USING REMOTE CAMERA TECHNIQUES TO STUDY BLACK-LEGGED KITTIWAKE

(*RISSA TRIDACTYLA*) PRODUCTIVITY IN RESURRECTION BAY

IN THE NORTHERN GULF OF ALASKA

By

Sarah Ann Tanedo

RECOMMENDED: Anne Beaudreau

Dr. Anne Beaudreau

Dr. Peter Winsor

Dr. Tuula Hollmén
Advisory Committee Chair

Dr. Sarah Mincks Hardy
Program Head, Marine Sciences and Limnology

APPROVED:

Dr. S. Bradley Moran
Dean, School of Fisheries and Ocean Sciences

Dr. John Eichelberger
Dean of the Graduate School

12 May 2016

Date

USING REMOTE CAMERA TECHNIQUES TO STUDY BLACK-LEGGED KITTIWAKE (*RISSA TRIDACTYLA*) PRODUCTIVITY IN RESURRECTION BAY IN THE NORTHERN GULF OF ALASKA

A

THESIS

Presented to the Faculty

of the University of Alaska Fairbanks

in Partial Fulfillment of the Requirements

for the Degree of

MASTER OF SCIENCE

By

Sarah Tanedo, B.S.

Fairbanks, AK

May 2016

Abstract

Monitoring sentinel species in environments undergoing ecosystem change is essential to understanding how the organisms living in these habitats will respond. Seabirds are considered sensitive to shifts in their local environment and have been used as sentinels but many species occupy remote locations, posing logistical challenges for long-term studies. Remote camera techniques offer a possible alternative to other methods of monitoring seabirds during their breeding seasons. To investigate the use of remote camera techniques to study cliff-nesting seabirds and identify factors influencing their productivity, a remote video-camera system was used to collect 6 years (2010-2015) of reproductive data from a sub-colony of Black-legged Kittiwakes (*Rissa tridactyla*) in Resurrection Bay near Seward, Alaska. The first objective was to refine remote camera techniques by investigating the influence of 1) observation frequency and 2) observation type (video or still image) on estimates of productivity. Observation frequency from daily up to one week intervals did not have a significant effect on estimates of productivity. Observations made twice annually were found to be significantly different from estimates of productivity calculated using daily observation frequency. Still image and video methods of observation did not significantly affect estimates of productivity. The second objective was to identify factors that influence reproductive success of kittiwakes at Cape Resurrection by 1) determining the effect of nest characteristics on individual nest success, 2) identifying the effect of behavior of breeding adults during the incubation period on hatch success, 3) determining the effect of seasonal weather patterns on loss events, and 4) investigating the relationship between annual productivity and sea surface temperature (SST) over a 5 year period. Model analysis of nest characteristics on individual nest success indicated that mainland/island location and nest height above water influenced individual nest success. Behavior of breeding adults did not

influence hatch success. Nest loss was influenced by average wind speeds. Annual SST was not correlated with annual productivity over a 5 year time period. Based on the results of this study, I recommend remote camera technologies for the purpose of studying cliff-nesting seabirds in remote locations and found them a useful tool for identifying and tracking factors that influence the breeding success of these populations over a multiyear time period.

Dedication Page

A project like this is a summation of the contributions and support of numerous people and I wouldn't have been able to complete it without them. First and foremost, I'd like to thank my advisor, Tuula Hollmén, for meeting with me back in 2011 and giving me a chance to become her graduate student. It goes without saying that I wouldn't have completed this thesis without her guidance and support these past few years. I would also like to thank committee members Anne Beaudreau and Peter Winsor for providing extensive knowledge concerning ecology and oceanographic processes. The combined constructive criticism and guidance from my entire committee was an invaluable resource to improve not only my thesis but my ability as a researcher.

The Alaska Sealife Center was also instrumental in providing the ability to perform this project and countless staff, interns, and volunteers have been a great help in making this project possible, but I would like to thank a few people in particular. John Maniscalco and Sadie Ulman collected all video and still image records prior to 2013, assisted in various boating trips out to my field site in order to collect more detailed data and install more monitoring equipment, and answered my countless questions regarding the camera equipment and analyses for this project. Pam Parker was endlessly patient in working with me to share the monitoring equipment and providing assistance concerning the software used to operate the cameras.

I would also like to thank the many friends who have supported me through the years of not only my thesis, but throughout my entire science career. They have kept me sane and upbeat throughout the years of completing this thesis and provided a lot of the help I needed to fine tune analyses. I wouldn't have been able to get through this thesis and evolved so much as a scientist without the assistance, support, and guidance of my friends both within and outside the research

field. Finally, I wouldn't be here today without the love and support from my family, in particular my Mom and Dad, who have always supported my adventurous character and inquisitive passion for nature. Thank you for always encouraging me to chase my dreams, no matter where they may take me.

Table of Contents

Page

List of Figures

List of Tables

List of Appendices

Acknowledgements

I would like to thank the many sources of funding that supported this project. The National Park Service and the Ocean Alaska Science and Learning Center supported me throughout my thesis and provided the funding to collect a majority of the data for this project. The North Pacific Research Board granted the resources to support me through my last year of graduate school by awarding me the Graduate Student Research Award. The University of Alaska Fairbanks School of Fisheries and Ocean Sciences contributed the funds to start my graduate career by awarding me the Teaching Assistantship I needed to support me through my first year of graduate school. The Robert & Kathleen Byrd Award provided the sources to purchase a weather station to obtain local weather patterns at the study site as well as provided the finances to attend multiple conferences and present some of the results of my research. The United States Geological Survey also provided funding to attend a conference to present the results of some of my research.

In addition to my sources of funding, I would also like to acknowledge the various people, agencies, and organizations that helped develop and refine the project, assisted in collection of data, and provided the tools, equipment, and space to conduct my research. Tuula Hollmén was an invaluable source of avian knowledge and helped guide me through the project. Anne Beaudreau and Peter Winsor provided insightful knowledge pertaining to the environment and ecology of the marine habitat of my study species. I would also like to thank John Maniscalco and Sadie Ulman for collecting all the data prior to 2013, guiding me around the equipment, and providing answers to the countless questions I had regarding analysis and remote monitoring equipment. I would also like to acknowledge the staff, volunteers, and interns who assisted in data collection and field trips throughout the years. The Alaska SeaLife Center provided much of the equipment, space, and support I needed to conduct my research. The University of Alaska Fairbanks Graduate School and the School of Fisheries and Ocean Sciences provided logistics and guidance throughout my graduate career. Operating the cameras would not have been possible without the support of the Alaska Maritime National Wildlife Refuge for permitting the use of part of the refuge for image transmission. Protocols were reviewed and approved by the Institutional Animal Care and use Committee at the University of Alaska Fairbanks (Appendix A, Appendix B).

INTRODUCTION

With each passing year, changing ecosystem dynamics in marine environments caused by shifting local climate patterns are increasingly concerning. Monitoring sentinel species in these environments is essential to understand how changing dynamics affect the organisms inhabiting these ecosystems. Seabirds have been considered as a potential means of monitoring the health of the local environment for decades. Many species are sensitive to shifts in their local environment and often indicate change through shifts in their reproductive patterns (Byrd et al. 2008b). Monitoring seabirds, particularly in northern marine latitudes where shifting climate is of high concern, can be challenging. Many species nest in remote, hard to reach locations and are difficult to observe frequently. Determining estimates of productivity or identifying the timing of important reproductive events, which can also serve as a signal of changes in the local environment, ideally requires frequent observation, which can be costly. To address these issues, several studies have used remote camera technology as a means of monitoring seabirds throughout the breeding season (Mudge et al. 1987, Zador and Piatt 1999, Ambagis 2004, Wanless et al. 2007, Lorentzen et al. 2012, Per Huffeldt and Merkel 2013, Southwell and Emmerson 2015).

Remote camera technology offers the opportunity to monitor seabirds in remote locations at a distance without disturbance. Observations recorded using remote camera technologies are permanent video or image documentation of events occurring at the colony and can be reviewed more than once to verify observations. Using remote observation tools to observe seabirds has been used for decades to monitor a variety of aspects of seabird ecology, such as daily occupancy or estimates of productivity (Mudge et al. 1987, Lorentzen et al. 2012, Per Huffeldt and Merkel 2013, Southwell and Emmerson 2015). Equipment varies in cost and complexity, from small time-lapse cameras operating via solar panel to video cameras that can be remotely operated. The relative portability and size of most pieces of remote technology (i.e. time-lapse photography) makes installation simple and may permit the observation of colonies that would be challenging to monitor using other approaches. Some locations, for example, may not be suitable to establish a camp for consistent onsite observation or may be too remote for frequent boat based surveys (Per Huffeldt and Merkel 2013). Mounting remote camera technology to monitor target colonies over a breeding season may make observation in these locations possible. Using remote camera techniques to replace or augment existing techniques, such as boat based surveys, could also increase the efficiency of data collection or improve the quality of data of pre-existing projects (Per Huffeldt and Merkel 2013). Not all seabirds share the same reproductive strategies, however, and not all equipment and technique types of remote observation may work for every species. Developing remote camera techniques and refining them for individual locations and study designs could prove to be a valuable tool for monitoring breeding populations of seabirds and tracking the response of reproductive success to changing parameters in its environment.

