Haul-out Counts and Photo-Identification of Pinnipeds in Narragansett Bay, Rhode Island: 2015/16 Annual Progress Report

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December 2016

Suggested Citation:

Moll, T.E., J.S. Krumholz, G.H. Mitchell, C.G. Tompsett, T.E. Vars, and Z.D. Singer-Leavitt. 2016. *Haul-out Counts and Photo-Identification of Pinnipeds in Narragansett Bay, Rhode Island: 2015/16 Annual Progress Report*. Prepared for U.S. Fleet Forces Command, Norfolk, Virginia. December 2016.

Cover Photo Credit:

Harbor seal (*Phoca vitulina*) *hauled out at a survey site in Narragansett Bay, RI.* Cover photo by Glenn Mitchell, Photo taken under NMFS General Authorization Permit #19826-00.

This project is funded by U.S. Fleet Forces Command and carried out by Naval Undersea Warfare Center Division, Newport as part of the U.S. Navy's data gap program.

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Acronyms and Abbreviations

NOAA	National Oceanic and Atmospheric Administration
Photo-ID	Photo-identification
SIFT	Signal Invariant Feature Transform
U.S.	United States

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1. Introduction and Background

Harbor seals (*Phoca vitulina concolor*) and gray seals (*Halichoerus grypus*) occur along the Atlantic coast of the United States (U.S.) and are protected under the Marine Mammal Protection Act. 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). Harbor and gray seal distribution appears to be shifting, and in recent years there have been an increased number of seals reported in southern New England and the mid-Atlantic region (Kenney 2014; Waring et al. 2014). Occasional sightings and strandings had 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 haul-out sites have been discovered in the lower Chesapeake Bay, Virginia and near Oregon Inlet, North Carolina (Waring et al. 2014). This study focuses on a harbor seal haul-out site near Naval Station Newport in Narragansett Bay, Rhode Island. This report presents an analysis of seal counts and environmental parameters in addition to a preliminary assessment of photo-identification (photo-ID) techniques.

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. Haul-out 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, as they require this time to rest and warm up, but can easily be startled and "flush" back into the water by loud noise or close proximity of humans, boats, aircraft etc. Repeated flushing of haul-outs can have numerous deleterious effects including reduced pupping success, behavior changes, and abandoning the haul-out (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 haul-out 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 haul-out 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 haul-out studied in this project is on a rocky outcropping known as "The Sisters" located near Coddington

Point on Naval Station Newport (Figure 1). This haul-out 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 haul-out study area on Naval Station Newport

Figure 2. Photo showing Naval Station Newport haul-out from typical photographic vantage point. Photos were taken adjacent to a jogging path which runs parallel to shore, approximately 150 meters from the haul-out (Photo: T. Moll, Photo taken under NMFS General Authorization Permit #19826-00)

1.2 Project Goals

The overall goal of this project is to gain an understanding of seal movement and behavior to assist the Navy in determining potential impacts from Navy training and testing. Monitoring the Naval Station Newport site will help the Navy understand trends in seasonal movements, site fidelity, and relative abundance in close proximity to Navy activity. By establishing a record of seal presence and abundance, we can further our understanding of the general ecology of the population in Narragansett Bay, and whether this population is impacted by present or future human disturbance. We also aim to pilot test several software programs designed to photo match individual animals based on pelage patterns, a process which has been used successfully with other similar marine mammal species (Bolger 2012; Hiby et al. 2007; Paterson et al. 2013), and with some 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 haul-out 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), a series of systematic, land-based counts of all seal species were conducted from a walking path in close proximity to the haul-out (Figure 2). Counts were made approximately once per week during the daytime and at low tide. An effort was made to conduct the count 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 used the maximum observed number of seals "hauled out" and "present" (including both hauled out and in water seals) across each of these three surveys, consistent with similar studies by Grellier et al. (1996) and Pauli and Terhune (1987). Unless otherwise specified, seal count data was 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 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 will 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	Shut-ter 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 haul-out
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. These environmental data were supplemented with higher 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 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). Environmental data were used to investigate relationships between seal presence/abundance and environmental parameters.

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

Photos were sorted and processed for matching using software-aided and manual matching techniques to compare and identify individual seals. We are currently investigating the use of a large database format for managing seal images and associated environmental data.

2.2 Photo-Identification Methods

Two software packages, Wild-ID and Extract Compare, were investigated for their capability to serve as an aide to manual matching and improve our ability to recognize repeated visitors to the haul-out. For both software packages, we used a subset of the cropped photos to build a catalog of known matches (different photographs of the same seal on the same day, ideally from different angles) and known non-matches (photographs of other seals from the same day) to test 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 determine the optimal similarity score threshold for each program, which would provide enough sensitivity to minimize false negatives, while maintaining a low false positive rate. This analysis compares the reliability of the two software programs to match individuals and maintain a low false positive rate. The similarity score threshold aids the interpretation of potential matches and determines if a true match exists. The user thus controls the outcome and can reject those images with improbable match odds.

Wild-ID (http://software.dartmouth.edu/Macintosh/Academic/Wild-ID_1.0.0.) is free photo matching software that employs the Signal Invariant Feature Transform (SIFT) algorithm that compares variable patterns within photographs. SIFT is a convenient pattern-matching algorithm because selected keypoints are somewhat robust to variation of photograph scale and rotation (Bolger 2012). The software compares an image to all other images in the database using these keypoint maps, providing the user with a ranked list of the highest scoring matches for each image based on their similarity. Similarity scores range from 0.0 (no similarity) to 1.0 (complete similarity) and provide a standardized measure of pattern resemblance contained within the image pairs.

This software is relatively simple to use and can easily identify likely matches (Figure 4). However, the software is labor intensive. The user must crop all images to minimize background and remove parts of individuals that are not the subject. Wild-ID also requires that the user create an external database to log matches between days. When a cropped image is processed, Wild-ID has been shown to reliably produce matches in a variety of terrestrial species as diverse as giraffe and salamander (e.g. Bendik et al. 2013; Bolger 2012; Morrison and Bolger 2014). Wild-ID can compare the same aspect in one cropped image to that shown in another to produce a “match pair” but cannot match different sides of the same animal to one another (e.g. left and right flanks). Given that the project goal was simply to determine the number of matching seals for the purpose of understanding site fidelity, the best available aspect (i.e., dorsal, ventral, right and left flanks) of each seal was cropped and used to test for matches against all available images. This method, however, produces a high false negative rate.

