Distribution and Abundance of Harbor Seals in Cook Inlet, Alaska. Task II: Assessment of Factors Influencing Harbor Seal Haul-out Behavior Using Remote Time-Lapse Cameras, 2003-2005

FINAL REPORT

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Prepared for
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This study was funded by the U.S. Department of the Interior, Bureau of Ocean Energy Management (BOEM), through Inter-agency Agreement No. 0103RU72448 with the U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, as part of the MMS Alaska Environmental Studies Program.

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CITE REPORT AS

Boveng, P.L., J.M. London, and O. Badajos. 2011. Distribution and abundance of harbor seals in Cook Inlet, Alaska. Task II: Assessment of Factors Influencing Harbor Seal Haul-out Behavior Using Remote Time-Lapse Cameras, 2003-2005. Final Report. BOEM Report 2011-064. Bureau of Ocean Energy Management, Alaska Outer Continental Shelf Region, Anchorage, Alaska, USA. 50 pp.

PROJECT ORGANIZATION

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ABSTRACT

Harbor seals are particularly vulnerable to acute and chronic environmental impacts, such as those that could result from industrial accidents such as oil spills. Previous studies of the haul-out behavior of harbor seals in Alaska have been conducted in August, to coincide with the seals' molting period. Haul-out patterns at other times of year are not well known, although long-term, land-based studies have been conducted at a few selected sites, primarily during summer months. Visual counts of seals made by observers at these field sites can be useful for recording haul-out patterns during selected times of the year, however, obtaining daily counts at multiple haul-out sites over many months to a year would be extremely labor intensive and costly. A thorough description of changes in harbor seal haul-out behavior in a region as large as Cook Inlet requires a different approach than has been used in the past.

The advent of high-resolution digital cameras with large memory capacities and low power consumption has enhanced the prospects for using relatively low cost time-lapse photography for long-term monitoring of wildlife and other natural resources in remote locations. We developed and assembled a digital time-lapse photography system from commercially available components, and used the system from 2003 to 2005 to assess harbor seal haul-out behavior year-round at five haul-out sites in Cook Inlet. The primary objective of this project was to identify factors that impacted the haul-out behavior of harbor seals in Cook Inlet and to quantify the relationship between haul-out patterns and these factors.

Fourteen remote time-lapse camera systems were deployed in 2003-2004 at the following five harbor seal haul-out sites: Aurora Rock, Anchor Point, and Augustine Island East, West-1 and West-2. After deployment, however, a few key factors prevented us from completing the majority of our objectives. The greatest obstacle to success of this project was the unreliability of the camera/controller combination that we selected. Even with frequent maintenance visits, one or more cameras at each site continued to fail for unknown reasons, and as a result we obtained only partial photographic coverage of the haul-out sites. Without accurate hourly seal counts, we were unable to address the original objectives of this project and relate the numbers of seals on a haul-out to specific covariates such as weather conditions, tidal height, time of day, and date in seasonal life-history cycle. The original objectives, however, were met even more effectively by addition of Task III to this project, which enabled satellite-tagging of a large

sample of harbor seals; the satellite tags provided detailed haul-out time lines that will be analyzed to identify and describe the key factors in harbor seal haul-out behavior and to estimate total abundance from aerial survey counts of seals ashore.

Additional considerations for the use of time-lapse photography for investigation of harbor seal haul-out patterns are ensuring complete photographic coverage of the haul-out area and good photographic quality. If a more technically sound solution for a camera/controller combination becomes available, these issues will also need to be addressed in any future study.

KEY WORDS: harbor seal, *Phoca vitulina*, haul-out, abundance, Cook Inlet, time-lapse photography

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INTRODUCTION

In Alaska, harbor seals (*Phoca vitulina richardii*) occupy a broad geographic range from approximately 130°W to 172°E (over 3,500 km east to west) and from 61°N to 51°N (over 1,000 km north to south) (Frost et al. 1982). In recent decades, their abundance has declined at several Alaska locations. For example, counts of harbor seals at Tugidak Island declined 85% between 1976 and 1988 (Pitcher 1990) and counts in Prince William Sound suggest population declines of approximately 63% between 1984 and 1997 (Frost et al. 1999). In the Aleutian Islands, counts declined 67% between the early 1980s and 1999 (Small et al. 2008). The significance and causes of these declines are unknown, but there is concern about the present and future status of Alaska harbor seal populations, most notably in the Gulf of Alaska. Declining populations of Steller sea lions (*Eumetopias jubatus*), which are sympatric with harbor seals through most of their range, have added to concerns about what may be happening to harbor seal populations; the western stock of Steller sea lions has declined by over 70% since the mid-1960s (Loughlin et al. 1992) and was listed in 1997 as “endangered” under the U.S. Endangered Species Act.

Harbor seals are particularly vulnerable to acute and chronic environmental impacts, such as those that could result from industrial accidents such as oil spills (Frost et al. 1994a, Frost et al. 1994b, Spraker et al. 1994, Hoover-Miller et al. 2001). If an oil spill were to occur, harbor seals would be at risk for direct exposure to oil both at sea and ashore when they haul out (Lowry et al. 1994). Harbor seals tend to haul out at specific sites, which can readily be identified and monitored by aerial surveys. However, the number of harbor seals that haul out at a particular site, and would thus be at risk if the site was oiled, varies considerably through time, between sites, and with weather conditions (e.g., Huber et al. 2001).

Much of the variability in haul-out numbers may be explained by life history and environmental factors that alter the haul-out behavior of seals (Watts 1996, Frost et al. 1999, Boveng et al. 2003). The number of harbor seals hauled out varies seasonally, generally peaking during pupping and molting seasons (e.g., Brown and Mate 1983, Calambokidis et al. 1987, Jemison and Kelly 2001). This seasonal effect can be quite dramatic over short time periods. For example, the number of seals hauled out can decrease by 85% in the last three weeks of the molt season (Mathews and Kelly 1996). Harbor seals also tend to haul out in higher numbers during each day around mid-day and low tide, although the relative importance of these two factors varies between sites (e.g., Allen et al. 1984, Stewart 1984, Thompson et al. 1989, Watts 1996). Inclement weather also can reduce the number of seals hauled out on a given day (e.g., Schneider and Payne 1983, Watts 1992), particularly during the molt season when seals apparently haul out to increase their skin temperature and, thus, molt more efficiently (Feltz and Fay 1966, Boily 1995).

Previous studies of the haul-out behavior of harbor seals in Alaska have been conducted in August, to coincide with the seals' molting period (Simpkins et al. 2003). Haul-out patterns at other times of year are not well known, although long-term, land-based studies have been conducted at a few selected sites, primarily during summer months (e.g., Tugidak Island from April - September; Jemison and Kelly 2001). Although visual counts of seals made by observers at these field sites can be useful for recording haul-out patterns during selected times of the year (e.g., summer), obtaining daily counts at multiple haul-out sites over many months to a year would be extremely labor intensive and costly. A thorough description of the changes in a large region such as Cook Inlet requires a different approach than has been used in the past. Of particular importance is a quantitative description of the factors that affect the numbers of seals that haul out, such as date, tide height, time of day, and weather. Recent studies have made considerable progress in understanding the relationships between haul-out behavior and these covariate factors during a survey period in August (e.g., Boveng et al. 2003, Simpkins et al. 2003), but a new survey technique is needed to extend that understanding to all seasons and to better understand the complex interactions of date, time of day, weather, and tide height. The relationships between haul-out behavior and these covariates will also be important in models evaluating potential impacts of industrial accidents such as oil spills.

The advent of high-resolution digital cameras with large memory capacities and low power consumption has enhanced the prospects for using relatively low cost time-lapse photography for long-term monitoring of wildlife and other natural resources in remote locations. We developed and assembled a digital time-lapse photography system from commercially available components, and used the system from 2003 to 2005 to assess harbor seal haul-out behavior year-round at five haul-out sites in Cook Inlet.

OBJECTIVES

The primary objective of this project was to identify factors that impacted the haul-out behavior of harbor seals at five sites in Cook Inlet and to quantify the relationship between haul-out patterns and these factors. The study was designed to address the following questions:

1. How do changes in specific covariates (weather conditions, tidal height, time of day, date in

seasonal life-history cycle) impact the haul-out behavior of harbor seals, and what is the combined impact of all the covariates taken together?

2. What is the relative importance of the various covariates on the haul-out behavior of harbor seals?
3. Does the relative importance or impact of specific covariates on harbor seal haul-out behavior change over the course of the seals' seasonal life-history cycle? For example, are seals more, or less, sensitive to changes in weather conditions during the molting season (August - September) than during other times of the year?

A secondary objective was to develop a time-lapse digital camera system from off-the-shelf components, that would be simple to deploy and maintain, and that would be inexpensive enough to deploy at multiple representative harbor seal haul-out sites around the Cook Inlet study area.

METHODS

Camera Systems

We began with a Nikon Coolpix 5700® camera (5.0 Megapixel resolution, 8x optical zoom), selected for its suitable resolution, ability to use high capacity (1 – 2 GB) Compact Flash memory storage cards, and compatibility with an external time-lapse controller (Harbortronics Digisnap 2800® modified by manufacturer for cold temperature operation). The camera and time-lapse controller were placed in an insulated camera housing (Extreme CCTV EX28® with pan/tilt mounting hardware) that was mounted on a vertical post (6" X 6" pressure-treated lumber or 4" X 4" fiberglass obtained from GroundsForPlay®), supported by wire rope attached to earth anchors or expansion bolts placed in nearby rock. To reduce the complexity and maintenance associated with solar or wind-driven battery charging systems, the cameras and controllers were powered by high capacity external batteries (Automatic Power® air-depolarized alkaline battery AA3-1200; 4.5V, 1200Amp-hour, with 2 batteries required per camera). Based on laboratory measurements of the power consumption of the camera and controller, the rated capacity of the batteries was sufficient for at least 6 months of unattended operation.

Fourteen remote time-lapse camera systems were deployed in 2003-2004 at five different harbor seal haul-out sites (Aurora Rock, Anchor Point, and Augustine Island East, West-1 and West-2) in Cook Inlet (Table 1, Figure 1). Four time-lapse camera systems deployed as a unit at Aurora Rock are shown as an example in Figure 2. Each time-lapse camera system was set to take one photo per hour. In some cases, the time-lapse controller was used to restrict the photography to daylight hours in an effort to conserve battery life and memory capacity.

Each site was visited every few months, weather depending, to download photographs, swap batteries, and perform routine camera maintenance. After field testing the equipment, system malfunctions and data interruptions were encountered. To address apparent problems with short-term power supply, we: 1) increased the voltage from 9V to 12V at each site by adding cells to the batteries, 2) staggered the time-lapse schedule between cameras at each site (so no two cameras attempted to capture images simultaneously), and 3) added capacitors to the systems in case the 'transient' power requirements during the brief periods that the cameras were turned on at each time-lapse interval exceeded the capabilities of the batteries to supply short-term current.

After the power supply problems were resolved, the systems continued to fail for unknown reasons. Other modifications to the system included revising the initialization instructions for the camera controllers, and adding desiccants to the camera housings to reduce humidity. Still, we were unable to establish a reliable time-lapse camera system from off-the-shelf cameras and time-lapse controllers. There remained an intermittently occurring bug in either the cameras or controllers that neither we were unable to isolate and reproduce in testing. Given these difficulties, the cameras were removed from the housings and returned to the laboratory in the spring of 2005.

Table 1. Summary of camera locations and operations.

Camera Location	# Cameras	Camera Start	Camera End	# Photos
Aurora Rock	4 (A,B,C,D)	19 October 2003	11 October 2004	7,480
Anchor Point	2 (M,N)	12 May 2004	26 September 2004	2,278
Augustine Island East	3 (E,G,L)	10 May 2004	27 January 2005	6,062
Augustine Island West 1	2 (J,K)	7 May 2004	28 September 2004	2,143
Augustine Island West 2	3 (F,H,I)	10 May 2004	8 September 2004	3,254
Total	14	19 October 2003	27 January 2005	21,217

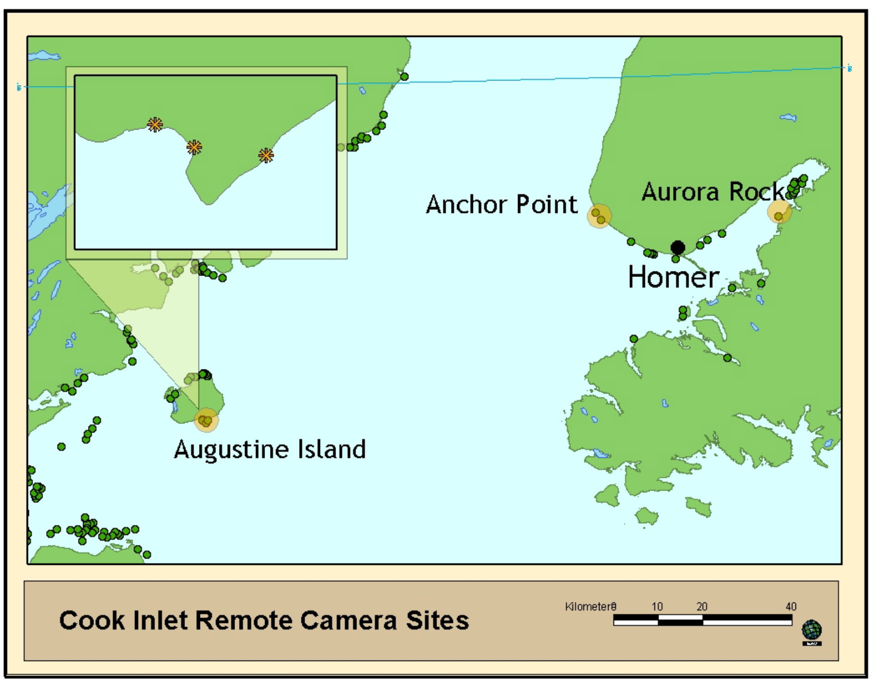


Figure 1. Locations of remote camera installations in southern Cook Inlet. Inset shows location of cameras installed at Augustine Island.