Colonial cliff-nesting seabirds are ideal candidates for monitoring via remote camera technology and the method has been applied at several locations (Lorentzen et al. 2012, Per Huffeldt and Merkel 2013). Reproductive strategies vary among species in this group, but all species nest on cliff-faces in relatively high densities (Danchin and Nelson 1991, Baird et al. 2009). Cliff-nesting permits important breeding events, such as nest creation and incubation, to be highly visible via remote camera technology. Colonial cliff-nesters also nest in high density, making it possible to monitor a large number of nests with a single camera. One of the more widely studied cliff-nesting seabird species is the Black-legged Kittiwake (*Rissa tridactyla*, kittiwake from here on) (Hatch et al. 1993, Frederiksen et al. 2007, Byrd et al. 2008a, Baird et al. 2009, Hatch 2013). This small species of gull has a circumpolar distribution in the northern hemisphere and is one of the most numerous seabirds in the world (Springer et al. 1996, Baird et al. 2009). Two subspecies of kittiwake are recognized, including *Rissa tridactyla tridactyla*, the Atlantic subspecies, and *Rissa tridactyla pollicaris*, the Pacific subspecies and the subject of this project (Denlinger 2006). Both subspecies are similar in appearance but differ in life history strategies. The Pacific subspecies generally has a longer lifespan and produces fewer chicks each breeding season, while the Atlantic subspecies lives a shorter life and is more prolific during the breeding season (Hatch et al. 1991, Schultner et al. 2013). Kittiwakes construct nests on rocky ledges using a combination of mud and plant material (Baird et al. 2009). Kittiwakes lay 1-3 eggs, with 1-2 eggs being more common for the Pacific subspecies. Pacific kittiwakes typically only fledge one chick, though years of good resource availability may result in a larger proportion of 2-fledgling nests (Gill et al. 2002). Estimates of productivity are usually determined by evaluating the number of fledglings produced per nest attempt (Hatch et al. 1991, Buck et al. 2007, Frederiksen et al. 2007). As annual productivity of Pacific kittiwakes is highly variable based on their life history strategies, estimates of productivity for this subspecies can vary from 0-1.8 fledglings produced per nest attempt (Hatch et al. 1991, 1993; Buck et al. 2007, Byrd et al. 2008b, Dragoo et al. 2013).

Estimates of productivity for Pacific kittiwakes can vary among years and this variability may be attributed to different factors based on the individual colony (Regehr et al. 1998, Kildaw 1999, Massaro et al. 2001, Frederiksen et al. 2007). Understanding the parameters that drive success for a colony of interest is vital to being able to identify when change on a larger, ecosystem-sized scale may be linked to estimates of productivity or timing of important reproductive events. Factors influencing colony productivity can differ in importance from colony to colony and is based largely on predator composition, local climate, behavioral strategies, and food resource availability/composition (Massaro et al. 2001, Byrd et al. 2008b, Hatch 2013). Some factors that influence productivity often remain relatively constant among regions. Individual nest success, for instance, is often influenced by adult attendance during the early brooding rearing period. Lack of adult presence during early brood rearing, an indication of insufficient food resources, increases the chance of failure of the nest due to predation or exposure of chicks to the elements (Roberts and Hatch 1993). Other factors may vary in importance between individual colonies. Colonies in the Gulf of Alaska (GOA), for example, are not influenced by sea ice cover while timing of nest initiation for colonies in the Pribilof Islands is driven by the retreat of sea ice cover (Baird 1990, Byrd et al. 2008b). Identifying the factors that most influence reproductive success is important when considering these individual colonies as an indicator site for a particular region.

To further develop and refine remote camera techniques for monitoring cliff-nesting seabirds in northern marine environments, this research project used and refined remote camera techniques to identify the factors that most influence kittiwake productivity in the GOA. The objectives of the first chapter were to 1) determine the effect of observation frequency on estimates of productivity for a cliff-nesting seabird, the Black-legged Kittiwake and 2) compare estimates of productivity calculated using video methods of monitoring with estimates calculated using still images to determine if the type of monitoring equipment used can influence estimates of productivity. The objectives of the second chapter were to determine 1) the effect of nest characteristics on individual nest success, 2) if individual behavior of breeding adults during the incubation period influenced hatch success, 3) if loss (nest, egg, and chick) events were influenced by weather patterns, and 4) if annual productivity and sea surface temperature were correlated over a 5-year time period.

REFERENCES

Ambagis, J. (2004). A comparison of census and monitoring techniques for Leach's Storm Petrel. Waterbirds 27:211–215. doi: 10.1675/1524-4695(2004)027[0211:ACOCAM]2.0.CO;2

Baird, P. H. (1990). Influence of abiotic factors and prey distribution on diet and reproductive success of three seabird species in Alaska. Ornis Scandinavica 21:224–235.

Baird, P. H., S. A. Hatch, and G. J. Robertson (2009). Black-legged Kittiwake (*Rissa tridactyla*). *The Birds of North America Online (A. Poole, Ed.). Ithaca: Cornell Lab of Ornithology*. [Online.] Available at http://bna.birds.cornell.edu/bna/species/092. doi: 10.2173/bna.92

Buck, C. L., K. M. O'Reilly, and S. D. Kildaw (2007). Interannual variability of Black-legged Kittiwake productivity is reflected in baseline plasma corticosterone. General and Comparative Endocrinology 150:430–436. doi: 10.1016/j.ygcen.2006.10.011

Byrd, G. V., J. A. Schmutz, and H. M. Renner (2008a). Contrasting population trends of piscivorous seabirds in the Pribilof Islands: A 30-year perspective. Deep Sea Research Part II: Topical Studies in Oceanography 55:1846–1855. doi: 10.1016/j.dsr2.2008.04.004

Byrd, G. V., W. J. Sydeman, H. M. Renner, and S. Minobe (2008b). Responses of piscivorous seabirds at the Pribilof Islands to ocean climate. Deep Sea Research Part II: Topical Studies in Oceanography 55:1856–1867. doi: 10.1016/j.dsr2.2008.04.015

Danchin, É., and J. B. Nelson (1991). Behavioral adaptations to cliff nesting in the Kittiwake (*Rissa tridactyla*): Convergences with the Gannet (*Sula bassana*) and the Black Noddy (*Anous tenuirostris*). Colonial Waterbirds 14:103–107.

Denlinger, L. M. (2006). Alaska Seabird Information Series. U.S. Fish and Wildl. Serv., Migr. Bird Manage., Nongame Program, Anchorage, AK Unpubl. Re:45–46.

Dragoo, D. E., H. M. Renner, and D. B. Irons (2013). Breeding status and population trends of seabirds in Alaska, 2012. U.S. Fish and Wildlife Service Report AMNWR 2013/05. Homer, Alaska.

Frederiksen, M., M. Edwards, R. A. Mavor, and S. Wanless (2007). Regional and annual variation in Black-legged Kittiwake breeding productivity is related to sea surface temperature. Marine Ecology Progress Series 350:137–143. doi: 10.3354/meps07126

Gill, V. A., S. A. Hatch, and R. B. Lanctot (2002). Sensitivity of breeding parameters to food supply in Black-legged Kittiwakes *Rissa tridactyla*. Ibis 144:268–283. doi: 10.1046/j.1474-919X.2002.00043.x

Hatch, S. A. (2013). Kittiwake diets and chick production signal a 2008 regime shift in the Northeast Pacific. Marine Ecology Progress Series 477:271–284. doi: 10.3354/meps10161

Hatch, S. A., G. V. Byrd, D. B. Irons, and G. L. Hunt Jr. (1993). Status and ecology of kittiwakes (*Rissa tridactyla* and *R. brevirostris*) in the North Pacific. In International Symposium of the Pacific Seabird Group, Canadian Wildlife Service, and the British Columbia Ministry of Environment, Lands and Parks. pp. 140–153.

Hatch, S. A., B. D. Roberts, and B. S. Fadely (1991). Adult survival of Black-legged Kittiwakes *Rissa tridactyla* in a Pacific colony. Ibis 135:247–254.

Kildaw, S. D. (1999). Competitive displacement? An experimental assessment of nest site preferences of cliff-nesting gulls. Ecology 80:576–586.

Lorentzen, E., R. Choquet, and H. Steen (2012). Modelling state uncertainty with photo series data for the estimation of breeding success in a cliff-nesting seabird. Journal of Ornithology 152:S477–S483. doi: 10.1007/s10336-011-0723-0

Massaro, M., J. W. Chardine, and I. L. Jones (2001). Relationships between Black-legged Kittiwake nest-site characteristics and susceptibility to predation by large gulls. The Condor 103:793–801.