An important factor in image analysis using Wild-ID is the aspect angle of the photograph. The scale and orientation invariance of SIFT allows for direct use of images taken at aspect angles greater than and less than 90°. Keypoint matching accuracy for SIFT is above 50% for viewpoint changes of up to 50°, beyond which the algorithm becomes unreliable and number of false negatives rises dramatically (Lowe 2004). Since false negatives were not a major concern given the goals of this study, we decided to analyze images up to this limit in order to provide the highest likelihood of identifying true positive matches, despite the elevated false negative rate relative to using only photos of animals taken at 90 ° to the camera. This decision was motivated by our preliminary work with Wild-ID, which demonstrated that the software could sometimes correctly match a marginal quality image to another of high quality.

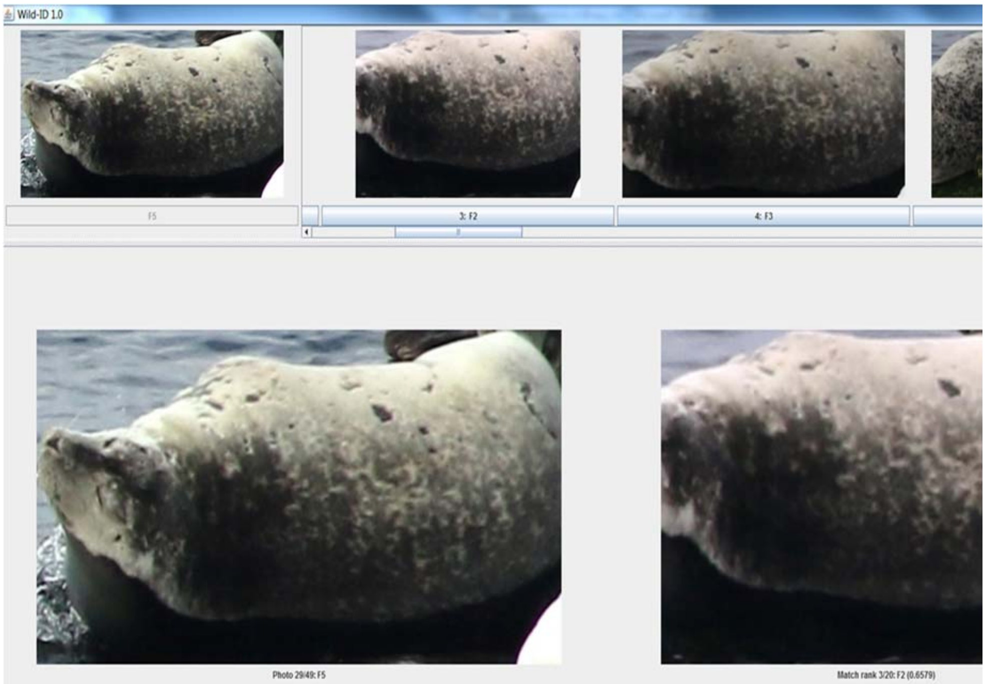

Figure 4. Processing pelage matching options using Wild-ID. Assisted by a similarity score (bottom right), the user selects the best match from the 20 best matches identified by the algorithm, or identifies the seal as unique (no previous matches in the database).

Extract Compare (http://conservationresearch.org.uk/Home/ExtractCompare/index.html) uses a similar pattern-matching algorithm, and pairs it with a 3-D wireframe surface model (Figure 5). Extract Compare has a more robust adjustment for differences in contrast between photos compared to Wild-ID, which allows improved matching of seals at different aspect angles and allows pattern matching of head and neck pelage. This software also includes a built-in database, which allows tracking of repeat encounters and links the right and left sides of the same animal. In combination, these enhancements dramatically reduce the false negative rate compared to Wild-ID 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 Extract Compare uses an internal database, it is not necessary to organize and pre-crop images before loading. Furthermore, Extract Compare does allow for multiple aspect angles and even multiple seals to be extracted from each image. Therefore, we simply selected the sharpest available image of each seal for extraction, and extracted all viable aspects from that seal (e.g. head/neck, right/left flank, abdomen). In general, seals did not shift position substantially during monitoring, but whenever possible, additional aspects captured in multiple photos were analyzed to capture the maximum number of aspects for each seal.

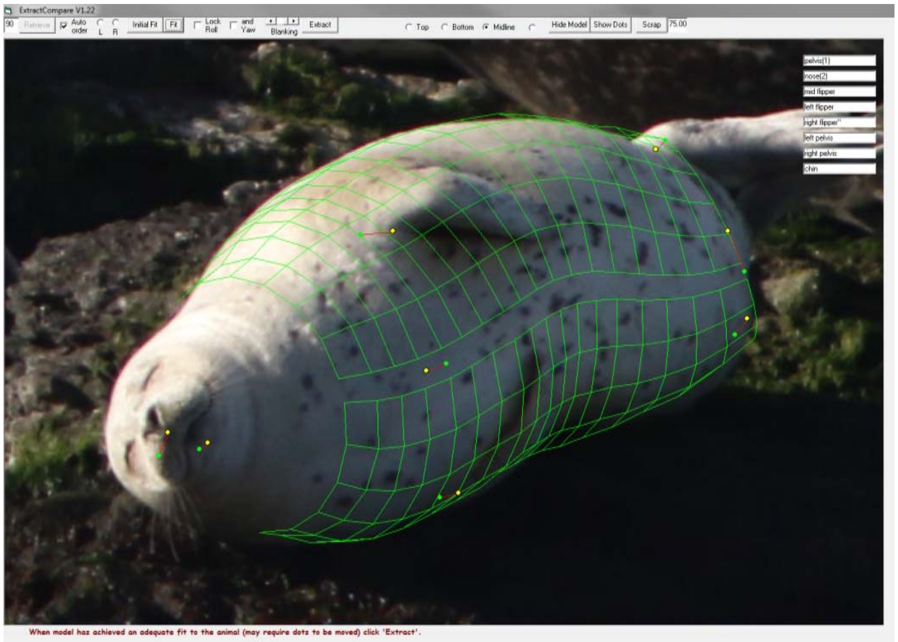

Figure 5. Extracting pelage patterns from a harbor seal abdomen using Extract Compare. The wire frame analysis compensates for differences in rotation and aspect between images

3. Results

3.1 Haul-out Counts: 2014/2015 and 2015/2016 Field Seasons

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 haul-out site is obscured from view. The first seal observation of the 2014-2015 season was on December 4, 2014, although it is possible that seals arrived in Narragansett Bay earlier since monitoring did not occur until that date. The last seal of the season was observed on May 6, 2015, although monitoring continued for several weeks afterward. Approximately 693 seals were observed during 46 survey days. Seals were observed on 36 of 46 (78%) days, with a nonzero minimum count of one and maximum count of 44. On days when seals were observed, the average number of animals sighted was 19 (Figure 6).