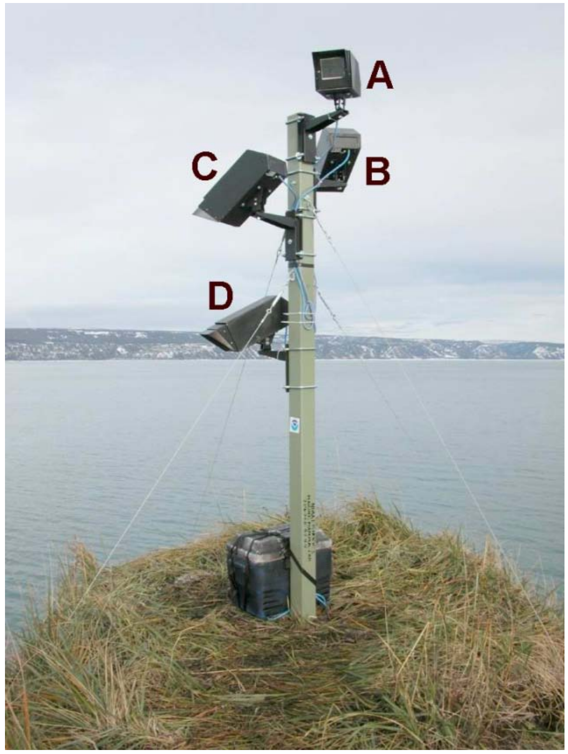


Figure 2. Photograph of time-lapse camera systems deployed at Aurora Rock in Kachemak Bay. Four cameras (A – D), with time-lapse controllers, were attached to one support post anchored with guy wires. The cameras were aimed to ensure complete coverage.

Weather Data

Aurora Rock

Weather data for Aurora Rock were collected from multiple sources. The Kachemak Bay Research Reserve provided hourly measurements of air temperature, barometric pressure, wind speed, wind direction, relative humidity, downwelling irradiance and precipitation from a weather station located at the end of the Homer Spit. Hourly tide heights, sunrise, and sunset times were calculated from the software *Tides & Currents 3.0i* (Nobeltec Corporation), using Bear Cove as the closest tidal site. A Hobo data logger (Onset Computer Corp) placed in the camera housing unit was also used to record air temperature, relative humidity, dew point, and absolute humidity.

Augustine Island

Weather data for Augustine Island were obtained from the National Data Buoy Center C-MAN station (http://www.ndbc.noaa.gov/). The station ID is AUGA2 and the site is located 9.1 m above mean sea level at 59°22'42" N 153°20'54" W on Augustine Island. Hourly measurements of air temperature, barometric pressure, wind speed, wind direction, wind gusts, and dew point were collected. Parameters such as precipitation, relative humidity and downwelling irradiance were not monitored. Hourly tide heights, sunrise, and sunset times were calculated from *Tides & Currents 3.0i* (Nobe ltec Corporation), using Nordyke Island, Kamishak Bay as the closest tidal site. A Hobo data logger (Onset Computer Corp) placed in two of the camera housing units were also used to record air temperature, relative humidity, dew point, and absolute humidity.

Anchor Point

Weather data for Anchor Point were obtained from the National Data Buoy Center C-MAN station (http://www.ndbc.noaa.gov/). The station ID is FILA2 and the site is located 17.9 m above mean sea level at 59°19'54" N 151°59'42" W on Flat Island, Kachemak Bay. Although at the mouth of Kachemak Bay, Flat Island was chosen because it is the closest weather station to the Anchor Point camera site with similar weather conditions. Hourly measurements of air temperature, barometric pressure, wind speed, wind direction, wind gusts, and dew point were collected. Parameters such as precipitation, relative humidity and downwelling irradiance were not monitored. Hourly tide heights, sunrise, and sunset times were calculated from *Tides & Currents 3.0i* (Nobeltec Corporation), using Anchor Point, Cook Inlet as the closest tidal site. A Hobo data logger (Onset Computer Corp) placed in the camera housing unit was also used to record air temperature, relative humidity, dew point, and absolute humidity.

Database

A relational database was created in Microsoft Access. For each picture taken, the date, time, number of seals hauled out, and a rating of the view were recorded along with camera system information such as camera ID, digisnap ID, and data card ID (Table 2). Additional information, such as number of pups, number of seals in the water, otters, and eagles (Table 3), was recorded for the Aurora Rock location.

Table 2. Parameters recorded for each photograph.

Date	Date photograph was taken
Time	Time photograph was taken, rounded to the closest hour (Alaska Standard Time)
Adult	Number of seals ashore in photo
Card	Data card ID
Digisnap	Digisnap ID
Camera	Camera ID
View	Good; OK; Bad; No Photo; No View (due to darkness, precipitation, etc). A rating of the photo was given to answer the question: can the seals be seen? This parameter is not a rating of count accuracy. For example, the view could be 'good', because it is a clear view of the seals, but count accuracy could be low because the seals were far away and photographed at a low resolution. OK and Bad views did negatively affect count accuracy, however, but were a result of weather conditions such as fog, wind, and rain. Because all of the photographs were taken from the same spot with the same resolution, count accuracy was rated overall for each site and not for each photograph.
Missed	(Yes/No) This box was checked if there were seals cut off on the edge of the frame, implying that there were seals on the haul-out that could not be seen by the cameras.
Photo	Link to original digital photograph. Naming scheme = "Camera Location_ Camera ID_Year_Month_Day_Hour.jpg" For example, AI_F_2004_05_09_17.jpg Camera locations are: AP=Anchor Point; AR=Aurora Rock; AI=Augustine Island Camera ID are the letters A through N (14 individual cameras)
Disturbance	(Yes/No) Was there a known disturbance to the haul-out?

Comments	Any comments such as description of disturbance, notes on weather, maintenance notes, etc.

Table 3. Additional parameters recorded at Aurora Rock only.

Pup	Number of pups ashore in photo (cameras B, C, and D only). Pups were counted from when they were first seen through the month of June. (22 May — 30 June 2004)
Swim	Number of seals swimming in photo (cameras A, B, C, and D only)
Otter	Number of otters ashore in photo. Otters are often-times difficult to see on the rocks, especially pups. The otter count is an estimate of animals ashore (cameras A, B, C, and D only)
OtterSwim	Number of otters swimming in photo (cameras A, B, C, and D only)
Eagle	Number of eagles in photo (cameras A, B, C, and D only)

RESULTS

Aurora Rock

Cameras A, B, C, & D

Aurora Rock is a small islet, and all four cameras were pointed in different directions, providing photographic coverage over nearly all of the areas where harbor seals have been observed to haul out on the islet (Figure 3). The Aurora Rock cameras began taking pictures on 19 October 2003, and the last picture was taken a year later on 11 October 2004, amounting to 3,821 hours of coverage (Table 4). Between 6 April and 10 August 2004, the camera systems were programmed to capture one image per hour from 6:00 to 22:00. Due to shorter day length, the cameras were re-programmed to capture images between 10:00 and 18:00 at all other times of the year (Figure 5). A total of 7,480 photographs were taken, and seals were present in 1,092 (15%) of the photographs (Table 5). Using the hourly data to create a histogram of the time of day seals came out of the water shows that the greatest number of seals was hauled out at 10:00 and the smallest numbers of seals were hauled out after 18:00 (Figure 6). Camera malfunction posed a significant obstacle for interpreting patterns of seal haul-out behavior from the Aurora Rock data set; despite frequent camera maintenance visits, all four cameras were taking pictures simultaneously only 88 times (Table 4, Figure 4).

Camera A seemed to be the most important view as seals were present on nearly all dates when the camera was working, even as early as February (Figure 7 a-d). Camera A was not working from 26 October 2003 – 21 February 2004, so it is unknown whether seals were using Aurora during this time. Seals were not seen on cameras B and C until mid-April 2004, even though the cameras were working since February. Camera D was not working for much of the study so it was difficult to tell whether seals were consistently using this side of the islet.

Sea otters were seen in photographs at all times of the year, both rafted up in the water and resting on the island in large groups (Table 6). Sea otters were counted in all photographs in which they were present, however, they were more difficult to detect and count than harbor seals. The counts therefore represent an estimate of sea otters that were resting on the island. Otters were most commonly seen on camera B, and were present in the highest numbers during the winter months (Figure 8). Camera B did not take photographs from 20 June – 10 August 2004, so it is unknown if sea otters were using Aurora Rock during the summer months.

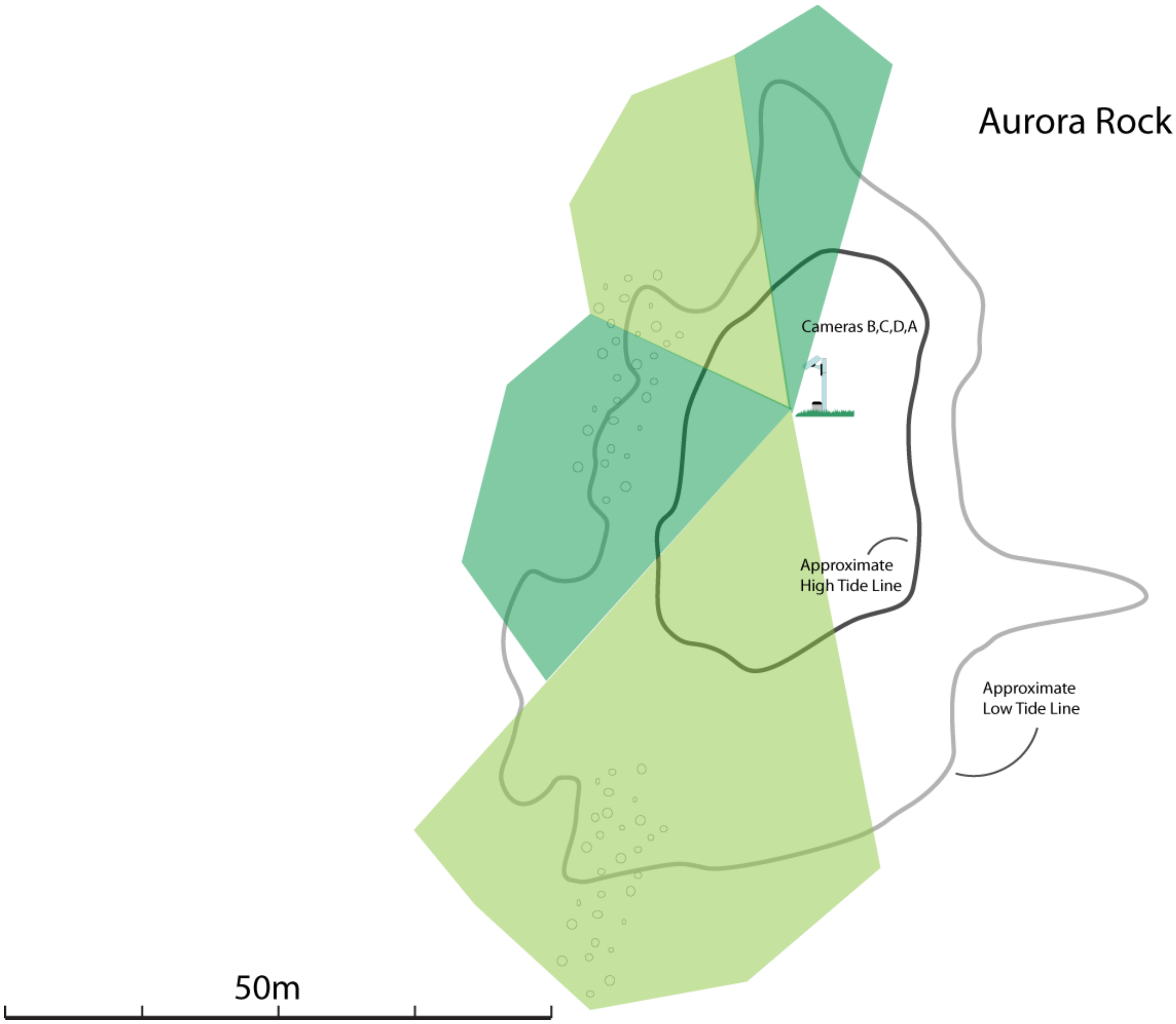


Figure 3. Schematic/photograph of time-lapse camera systems deployed at Aurora Rock in Kachemak Bay. Four cameras, with time-lapse controllers, were attached to one support post that was anchored to the top of the island. The fields of view are labeled for each of the four cameras, A-D. The cameras were aimed to ensure complete coverage of all haul-out areas surrounding the islet. The arc labeled X was not included in the view of any cameras because seals were never hauled out in that area during surveys in June, August, or October 2003.

Table 4. Summary of Aurora Rock camera operation. A record equals one hour of coverage during one day.

Cameras start	10/19/2003 10:00 AM
Cameras stop	10/11/2004 10:00 AM
Total number of records (at least 1 camera working)	3,821
Number of records where all 4 cameras were working	88

Table 5. Summary of harbor seal haul-outs by camera view at Aurora Rock. Pups were able to be counted on cameras B, C, & D. Pups were not counted on camera A, however, because the lower camera angle and longer distance to the seals made it difficult to distinguish pups from adults.

Camera view	Number of photographs	Number of photographs where seals were present (>0)	%Time seals were present	Max # of seals in frame	Avg. # of seals (when >0) in frame	Max # of pups (June) in frame
A	1,797	517	29%	82	17	N/A
B	2,507	298	12%	52	13	9
C	2,680	248	9%	65	12	6
D	496	29	6%	12	2	2
Total	7,480	1,092	15%			

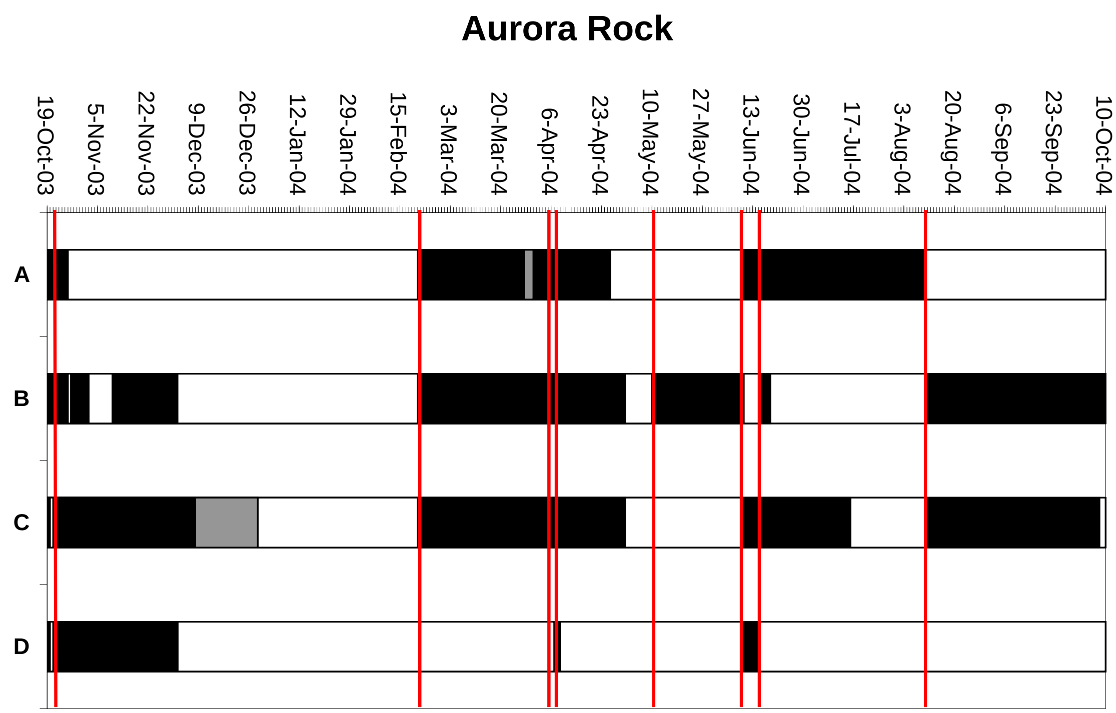


Figure 4. Temporal coverage of time-lapse camera imagery collected at Aurora Rock between 19 October 2003 and 11 October 2004. Cameras A-D are represented on the y-axis, with dates on the x-axis. Red lines represent when maintenance was performed on the camera systems and photographs were downloaded. Black segments of the bars represent time periods in which imagery was captured throughout the day, grey segments are periods when the cameras took pictures, but the images were obscured by weather, and white segments are when no photographs were taken due to loss of power or camera malfunction. Between 6 April and 10 August, the camera systems were programmed to capture one image per hour from 6:00 to 22:00. Due to shorter day length, the cameras were re-programmed to capture images between 10:00 and 18:00 at all other times of the year.