Mudge, G. P., S. J. Aspinall, and C. H. Crooke (1987). A photographic study of seabird attendance at Moray Firth colonies outside the breeding season. Bird Study 34:28–36. doi: 10.1080/00063658709476932

Per Huffeldt, N., and F. R. Merkel (2013). Remote time-lapse photography as a monitoring tool for colonial breeding seabirds : A case study using Thick-billed Murres (*Uria lomvia*). Waterbirds 36:330–341.

Regehr, H. M., M. S. Rodway, and W. A. Montevecchi (1998). Antipredator benefits of nest-site selection in Black-legged Kittiwakes. Canadian Journal of Zoology 76:910–915. doi: 10.1139/cjz-76-5-910

Roberts, B. D., and S. A. Hatch (1993). Behavioral ecology of Black-Legged Kittiwakes during chick rearing in a failing colony. The Condor 95:330–342.

Schultner, J., A. S. Kitaysky, G. W. Gabrielsen, S. A. Hatch, and C. Bech (2013). Differential reproductive responses to stress reveal the role of life-history strategies within a species. Proceedings of the Royal Society 280:20132090.

Southwell, C., and L. Emmerson (2015). Remotely-operating camera network expands Antarctic seabird observations of key breeding parameters for ecosystem monitoring and management. Journal for Nature Conservation 23:1–8. doi: 10.1016/j.jnc.2014.11.002

Springer, A. M., J. F. Piatt, and G. V. V. Vliet (1996). Sea birds as proxies of marine habitats and food webs in the western Aleutian Arc. Fisheries Oceanography 5:45–55.

Wanless, R. M., A. Angel, R. J. Cuthbert, G. M. Hilton, and P. G. Ryan (2007). Can predation by invasive mice drive seabird extinctions? Biology Letters 3:241–244. doi: 10.1098/rsbl.2007.0120

Zador, S. G., and J. F. Piatt (1999). Time-budgets of common murres at a declining and increasing colony in Alaska. The Condor 101:149–152.

CHAPTER 1: REFINING REMOTE OBSERVATION: ASSESSMENT OF MONITORING TECHNIQUES FOR BLACK-LEGGED KITTIWAKES (*RISSA TRIDACTYLA*) IN RESURRECTION BAY IN THE NORTHERN GULF OF ALASKA[1]

1.1 INTRODUCTION

Remote camera methods have been used increasingly as a monitoring tool for observing wildlife. These techniques offer a unique chance to observe wildlife from afar with minimal disturbance to the animals, and have been used successfully as an alternative to active onsite observation (Per Huffeldt and Merkel 2013). Time-lapse photography and video-camera gear have been used for diverse research applications, from determining salmon escapement in rivers to monitoring passerine nests for reproductive behavior and predation events (Hatch et al. 1994, McQuillen and Brewer 2000). Remote monitoring equipment can be useful for consistent and cost efficient monitoring of wildlife in remote locations (Lorentzen et al. 2012, Per Huffeldt and Merkel 2013, Southwell and Emmerson 2015). Cliff-nesting seabirds, such as the Black-legged Kittiwake (*Rissa tridactyla*), are good candidates for monitoring via remote camera methods due to the challenge of surveying nest sites *in situ*.

Historically, monitoring of reproductive health of kittiwakes has been conducted using binoculars or still image photography from boat based surveys or land-based observation (Roberts and Hatch 1993, Walsh et al. 1995). The frequency of observation for reproductive health can vary from as infrequently as twice annual to as frequently as daily observations (Gill and Hatch 2002, Buck et al. 2007, Byrd et al. 2008). Twice annual observation methods typically involve taking images or conducting live counts of nests at the beginning of the breeding season,

---

[1] Tanedo, S. and Hollmén, T. 2016. Refining Remote Observation: Assessment of Monitoring Techniques for Black-Legged Kittiwakes (*Rissa Tridactyla*) in Resurrection Bay in the Northern Gulf of Alaska. Prepared for submission in *The Condor*.

once nests are established, and again at the end of the breeding season for chicks, when nestlings have nearly fledged. Productivity is calculated from the total number of hatchlings per nests observed (Suryan and Irons 2001, Buck et al. 2007). This method minimizes time spent observing kittiwakes but may result in imprecise estimates of total number of hatchlings, due to limited observations outside of the nest creation and fledging periods. A more commonly used method to assess productivity is to conduct live or still image observation at pre-established plot sites several times a week. Using this approach, productivity is calculated by determining the number of fledglings produced per nest attempt (Walsh et al. 1995, Regehr and Montevecchi 1997, Byrd et al. 2008). Depending on the project design, a chick is considered a fledgling once it has been observed flying or is 40 days old, the average fledge age (Gill and Hatch 2002). The frequency of observation varies across studies, but many have used an interval of 3-5 days (Hunt Jr. et al. 1986, Hatch and Hatch 1988, Regehr and Montevecchi 1997, Coulson and Fairweather 2001, Frederiksen et al. 2013). More frequent observation permits for more detailed data on phenology of reproduction, such as number of hatchlings or timing of incubation. The greatest level of detail can be obtained through daily observation of breeding kittiwakes (Jodice et al. 2002, Gill et al. 2002, Degeorges et al. 2010); however, daily access to colonies can be challenging, especially for those in remote locations.

To my knowledge, the effect of frequency of observation on estimates of productivity has not been studied in seabirds; however, observation frequency has been shown to affect productivity estimates for other avian species. A study monitoring colonial nesting Griffon Vultures (*Gyps fulvus*) investigated the effect of observation frequency on population and productivity estimates. This study found that increased monitoring frequency increased accuracy of detection of breeding pairs of Griffon Vultures (Martínez et al. 1997). Based on these findings, I hypothesize that high observation frequency of cliff-nesting seabirds throughout the breeding season could more accurately detect initial brooding dates, making calculation of chick age more accurate. Multiple observations a day also increases the ability to detect patterns in behavior of breeding seabirds, such as diurnal trends. Frequent observation, however, can be costly and time consuming to conduct, making it an unrealistic approach to some study sites or projects (Per Huffeldt and Merkel 2013). Using remote camera methods, such as time-lapse photography or remotely operated video cameras, could be an effective alternative to live onsite observation by staff.

Remote monitoring methods have the ability to obtain high frequency data with minimal effort while simultaneously providing the ability to permanently record observations for later review. Video and still image methods of remote observation have been used for years to monitor nest-box nesting species of terrestrial birds with great success and, in some cases, has been found to exceed other monitoring techniques (McQuillen and Brewer 2000, Pierce and Pobprasert 2007). Using these techniques for seabird reproductive monitoring is still a relatively novel concept. Depending on the breeding strategy of some seabird species, remote camera methods must be adapted for each habitat and species to obtain target data. Burrow-nesting species, for instance, can be notoriously difficult to monitor, with the traditional method of censusing species (i.e., "grubbing", reaching in a burrow to determine occupancy) being highly invasive and often inaccurate. In one study of burrow-nesting species, remote monitoring offered a less invasive, though more costly method of determining burrow occupancy (Ambagis 2004). For colonial-nesting species, remote camera techniques have the added benefit of being able to record a large number of observations over a long-period of time without disturbance.

A variety of methods have been used for remote monitoring of seabirds, each presenting different trade-offs among resolution and duration of observations, cost, and processing time. Time-lapse photography is the most common remote method of monitoring seabirds in published literature (Lorentzen et al. 2012, Per Huffeldt and Merkel 2013, Southwell and Emmerson 2015). It has been successfully used to not only monitor breeding success of Thick-billed Murres (*Uria lomvia*) but also monitor diurnal occupancy, providing the data to assess ecological links between breeding seabirds and environmental trends (Per Huffeldt and Merkel 2013). Time-lapse photography has also been used successfully to monitor breeding success of Adélie Penguins (*Pygoscelis adeliae*) in Antarctica (Southwell and Emmerson 2015). Video-monitoring techniques are less commonly used as a method of remote monitoring, but can provide a better ability to describe behaviors, such as copulation or predation events (Danchin 1988, Pierce and Pobprasert 2007, Wanless et al. 2007). Increased frequency of observation could also improve detection rates of target behaviors, but can increase the demand for greater media memory and can be more labor intensive to analyze (Per Huffeldt and Merkel 2013).

To summarize, remote monitoring methods have the potential to be useful tools to supplement or even replace many *in situ* monitoring techniques used to study cliff-nesting seabirds, but estimates of productivity could vary across sampling frequencies and types of monitoring equipment. Determining the effects of observation frequency and equipment type on estimates of productivity for cliff-nesting seabirds will provide much needed guidance for the design of remote monitoring studies. The objectives of this study were to 1) determine the effect of observation frequency on estimates of productivity for a cliff-nesting seabird, the Black-legged Kittiwake and 2) compare estimates of productivity calculated using video methods of monitoring with estimates calculated using still images to determine if the type of monitoring equipment used can influence estimates of productivity.