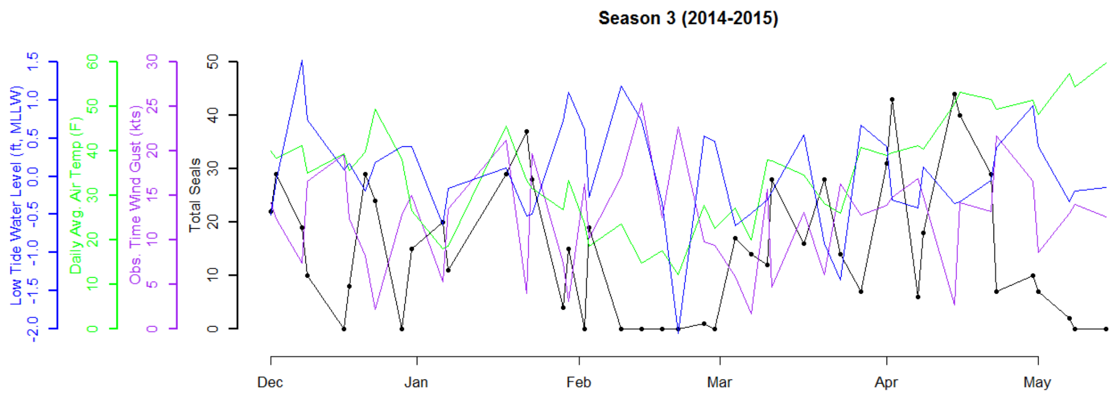

Figure 6. Seal counts with key environmental variables during the 2014-2015 field season.

Weekly monitoring began in August 2015 for the 2015-2016 season and seals were first observed on November 5, 2015. The last seal of the season was observed on May 4, 2016, although monitoring continued for several more weeks. During 29 survey days including and following November 5, 2015, a total of 624 seals were observed. Seals were observed on 26 of 29 (90%) of days, and were hauled out on 22 of 29 (76%) days, with a nonzero minimum count of one and maximum count of 49. On days when seals were observed, the average number of animals sighted was 24. No gray seals were positively identified during the season. Over the course of the season, one flush was observed following someone (not from the observation team) walking onto the beach.

Since monitoring this haul-out began in 2010, 1,644 seals were observed during 129 survey days. Over the course of the study, seals were observed on approximately 67% 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 18.8 seals per day on days when seals were observed.

The peak number of seals per observation tends to be in early spring (March/April), with counts frequently exceeding 30 animals per day on days when seals were present (Figure 7). A dip in seal abundance occurred in February, which was the coldest month, both in terms of water temperature (Figure 8) and air temperature (Figure 9). The haul-out site was covered in ice for much of February 2015, which likely caused the pronounced dip in occurrence in 2014-2015 compared to the milder winter of 2015-2016.

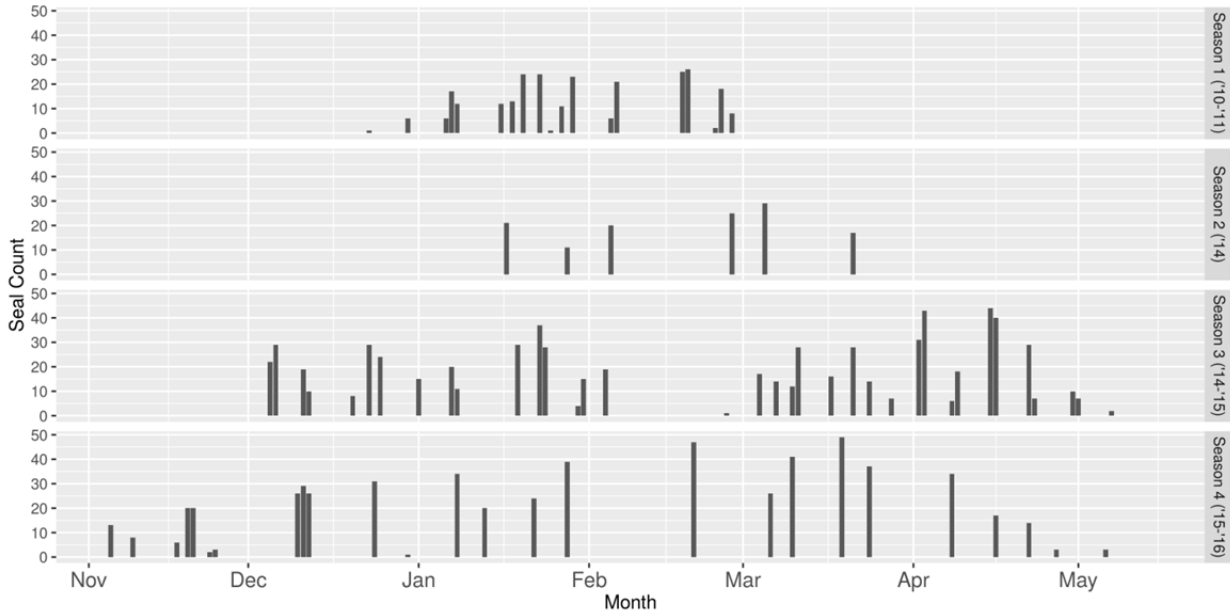

Figure 7. Seal counts over time for all field seasons.

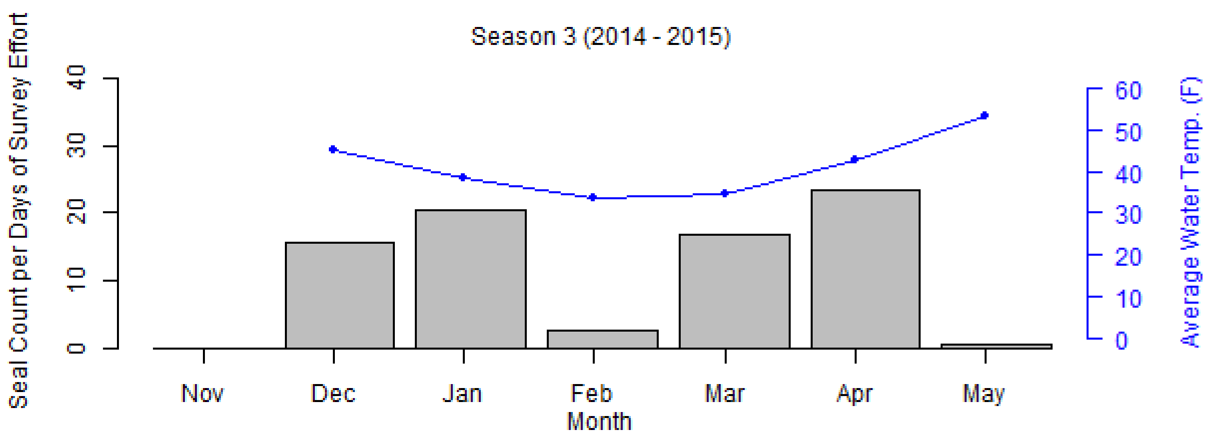

Figure 8. Average seal count by month with corresponding water temperature (2014-2015 field season)