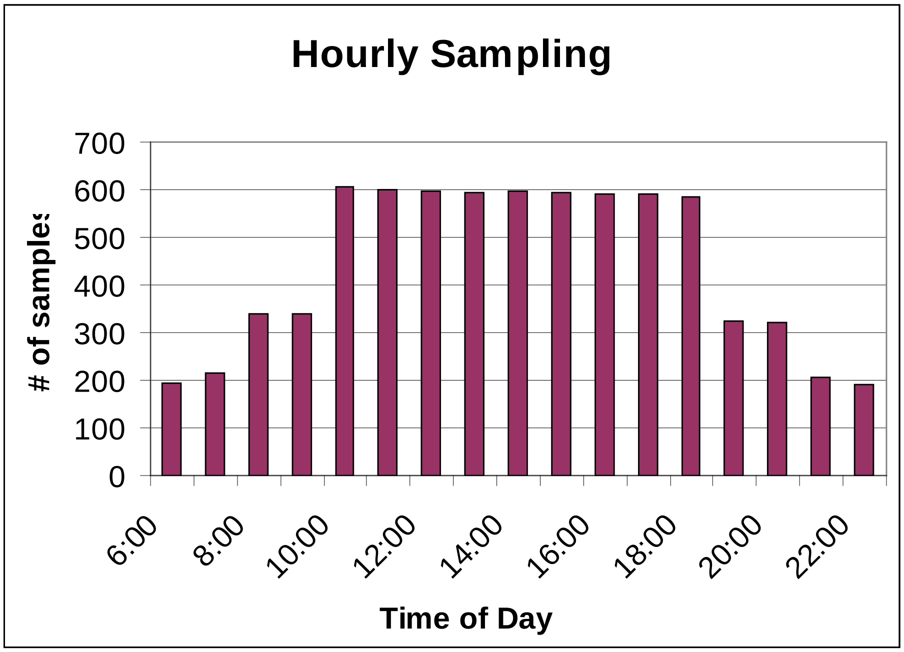


Figure 5. Histogram of sampling scheme from Aurora Rock. 10:00-18:00 were sampled equally, approximately 600 times. Due to darkness, earlier and later times were sampled less frequently.

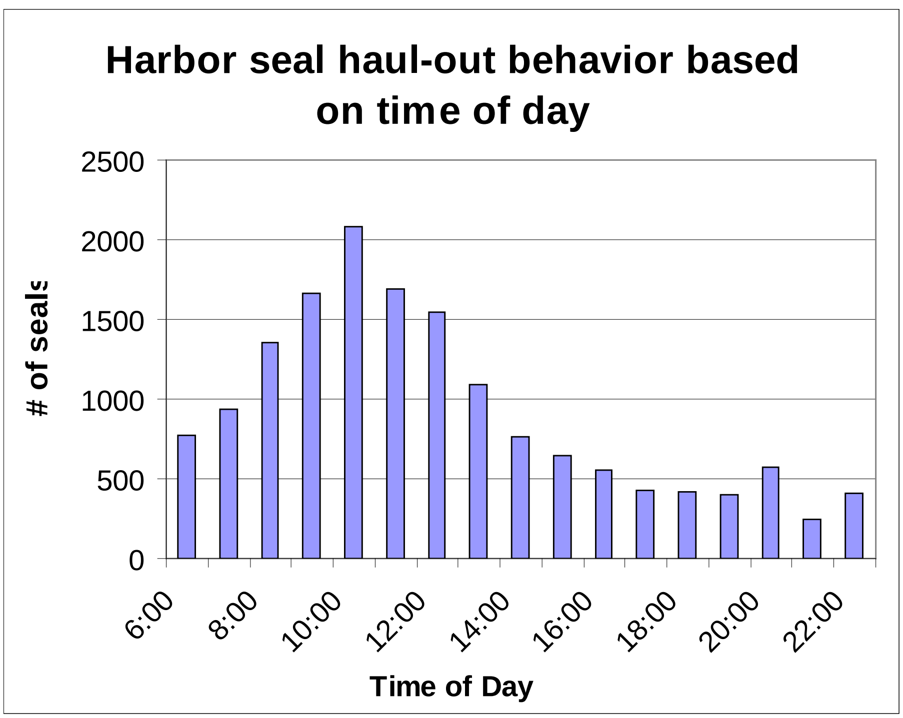
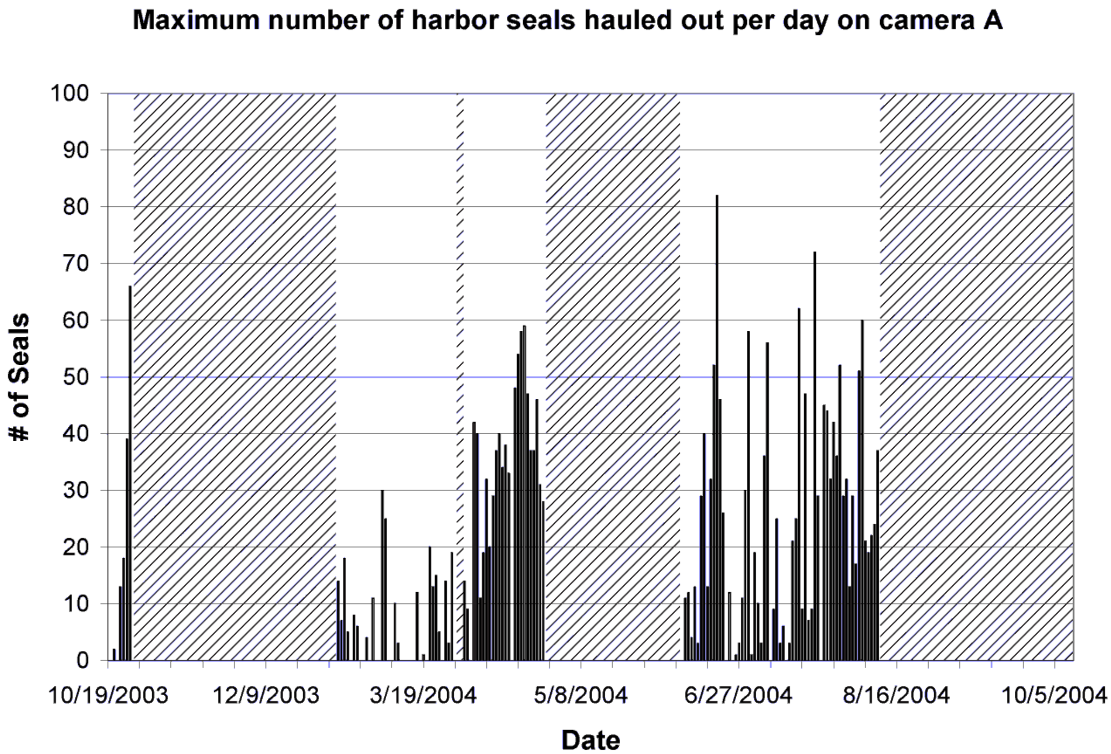
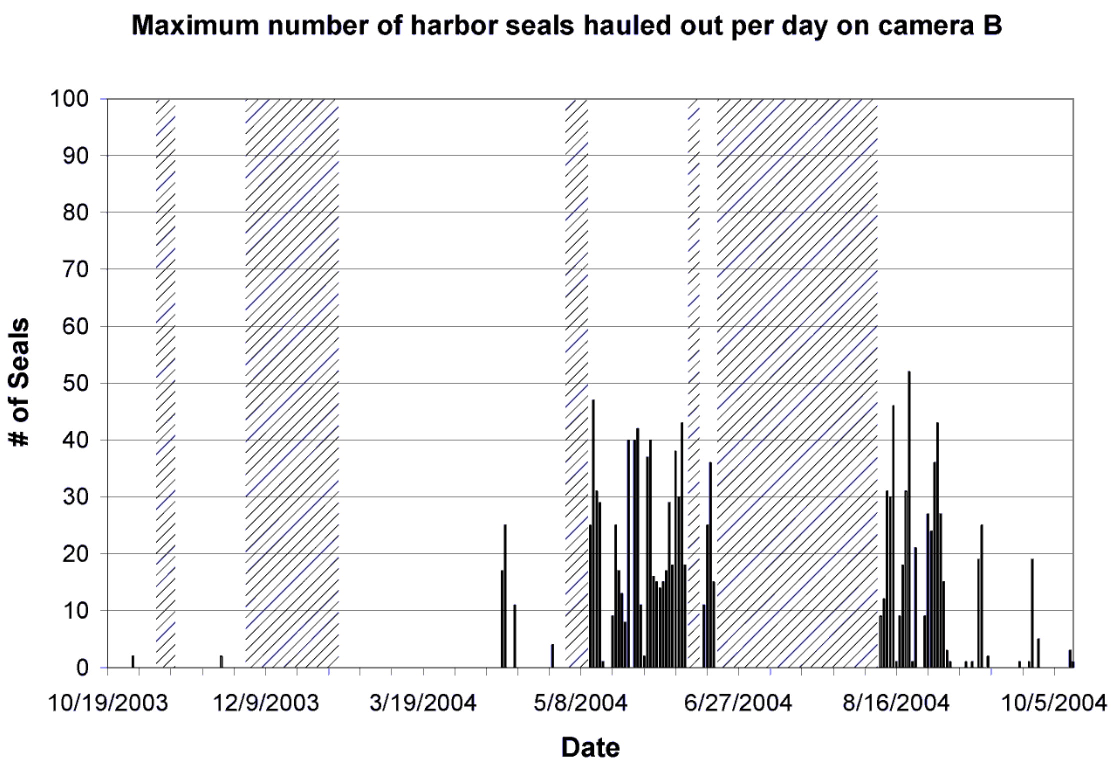


Figure 6. Histogram of hourly haul-out behavior from Aurora Rock. Hours 10:00-18:00 were sampled equally, while hours outside of that range were not sampled before 6 April 2004 and after 10 August 2004, due to shorter day lengths (see Figure 5).

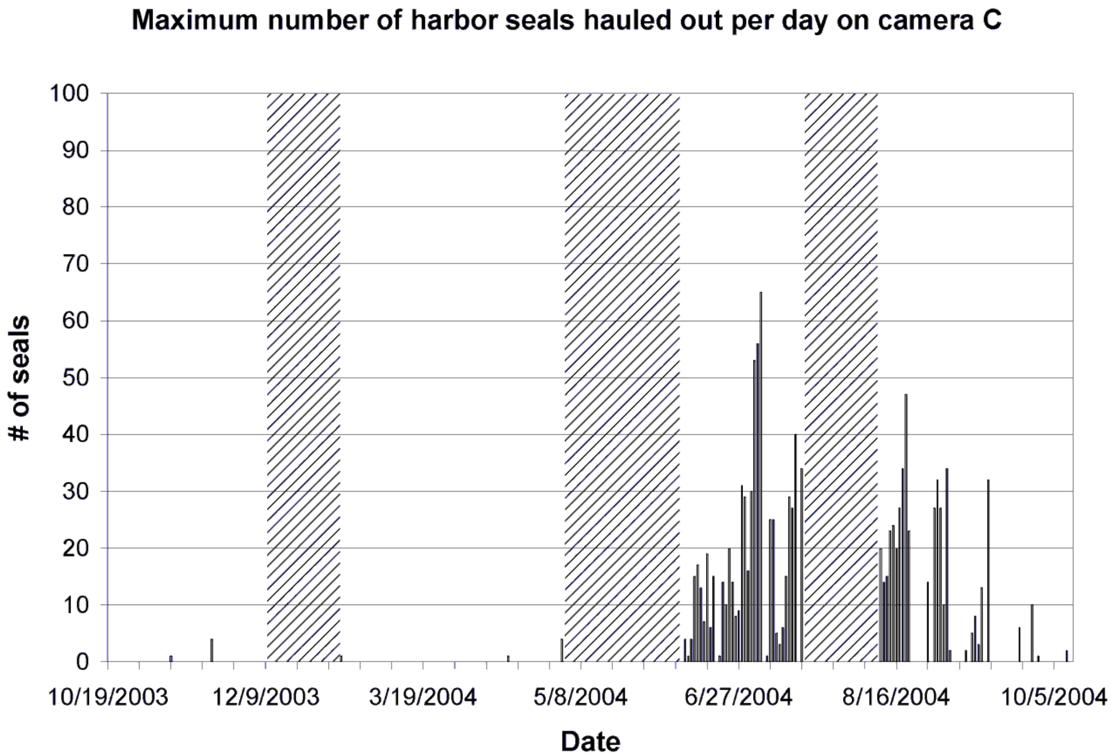
A.


Maximum number of harbor seals hauled out per day on camera A
100
90
80
70
60
50
40
30
20
10
0
# of Seals
10/19/2003
12/9/2003
3/19/2004
5/8/2004
6/27/2004
8/16/2004
10/5/2004
Date

B.


Maximum number of harbor seals hauled out per day on camera B
100
90
80
70
60
50
40
30
20
10
0
# of Seals
10/19/2003
12/9/2003
3/19/2004
5/8/2004
6/27/2004
8/16/2004
10/5/2004
Date

C.



D.

