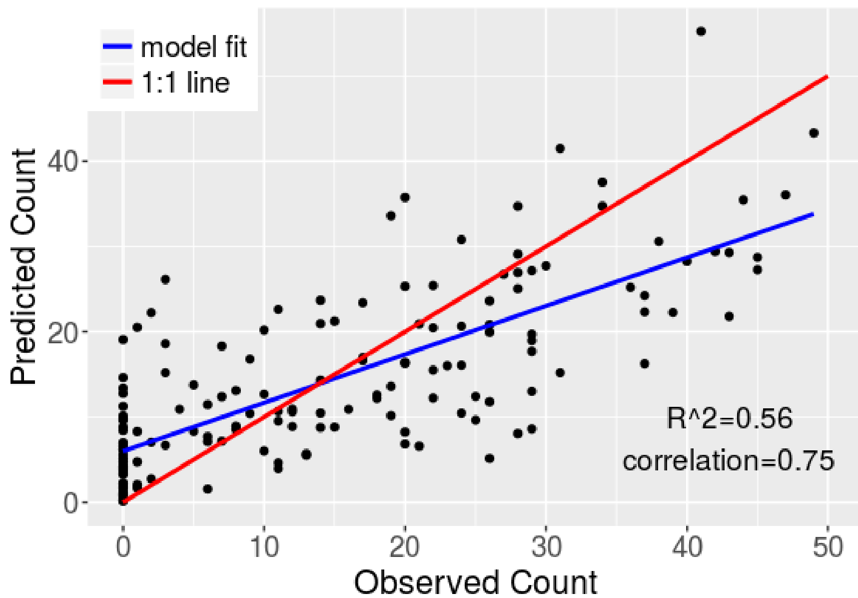

Figure 8. Correlation between model-predicted and observed seal counts. The blue line indicates average model fit, whereas the red line indicates a perfect 1:1 correspondence.

Seals were increasingly likely to haul out during adverse conditions (cold air temperatures, high winds) with each subsequent year (Figure 9), possibly because of increasing population numbers.

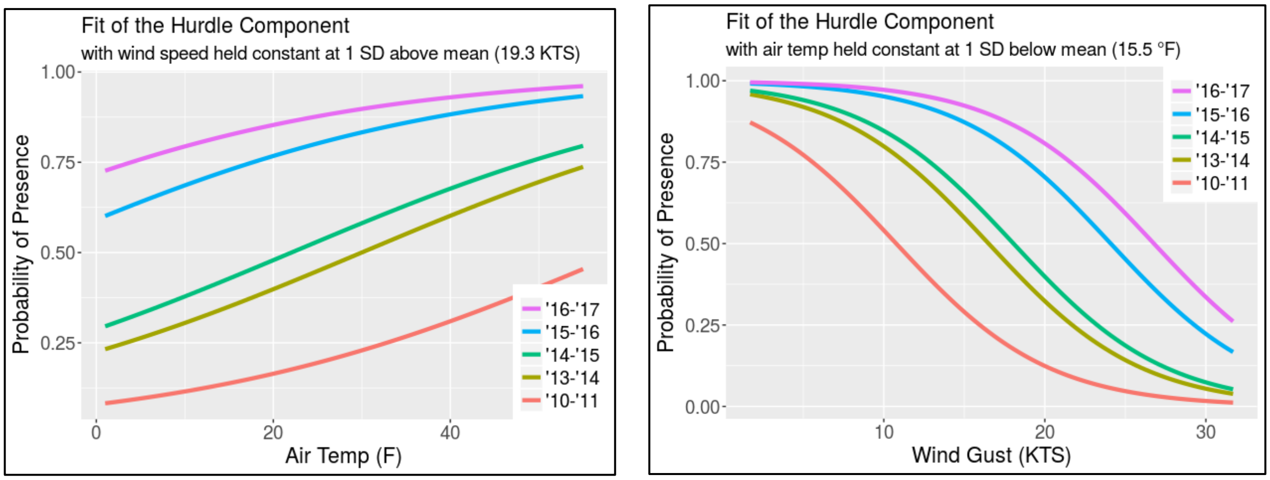

Figure 9. Model-predicted probability of seals hauling out under varying air temperatures and fixed wind speed (left), and varying wind speed and fixed air temperature (right) for each year.

Similarly, when fed ideal environmental conditions (e.g., highest observed air temperature, lowest observed wind speed), the model outputs occupancy levels well beyond what the haulout can support, suggesting overcrowding may be a limiting factor in the number of seals able to use the haulout (Table 6).

Table 6. Observed maximum seal count vs. theoretical maximum seal count under ideal conditions for each season.

Season	Observed Maximum Count	Predicted Maximum Count Under Ideal Conditions
'10-'11	26	73
'13-'14	29	126
‘14-'15	44	111
'15-'16	49	161
'16-'17	45	126

Assuming consistent environmental conditions across all observations, the model predicts an increasing number of seals from year to year (Figure 10). This upward trend persists even after adjusting for variation in the observational data via bootstrapping.