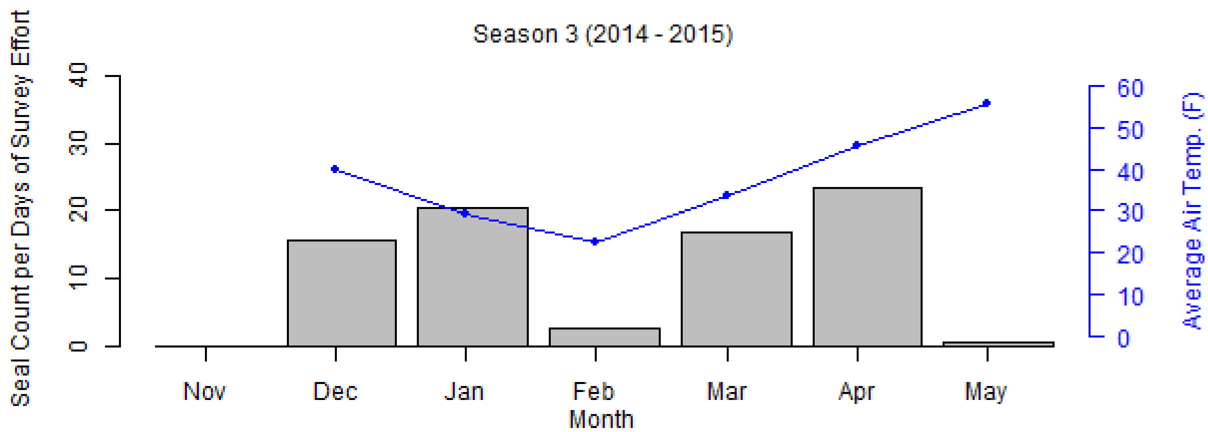

Figure 9. Average seal count by month with corresponding air temperature (2014-2015 field season)

We compared seal counts and presence/absence to environmental variables to investigate for patterns that might explain variations in seal count during the season (Table 3). Although many parameters showed a discernable relationship, the strongest relationships were with wind speed, water level at time of sampling (e.g. proximity to low tide and the magnitude of the low tide), and air temperature.

Table 3. Strongest correlations between seal abundance and environmental variables. The absolute value of Spearman's Rho indicates strength of correlation, ranging from 0 (weakest) to 1 (strongest), with the sign (+ or -) denoting positive or negative correlation. Variables are from the NOAA weather station located at Naval Station Newport unless otherwise noted.

Environmental Variable	Correlation with Seal Count (Spearman's Rho)
Observation Time Wind Gust	-0.41
Daily Maximum Wind Gust (Newport Airport)	-0.41
Observation Time Wind Speed	-0.35
Daily Average Air Temperature	0.31
Daily Average Wind Speed (Newport Airport)	-0.31
Daily Average Air Temperature (Newport Airport)	0.30
Observation Time Air Temperature	0.29
Observation Time Water Level	-0.28
Observation Time Barometric Pressure	0.28
Daily Average Air-Water Temperature Difference	0.27
Minutes Before or After Low Tide	-0.27
Low Tide Water Level	-0.26
Observation Time Air-Water Temperature Difference	0.24
Daily Average Barometric Pressure	0.24
Daily Average Water Temperature	0.21
Observation Time Water Temperature	0.18

Wind speed and direction appeared to have a substantial impact on the number of seals hauled out (Figure 10). In general, higher wind speeds corresponded to lower seal counts. Moderately strong winds from the south and west (directions from which the haul-out is protected) occasionally corresponded to large numbers of seals, while stronger winds from the north and east (with larger fetch) had a greater impact on seal abundance.