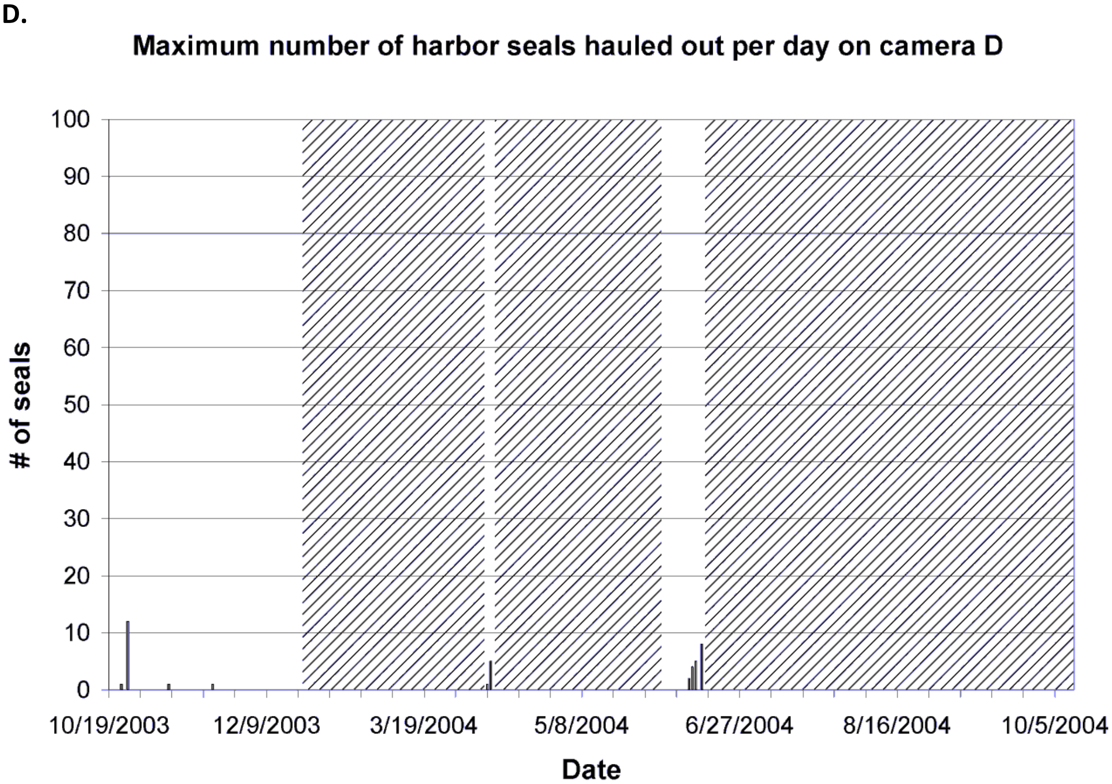


Figure 7. (a-d). Maximum number of harbor seals hauled out per day on cameras A, B, C, or D at Aurora Rock. The hatched areas represent times when the cameras were not working and no photographs were taken.

Table 6. Summary of sea otter haul-outs by camera view. Otters hauled out at Aurora rock throughout the year, mostly on camera B. Otters were more difficult to count because they blended into the rocky substrate. It was also difficult to tell when otter pups were present. Therefore, the otter counts represent an estimate rather than an exact number. A record corresponds to one hourly photograph.

Camera View	Number of records	Number of records where otters were present (>0)	%Time otters were present	Max # of otters in frame	Avg. # of otters in frame (when >0)	# times seals and otters used haul-out simultaneously
A	1,797	101	6%	17	5	7
B	2,507	268	11%	30	6	59
C	2,680	49	2%	7	2	6
D	496	9	2%	11	3	0
Total	7,480	427	6%			

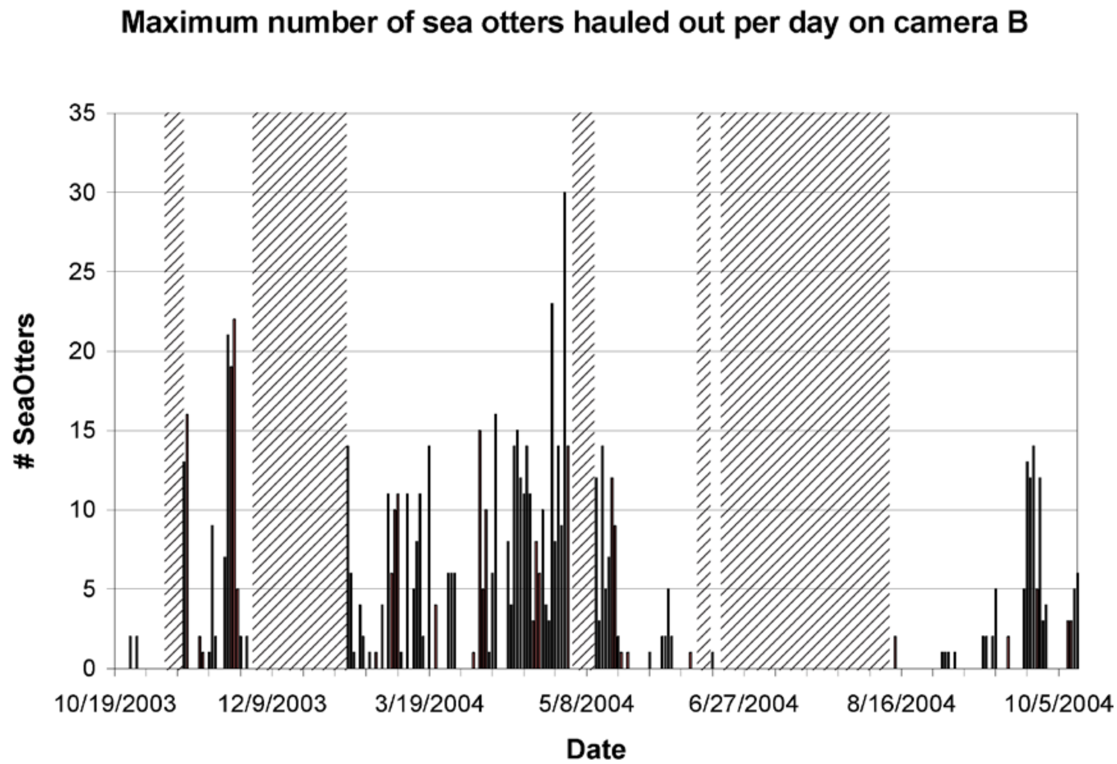


Figure 8. Maximum number of sea otters hauled out per day on camera B at Aurora Rock. The hatched areas represent times when camera B was not working and there were no photographs.

Augustine Island (East)

Cameras E, G, & L

The cameras began taking pictures on 10 May 2004, and the last picture taken was on 27 January 2005, amounting to 3,768 hours of coverage (Table 7). Between 10 May and 7 August, the camera systems were programmed to capture one image per hour from 6:00 to 22:00. Due to shorter day length, the cameras were re-programmed to capture images from 8:00 to 20:00 between 8 August and 27 January.

A total of 6,062 photographs were taken between the 3 cameras, and seals were present in 427 (7%) of the photographs (Table 8).

All three camera views were changed during the maintenance visit on 8 August (Figure 9). Originally, camera E photographed an overview of the beach, but also had complete coverage of the foreground area. By August, the wind had most likely knocked the camera housing gradually to one side, and much of the foreground was cut off. After the maintenance visit on 8 August, the cameras were readjusted and there was better overlapping coverage than before. Because of the change in view, counts from individual cameras before 8 August are not directly comparable to counts on the same camera after 8 August.

After 8 August, Camera L took the most panoramic pictures, and hence had more seals in each frame than the other two cameras (Figure 9). Camera E looked almost straight down, overlapping with L in the foreground, while camera G used the zoom feature to take pictures of seals that were the farthest away, also overlapping with camera L.

Camera L had the best overview of the seals, though the resolution was poor. The counts on camera L therefore represent a rough estimate instead of an exact number. The photographs start out at high resolution in the foreground, and become increasingly blurry as the seals were located farther away. In large groups of tightly packed seals, it was difficult to distinguish individuals during the counts. Camera G and E both had good resolution and counts were fairly easy. They were meant to overlap with camera L, however, so they both have poor coverage of the beach (Figure 9).

All three cameras were operating during 1,335 hours of coverage from 10 May – 1 August 2004, but no seals were seen to use the haul-out during that time. Seals did appear in the photographs from 1 August – 21 September, but camera G was the only camera functioning after 15 August (Figure 10, Figure 11a-c). There were only a few hours of one day, 1 August, when all three cameras were taking pictures simultaneously and seals were present. However, due to glare and poor directional coverage from camera E, the photos on 1 August still did not provide a complete count.

Table 7. Summary of Augustine Island (East) camera operation. A record corresponds to one hourly photograph.

Cameras start	10 May 2004
Cameras stop	27 January 2005
Total number of records (at least 1 camera working)	3,768
Number of records where all 3 cameras were working	1,335

Table 8. Summary of harbor seal haul-outs by camera view at Augustine Island (East). Pups were not counted in any of the photographs.

Camera view	Number of photographs	Number of photographs where seals were present (>0)	% Time seals were present	Max # of seals in frame	Avg. # of seals (when >0) in frame
E	1,431	32	2%	135	79
G	3,084	272	9%	298	84
L	1,547	123	8%	479	226
Total	6,062	427	7%		

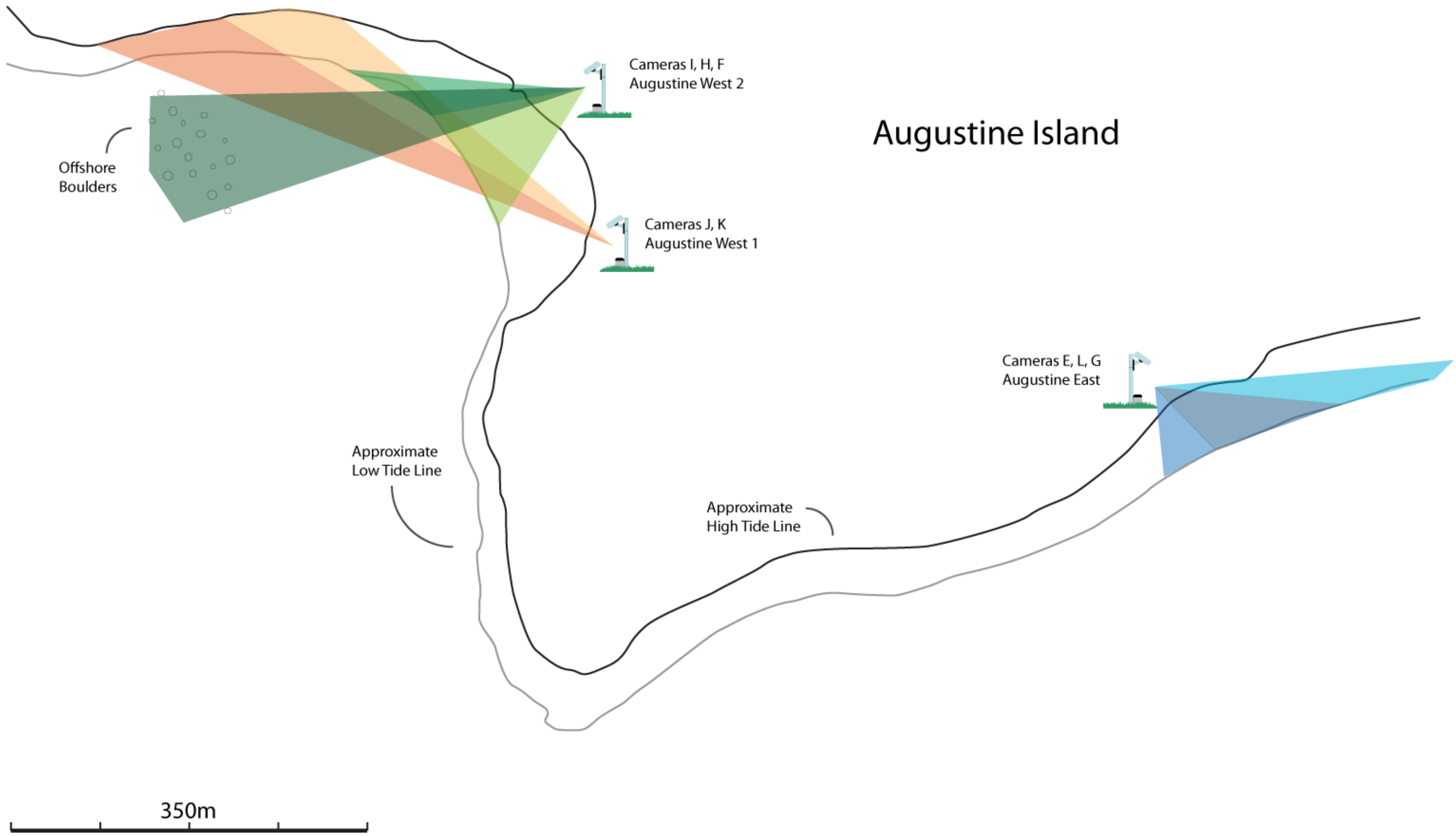


Figure 9. Schematic view of the cameras on Augustine Island. Prior to 8 August, Camera E took the most panoramic pictures, while cameras G and L were zoomed to the far edge of camera E's view. Seals were only present in photographs between 1-8 August. After 8 August, Camera L took the most panoramic pictures, while cameras E and G focused on the edges of camera L's view. Camera views on Augustine Island (West-1 and West-2) remained constant. At low tide, the water would recede completely from the camera views of the beach. Camera I and H used the zoom lens to focus on offshore rocks, while camera F took a panoramic view of the entire beach.