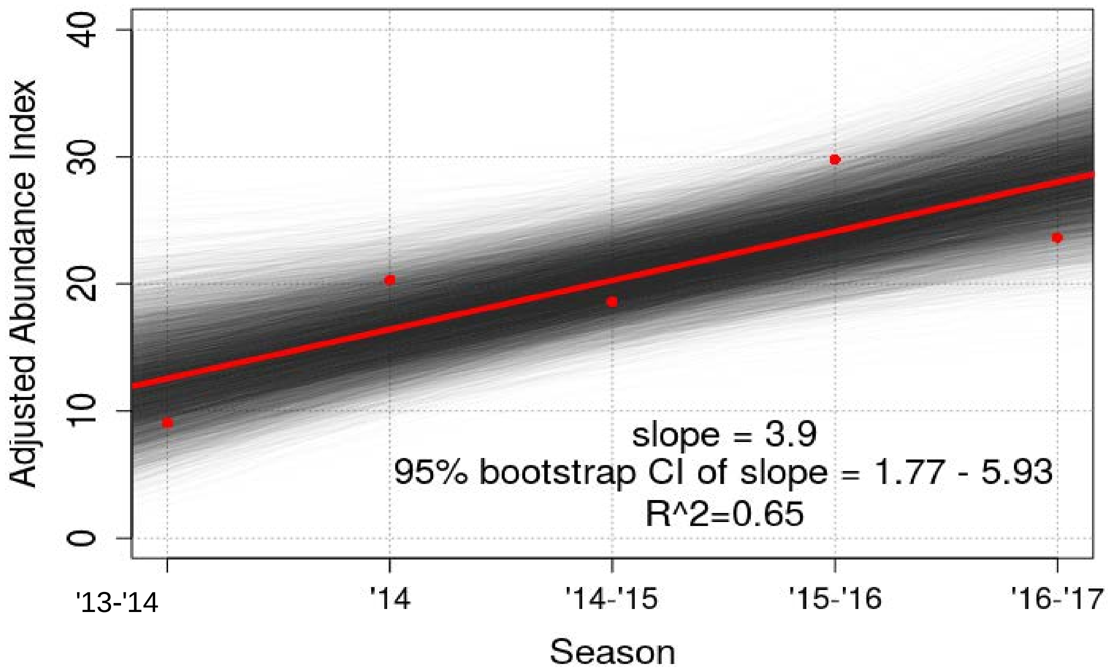

Figure 10. Bootstrapped, adjusted abundance index created by standardizing environmental parameters to remove the impact of yearly environmental variation.

The final set of environmental variables in the model indicates that water temperature (warmer = more seals), wind direction (sheltered = more seals), water level (lower = more seals), wind gust speed (lower = more seals), wind chill temperature (higher = more seals), and proximity of the observation time to solar noon (closer = more seals) were significant predictors (ordered strongest to weakest) of seal abundance. Wind gust speed had a stronger role in determining seal presence/absence, however, followed by daily minimum temperature. The effect of observation year was also more pronounced for the presence/absence component than the abundance component.

We were able to simplify the interaction between wind speed and wind direction vs. seal abundance. Initial exploration revealed a generally declining trend in seal count as wind speed increased (Figure 11), but without a strong directional signal. By binning wind directions into exposed (northwest) and exposed (southeast) aspects, we arrived at a more useful (for predictive purposes) and interpretable characterization of wind direction (Figure 12).

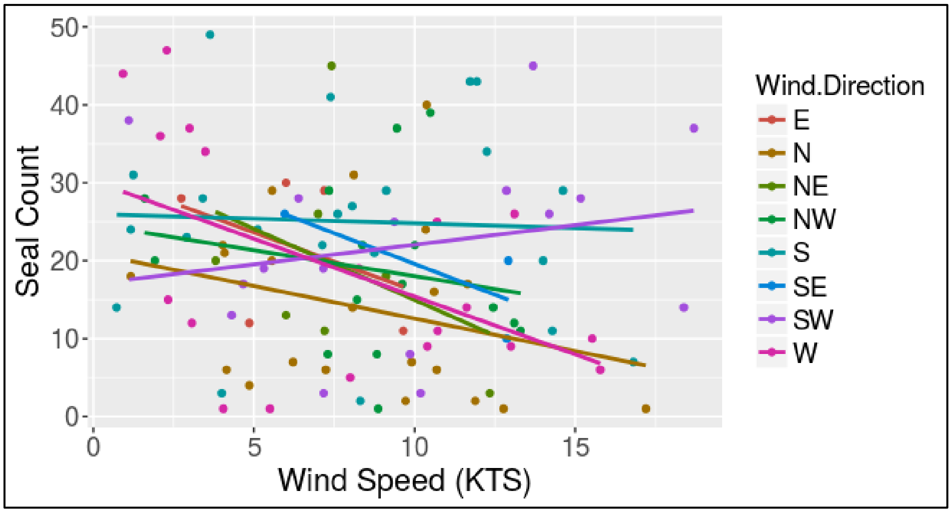

Figure 11. Relationship between wind speed and seal count for eight (cardinal + intercardinal) wind directions.