1.2 METHODS

1.2.1 Study Site and Monitoring Design

The remote camera used to monitor kittiwakes was positioned 1.5 km north of Cape Resurrection (59°52'57.80"N, 149°17'35.34"W) in Resurrection Bay near Seward, AK (Figure 1.1). The camera was situated opposite a sub-colony of nesting kittiwakes that were divided into 2 study locations, an island and a mainland location. The camera was located ~78 m (± 11 m) from the island location and ~118 m (± 8 m) from the mainland location (Figure 1.2). Camera was equipped with 12-18x optical and digital zoom and had the ability to be tilted, zoomed, and moved to observe different sites. Cameras were also equipped with windshield wipers to maintain a clean lens for observation. Signals for camera control were sent through a Category 5 cable to the signal tower located onsite and were sent to the control tower on Chiswell Island to be repeated back to the operation site (Maniscalco et al. 2006). The camera was operated remotely from a location 25 km north of the study site from a computer system at the Alaska SeaLife Center in Seward, Alaska.

The sub-colony consisted of ~2,000 breeding pairs of kittiwakes, 14% of the entire breeding population, that nest around Cape Resurrection (Hollmén, unpublished data). Seventeen plots each ~4 m x 3 m were randomly selected to represent the sub-colony. Plots 1-9 were located on a south facing island and plots 10-17 were located on a south-facing rocky outcropping attached to the mainland (Figure 1.3). The number of locations monitored within each plot ranged from 6 to 16 for a total of 149 locations. Plots and locations were identified in digital images based on natural markers and were clearly marked in reference sheets for easy clarification of specific locations (Figure 1.4). Once a plot was located and centered in the viewing screen, the camera was held stationary for a minimum of 30 seconds to record video. A still image screenshot at the end of the video accompanied each video recording.

Sites were monitored consistently throughout the breeding seasons (May-August) of 2013-2015 and locations were monitored every year regardless of nest presence in a particular year. The study site was monitored twice daily, to the extent possible, at 9:30 am and 4:30 pm. During 2014, the colony was monitored additionally at 7:30 am. While every effort was made to meet the target of daily multiple observations, it was not always possible due to weather, technological, and staffing conflicts. Observations began in the second or third week of May and ended the last week of August (2013: May 14-August 29, 2014: May 6-August 31, 2015: May 11-August 25) encompassing the entire breeding season for kittiwakes at the local site. Recordings of video and still images were made by the same observer in 2013 and 2014. In 2015, the original observer recorded all morning observations and evening observations Sunday-Monday. An intern recorded evening observations from Tuesday to Saturday (9.3% of all observations recorded). Review of recordings for target reproductive behaviors was conducted by the same observer (S. Tanedo).

1.2.2 Estimating Productivity from Monitoring Data

Target reproductive behaviors included presence of a nest, nest attempt, physical presence and number of adults/chicks, incubation behavior, and brooding behavior. First observation of new nesting material at the nest location was considered the first nest attempt. A nest was considered lost if more than fifty percent of the original nesting material was gone. If a nest was lost and rebuilt, the rebuild day was recorded to indicate a second nest attempt. Incubation was determined using specific behavioral cues, such as shifting an egg (video) or specific posture indicative of incubation (video/image). Brooding behavior was determined in a similar manner, using specific behavioral movement (video) or postures (video/image) to determine if a bird was brooding over a very young chick. Brooding behavior was still marked as brooding if a chick was clearly present and the adult was not actively performing the behavior. This method ensured that the presence of a chick was recorded, even when it wasn't physically seen by the observer. A chick was considered lost if it permanently disappeared from view for the rest of the season or if it was not observed every day after the minimum fledge date. A minimum fledge date was established for this project because fledged chicks were observed occupying failed sites (a pair that had lost a nest, egg, or chick). As chicks could not be individually identified, if the resident chick was not observed for a day after the minimum fledge date, an observer could not confidently state that any chick residing on the nest afterwards belonged to the nest. The minimum fledge date was determined as 40 days (the age that a chick is considered fledged, Gill and Hatch 2002) from the minimum observed hatch date from any year. In the instance that a fledgling landed on a failed site, the fledgling was recorded and not considered for productivity (these were referred to as "fledgling hanging out" or FHO).

Productivity was calculated as the number of fledglings produced per nest attempt. Total nest attempts were calculated by summing total nest attempts made at each location for that breeding season. Chick age was determined by calculating the number of days between the first day of observed brooding behavior (assumed hatch date) and the last day the chick was observed daily. In the case of 2-chick nests, the second chick's age was calculated from the first observed hatch date to the last day 2 chicks were seen on the nest. Chicks were considered fledged once they had reached 40 days of age.

1.2.3 Effects of Observation Frequency

Observations recorded for the 2013-2015 breeding seasons were used to determine the effect of observation frequency on estimates of productivity. Records were systematically reduced from the original data set to target observation intervals. Target intervals were 2-, 3-, 4-, 5-, 6-, and 7-day intervals (interval data) between observations, chosen to reflect observation frequencies commonly used in other studies (Coulson and Fairweather 2001, Gill and Hatch 2002, Byrd et al. 2008). In addition, a target interval of 2 times per year (once in June and once in August, referred to as twice annual data), an observation frequency that is also commonly used in other studies, was included (Suryan and Irons 2001, Buck et al. 2007). For twice annual data, productivity was calculated as total chicks observed in August divided by the total nests observed in June (Buck et al. 2007). An interval start date was randomly selected from the first 5 observations of each month. To maintain consistency across all 3 years, only morning observations were used for the analysis. Twice annual data were calculated by randomly selecting a single day during June 15-24 (total nest count) and a single day during August 4-14 (total chick count) for estimates of productivity. Monte Carlo simulations were run with 1000 repetitions for each interval. To produce the data set (representing daily observations) that would be used as the control for both analyses (interval and twice annual), 0-3 days were randomly chosen within the time periods of important reproductive events (early hatch dates in July and fledging period in August) and observations from these dates were deleted. Productivity was then calculated from the new data set. This was run in a Monte Carlo simulation with 1000 repetitions to simulate potential weather/technological difficulties and to produce a comparable vector of probabilities to test against the interval data. A Friedman's test, used to test for differences between groups (groups being intervals in this analysis) and tolerant of non-normal data and data with unequal variance, was used to determine if a significant difference existed between original data and interval data ($\alpha = 0.05$). *Post-hoc* comparisons between each pair of intervals were produced from the same function used to conduct the Friedman's test (Galili 2010, R Core Team 2015). The original data and twice annual data were normally distributed so repeated measures ANOVA was chosen to determine if there was a significant difference between means ($\alpha = 0.05$).

1.2.4 Effects of Monitoring Equipment Type

Productivity was calculated from still images using the same methods used to calculate productivity from video footage. As the same number of observations existed for both video and still image methods, the entire data set (2013-2015) was used for the analysis. Individual nest success (number of fledglings produced per nest) was calculated for each nest for each equipment type and year. The response variable used for analysis was individual nest success, with 0, 1, or 2 fledglings produced per nest as a possible response. Due to the high number of zeros and the repeated observation of the same locations, a zero-inflated generalized linear mixed effects model (ZIGLMM) was used to model nest success as a function of year and equipment type. The ZIGLMM model with a zero-inflated correction factor was run with a negative binomial distribution with location as a random effect using the "glmmADMB" package in R (Fournier et al. 2012, Skaug et al. 2014, R Core Team 2015).

1.3 RESULTS

1.3.1 Estimating Productivity from Monitoring Data

The mean nest initiation dates ranged from May 19-25 (Table 1.1). Mean egg laying dates ranged from June 2-5 with mean hatch dates approximately 32-33 days later at July 5-7 (Table 1.1). Mean fledge dates differed by a day and ranged from August 14-15 between all 3 years (Table 1.1). The earliest identified hatch date observed during the entire project was June

25. The minimum fledge date was calculated by adding 40 days from the minimum hatch date and was determined to be August 6. Nests that were considered failed due to a missing date of observation after the minimum fledge date, but that had a consistent (>3 consecutive days) fledgling presence accounted for 36.1% (2013), 16.7% (2014), and 38.4% (2015) of total chick loss during August (fledging month). Nests that experienced chick failure in July and did not re-nest or never hatched a chick consisted of 10.7% (2013), 19.0% (2014), and 25% (2015) of total FHOs sighted in August. Total nest attempts ranged from 149-156 (Figure 1.5). Total hatchlings ranged from 105-128 with a range of 55-69 of those hatchlings becoming fledglings (Figure 1.5). Two-chick nests consisted of 17-26 of the total nests that hatched a chick, with 11-12 of those nests successfully fledging both chicks (Figure 1.5).