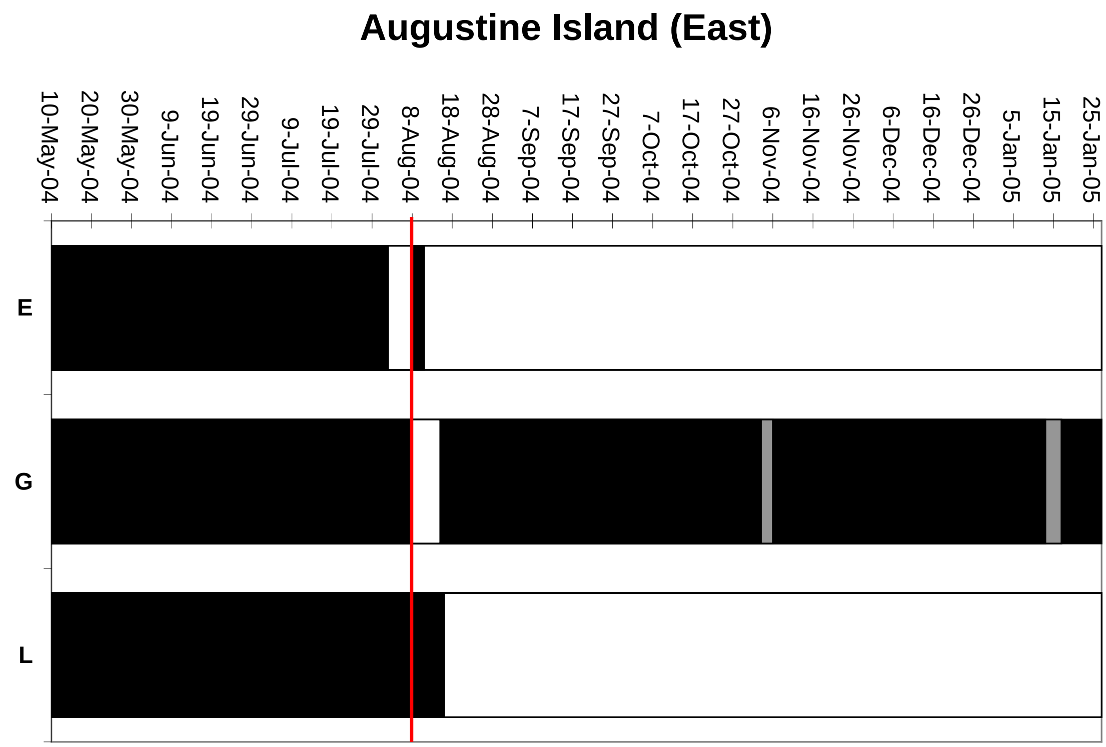
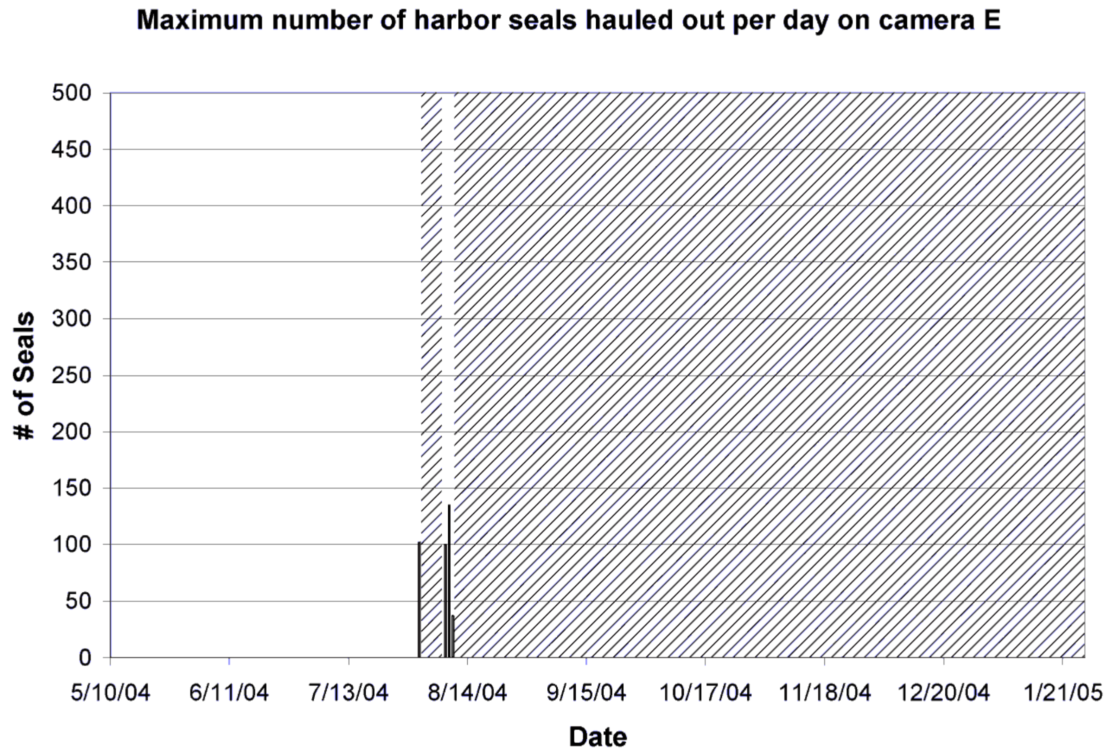
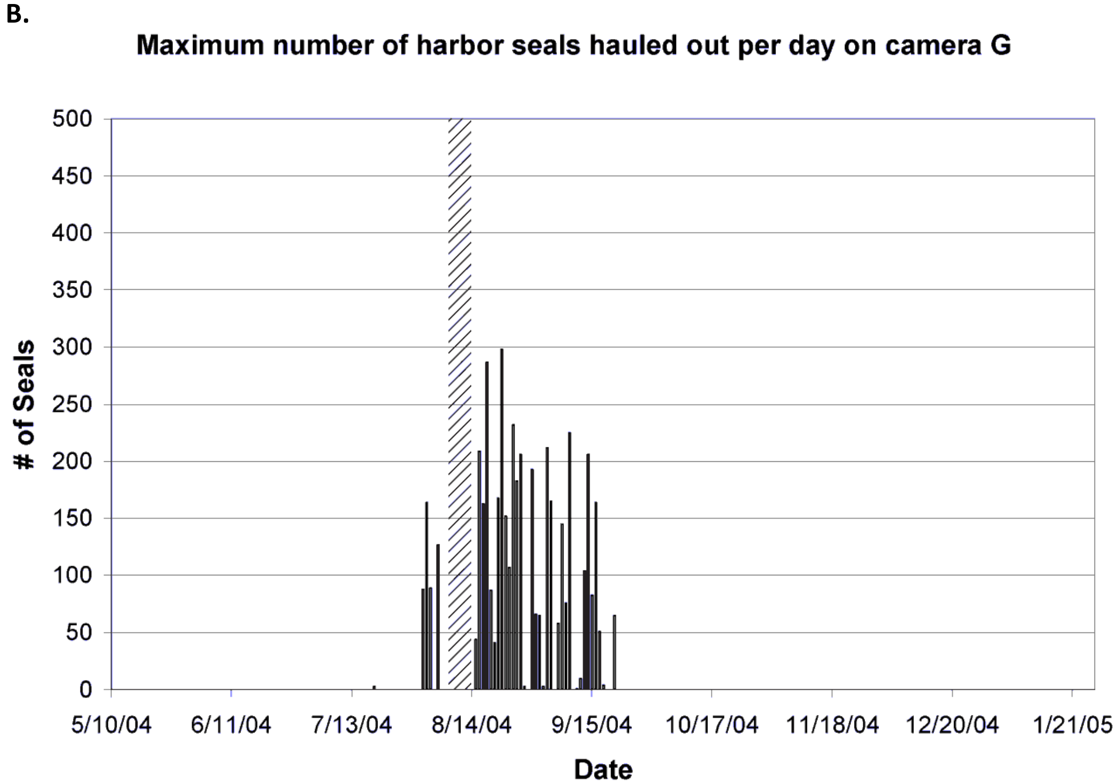


Figure 10. Temporal coverage of time-lapse camera imagery collected at Augustine Island (East) between 10 May 2004 and 27 January 2005. Cameras E, G, and L, are represented on the y-axis, with dates on the x-axis. The red line represents when maintenance was performed on the camera systems and photographs were downloaded. Black segments of the bars represent time periods in which imagery was captured throughout the day, grey segments are periods when the cameras took pictures, but the images were obscured by weather, and white segments are when no photographs were taken due to loss of power or camera malfunction. Between 10 May and 7 August, the camera systems were programmed to capture one image per hour from 6:00 to 22:00. Due to shorter day length, the cameras were re-programmed to capture images from 8:00 to 20:00 between 8 August and 27 January.

A.


Maximum number of harbor seals hauled out per day on camera E
500
450
400
350
300
250
200
150
100
50
0
# of Seals
5/10/04
6/11/04
7/13/04
8/14/04
9/15/04
10/17/04
11/18/04
12/20/04
1/21/05
Date

B.


Maximum number of harbor seals hauled out per day on camera G
500
450
400
350
300
250
200
150
100
50
0
# of Seals
5/10/04
6/11/04
7/13/04
8/14/04
9/15/04
10/17/04
11/18/04
12/20/04
1/21/05
Date

c.

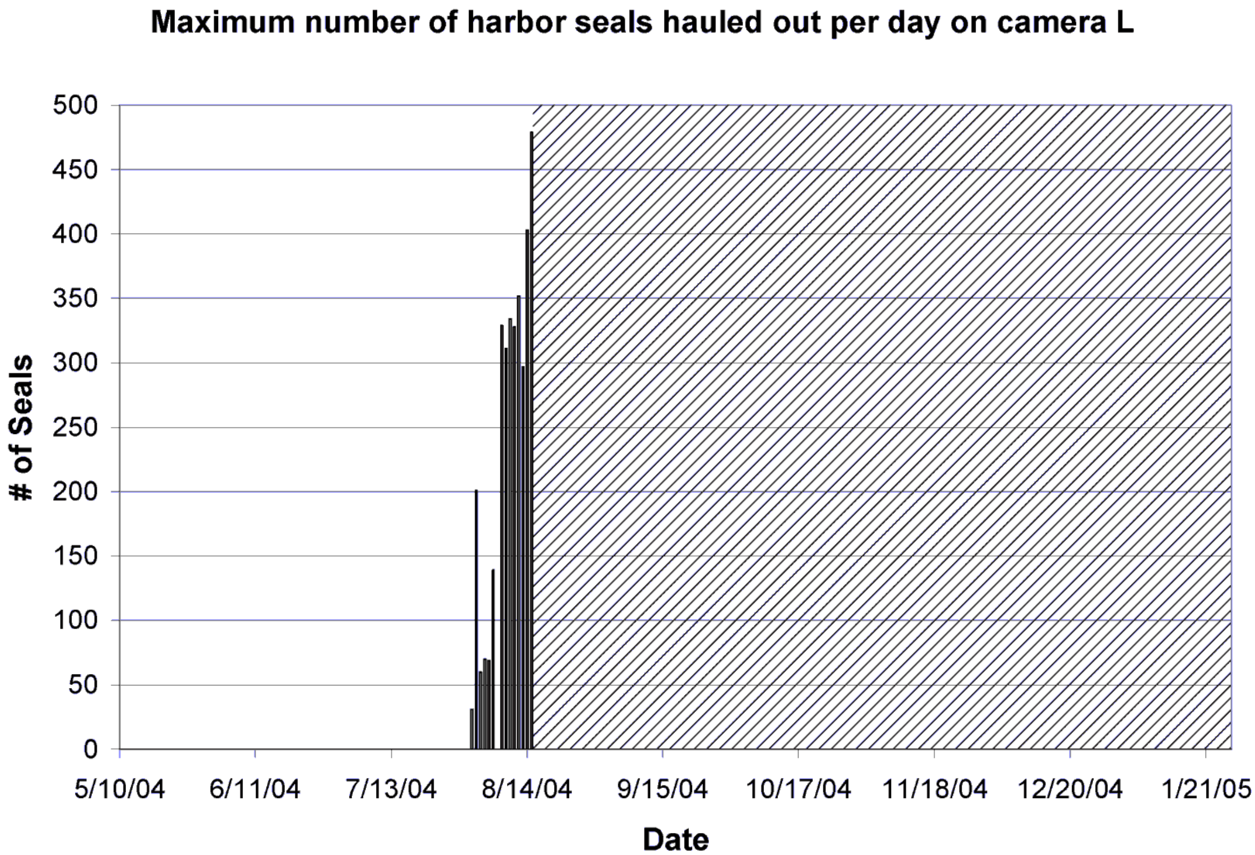


Figure 11. (a-c). Maximum number of harbor seals hauled out per day on cameras E, G, and L at Augustine Island (East). The hatched areas represent times when the cameras were not working and no photographs were taken.

Augustine Island (West-1)

Cameras J & K

The cameras began taking pictures on 7 May 2004, and the last picture was taken on 28 September 2004. Between 7 May and 7 August, the camera systems were programmed to capture one image per hour from 6:00 to 22:00. Due to shorter day length, the cameras were re-programmed to capture images from 8:00 to 20:00 between 8 August and 28 September. There were 2,243 hours of photographic coverage, with both cameras operating simultaneously only during 243 of those hours (Table 9). Between 2 cameras, a total of 2,136 photographs were taken, and seals were present in 426 (20%) of the pictures (Table 10).

Cameras J and K were positioned to take overlapping photographs of the beach (Figure 9). Although seals were frequently seen on photographs from camera J, no seals were seen in the camera K view (Table 10). This is most likely because camera K was not operating from 8 May until 7 August, the time when seals were seen to use this beach (Figure 13a-b, Figure 14). In July, groups of seals were oftentimes cut off on the edge of the picture taken by camera J. Camera K would have taken pictures of these ‘off camera’ seals, had it been operating.

When counting, it was extremely difficult to detect individual seals and distinguish between seals and rocks. Because of low photographic resolution, the counts represent an estimate of seals on the beach instead of an exact number, and pup counts were not possible from any of the photographs from Augustine Island (West-1).

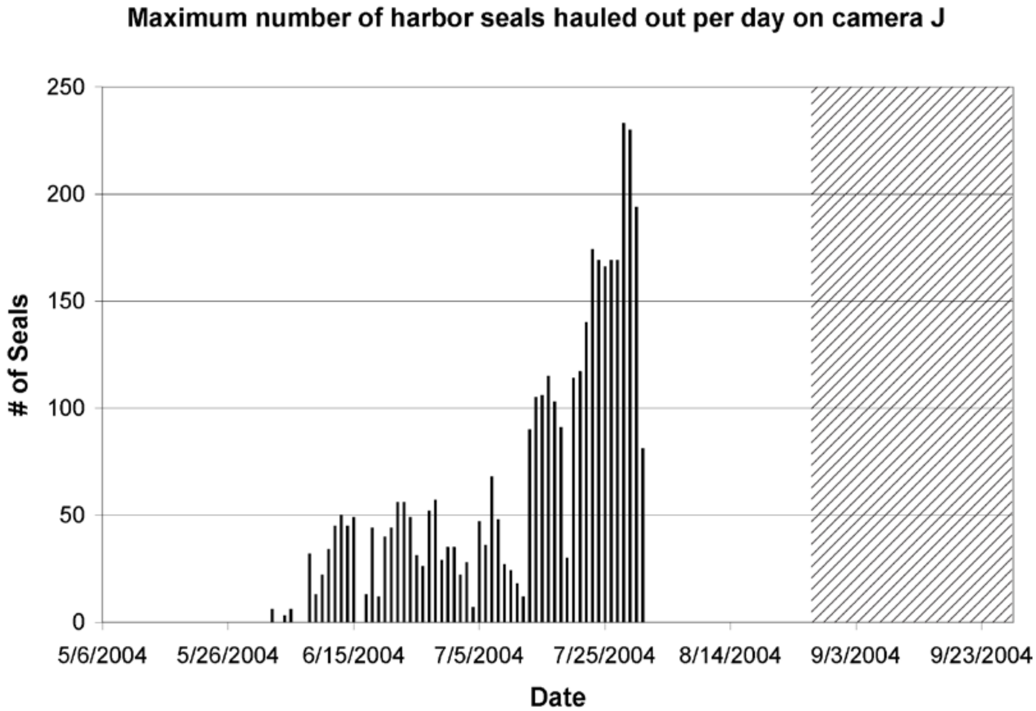
Table 9. Summary of Augustine Island (West-1) camera operation. A record equals one hour of coverage during one day.