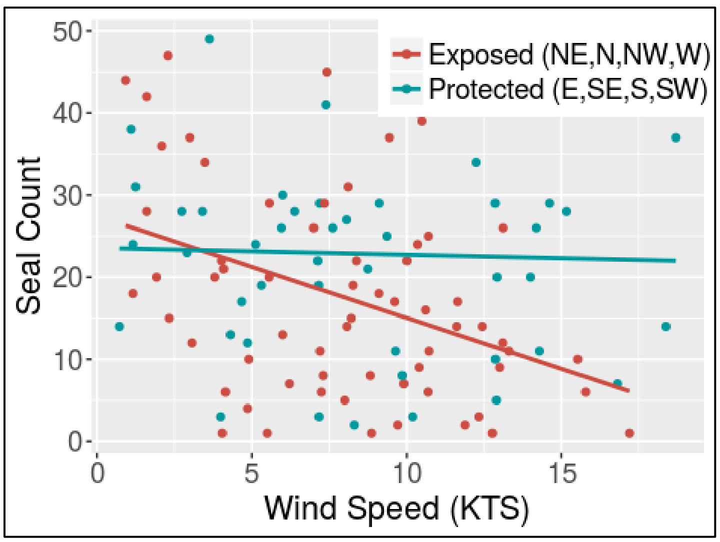

Figure 12. Relationship between wind speed and seal count for exposed vs. protected wind directions (ANCOVA interaction: t=2.5, p=0.0135, df=147).

3.3 Photo-Identification

3.3.1 ExtractCompare™ Results

In Moll et al., (2016), we developed effective methods of collecting and processing *ExtractCompare*™ data. While we remain unable to use the full suite of capabilities theoretically present in *ExtractCompare*™, by limiting our analysis to abdomen extracts only, we were able to produce a usable photo-ID dataset. Time constraints restricted us to analyzing only one complete season of data, and we chose the 2015-2016 season for this, because this season had the largest number of high quality photographs, and because this allowed us to compare our results, at least qualitatively, to the Wild-ID results from our previous years' study (Moll et al. 2016).

From a photographic standpoint, the 2015-2016 field season had 30 observation sessions. This includes the sessions reported on above, as well as additional "ad hoc" sessions where photographs were taken, but environmental and formal count data were not collected, so these sessions were excluded from other portions of the analysis. We were able to identify a usable (quality 3 or higher) abdomen extract on roughly 25% of the animals observed overall (Table 7). From this, *ExtractCompare*™ identified 87 matches of 27 unique individuals. Over half of the individuals for which at least one match exists were re-sighted several times, and one individual, nicknamed "Fivespot", who was abdomen captured eight times.

Table 7. Capture statistics from *ExtractCompare.* Subscripts refer to parameters in Equation 1: population estimation.

2015-2016 Field Season Results	
Outcome	Number
Observation Sessions	30
Observed Seals	624
Abdomen Captures (m_1,n_2)	159 (25% of observations)
Matches (m_2)	87 (54% of captures)
Unique Individuals Matched	27
Multiple (>3) Resightings	14
Most Resightings for Single Animal	8*

*Individual in question had many unique markings, which made identification easier.

In terms of quantifying the performance of *ExtractCompare*™ and comparing to previous results using Wild-ID, it is necessary to assess the four potential situations which can arise in photo-ID protocols, and to assess the performance of the software under each scenario (Figure 13). *ExtractCompare*™ does not actively select matches, but rather provides a ranked list of matches and a similarity score, relying on the user to select the actual match from the list of proposed images. Thus, we considered any matches within the top 20 ranked potential matches proposed by the software to be "true positives." Matches found outside of the top 20, which were largely based on visual confirmation of unique patterns outside of the extraction area, are considered "false negatives" — animals that actually match, but that the system misses. However, it is important to note that our ability to detect false negatives is predicated on there being unique markings by which the user can visually confirm a match. Since many of our animals have few or no unique markings, it is likely that there are additional false negatives that were not picked up in manual analysis. Of all of the known matches, *ExtractCompare*™ correctly identifies the match approximately 80% of the time (Figure 14), which is a substantial improvement over Wild-ID (Moll et al. 2016), but still leaves room for improvement. However, this estimate does not consider the possibility of additional matches that were missed by the software, and not picked up by the analyst due to lack of distinctive pelage marks, so the actual false negative percentage is probably even higher. Nonetheless, unlike Wild-ID, *ExtractCompare*™ provides similarity scores which allow for the use of a score threshold (in our case, about 0.2) below which no false positives are produced. For the purposes of many population type analyses, avoiding false positives is preferable to introducing false negatives.