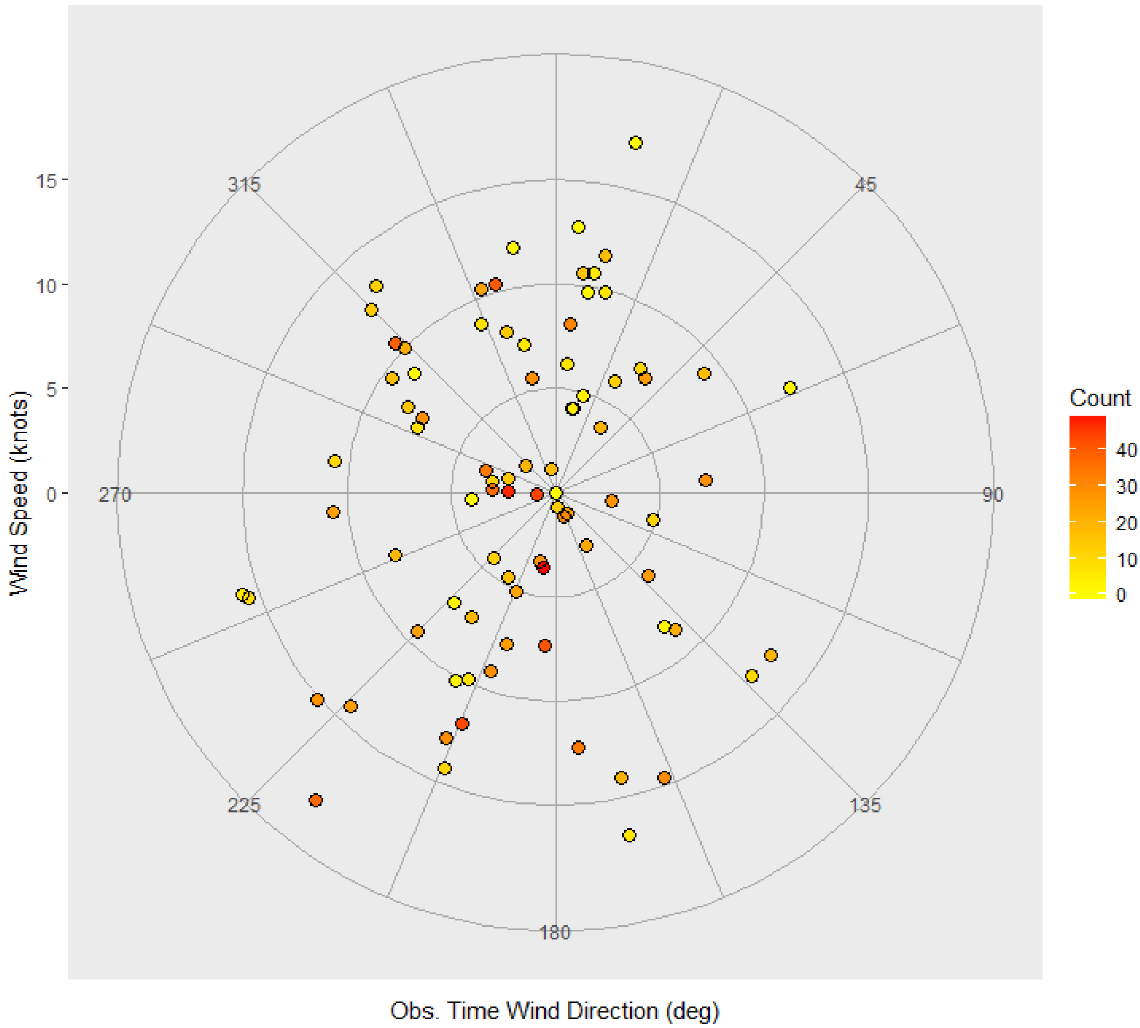

Figure 10. Seal abundance relative to wind speed and direction at time of observation (all seasons).

Temperature does appear to have an impact on seal abundance, but at least during the observation period, the relationship does not appear to be linear (Figure 11). Counts are lower on the coldest days, peak between about 38-45°F, and then decline again as temperatures warm towards the end of the season. This pattern can also be seen in the mid-season dip in observed haul-outs during the month of February, which is usually the coldest month (Figure 8)

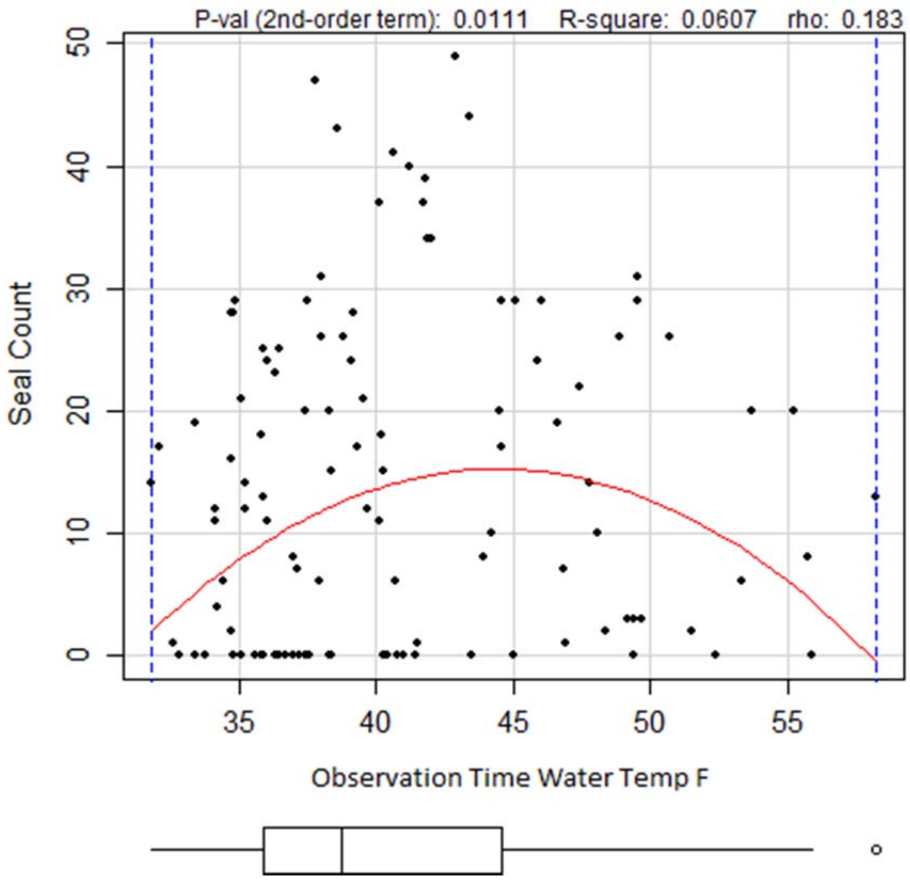

Figure 11. Seal count by water temperature at time of observation (all seasons). P value and R^2 are presented for the quadratic component of the relationship. The P value indicates that a quadratic fit is statistically better than a linear fit, while the R^2 describes the amount of additional variation explained by the quadratic term. The box and whiskers plot shows the mean, and upper and lower quartile, as well as the range of observed values.

Air temperature also seems to impact the number of seals hauled out, though not exactly in the same way as water temperature. A relatively strong linear relationship between air temperature and seal abundance is present, which only breaks down at the warmest of air temperatures, generally when the seals are leaving, or have already left for other reasons (Figure 12). Since one of the main reasons seals haul out during feeding season is thermoregulation, we would expect to see few seals hauled out when air temperatures are very cold. This pattern corresponds with the temporal pattern (Figure 9) of high seal numbers in December, early January, and March, with lower numbers during the very coldest part of winter.