Cameras start	7 May 2004
Cameras stop	28 September 2004
Total number of records (at least 1 camera working)	2,243
Number of records where both cameras were working	243

Table 10. Summary of harbor seal haul-outs by camera view at Augustine Island (West-1). Pups were not counted in any of the photographs.

Camera view	Number of photographs	Number of photographs where seals were present (>0)	% Time seals were present	Max # of seals in frame	Avg. # of seals (when >0) in frame
J	1,576	426	27%	233	47
K	560	0	0%	0	0
Total	2,136	426	20%		

A.



B.

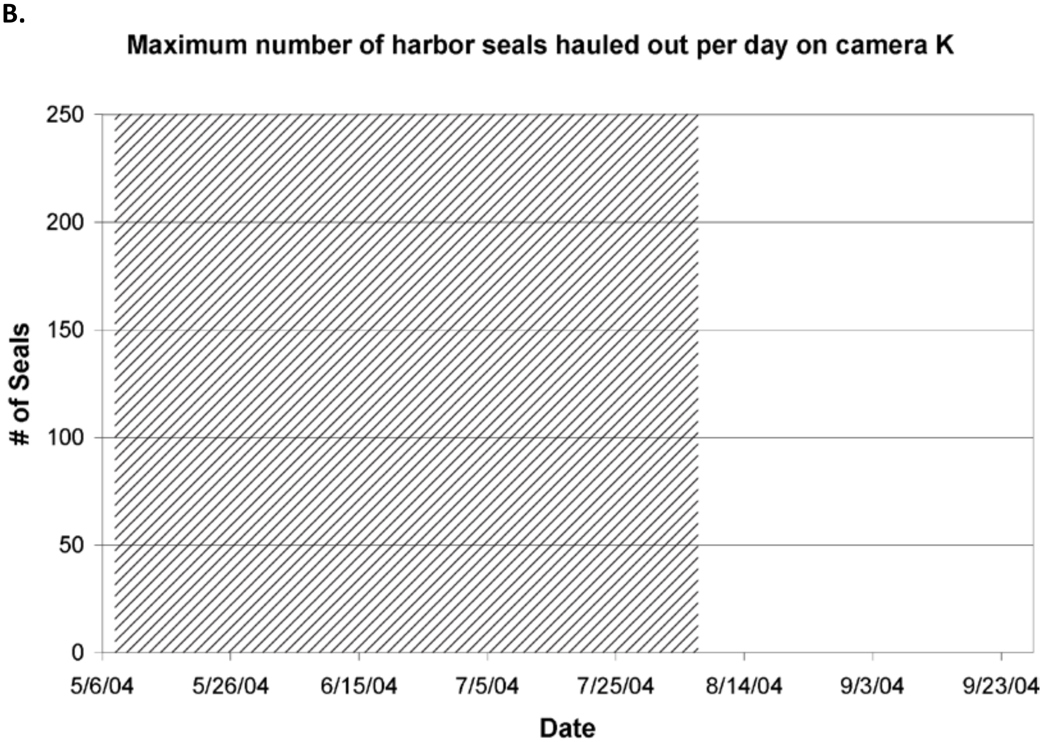


Figure 12 (a-b). Maximum number of harbor seals hauled out per day on cameras J and K at Augustine Island (West-1). The hatched areas represent times when the cameras were not working and no photographs were taken.

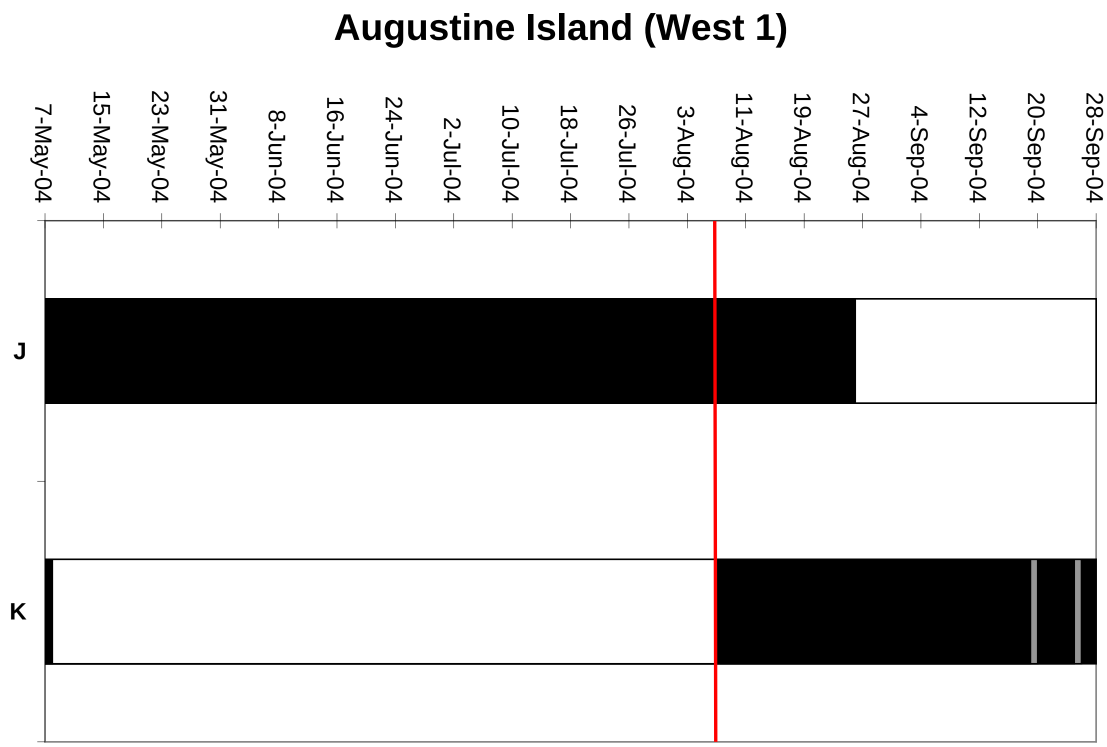


Figure 13. Temporal coverage of time-lapse camera imagery collected at Augustine Island (West-1) between 7 May and 28 September 2004. Cameras J and K, are represented on the y-axis, with dates on the x-axis. The red line represents when maintenance was performed on the camera systems and photographs were downloaded. Black segments of the bars represent time periods in which imagery was captured throughout the day, grey segments are periods when the cameras took pictures, but the images were obscured by weather, and white segments are when no photographs were taken due to loss of power or camera malfunction. Between 7 May and 7 August, the camera systems were programmed to capture one image per hour from 6:00 to 22:00. Due to shorter day length, the cameras were re-programmed to capture images from 8:00 to 20:00 between 8 August and 28 September.

Augustine Island (West-2)

Cameras I, H, & F

The cameras began taking pictures on 10 May 2004, and the last picture was taken on 8 September 2004. Between 10 May and 7 August, the camera systems were programmed to capture one image per hour from 6:00 to 22:00. Due to shorter day length, the cameras were re-programmed to capture images from 8:00 to 20:00 between 8 August and 8 September. There were 1,776 hours of photographic coverage, with all three cameras operating simultaneously only during 497 of those hours (Table 11, Figure 14). A total of 3,254 photographs were taken, and seals were present in 249 (8%) of the pictures (Table 12).

Cameras H and I were positioned to take overlapping photographs of offshore rocks, while camera F took a panoramic picture of the entire beach (Figure 9). Seals were present on the offshore rocks on many of the days when the cameras were operating (Figure 15a-c), though the counts should be considered approximate; because of the long distance to the seals and low camera angle, it was very difficult to discern whether some of the exposed rocks had seals resting on them.

Table 11. Summary of Augustine Island (West 2) camera operation. A record equals one hour of coverage during one day.

Cameras start	5/10/2004 6:00:00 AM
Cameras stop	9/8/2004 8:00:00 PM
Total number of records (at least 1 camera working)	1,776
Number of records where all 3 cameras were working	497

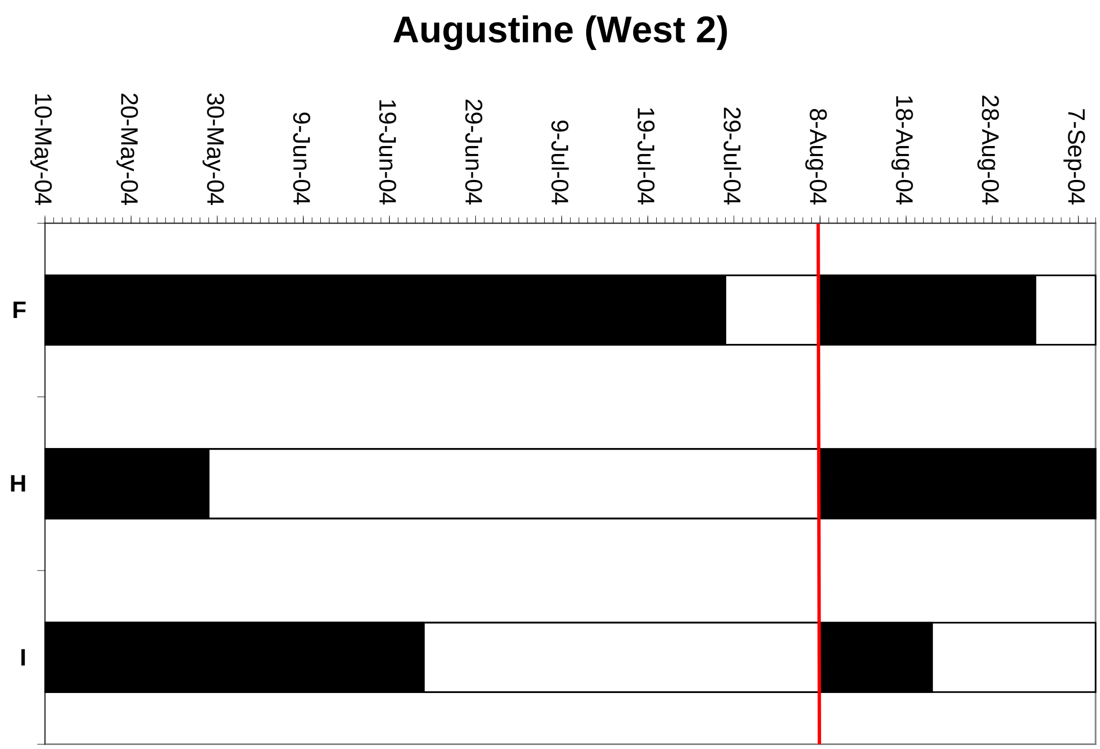
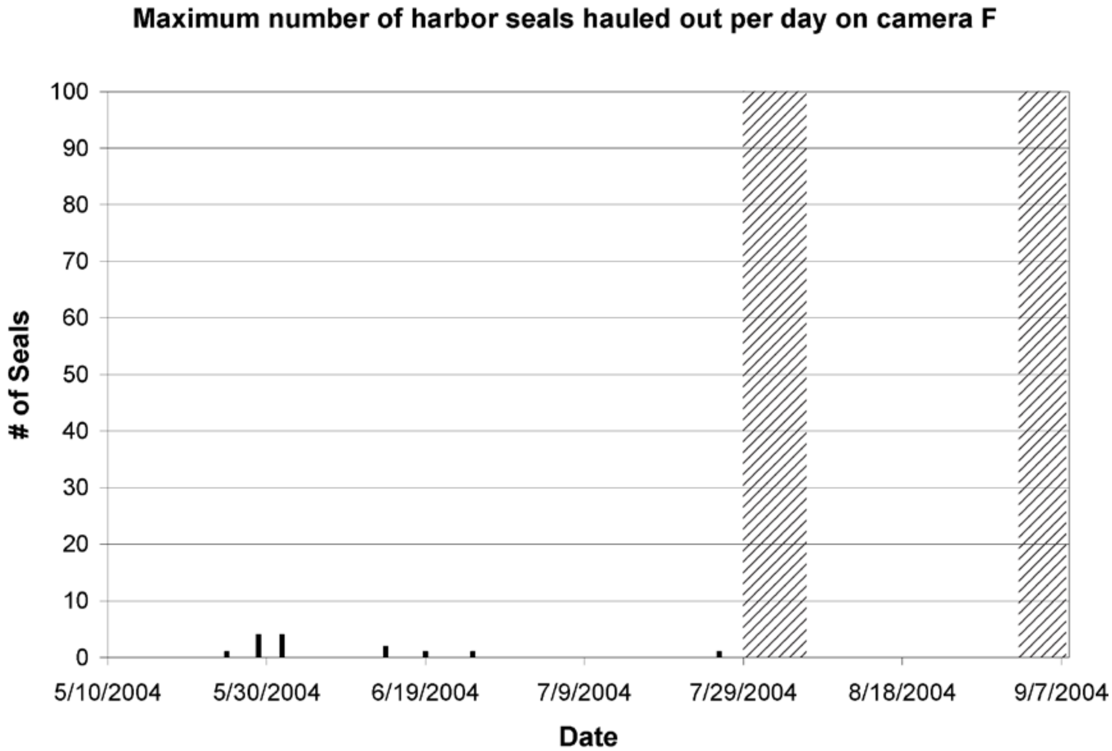


Figure 14. Temporal coverage of time-lapse camera imagery collected at Augustine Island (West-2) between 10 May and 8 September 2004. Cameras F, H, and I, are represented on the y-axis, with dates on the x-axis. The red line represents when maintenance was performed on the camera systems and photographs were downloaded. Black segments of the bars represent time periods in which imagery was captured throughout the day, and white segments are when no photographs were taken due to loss of power or camera malfunction. Between 10 May and 7 August, the camera systems were programmed to capture one image per hour from 6:00 to 22:00. Due to shorter day length, the cameras were re-programmed to capture images from 8:00 to 20:00 between 8 August and 8 September.