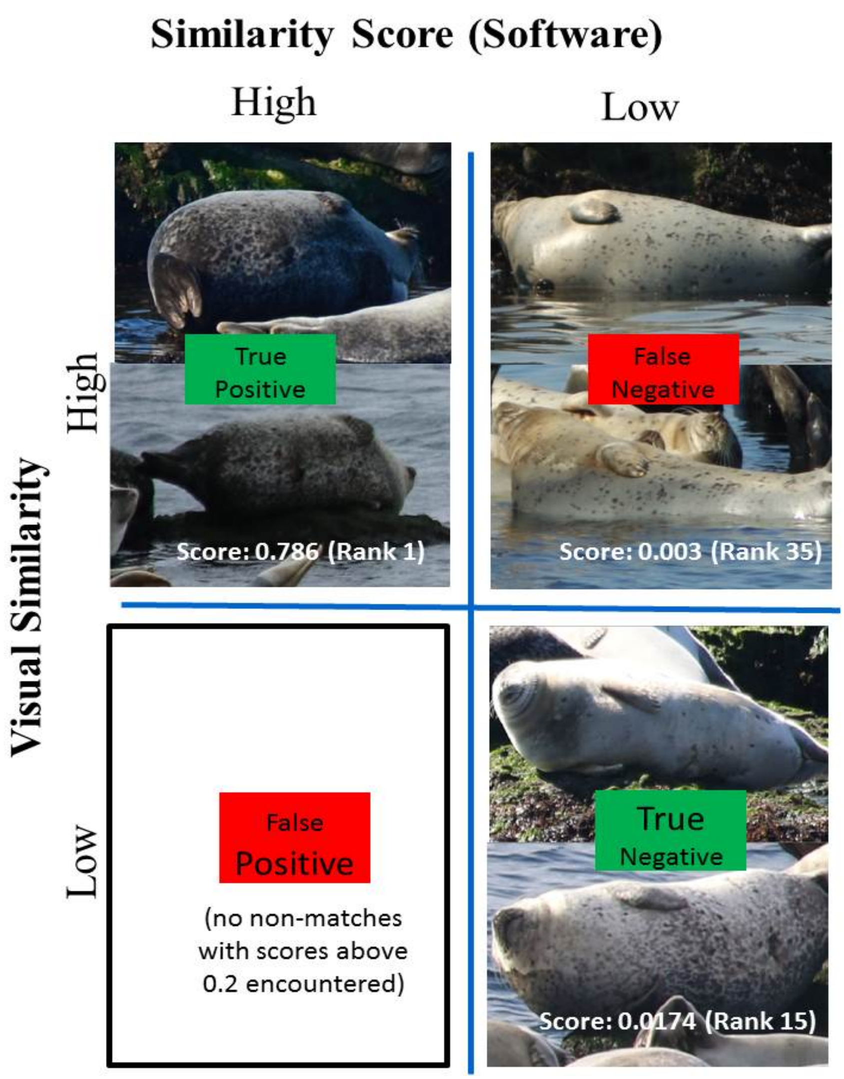

Figure 13. Possible photo matching results from *ExtractCompare™*. True positive: the software correctly identifies a match by score and/or rank. False negative: the software misses a match (sometimes caught by user). False positive: software places high confidence in non-matching seal pair (did not occur). True Negative: The software correctly does not find a match for the seal in question.