1.3.2 Effects of Observation Frequency

Observations for 2013-2015 were reduced from the original data set to the target intervals. The original data sets with all time periods included were approximately daily observations, with approximately 10-20% missing days total throughout the season (Table 1.2). The majority of missing days were due to lack of staff availability to record video with only 6 days missed due to weather. Estimates of productivity decreased slightly with decreased frequency of observations (up to 7-day intervals), with the exception of twice-annual observations (Figure 1.6). This decrease differed between years, with estimates of productivity decreasing more in 2014 than in 2013 or 2015 (Figure 1.6). Productivity estimates derived from the original data and the interval data were not significantly different (Friedman's test: t=2.83, p=0.069); however, original data set and the twice annual data yielded significantly different productivity estimates (repeated measures ANOVA: f=36.79, p=0.026).

1.3.3 Effects of Monitoring Equipment Type

Nest initiation, incubation initiation, and hatching initiation differed very little between methods, with 1-3 days difference in mean date (Table 1.3). The average fledge date didn't differ between methods (Table 1.3). Nest attempts were the same for both methods of observation and the difference in total hatchlings ranged 1-7 (Figure 1.7). Productivity estimates calculated from video observations were 0.369 (2013), 0.442 (2014), and 0.397 (2015). Productivity estimates from still image observations were 0.315 (2013), 0.404 (2014), and 0.359 (2015). Variation in estimates of productivity between video and still image methods of observation was not found to be significantly different, based on the results of the ZIGLMM (z=1.07, p=0.287). Diagnostic figures indicated normal distribution of residuals with a few outliers, which was to be expected with zero-inflated data.

1.4 DISCUSSION

Using remote camera techniques to monitor a sub-colony of Black-legged Kittiwakes was a reliable and useful method of monitoring reproductive success of a breeding seabird. Decreasing observation frequency from daily up to 7-day intervals did not significantly influence estimates of productivity while twice annual observations significantly overestimated productivity. Method of remote camera observation (still image vs. video) did not significantly affect estimates of productivity.

1.4.1 Estimating Productivity from Monitoring Data

Monitoring the sub-colony of kittiwakes using remote camera methods from 2013-2015 was a useful alternative method for monitoring reproductive success of breeding kittiwakes. Overall, cameras had few issues that resulted in failure of observation. A total of 1.8% of the days of possible observations was missed due to low battery power during inclement weather for all 3 years. Low batteries were caused by failure of the solar panels to properly charge batteries due to inclement weather. Incidences of low batteries causing failure of observation were also due to low battery power at repeater stations and not at the camera site. For future studies, I recommend using the minimum number of repeaters between the camera site and the controlling station.

Recording of study sites was conducted by the same observer for 90.7% of all observations and review of data for reproductive behavior was conducted by the same observer for all 3 years, minimizing any inter-observer discrepancy in the data. Review of materials by a single observer may not always be possible with all monitoring projects and observer bias could exist between multiple reviewers. While observer bias was not investigated for this project, remote camera methods provide permanent records of observations and offer the opportunity to investigate if observer bias is present. Should observer bias present a problem for a remote monitoring program, alterations could be made to protocols and behavioral references to decrease the potential for bias.

Video and still image recordings were commonly of consistent, readable quality and straightforward to obtain. Operating the remote camera system was simple and made monitoring a large number of cliff-nesting seabirds at a distance easy to accomplish. There were, however, some disadvantages to using this remote camera technology. Image quality could vary depending on the weather. Due to the design of the remote camera system, sunny days were more likely to experience interference (static across the image), making later review difficult. High glare on sunny days could also make review of observations difficult by whiting out study subjects and making it challenging to identify bird behavior. Review of video and still image recordings was occasionally time-consuming to conduct, as individual birds sometimes had to be scrutinized closely to identify behavior. Overall, the remote camera system was a reliable and useful method for monitoring kittiwake productivity and was mainly limited in observation by staffing availability.

1.4.2 Effects of Observation Frequency

Decreased observation frequency (excluding twice annual) did not differ significantly from the original data set, though a downward trend in productivity with decreased observation frequency was indicated. The effect of observation frequency could vary between years, as a steeper decline in estimates of productivity with decreased observation was present in 2014 while 2013 and 2015 showed a more gradual decline. Yearly variation in the effect of observation frequency, however, could indicate that anomalies between years, such as increased frequency of poor quality observation, could influence the strength of the effect and should be kept in mind for project design. Additionally, while not investigated in this study, decreased observation frequency can also decrease date accuracy of initiation of important reproductive behaviors, such as incubation or hatching initiation. Depending on project objective, this could alter the detection of important response variables, such as nest creation, known to be an indicator of shifts in local climate (Byrd et al. 2008).

Twice annual observation significantly overestimated productivity compared to the original data set. These results were expected, as the typical method of calculating productivity when only conducting twice annual observations is counting every chick seen as a fledgling before the average fledging period. Total nests are counted instead of total nest attempts, causing an increase in productivity by omitting nest loss events. Chicks can also be lost after the fledgling count survey due to storms, as has happened multiple times in the data set used in this study. Estimates of productivity for twice annual observation were a little over 1.5 times more than productivity calculated using more frequent observation methods. This suggests some strong implications for comparisons between colonies using different observation frequencies, as the different techniques produce vastly different results and could inaccurately represent colony health. Comparing colonies both within and between regions is an important technique of assessing regional trends and health, contrasting colonies using such different techniques is misrepresenting the health of individual colonies and insinuating that some colonies may be less reproductively fit based entirely on technique discrepancy.

Twice annual observation is designed to obtain an estimate of a large sample size with minimal staff involvement and the shortest amount of time spent in the field, but improved technology is making remote monitoring more economical and easier to operate, allowing frequent observation to be more attainable to projects with limited funding. This technology also provides permanent records, creating a database of media that can be revisited at a later date to affirm certain events or provide a learning tool for new biologists. The data provided by this study suggests that not only is frequent observation recommended for accurate estimates of productivity and detection of important reproductive events, but it is attainable by remote monitoring technology, providing an alternative to frequent and costly onsite monitoring of remote seabird colonies.

1.4.3 Effects of Monitoring Equipment Type

Estimates of productivity for video and still image methods of observation did not differ significantly, though still image estimates of productivity were slightly lower. Still image methods averaged approximately 0.04-0.05 fewer fledglings per nest attempt than video estimates, a negligible difference in estimates of productivity. The minor discrepancy between methods was due to lack of observation during important dates used for calculation of chick age.

Mean hatch date differed by 1 day between methods and was mainly due to missed behavioral cues that were not caught with image observations but could be observed with video methods. Earlier hatch dates were detected in video observations because birds with very young chicks sometimes exhibit subtle behaviors that can only be detected through video observation or very precise timing of imaging. Eight fledging dates were missed in still image observation and were detected in video observations due to either the adult or the fledgling moving just enough for positive identification. All other discrepancies were a combination of both missed hatch and fledge dates.

Demonstrating that still image methods of observation do not differ significantly from video methods is a valuable distinction, as remote operation of still image equipment is both easier and cheaper to maintain than remote video methods of monitoring. Remotely operating video cameras can be logistically challenging, as indicated in this project. The cameras used in this project operate using multiple repeater towers to transmit the signal to the cameras to monitor seabirds. The ability to move the camera and record video 25 km away is tremendously useful to monitor a large sample size closely, but can be costly to maintain and comes with the added problems of maintaining a considerable source of power and large memory resources. Still image methods of monitoring often require less power to operate and can be completely independent of having to use repeater towers, such as in time-lapse photography. The removal of the need for repeater towers could also decrease the frequency of failure of observation due to battery limitations. A waterproof housing with a solar panel or wind generator and a car battery is sufficient for powering a time-lapse camera through an entire breeding season. One of the disadvantages, however, is the loss of the ability to monitor a large area with a single piece of equipment. Time-lapse photography is usually installed to monitor a fixed location (Per Huffeldt and Merkel 2013, Southwell and Emmerson 2015). In the case of using it for monitoring cliff-nesting seabirds, multiple cameras would have to be used to cover the same monitoring area as covered in this project. Additionally, this project was conducted using the same equipment at the same zoom to obtain video and still images. Both types of observation were identical in terms of visual quality. To maintain the same quality of data collection, still image equipment used to monitor cliff-nesting seabirds should have the ability to zoom in far enough to accurately identify target reproductive behaviors.

1.5 CONCLUSION

Remote monitoring methods offer a promising alternative method of monitoring cliff-nesting seabird productivity for long periods of time with low cost and minimal staffing. Based on the analysis of both objectives, understanding the difference between monitoring methods and determining the advantages and disadvantages of each technique is vital for project design. Decreasing observation frequency to as low as once per week did not significantly change estimates of productivity, but indicated a steady downward trend in estimates from daily observation to each increase in interval of observation. Twice annual observation significantly overestimated productivity. Still image monitoring is less likely to capture events such as feeding or early brooding behaviors due to lack of movement but estimates of productivity do not significantly differ from estimates calculated using video methods of observation. Video monitoring methods can be expensive to purchase and operate and require a lot of memory for storage of records of media. Time-lapse photography methods are more commonly available and more readily setup for long-term monitoring throughout the breeding season with minimal disturbance to the colony. More importantly, remote methods based on images over video are less expensive to purchase and operate. Based on these results, I conclude that if study objectives are for monitoring purposes to determine important reproductive parameters (such as productivity) or timing of reproductive events (such as incubation initiation), the results of this study suggest that frequent observation utilizing still image methods of remote monitoring are an excellent alternative to video methods of monitoring.