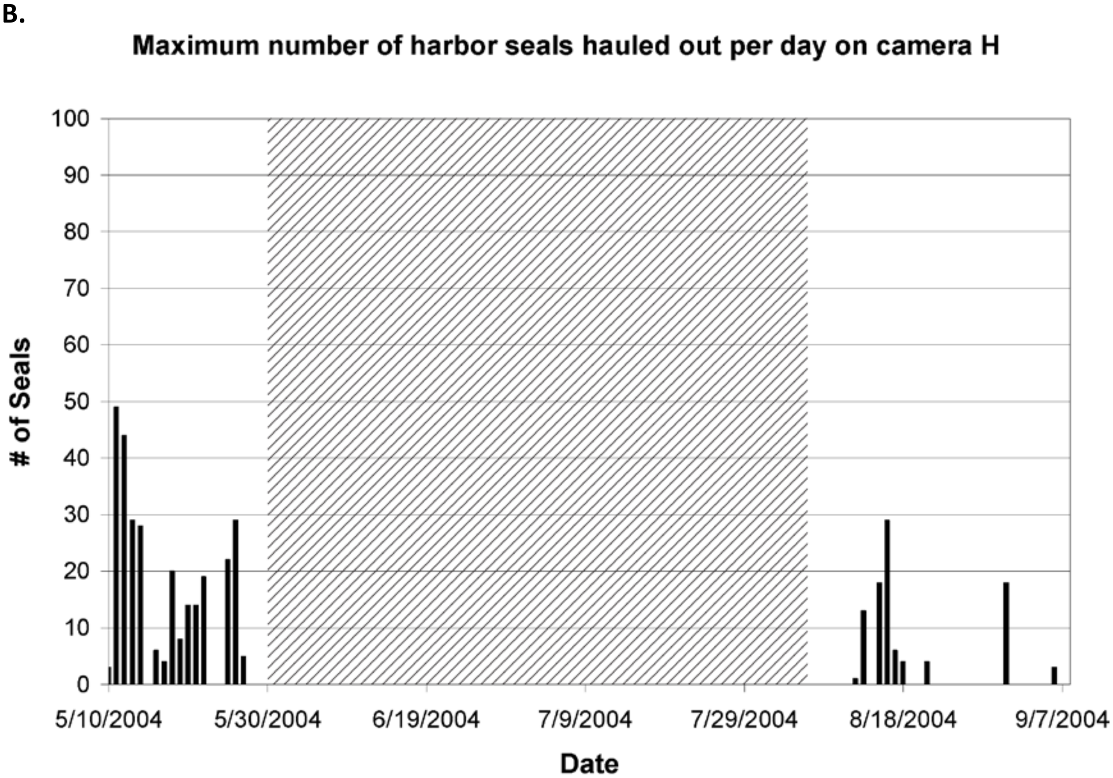
Table 12. Summary of harbor seal haul-outs by camera view at Augustine Island (West-2). Pups were not counted in any of the photographs.

Camera view	Number of photographs	Number of photographs where seals were present (>0)	%Time seals were present	Max # of seals in frame	Avg. # of seals (when >0) in frame
F	1,670	13	1%	4	2
H	673	94	14%	49	9
I	911	142	16%	51	8
Total	3,254	249	8%		

A.


Maximum number of harbor seals hauled out per day on camera F
# of Seals
100
90
80
70
60
50
40
30
20
10
0
5/10/2004
5/30/2004
6/19/2004
7/9/2004
7/29/2004
8/18/2004
9/7/2004
Date

B.


Maximum number of harbor seals hauled out per day on camera H
# of Seals
100
90
80
70
60
50
40
30
20
10
0
5/10/2004
5/30/2004
6/19/2004
7/9/2004
7/29/2004
8/18/2004
9/7/2004
Date

C.

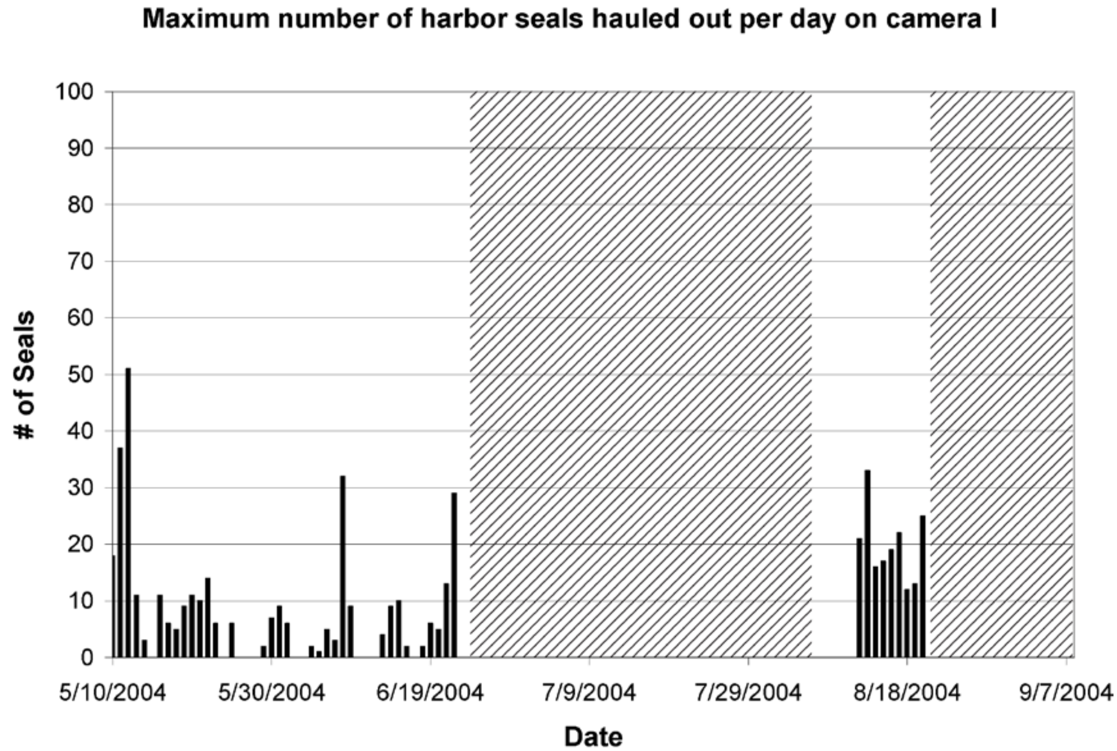


Figure 15 (a-c). Maximum number of harbor seals hauled out per day on cameras F, H, and I at Augustine Island (West-2). The hatched areas represent times when the cameras were not working and no photographs were taken.

Anchor Point

Cameras M & N

The cameras began taking pictures on 12 May 2004, and the last picture was taken on 26 September 2004. Between 12 May and 5 August, the camera systems were programmed to capture one image per hour from 6:00 to 22:00. Due to shorter day length, the cameras were re-programmed to capture images from 8:00 to 20:00 between 6 August and 26 September. There were 1,463 hours of photographic coverage, with both cameras operating simultaneously during 842 of those hours (Table 13, Figure 16). A total of 2,278 photographs was obtained, and seals were present in 233 (10%) of the pictures (Table 14).

Cameras M and N were positioned to take overlapping photographs of offshore rocks (Figure 17). During the maintenance visit on 8 June, the view of camera M was changed and the image resolution improved dramatically. As a result, the count accuracy after 8 June was much improved.

Seals were present on the offshore rocks frequently during the periods that the cameras were operating (Figure 18a-b), although the counts represent estimates before 8 June. This haul-out was tide dependent and the rocks would be submerged at high tide. During very low tide, however, seals may have been present further offshore, too far away to reliably detect and count seals.

Table 13. Summary of Anchor Point camera operation. A record equals one hour of coverage during one day.

Cameras start	5/12/2004 6:00:00 AM
Cameras stop	9/26/2004 9:00:00 AM
Total number of records (at least 1 camera working)	1,463
Number of records where both cameras were working	842

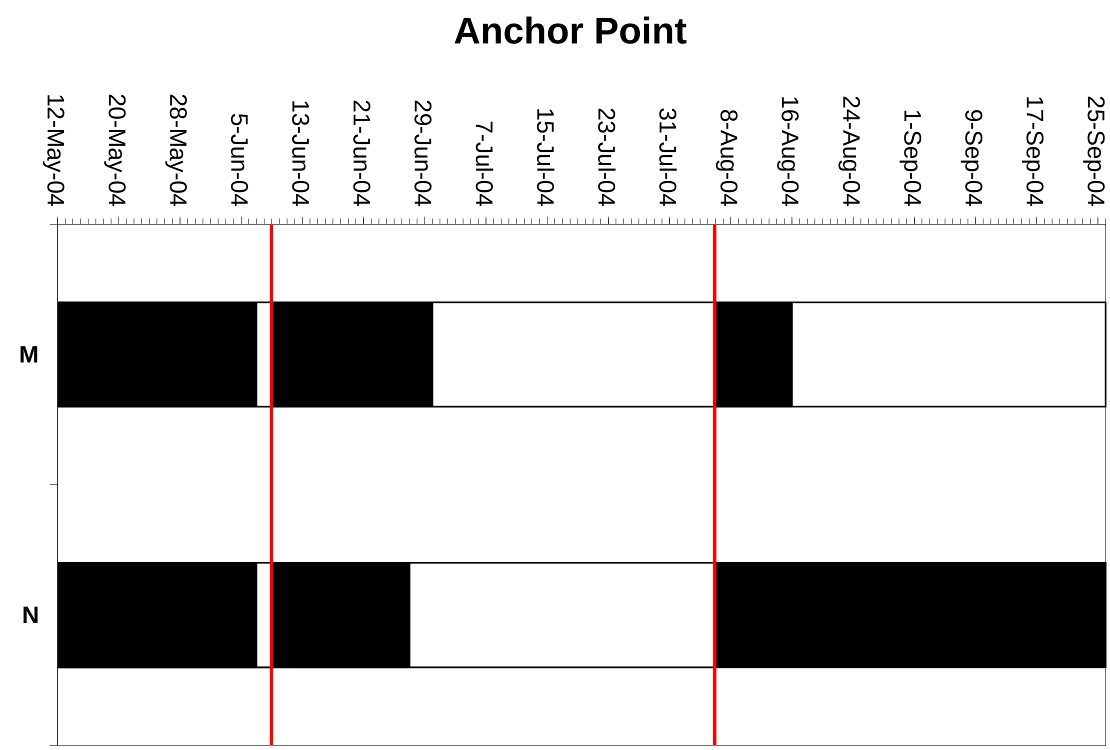


Figure 16. Temporal coverage of time-lapse camera imagery collected at Anchor Point between 12 May and 26 September 2004. Cameras M and N are represented on the y-axis, with dates on the x-axis. The red line represents when maintenance was performed on the camera systems and photographs were downloaded. Black segments of the bars represent time periods in which imagery was captured throughout the day, and white segments are when no photographs were taken due to loss of power or camera malfunction. Between 12 May and 5 August, the camera systems were programmed to capture one image per hour from 6:00 to 22:00. Due to shorter day length, the cameras were re-programmed to capture images from 8:00 to 20:00 between 6 August and 26 September.

Table 14. Summary of harbor seal haul-outs by camera view at Anchor Point. Pups were not counted in any of the photographs.

Camera view	Number of photographs	Number of photographs where seals were present (>0)	%Time seals were present	Max # of seals in frame	Avg. # of seals (when >0) in frame
M	898	92	10%	75	11
N	1,380	141	10%	96	10
Total	2,278	233	10%		

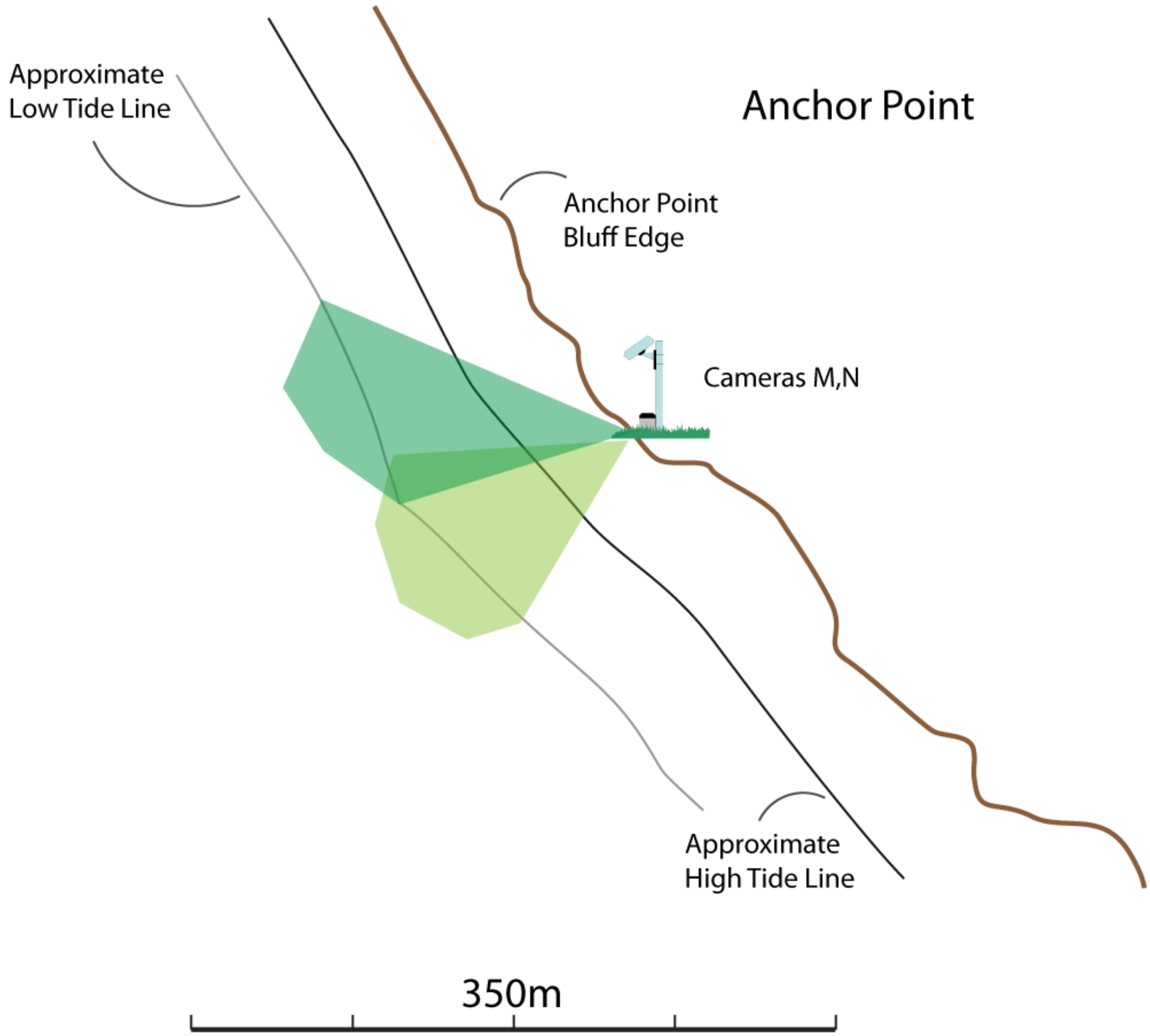
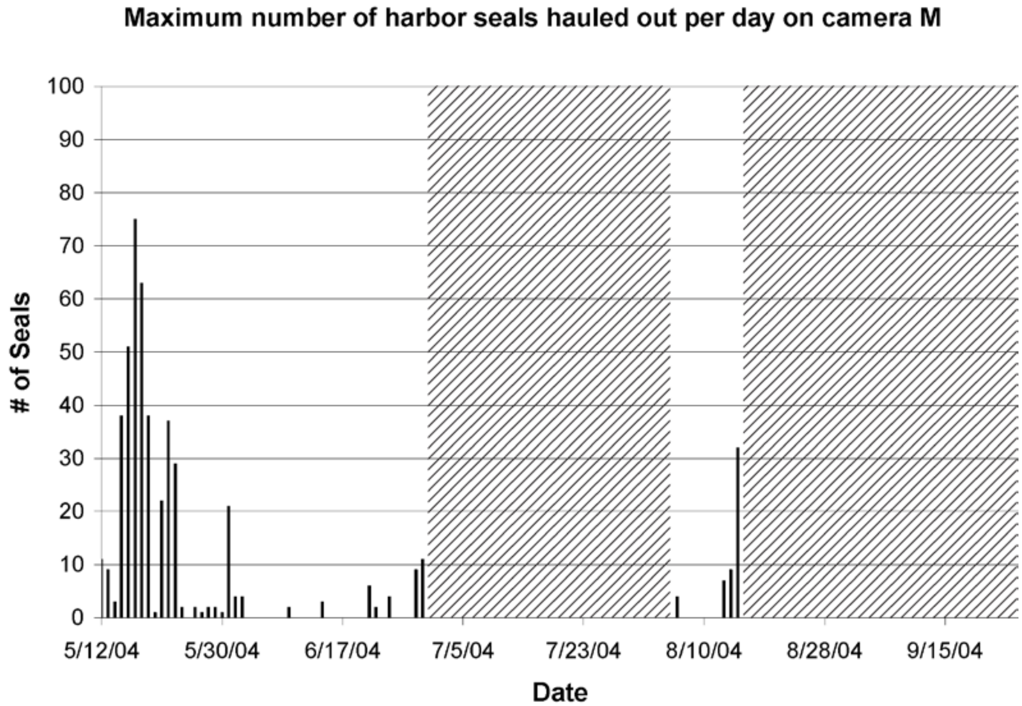