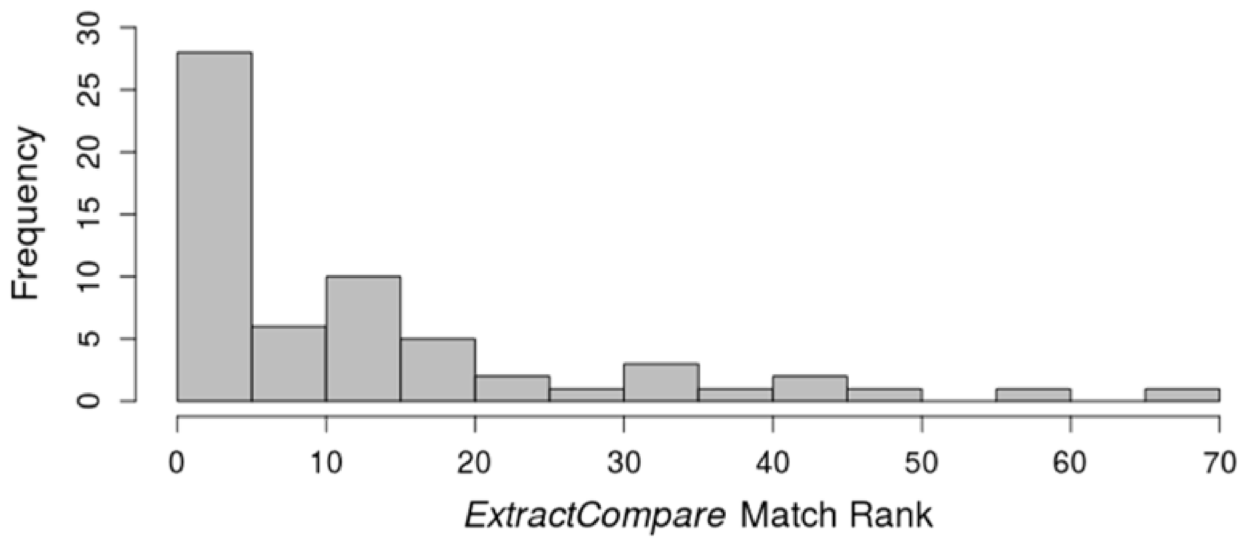

Figure 14. Histogram of *ExtractCompare™* match ranks for matching photos. Most matches were among the highest ranked photos, which saved time by reducing the number of photo pairs which had to be visually compared.

3.3.2 Population Estimation

Given various types of mark-recapture data, it becomes possible to compare the ratio of "marked" (in this case matching) recaptures to unmarked recaptures, and use this as a proxy estimate for population. Depending on the complexity of the data (number of years, closed vs. open population, single or multiple resighting efforts) there are a wide variety of models which can be used to arrive at this estimate. The Lincoln-Peterson approach is a relatively simple model, appropriate for the complexity of data collected in this study. Modified for a mark-resight approach with multiple resighting efforts, it can be expressed mathematically as:

Equation 1: $$N = \frac{m_1 n_2}{m_2}$$

Where N is the number of animals in the population (which in this case, means the number of animals using this haulout), m_1 = # of marked animals in the population, n_2 = total # of marked and unmarked animals observed, and m_2 = # of marked animals seen (Table 7). This produces a population estimate of 290 animals using the haulout during this time period. Given that false negatives drive this population estimate up, in cases where a false negative rate can be calculated or estimated, the population estimate can be adjusted down accordingly. We are not able to comprehensively assess the false negative rate of *ExtractCompare*™ given existing resources. However, if we conservatively use the 20% false negative rate estimated in Section 3.3.1, which is roughly in line with the false negative rates determined in previous work (Moll et al. 2016), our population estimate adjusts down to approximately 240 animals.

4. Discussion

4.1 Population and Haulout Usage

Although we have only a short time series to base general conclusions about population trends, the number of seals observed in each season, and the utilization of the haulout does seem to be steadily increasing. The time of first observation held steady from 2015/2016 to 2016/2017, but has increased over the course of the project, and the average number of seals counted each day has also increased over time (Table 8, see section 3.1 for more detail). In addition, the portion of observations with seals present and hauled out has increased over time. The decrease in proportion of days where no seals are present may be an indication of resource pressure on the haulout, a finding which is generally confirmed by modeling results suggesting that even over our short time series, seals are willing to haul out in more adverse conditions now than in 2010. If haulout space is limited, and populations are increasing, we would expect to see animals hauled out more frequently and in a broader range of environmental conditions.

Table 8. Seasonal survey effort (counting only days between first and last observation), total seal count, and effort-normalized average (number of seals observed per "in season" day) at the haulout site.

Season	"In Season" Effort	Total Seal Count	Average Count (including zeroes)	Frequency of non-zero observation
2010 – 2011	37	256	7	51%
2013 – 2014	10	123	12	60%
2014 – 2015	44	693	16	82%
2015 – 2016	29	573	20	90%
2016 – 2017	30	624	21	93%

Independent unpublished static haulout counts conducted by Save the Bay (www.savebay.org) estimate the number of seals hauled out during low tide in peak season to be on the order of 600 animals and gradually increasing. While this method is not highly precise, and does not account for animals in the water, or for differences in environmental conditions between monitoring days (since they monitor only once per yer, see section 4.2 for more discussion on this), it does provide an order of magnitude estimate against which to gage haulout usage and site fidelity at The Sisters haulout.

Assuming a peak haulout count across the Bay of roughly 600, spread across 20+ known haulouts (Raposa and Dapp 2009), our localized population estimate of 240-290 animals using The Sisters haulout indicates a substantial amount of exchange in haulout usage. The data suggest that individual animals are using many different haulouts within Narragansett Bay, spending only a portion of the seal season in Narragansett Bay before moving elsewhere, or mix of the two. However, our capture-recapture results show individual animals returning many times to this haulout, with fidelity rates far in excess of what would be expected if animals were randomly distributed amongst the systems' 20+ known haulouts.