1.6 FIGURES

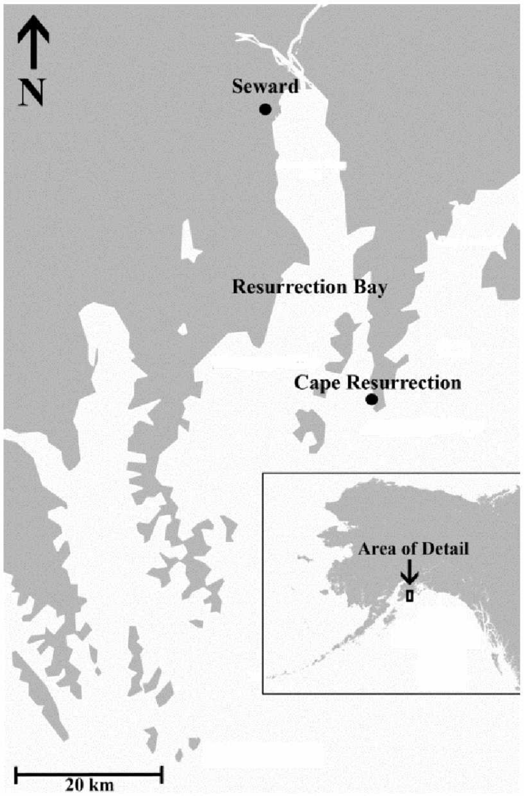

Figure 1.1: Map of study location.

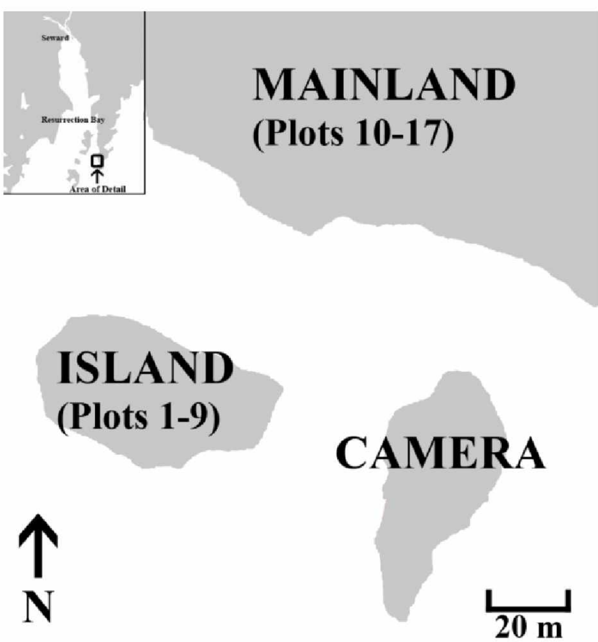

Figure 1.2: Map of island and mainland locations relative to the camera.

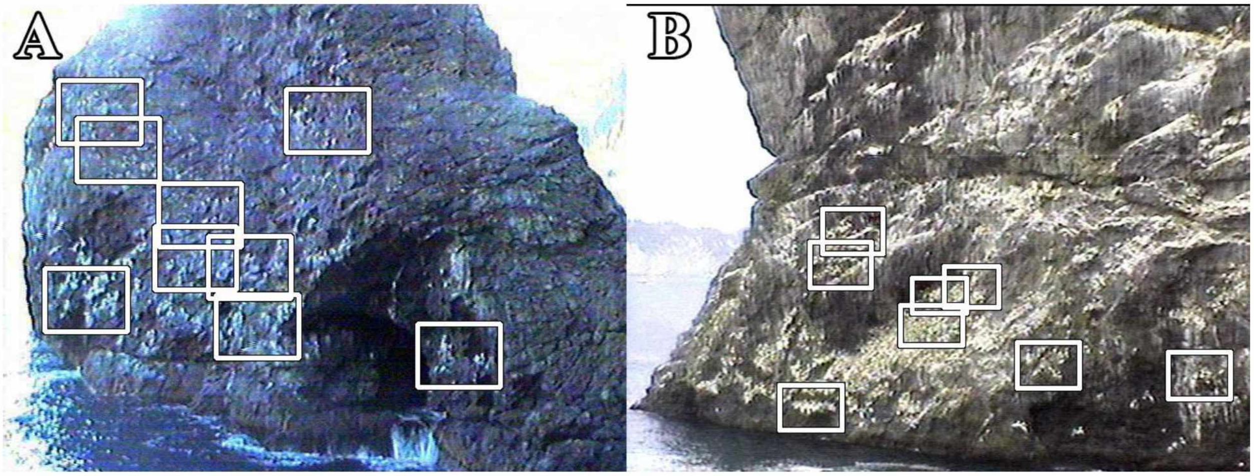

Figure 1.3: Island plots 1-9 (A) and mainland plots 10-17 (B).

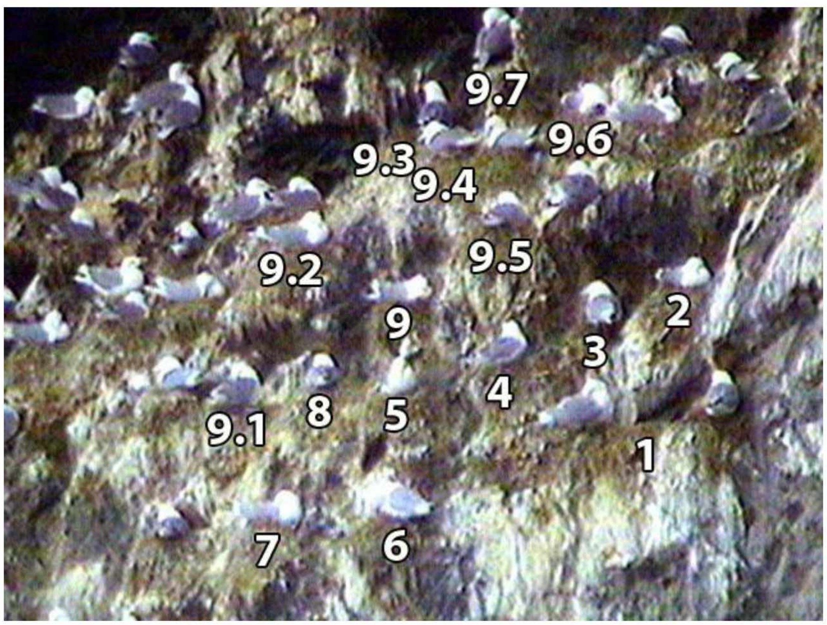

Figure 1.4: A typical view of a plot with labeled nest locations.

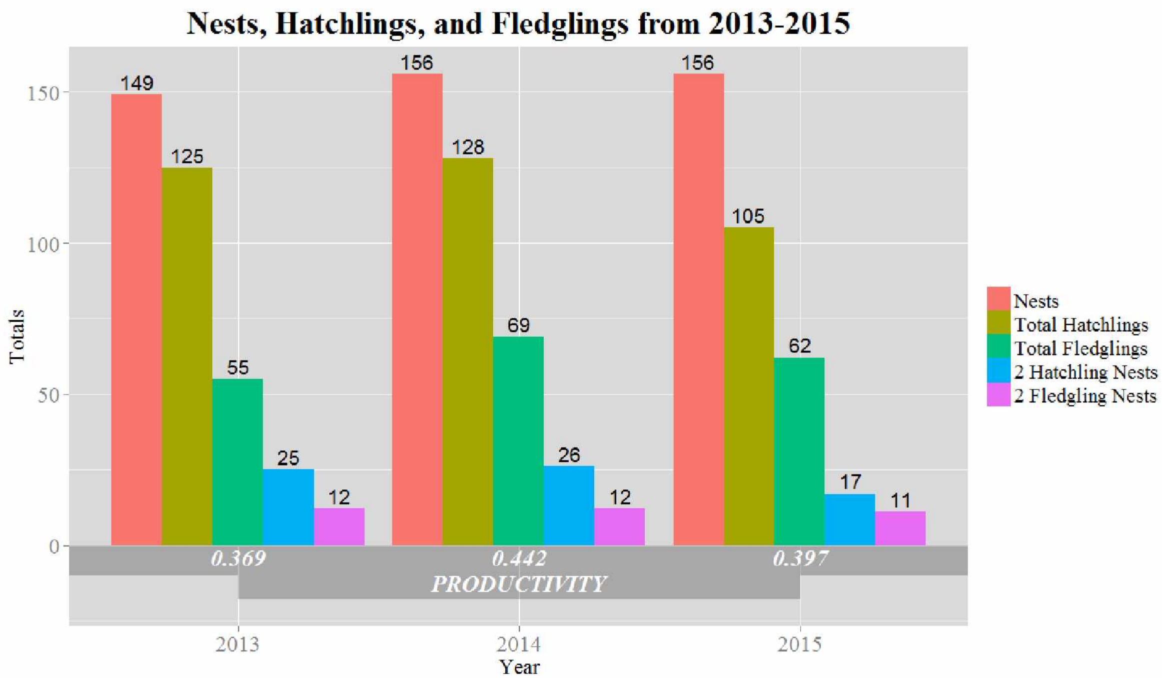

Figure 1.5: Total nests, hatchlings, and fledglings for 2013-2015. Two hatchling/fledgling nests represent part of the total.