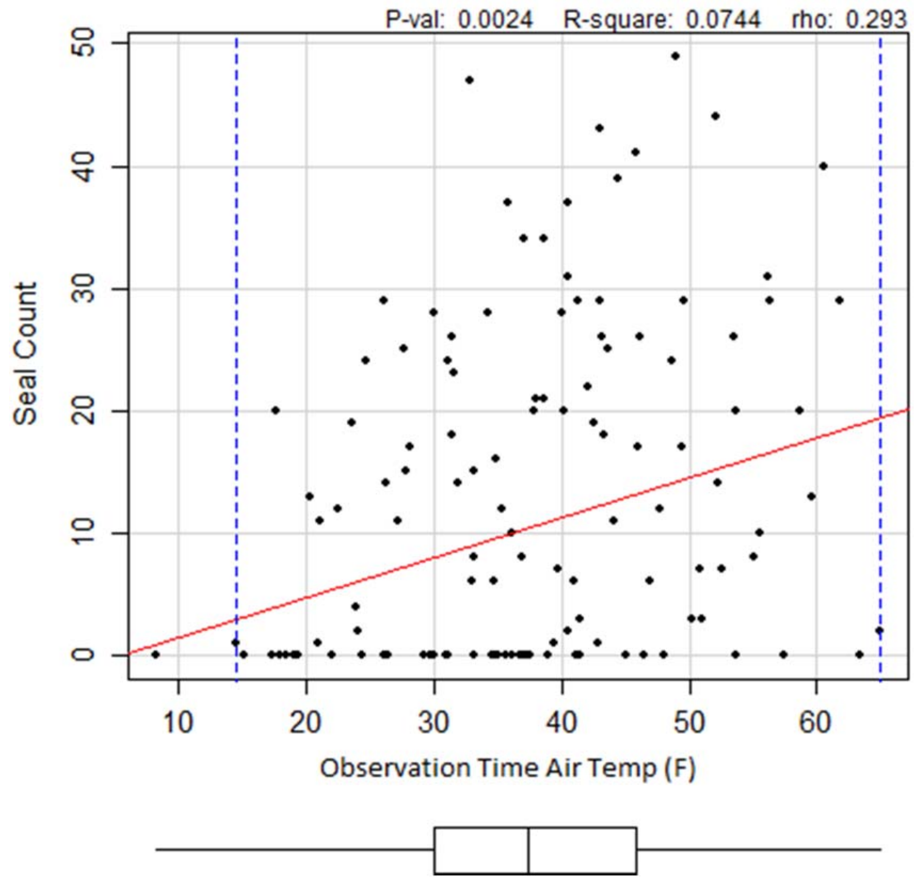

Figure 12. Seal count by air temperature at time of observation (all seasons). P value, R^2 and rho (correlation coefficient) are presented for the linear fit shown. Blue dotted lines indicate minimum and maximum temperatures at which seals were observed, though very few seals were observed in air temperatures below 20°F or above 62°F.

3.2 Photo-Identification

3.2.1 Wild ID

Wild-ID was used across the entire 2015-2016 field season, obtaining a usable crop for photo capture on 283 out of 624 (45%) observed seals during the season. Primary reasons for being unable to successfully photo-capture an animal included:

1) Observation: The animal was observed and counted, but never hauled out.
2) Obstruction: Obstructions such as rocks or other seals precluded capture of a large enough section of pelage to crop.
3) Aspect: The SIFT algorithm works best when the subject is photographed at 90° to the camera. Beyond 50° the algorithm is unreliable.
4) Environmental Conditions: Lighting, glare, reflection or shadow obscured the pelage pattern.

WILD-ID was tested using a database created from 498 cropped images from three days, which included 113 known matches (photos of the same animal on the same day) and 385 known non-matches (photos of different animals from the same day). The false negative and false positive rates were compared across a range of threshold similarity scores. Most known positive matches had similarity scores above 0.1, and most known negatives had similarity scores below 0.01, but scores between 0.01 and 0.1 were a mix of matches and non-matches (Figure 13).

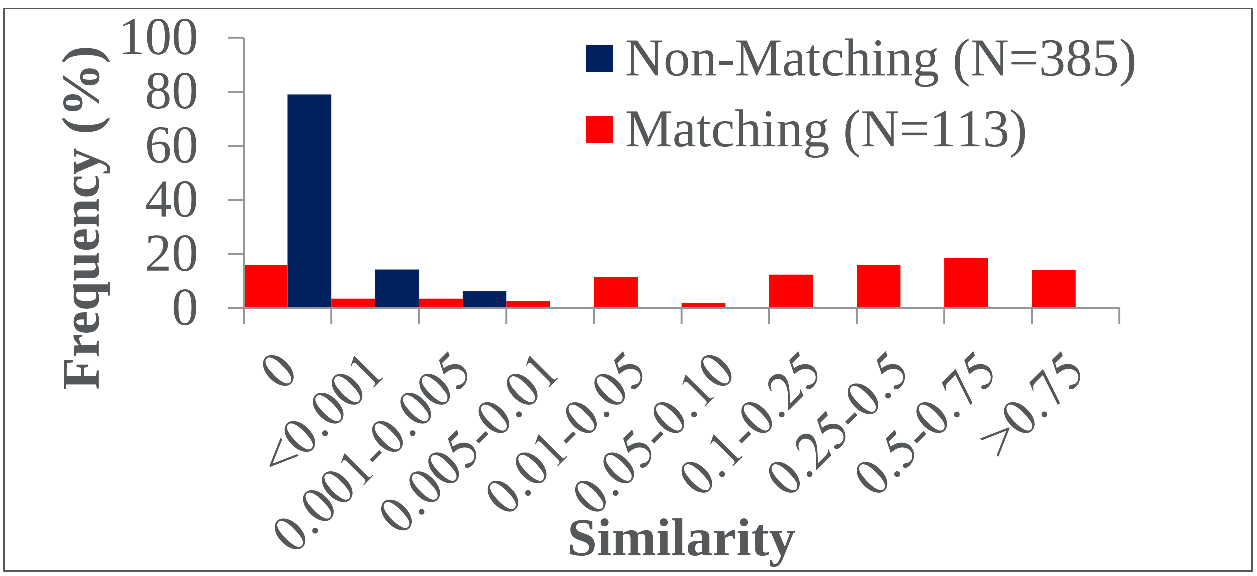

Figure 13. Frequency analysis of similarity scores for known matching and known non matching seals using Wild-ID.

Based on the goals of this study to quantify seal presence and understand site fidelity by individuals, it was important to minimize false positive matches and have confidence that those seals identified by the software as returning seals were actually returning. Therefore, we selected a threshold similarity score of 0.01 because of the low false positive rate. A user screening all photos and only considering matches with similarity score >0.01 would have a very low false positive rate (<0.5%), but a false negative rate of at least 26% (Figure 14).