"Fivespot," for example, was confirmed based on abdomen extracts in 8 of 30 sampling events. Given that only about 1 in 4 seals were positioned in such a way as to facilitate photographic capture of the abdomen region (Table 7), it is likely that "Fivespot" was present on the haulout on additional days and not captured. Assuming the same catchability coefficient for all animals is not necessarily a robust assumption, because some animals do prefer specific portions of the haulout which may be easier or more difficult to photograph. However, the average catchability quotient of 0.25 would suggest that this animal was present nearly every day that monitoring was conducted, and manual photo review does identify "Fivespot" on several days when an abdomen capture was not possible. "Fivespot" has very distinctive pelage patterns on both the abdomen and neck/flank region, making this animal particularly easy to recognize and match either manually or using software. However, many animals have few or no distinctive pelage markings, making it possible that other seals were also present with very high frequency, but were only occasionally recognized by the software.

From a usage perspective, our data strongly support the hypothesis that some animals exhibit a higher degree of site fidelity than others, with a select group of animals regularly visiting the haulout throughout the season, and others coming and going during the season. Our work also shows that the pool of animals using The Sisters haulout is substantially larger than the 50 or so animals observed on the busiest days at the haulout, but less than half of the estimated population of the system. Beyond this, the uncertainty inherent in both the capture-recapture process using *ExtractCompare*™ (see section 4.4) limits our resolution.

Furthermore, while a basic Lincoln-Peterson method is among the most robust mark recapture protocols, we still cannot confirm that our study, in present form, adheres strictly to the assumptions of this model. Chiefly, Lincoln-Peterson has four assumptions: closed system, equal catchability before marking, equal catchability after marking, and no tag loss. While this technique is often used in cases where one or more of the assumptions are violated, it is necessary to acknowledge the uncertainty imposed by violating the assumptions of the model. It is a somewhat reasonable assumption that the population is closed, or nearly closed, at least over the course of each individual season. However, we noticed that some animals have a preference for highly visible portions of the haulout (while others presumably have a preference for the portions we can't see, or at least can't see well), which violates the equal catchability assumption. Furthermore, some animals do not have pelage unique enough to be reliably captured, though if (and only if) the behavior of those animals is the same as the behavior of the animals with distinctive pelage, and the analyst chooses to simply not mark indistinct animals to avoid false negatives, this issue is not mathematically problematic. The assumption of no tag loss equates to a lack of false negatives (animals which actually were recaptured, but were recorded as unique). This assumption is commonly violated, and can be corrected for with a tag loss (or in this case, a false negative) coefficient, but that requires an accurate estimate of the false negative rate, which is difficult to come by, particularly for seals with indistinct pelage patterns. We correct here using an estimated 20% false negative rate, but dedicated efforts to predict false negative rate could improve the accuracy of this estimate. An additional year of data would allow the use of more robust multi-year approaches (e.g., Jolly-Seber), but given the above uncertainties, which would only partially be addressed by additional data, it is unclear if a more robust model could be accurately parameterized, and whether this approach would produce quantitatively better results.

Lack of visually clear pelage patterns on many harbor seals is perhaps the greatest obstacle to continued and improved use of capture-recapture analysis for population estimation in this situation. A photographic vantage point which could capture both sides of a given animal (e.g. a boat or aerial drone) would mitigate this substantially, but adds cost and complexity, and introduces the risk of flushing the haulout, something which we have not documented as a direct response to our shore based photographic monitoring during the duration of the study.

4.2 Hurdle Model and Environmental Patterns

Our periodic sampling protocol limits the amount of data available for the model to estimate haulout usage under extreme conditions. However, this protocol has the benefit of allowing us to track things like proportion of days with seals present, and average number of seals per day, whereas if we targeted sampling for extreme days, we would bias our estimates. In theory, time permitting, we could continue weekly periodic sampling, with additional targeted sampling to improve model parameterization, but not included in efforts to estimate population or track usage over time.

The number of seals counted on a given day varies substantially based on weather and oceanography. Employing a multivariate abundance model helps us to predict anticipated abundance given a weather forecast, and over time, may help us better understand how disturbance may be influencing haulout utilization, since disturbance is one of the factors influencing the residuals of the model. It also allows us to standardize counts of seals made under different environmental conditions, or to correct static haulout counts for the environmental conditions on the day in question, resulting in more robust estimates of population trends, at least at this specific haulout. The model could also be used to forecast how haulout usage might change under a range of future climate scenarios.

In general, the model performed well, with a strong correlation between modelled and observed seal abundance across seasons (Figure 8), years, and in a wide range of environmental conditions. Model residuals are largely unstructured, indicating that there are not large environmental data trends that the model is not capturing. However, there is a relatively large group of sample points for which the model predicts a low but non-zero abundance, and the observed data are a zero. In these cases, it seems the model is aware that the environmental conditions are not ideal, but since the hurdle component is not binary (i.e. it relies on a continuous logistic function to assign probability of presence), the resulting output ends up as low abundance, rather than complete absence.