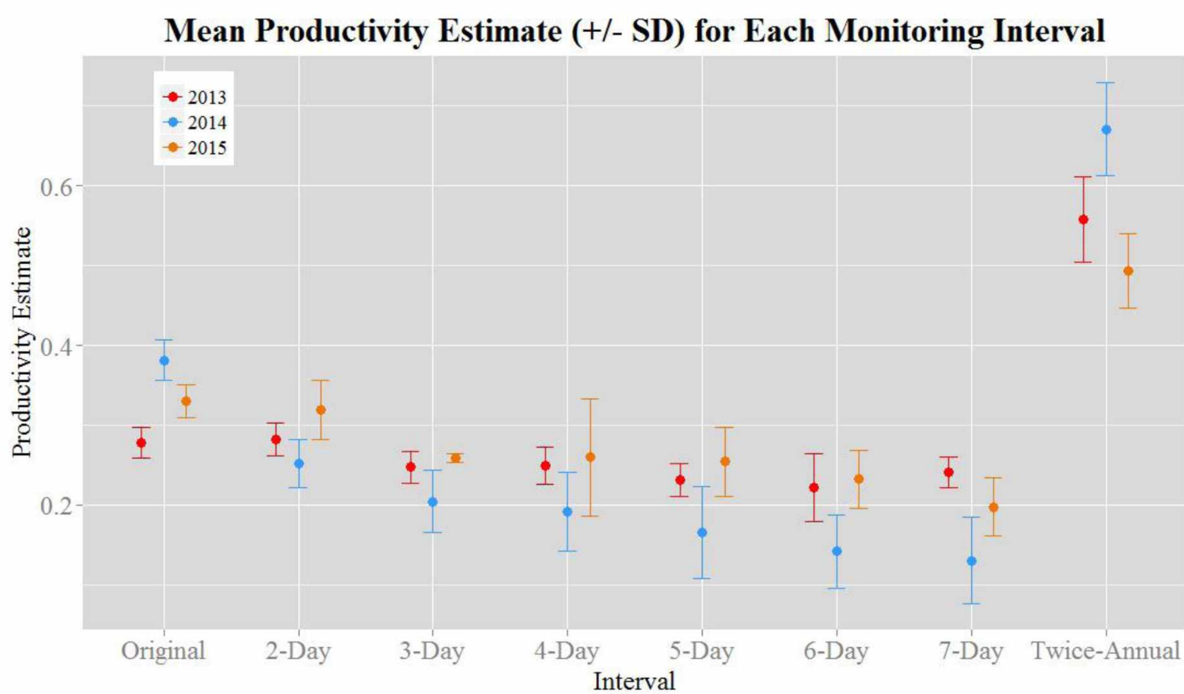

Figure 1.6: Mean productivity with standard deviation for each monitoring frequency.

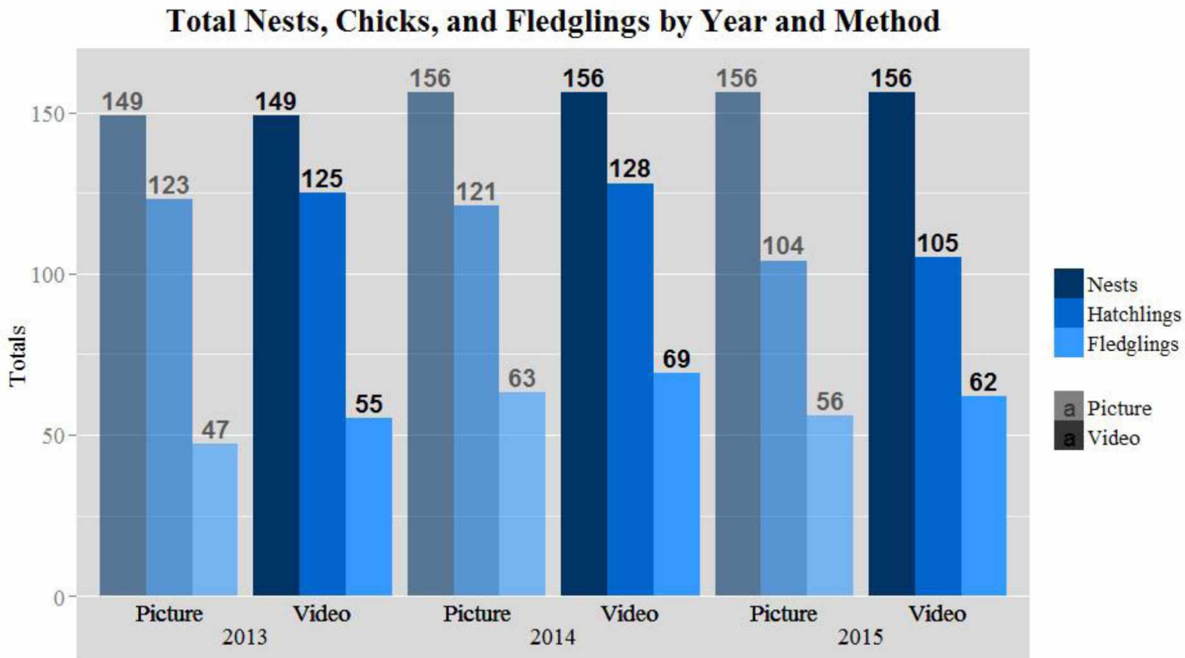

Figure 1.7: Total nests, chicks, and fledglings by year and method.

1.7 TABLES

Table 1.1: Mean dates of reproductive behaviors with standard deviation (SD).

Year	Nest		Incubation		Hatch		Fledge	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
2013	05/19	6.21	06/03	4.73	07/05	4.80	08/15	4.00
2014	05/25	3.96	06/05	5.26	07/07	4.57	08/15	3.46
2015	05/24	4.89	06/02	5.03	07/05	4.50	08/14	3.56

Table 1.2: Total observations by year.

Year	Time	Observations	Total Dates of Observation	Total Possible Dates of Observation	Missing Observations Due to Weather
2013	*10:00am*	61	85	107	6
	6:00pm	59			
2014	*7:30am*	66	105	117	0
	9:30am	84			
	4:30pm	76			
2015	*9:30am*	68	89	106	0
	4:30pm	71			

Table 1.3: Mean nest, incubation, hatch, and fledge initiation dates with standard deviation (SD) of still image and video observation methods.

Year	Equipment Type	Nest		Incubation		Hatch		Fledge	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD
2013	Still image	05/22	5.91	06/03	4.96	07/06	5.10	08/15	4.27
	Video	05/19	6.21	06/03	4.73	07/05	4.80	08/15	4.00
2014	Still image	05/27	3.41	06/07	5.12	07/07	5.02	08/15	3.52
	Video	05/25	3.96	06/05	5.26	07/07	4.57	08/15	3.46
2015	Still image	05/24	4.91	06/03	4.81	07/06	4.57	08/14	3.41
	Video	05/24	4.89	06/02	5.03	07/05	4.50	08/14	3.56

1.8 REFERENCES

Ambagis, J. (2004). A comparison of census and monitoring techniques for Leach's Storm Petrel. Waterbirds 27:211–215. doi: 10.1675/1524-4695(2004)027[0211:ACOCAM]2.0.CO;2

Buck, C. L., K. M. O'Reilly, and S. D. Kildaw (2007). Interannual variability of Black-legged Kittiwake productivity is reflected in baseline plasma corticosterone. General and Comparative Endocrinology 150:430–436. doi: 10.1016/j.ygcen.2006.10.011

Byrd, G. V., W. J. Sydeman, H. M. Renner, and S. Minobe (2008). Responses of piscivorous seabirds at the Pribilof Islands to ocean climate. Deep Sea Research Part II: Topical Studies in Oceanography 55:1856–1867. doi: 10.1016/j.dsr2.2008.04.015

Coulson, J. C., and J. A. Fairweather (2001). Reduced reproductive performance prior to death in the Black-legged Kittiwake : senescence or terminal illness? Journal of Avian Biology 32:146–152.