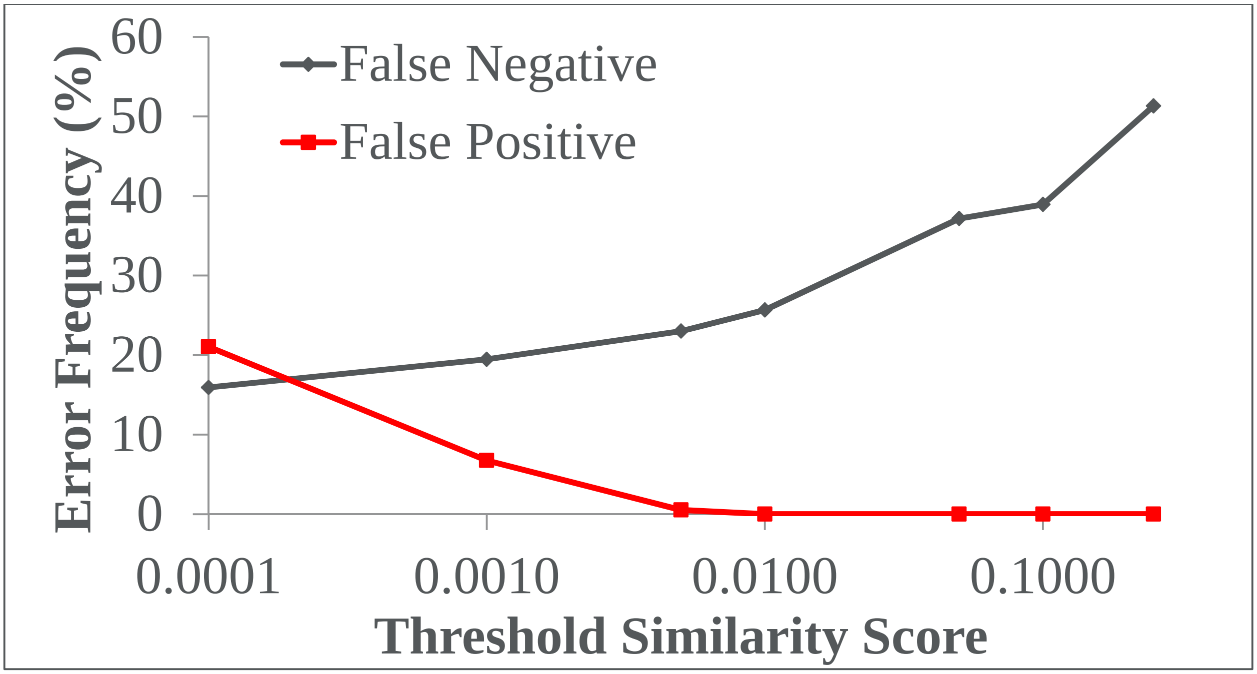

Figure 14. Frequency of false negative and false positive error across a range of threshold similarity scores using Wild-ID

The actual false negative rate would likely be much higher for an actual trial because all of the "known matches" used for this exercise were cropped from photographs with similar aspect angles. In the likely case that subsequent observations captured a different position or aspect angle of the seal, the false negative rate might be substantially higher. This false negative estimation also does not consider the rate of false negatives that would occur because this software is not able to match between the left and right sides of an animal. In a "real world" matching situation, the true false negative rate would be at least double this (52%). Reducing the similarity score threshold to 0.001 would decrease the false negative rate slightly, but would result in an order of magnitude increase in the false positive rate (to 6.8%).

By implementing this protocol across the entire season, we identified 38 matches, including seven animals which were observed on more than two days. The maximum number of observations for a single animal was ten (Table 4). In some cases the user was able to identify a confirmed visual match that was below the software threshold (a false negative). In those cases we often looked for another picture of one or both animals in the database to try to confirm or refute the match, either using Wild-ID or by eye. Particularly in cases where the animal had distinctive facial pelage (e.g. Figure 15), manual matching was able to identify many matches missed by Wild-ID. The high false negative rate associated with this process limits both the ability to assess if individual seals are returning to a haul-out and the potential to estimate the maximum duration that an individual animal is using the haul-out.

Table 4. Frequency of observation, photo capture ("mark"), and photo recapture for seals during the 2015-2016 field season.

Outcome	Frequency
Observed	624
Captured	283
Recaptured	38
Multi-Recapture	7

Figure 15. Example of seal with a distinctive facial marking. In many cases, repeat visitation by this animal, nicknamed "Boxer" due to his black eye, were false negative matches by the Wild-ID software, but easily detected manually by the observer.

3.2.2 Extract Compare

We experienced limited success with the Extract Compare software. After a long trial and de-bugging period, we were finally able to process a limited number of samples with Extract Compare. The process of outlining and fitting the wire frame to the animal for each aspect being extracted (e.g. head, neck, abdomen, flank, etc.) is very time consuming (3-5 minutes per aspect per animal per day) and has a steep learning curve. Once the wire frame is fit to the animal in the image, Extract Compare is able to handle many of the limitations experienced with Wild-ID, such as inability to account for differences in shading or rotation of the animal relative to the camera. We repeated the same process as performed during evaluation of Wild-ID, running a three-day sub-sample through Extract Compare. We were able to process and match images, but we were unable to output the similarity scores and conduct a histogram analysis due to what we assume is a bug in the testing protocol code that we have not been able to troubleshoot at this time. Thus, we are limited to qualitative comparisons of Wild-ID and Extract Compare for this task.

In general, the similarity scores produced by Extract Compare are much higher than those for Wild-ID, with most known matches scoring 0.5 or higher. Though a more quantitative analysis is necessary to confirm, we would expect that the threshold similarity score for Extract Compare would be about 0.2-0.3 (vs. 0.01 for Wild-ID). While these similarity scores are not directly comparable, this increase still indicates greatly improved sensitivity. The rate of false positives produced by the software, even using a threshold acceptance score of 0.3, is much higher, requiring user intervention to reject many potential matches for each verifiable match. The number of false positive matches may be mitigated as more photos are entered into the database because Extract Compare has the ability to show the user multiple images of the same seal against which to compare. Regardless, while precision is much higher, user effort is also higher with the increased processing time.

The improved sensitivity of Extract Compare produced a lower false negative rate (<10%) compared to Wild-ID (26%). Extract Compare is able to link left and right images of the same seal. In theory, this feature could dramatically lower the false negative rate. However, in order for this feature to be successful, the user must capture a left and right image of the same seal on the same day and manually associate them, which may be logistically challenging.

Extract Compare has a number of internal database features that permit tracking, storage, and association of animals (e.g. for multi-site comparisons, or tracking frequency of a calf with or without the mother), which could prove useful for a larger project, but which we have not yet examined for their functionality or ease of use.

4. Discussion

4.1 Population and Environmental Trends

Although we have only a very short time series to base general conclusions about population trends, the number of seals observed in each season does seem to be increasing. The time of first observation moved steadily earlier from 2010 to 2014 to 2015, and the average number of seals counted each day has increased over time (Table 5, see section 3.1 for more detail). Although the total number of observed animals in 2014-2015 was higher than 2015-2016, there were also several more observations made in that year. 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 haul-out. If haul-out 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. It is also possible given our limited sample size and sporadic sampling, that we simply did not sample as much in bad weather, or that the weather in general was more conducive to seals hauling out. This could be corrected by developing relationships between environmental variables and seal abundance, which is discussed in more detail below.