This could be rectified in future iterations of the model in a number of ways. The simplest approach would be to assign an empirically derived threshold likelihood below which the model rounds down the presence/absence multiplier to zero. A more complicated approach would be to employ a "valve" type presence absence model, whereby each component with a modeled contribution to presence absence becomes binary, with an assigned a threshold above (or below) which it returns "absent", and the presence/absence model is simply the product of the individual models, such that if any one criterion fails, the model returns a zero. The latter approach is qualitatively and ecologically easier to justify than an arbitrary threshold, but this approach also ignores the possibility of interaction effects (e.g., a wind speed of 15 kts might produce a zero at a temperature of 15^{o}F, but might not at a temperature of 40^{o}F).

One particularly interesting aspect of the modeled results, which we would not necessarily have considered *a priori* is the strong temporal component. Over the course of the time series, the model suggests higher seal abundance under marginal environmental conditions in each successive year (Figure 9). The effect is so pronounced that conditions which would result in < 40% likelihood of seal presence in 2010 are predicted at near 100% likelihood of presence in 2017 (Figure 9). Furthermore, while the years are independently modeled (that is, each year is a unique predictor), and thus, could arrange themselves in any order, for both the cases we examined (temperature and wind speed) the years arrange sequentially. Although there are other plausible explanations, the most logical explanation of this pattern is that the population of seals using the haulout is increasing substantially over the course of the dataset. If the haulouts in the system are all at or near capacity during ideal weather conditions (which The Sisters haulout certainly is), and each animal has a given thermoregulatory need for time spent hauled out, an increase in population would mean that animals would need to haul out under less ideal conditions in order to meet their thermoregulatory requirements. Furthermore, if hauling out in suboptimal conditions is less effective at meeting thermoregulatory needs, animals might need to haul out for additional hours to meet their needs, which, in turn, may result in animals hauled out under even less optimal conditions. Our haulout counts and weather independent modeling data (Table 8 and Figure 10) both generally support this hypothesis, though a causal link is impossible to establish without a dedicated empirical study.

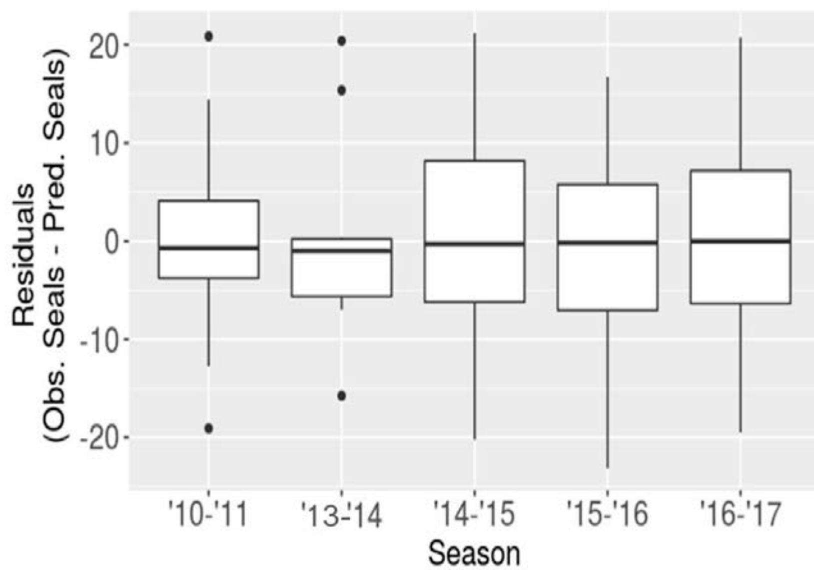

Figure 15. Modeled residuals for each season have means close to zero, but wide dispersion. One unaccounted for source of model variability is human disturbance (e.g., boat, aircraft or beach activity flushing the haulout).

4.3 Anthropogenic Disturbance

The seals at this haulout appear somewhat habituated to certain types of anthropogenic noise. We recorded potential disturbances during observations, including large container ships and boats nearby, pedestrian and vehicle traffic, helicopter and aircraft overflights, and sailors performing loud drills. We did not observe many behavioral responses and only observed one disturbance-related partial flush in 2016-2017, related to a relatively close helicopter overflight. We observed one full flush during our monitoring in 2015-2016, and one partial flush in 2014-2015. Most of the potential disturbance did not appear to elicit any measurable response from the animals already hauled out. Anecdotally, seals have been reported as flushing when someone was walking on the beach, which is closer to the haulout site than the jogging path and road. This beach is not often used, so it is possible that the seals were not accustomed to that disturbance, or that the distance was too close. A multivariate abundance model, as discussed above, might allow us to ascertain if close proximity of a container ship might reduce the amount of seals willing to haul out on a given day relative to other days with similar environmental conditions, or whether a day with no seals observed was likely due to environmental conditions precluding haulout, or possibly due to a disturbance occurring prior to the arrival of the monitoring team, something we can presently only speculate on based on number of animals in the water. Presently, most cases of potential disturbance noted by the observers resulted in no behavioral change by the animals, and we have only a few isolated cases of disturbance related flushing, so disturbance, while considered as a model parameter, was not particularly effective in predicting haulout abundance, though with sufficient additional observations, our ability to incorporate disturbance may improve.