Figure 17. Schematic view of the cameras at Anchor Point. Cameras M and N both took overlapping photos of seals on offshore rocks.

A.



B.

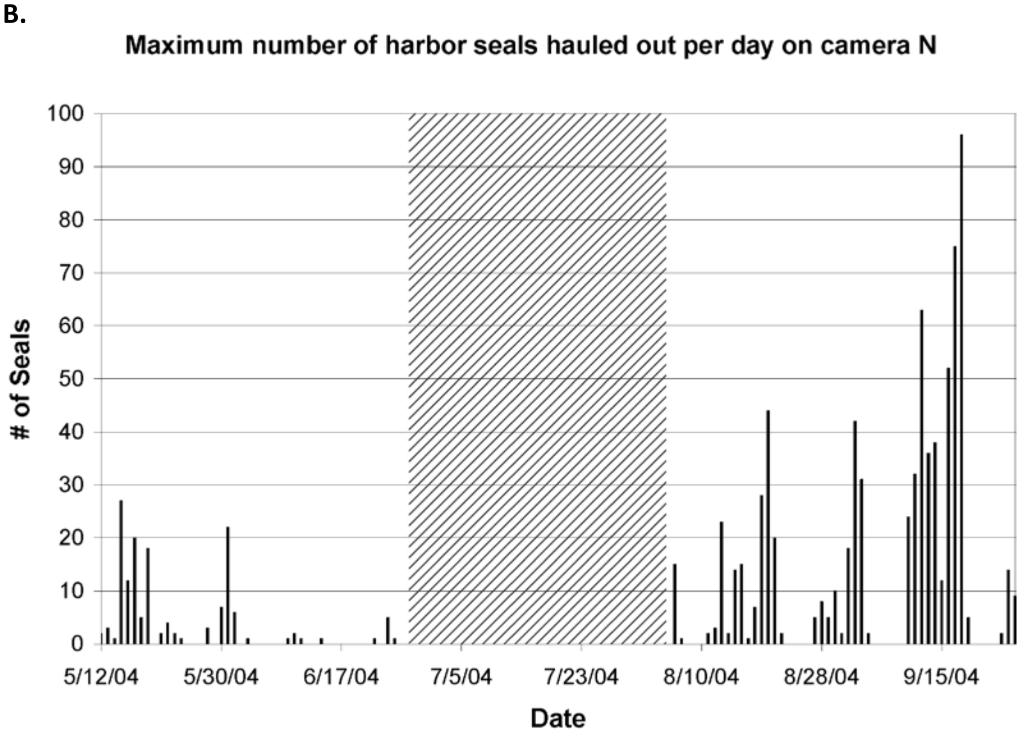


Figure 18 (a-b). Maximum number of harbor seals hauled out per day on cameras M and N at Anchor Point. The hatched areas represent times when the cameras were not working and no photographs were taken.

DISCUSSION

The greatest obstacle to success of this project was the unreliability of the camera/controller combination that we selected. Even with frequent maintenance visits, one or more cameras at each site continued to fail for unknown reasons, and as a result there was only partial photographic coverage of the haul-out sites. Without accurate hourly seal counts, we were unable to address the original objectives of this project and relate the numbers of seals on a haul-out to specific covariates such as weather conditions, tidal height, time of day, and date in seasonal life-history cycle. Our decision to discontinue efforts to develop a remote time-lapse camera system was based on the apparent intractability of the camera/controller problem, the experiences of others working to develop similar systems from the same components, and the availability of alternative means for achieving the primary objective by satellite telemetry of harbor seal haul-out behavior, funded by MMS as Task III under this Interagency Agreement.

Several discussions were held with an engineer from Scientific Fisheries, Inc. (SciFish) of Anchorage, Alaska, who had independently developed a similar system based on the same camera and time-lapse controller components. As of summer 2005, SciFish had come to the same conclusion that we did with respect to the intractability of resolving the bug in the camera or controller that caused random interruptions and failures of the systems. SciFish expressed the intent to develop a custom time-lapse controller, an electronics engineering task that was beyond the scope of our intended goal of assembling an inexpensive system with commercially available components. We also corresponded with Anne Hoover-Miller of the Alaska SeaLife Center in Seward, Alaska, about her experience in attempting to deploy a camera system based on our design. Although she explored alternative means for powering the system, using common lead-acid batteries and solar charging panels, she encountered similar problems with camera and controller reliability.

We believe that low cost methods for year-round monitoring of harbor seal numbers ashore and haul-out behavior related to specific covariates would still be valuable to develop. Although we could not locate suitable alternatives among the commercially-available components in 2005, the rapid evolution of digital camera technology may yet result in a simple, highly-reliable camera and interval controller. To assist others who may pursue similar objectives in the future, we have compiled below a summary of considerations for this type of study that we believe will need to be taken into account even if a suitable technical solution can be found for the system components. Two very important considerations for this type of study are complete photographic coverage of the haul-out and good photographic quality.

Site Selection for Complete Coverage of Seal Haul-out Groups

The ability to have complete photographic coverage of a haul-out is critical when choosing a site for remote time-lapse cameras. Moreover, the need for photographic resolution to reliably detect and count seals imposes a trade-off between coverage area and accuracy of seal counts. We found it quite challenging to locate seal haul-out sites that were

1. Sufficiently accessible to allow maintenance visits every 2-3 months;
2. Clearly visible from a vantage point with enough elevation to prevent significant numbers of seals being obscured by rocks, terrain, and other seals;
3. Discrete, so that they were not simply a portion of a continuum of sites used as alternatives by a local group of seals; and
4. Small enough in extent that they could be covered with a reasonable number of (i.e., 5 or fewer) cameras.

In Cook Inlet, these constraints were exacerbated by tidal ranges that can exceed 29 feet in some locations (http://tidesandcurrents.noaa.gov/tides07/tab2wc2b.html#154). The large tidal range became a problem at the Augustine Island East cameras, as a high tide would push the seals out of view and the camera would be photographing the water. Of the sampled areas, Aurora Rock was the most ideal site for complete photographic coverage because all sides of the island could be easily monitored. If seals moved up or down on the beach or to another part of the haul-out, they would typically remain in view of one of the cameras.

Camera Positioning for Photographic Quality

Even when a site can be found that meets the requirements listed above, there are further considerations for whether adequate photographs can be obtained for monitoring numbers of seals ashore. The primary considerations are distance to seals and the elevation and azimuth (i.e., compass direction) of the camera view. Large distances (i.e., >200 m) from the camera require the use of high image resolution, telephoto (optical zoom) magnification, a very stable mounting system, and perhaps a combination of several or all of these factors, to acquire photographs suitable for counting seals. Telephoto magnification is confounded by vibration of the mounting system, degradation of the optical quality at high zoom factors, and greater accumulated effects of haze and particulates in the air over large distances. Very small distances (i.e., <20 m) from the camera vantage to seal haul-out sites can present challenges, as well, such as obtaining a sufficiently wide view to encompass the site with a reasonable number of camera systems.

The elevation and azimuth of the camera view both influence the incidence of solar glare. Low camera elevations and southwesterly to southeasterly azimuths are more susceptible to glare than high angles and northerly azimuths.

High-quality photographs for counting harbor seals relies on the following: high camera angle, short distance to seals (or zoom lens), and/or high resolution. A high camera angle allows for better counting when seals are tightly packed together on the beach, while the distance to the seals determines what resolution is needed in the photographs. In the Augustine Island and Anchor Point photographs, it was difficult to tell the difference between individual seals in a group and between seals and rocks when the seals were scattered on offshore rocks. Thus, there was low accuracy in the counts. Land haul-outs were easier to photograph than offshore rocks, as offshore rocks usually have a long distance to the seals and a low camera angle, which leads to a poor view of the seals.

Aurora Rock

Of the five study areas, Aurora Rock has the best data set, yet it is plagued with gaps due to recurrent camera malfunctions. As a location, Aurora Rock has great potential for monitoring year-round harbor seal haul-out behavior because it is easily accessible, has good beach coverage, and excellent camera views. It has a relatively low number of seals, however, and during the 88 hours of complete coverage, the highest count of seals was only 66 animals.

Aurora Rock is unique because the entire island can be easily monitored, and seals using the haul-out can never be in a spot that wasn't photographed (i.e., pushed out of view by the tides). Because of the high camera angle and low distance to the seals, this was also the only location with high-quality, clear photographs. Pups could easily be counted on all cameras except camera A. If the photographic resolution was increased on camera A, pups could be accurately counted on all sides of the island.

The Aurora Rock data showed that seals hauled out on the island year-round, preferring the northern side of the island monitored by camera A during the winter months. Seals showed a strong diel pattern with more seals using the haul-out around 10 AM. The haul-out was also tidally dependent, as the island became steep and unusable to seals during a high tide. Additionally, the data showed that harbor seals shared the island with a substantial number of sea otters that also utilized the island throughout the year.

Augustine Island

Augustine Island is a remote site and an active volcano. This made it difficult to visit the cameras on a regular basis to download pictures and perform routine camera maintenance.

It was interesting to note that seals regularly used the western Augustine (West-1) site until 31 July, and then did not haul-out at that location anymore. At the eastern Augustine site, however, no seals were seen to use the beach until 1 August, despite complete photographic coverage. It is possible that the seals moved from the western Augustine site to the eastern Augustine site on 1 August.

East

The Eastern Augustine Island dataset has multiple problems, the biggest being incomplete photographic coverage. Although there were 1,335 hours of coverage when all cameras were working, there were zero seals on the beach. There is not one complete count when seals were present.

When photos were taken of seals, the data suffers from poor photographic resolution (camera L) and missed seals (camera G). Camera L had a great overview of the haul-out, however, at the far end of the frame, the seals appeared blurry and tightly packed together. Therefore, the counts from camera L have a low accuracy. The hourly counts of seals from camera G are deceiving because the camera was stationary and would take a photo of the same spot over time. In contrast, the tide would push the seals in and out of view, but not necessarily on or off of the beach. Taken at face value, this would make the number of seals to be highly correlated with tide stage (high tide = no seals). In reality, the seals were pushed out of view on the haul-out, and the camera was taking pictures of the water at high tide.

Because there was total coverage of the beach from May through August, we know that seals only use this beach during the molting season, and not during the pupping season (Figure 12a-c). Although camera G was the only camera to take pictures after 15 August, the overall trend is probably representative of the beach, indicating a peak of seals hauled out in mid to late august, with decreasing usage of the beach throughout September (Figure 12b).

West-1

Harbor seals were seen to use this beach in increasing numbers from 2 June until 31 July, and no seals were seen on the beach despite complete coverage in August. Although camera K was not working before August, the overall trend seen on camera J is probably representative of the beach (Figure 14b). Nevertheless, there was not one complete count when seals were present on the beach.

Besides camera malfunctions, the biggest problem with the West-1 site was photographic resolution. Seals were extremely difficult to see and could not be counted with any accuracy. The camera angle was very low and the seals were far away, making them appear the same as rocks. All counts from this location are an estimate of the number of seals on the beach as they could not be seen clearly.

West-2

Seals were infrequently seen on land (camera F), and this site mostly focused on seals hauled out on offshore rocks. The cameras had very bad views of the haul-outs and the counts are highly inaccurate and should be used to look at broad patterns only. The counts from hour to hour varied depending on the quality of the light, and are not necessarily representative of more or less seals. This site is tide dependent as the rocks were submerged at high tide. A low tide might appear to have less seals as well, however seals could oftentimes be seen hauled out on rocks further offshore in deeper water, but too far away to be counted.

Anchor Point

Seals were seen consistently on the offshore rocks between May and September whenever the cameras were running. Low photographic resolution led to poor counts before the 8 June maintenance visit. After the photographic resolution was improved, the counts became more accurate. The counts should still be viewed as an estimate, but the overall trends ought to be accurate.

Similar to the Augustine Island West-2 site, this haul-out was tide dependent. The rocks would be completely submerged during higher tides. The seals did not appear to use the site during extremely low tides, however, it is possible that they were hauled out on rocks further offshore where they were too far away from the cameras to be seen or counted.

ACKNOWLEDGMENTS

We were grateful to receive the generous and skillful assistance of Ori Badajos, Steve Baird, Michael Cameron, Shawn Dahle, Jennifer De Groot, Kim Donahue, John Jansen, and Scott Pegau, during the logistics and field portions of this project. Capt. Pete Wedin, Steve Fogg, Jeff Johnson, Maritime Helicopters, Northwind Aviation and the many kind people and merchants of Homer, Alaska were also very helpful. We are extremely grateful to the Bureau of Ocean Energy Management, and especially Chuck Monnett for the support that enabled us to conduct this work.

PRESENTATIONS AND PUBLICATIONS

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