Table 5. 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 haul-out site.

Season	"In Season" Effort	Total Seal Count	Average Count	Frequency of non-zero observation
2010 - 2011	37	256	7	51%
2014	10	123	12	60%
2014 - 2015	44	693	16	82%
2015 - 2016	29	624	22	90%

The number of seals counted on a given day varies substantially based on weather and oceanography. It seems likely that some conditions influence the number of seals hauling out (e.g., air or water temperature, waves, wind) once they exceed a certain threshold. Statistically, this weakens the strength of univariate correlations. For example, in attempting to correlate air temperature and seal presence, other factors that may work in combination (e.g., wind speed and direction) may influence the number of seals hauling out. Some factors such as tide cycle and level can greatly reduce the amount of exposed rock, regardless of the air temperature. Despite this, there are clear patterns between seal numbers and environmental data. We propose that future efforts work towards the creation of a multivariate abundance model (e.g., a hurdle model), which uses certain conditions to predict presence/absence and then other conditions, given presence, to predict abundance. This would help us improve our understanding of how seal behavior is influenced by environmental variables in Narragansett Bay. Employing a multivariate abundance model would allow us to predict anticipated abundance given a weather forecast, and better understand how disturbance may be influencing haul-out utilization. It would also allow us to standardize counts of seals made under different environmental conditions, resulting in more robust estimates of population trends, at least at this specific haul-out.

The seals at this haul-out 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, and sailors performing loud drills. We did not observe many behavioral responses and only observed one disturbance-related full flush during our observations 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. The seals were seen flushing when someone was reported walking on the beach, which is closer to the haul-out 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 proposed 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.

4.2 Photo-Identification

We were able to use both photo-ID programs with limited success. While Wild-ID is simple, easy and fast to learn and use, we estimated that the false negative (missed matches) rate exceeded 50%. For example, Wild-ID successfully matched “Boxer” (Figure 15) only once, although visual ID confirmed presence 10 times. The high false negative rate significantly limits the utility of the software for harbor seal identification, to the point where it is not much better, if at all, than manually matching seals. The software may be more efficient than manual matching when using a large database. Wild-ID does provide enough information for us to know that many seals do return to the same haul-out, and at least a few seals do so regularly for at least several weeks. Some seals were observed frequently in the beginning of the season, but less so towards the end, and others seemed to only start using the haul-out later in the season, but once established, were semi-regular visitors.

Wild-ID was found to be highly dependent on photo quality to get a good match. In particular, the aspect angle of the photo and the sharpness and contrast of the pelage in the cropped image were critical. Wild-ID was occasionally able to make a match with a less sharp or partially obscured second image. Even though the false negative rate among images processed may be higher if marginal quality images are included in the database, the number of true positives identified would also increase so, depending on the goals of the project, it may be beneficial to include or exclude these marginal images. The false negative rate could be reduced by reviewing only seals with distinctive pelage marks, which are easier for the software to ID. For our study, since we were looking only to maximize true positives, these images were included in analysis. When including these images, we were still only able to capture about half of the seals present and fewer on days when the haul-out was very crowded. Regardless of how images are included or excluded from the catalog, cropped, and processed, the false negative rate is likely to be a barrier to using this software package for anything other than qualitative analyses.

Another limitation of Wild-ID is that multiple matches in a database cannot be easily logged. Once a match is accepted by the user, the software will automatically index to the next focal image. As a result, recapture data presented in Table 4 represents conservative minimum estimates. Because the software is limited to pairwise comparisons, the user effort grows geometrically as the size of the photo database increases, which could make the program unwieldy for comparisons across multiple sites or years.

Extract Compare 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 much lower false negative rate. The actual false negative rate would improve even further with Extract-Compare’s ability to match the right and left side of an animal, which theoretically eliminates half of the false negatives. However, given that the seals at this particular haul-out are generally lethargic and rarely change position and the positioning of the haul-out, the photographer is unable to move around much to capture different angles (vs. a boat survey where you could shoot from alternate sides of the outcrop). It is unclear how often we would be able to successfully accomplish this, because it requires a known photograph of both the right and left sides of the animal to implement. 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.

Although Extract Compare is substantially more powerful than Wild-ID, it is much more difficult and time consuming to use, and many of the advanced features do not appear to be fully functional at this time. It certainly has much more potential, but requires additional testing and debugging time before it could be broadly implemented, and would require substantial training.

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. Extract Compare seems to be better at working through this, particularly for shading and contrast issues, but the problem is still present. Both software systems are 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 haul-out at Naval Station Newport intermittently over the last five 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 human activity or large-scale environmental patterns. Image analysis shows substantial re-use among the population, with confirmed re-sighting of 38 animals during the 2015-2016 season. However, conclusions from the photo-recapture study were limited due to limitations of the software packages used. Wild-ID provides useful re-sighting information, but the high (>50%) false negative rate precludes additional quantitative conclusions. Extract Compare offers a much higher level of utility, with a substantial reduction in false negative rate, but is difficult and time consuming to use, and some features still require additional troubleshooting.

We hope to continue investigating and troubleshooting the use of Extract Compare, as we believe this software to have much higher potential than Wild-ID. 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 a more thorough investigation of multivariate abundance modeling approaches. Development of a multivariate abundance model could help us understand how environmental conditions impact seal abundance, and therefore to correct for variability in survey effort, time of day, weather conditions, seasons, and years. This technique 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 first step in developing a population level estimate for the Naval Station Newport haul-out and/or for the Narragansett Bay population in general.

6. Acknowledgements

This project is funded by U.S. Fleet Forces Command and undertaken by the Naval Undersea Warfare Center Division, Newport as part of the U.S. Navy’s data gap program. We would like to thank Len Thomas at University of St. Andrews, Andrea Bogomolni at Woods Hole Oceanographic Institute, and Lisa Sette at the Center for Coastal Studies whose initial advice and feedback help to get this project off the ground.

From U.S. Fleet Forces Command, we would like to thank Laura Busch for her valuable feedback and continued support for this project. From Naval Undersea Warfare Center Division, Newport, we would like to thank Rob Davis and the Mission Environmental Planning Program for their valuable feedback and support for this project. Special thanks to Deanna Rees, Danielle Jones, and Brittany Bartlett from Naval Facilities Command Atlantic for their continued communication and collaboration on this project.

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