4.4 Photo-Identification Processes

ExtractCompare™ is a powerful software utility, capable of accurate matching, storage, and database creation of multiple images of each seal, features which would be very useful as the database gets larger. In our limited work with this software, we found it much more accurate than Wild-ID, with a lower false negative rate and a nearly non-existent false positive rate when the user employs appropriate thresholds. The actual false negative rate (exclusive of false negatives captured and corrected by the analyst) could be improved upon by restricting analysis to animals with distinctive pelage, or by modifying our protocols to incorporate *ExtractCompare™*'s ability to match the right and left side of an animal. However, given that the seals at this particular haulout rarely change position and the inability of the photographer to move around enough to capture different angles (vs. a boat survey where one could shoot from alternate sides of the outcrop), we would only very sporadically be able to capture a known photograph of both the right and left sides of a given animal. In previous cases where this feature was employed, a chase boat was used to distract the seals and get them to turn their bodies so both sides could be captured (Paterson et al. 2013), but this would be substantially outside the scope of this project and permits.

Although *ExtractCompare*™ is a potentially powerful tool, it is difficult and time consuming to use, and many of the advanced features do not appear to be fully implemented, or applicable to our level and type of survey effort. The program definitely saves time and improves accuracy of visual matching vs. using an image catalog, but a manual catalog theoretically allows the reviewer to compare multiple aspects (if present), and it is unclear at what number of images (if any) the software becomes more efficient than purely manual methods. In other words, the 5-10 minutes that it takes to crop, wireframe, and extract a photo may take as much or more time than the amount of time it would take to create an image catalog and manually compare the images in the catalog. It is also unclear if the automated approach offers any improvement in accuracy over manual matching. In retrospect, performing image extraction and comparison after each observation session as opposed to waiting until the end of a season to batch compare all the images may result in substantial time savings, since the number of image comparisons necessary is much lower at the beginning as opposed to end of the season. Furthermore, daily processing would allow the analyst to stop reviewing images after the first match, rather than having to continue scanning for secondary matches.

In general, harbor seals appear to be more difficult to photo match than other species for which photo mark-recapture has been successfully implemented. Their pelage is not as uniquely marked as gray seals, and many animals have few distinguishing marks. Because the predominant pelage patterns are small dots and spots, patterns can easily be confounded by glare or shade in the image and by wet, muddy, or ruffled (when dry) pelage. *ExtractCompare*™ seems to be better at working through this than Wild-ID, particularly for shading and contrast issues, but the problem is still present. The software is very good at matching seals with large clearly defined markings (e.g., uniquely shaped blotches, scars, etc.), but those seals are also easily matched visually without the aid of software.

5. Conclusions and Recommendations

Monitoring the haulout at Naval Station Newport intermittently over the last several years indicates a trend of increasing utilization by harbor seals. Since inception in 2011, we see more seals on average during each observation and a higher percentage of observations with a non-zero number of seals. We do not have adequate data at this time to correlate this trend to large-scale environmental patterns or human activity, but we do see some evidence of increased haulout utilization under marginal environmental conditions over the course of the study. Image analysis shows substantial re-use among the population, with 87 confirmed resightings of 27 unique animals during the 2015–2016 season. However, conclusions from the photo-recapture study were limited due to limitations of the software packages and mark-recapture models used. *ExtractCompare*™ software offers a much higher level of utility, with a substantial reduction in false negative rate vs. previous efforts with WildID or manual matching, but is difficult and time consuming to use, and some features still require additional troubleshooting.

We hope to employ *ExtractCompare*™ for an additional year, to see if there are well defined interannual patterns, as we have anecdotally observed several individuals returning over multiple years, and we believe this software to have much higher potential than Wild-ID. However, we also recommend continuing to monitor for availability of new software that may be more stable or reliable. Future directions include collaboration with other local entities doing seal monitoring (e.g., Woods Hole Oceanographic Institute, Narragansett Bay Estuarine Research Reserve, Save the Bay), and developing a comprehensive photo database for Narragansett Bay. We also recommend several modifications to our multivariate abundance modeling approach, which should improve its ability to discern between absence and low level presence. Application of this approach to other haulouts in the system, or to environmentally "correct" static haulout counts would improve our understanding of the haulout ecology of harbor seals in Narragansett Bay. This could also help us understand how anthropogenic impacts (e.g., sea level rise, disturbance, climate change) might impact seal abundance. Furthermore, this technique could begin to provide some insight into overall population patterns and trends, and would be the most logical next step in improving our ability to produce an accurate population level estimate for the Naval Station Newport haulout and/or for the Narragansett Bay population in general.

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