Danchin, É. (1988). Social interactions in kittiwake colonies : social facilitation and/or favourable social environment. Animal Behaviour 36:443–451.

Degeorges, A., F. Helfenstein, É. Danchin, R. H. Wagner, and S. Leclaire (2010). Family size and sex-specific parental effort in Black-legged Kittiwakes. Behaviour 147:1841–1862. doi: 10.1163/000579510X538872

Fournier, D. A., H. J. Skaug, J. Ancheta, J. Ianelli, A. Magnusson, M. Maunder, A. Nielsen, and J. Sibert (2012). AD Model Builder: using automatic differentiation for statistical inference of highly parameterized complex nonlinear models. _Optim. Methods Softw._, *27*, pp. 233-249.

Frederiksen, M., T. Anker-Nilssen, G. Beaugrand, and S. Wanless (2013). Climate, copepods and seabirds in the boreal Northeast Atlantic - current state and future outlook. Global Change Biology 19:364–72. doi: 10.1111/gcb.12072

Galili, T. (2010). Post hoc analysis for Friedman's Test (R code). [Online.] Available at http://www.r-statistics.com/2010/02/post-hoc-analysis-for-friedmans-test-r-code/.

Gill, V. A., and S. A. Hatch (2002). Components of productivity in Black-legged Kittiwakes *Rissa tridactyla*: response to supplemental feeding. Journal of Avian Biology 33:113–126. doi: 10.1034/j.1600-048X.2002.330201.x

Gill, V. A., S. A. Hatch, and R. B. Lanctot (2002). Sensitivity of breeding parameters to food supply in Black-legged Kittiwakes *Rissa tridactyla*. Ibis 144:268–283. doi: 10.1046/j.1474-919X.2002.00043.x

Hatch, D. R., M. Schwartzberg, and P. R. Mundy (1994). Estimation of pacific salmon escapement with a time-lapse video recording technique. North American Journal of Fisheries Management 14:626–635. doi: 10.1577/1548-8675(1994)014<0626:EOPSEW>2.3.CO;2

Hatch, S. A., and M. A. Hatch (1988). Colony attendance and population monitoring of Black-Legged Kittiwakes on the Semidi Islands, Alaska. The Condor 90:613–620.

Hunt Jr., G. L., Z. A. Eppley, and D. C. Schneider (1986). Reproductive performance of seabirds: The importance of population and colony size. The Auk 103:306–317.

Jodice, P. G. R., D. D. Roby, S. A. Hatch, V. A. Gill, R. B. Lanctot, and G. H. Visser (2002). Does food availability affect energy expenditure rates of nesting seabirds? A supplemental-feeding experiment with Black-legged Kittiwakes (*Rissa tridactyla*). Canadian Journal of Zoology 80:214–222. doi: 10.1139/Z01-221

Lorentzen, E., R. Choquet, and H. Steen (2012). Modelling state uncertainty with photo series data for the estimation of breeding success in a cliff-nesting seabird. Journal of Ornithology 152:S477–S483. doi: 10.1007/s10336-011-0723-0

Maniscalco, J. M., P. Parker, and S. Atkinson (2006). Interseasonal and interannual measures of maternal care among individual Steller Sea Lions (*Eumetopias Jubatus*). Journal of Mammalogy 87:304–311. doi: 10.1644/05-MAMM-A-163R2.1

Martínez, F., R. F. Rodríguez, and G. Blanco (1997). Effects of monitoring frequency on estimates of abundance, age distribution, and productivity of colonial Griffon Vultures. Journal of Field Ornithology 68:392–399.

McQuillen, H. L., and L. W. Brewer (2000). Methodological considerations for monitoring wild bird nests using video technology. Journal of Field Ornithology 71:167–172.

Per Huffeldt, N., and F. R. Merkel (2013). Remote time-lapse photography as a monitoring tool for colonial breeding seabirds : A case study using Thick-billed Murres (*Uria lomvia*). Waterbirds 36:330–341.

Pierce, A. J., and K. Pobprasert (2007). A portable system for continuous monitoring of bird nests using digital video recorders. Journal of Field Ornithology 78:322–328. doi: 10.1111/j.1557-9263.2007.00119.x

R Core Team (2015). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL http://www.R-project.org/.

Regehr, H. M., and W. A. Montevecchi (1997). Interactive effects of food shortage and predation on breeding failure of Black-legged Kittiwakes:indirect effects of fisheries activities and implications for indicator species. Marine Ecology Progress Series 155:249–260. doi: 10.3354/meps155249

Roberts, B. D., and S. A. Hatch (1993). Behavioral ecology of Black-Legged Kittiwakes during chick rearing in a failing colony. The Condor 95:330–342.

Skaug, H. J., D. A. Fournier, and B. Bolker (2014). _Generalized Linear Mixed Models using AD Model Builder_. R package version 0.8.0.

Southwell, C., and L. Emmerson (2015). Remotely-operating camera network expands Antarctic seabird observations of key breeding parameters for ecosystem monitoring and management. Journal for Nature Conservation 23:1–8. doi: 10.1016/j.jnc.2014.11.002

Suryan, R. M., and D. B. Irons (2001). Colony and population dynamics of Black-legged Kittiwakes in a heterogeneous environment. The Auk 118:636–649.

Walsh, P. M., D. J. Halley, M. P. Harris, A. del Nevo, I. M. W. Sim, and M. L. Tasker (1995). Seabird Monitoring Handbook for Britain and Ireland. JNCC/RSPB/ITE/Seabird Group, Petersborough.

Wanless, R. M., A. Angel, R. J. Cuthbert, G. M. Hilton, and P. G. Ryan (2007). Can predation by invasive mice drive seabird extinctions? Biology Letters 3:241–244. doi: 10.1098/rsbl.2007.0120

CHAPTER 2: USING REMOTE CAMERA TECHNIQUES TO IDENTIFY ENVIRONMENTAL AND BEHAVIORAL FACTORS INFLUENCING ANNUAL PRODUCTIVITY OF A COLONY OF BLACK-LEGGED KITTIWAKES (*RISSA TRIDACTYLA*) IN THE NORTHERN GULF OF ALASKA[1]

2.1 INTRODUCTION

Throughout the past few decades, monitoring changes in climate and how they affect species composition and ecosystem processes has become critically important, particularly in northern marine environments. Rapid climate change in northern latitudes has impacted organisms and communities in the marine environment (Harley et al. 2006, Piatt and Sydeman 2007, Bluhm et al. 2011, Sydeman et al. 2012). Seabird species have long been considered as some of the more sensitive organisms to changes in climate (Springer et al. 1996, Piatt and Sydeman 2007, Sydeman et al. 2012). Given the rapid pace of climate change, it is increasingly important to develop techniques to monitor seabird species that may be sensitive to environmental change and understand how seabird habitats are changing in response to shifting climate. Seabirds, however, often live in remote habitats and can be difficult to monitor consistently over long periods (Piatt and Sydeman 2007, Baird et al. 2009). As a result, several studies have opted to use remote camera techniques in place of live onsite observation as a tool for monitoring seabird species (Lorentzen et al. 2012, Per Huffeldt and Merkel 2013, Southwell and Emmerson 2015). Remote camera techniques offer a unique opportunity to monitor seabirds in remote locations at a distance for long periods of time without disturbance to the animal. This is particularly advantageous for monitoring cliff-nesting colonial seabird species, such as the

[1] Tanedo, S., Hollmén, T., Winsor, P., and Beaudreau, A. Using Remote Camera Techniques to Identify Environmental and Behavioral Factors Influencing Annual Productivity of a Colony of Black-Legged Kittiwakes (*Rissa Tridactyla*) in the Northern Gulf of Alaska. Prepared for submission in *The Condor*.

Black-legged Kittiwake (*Rissa tridactyla*), as nests are visible and a large sample size can be monitored from a single remote camera. Remote monitoring could be a valuable tool for assessing productivity and identifying climatic and other factors affecting breeding populations of kittiwakes and other seabirds.

Methods of monitoring kittiwake productivity and reproductive behavior can vary from study to study, but always consist of at least 2 observations per season, one at peak nesting and one at peak fledging (Suryan and Irons 2001, Buck et al. 2007). More frequent observations throughout the breeding season using remote camera techniques, however, provide an opportunity to record breeding behaviors, such as timing of nest initiation, or total number of chicks (Roberts and Hatch 1993, Massaro et al. 2001, Byrd et al. 2008). Factors influencing productivity may differ in importance from colony to colony, depending on habitat parameters and local ecosystem composition (Hunt Jr. et al. 1986, Regehr et al. 1998, Kildaw 1999, Piatt and Sydeman 2007, Baird et al. 2009). Some of the known factors that have the potential to influence kittiwake reproductive behavior include physical and biological characteristics of a nest site, individual variation in behavior, seasonal changes in weather, and annual changes in climate (Olsthoorn and Nelson 1990, Roberts and Hatch 1993, Regehr et al. 1998, Byrd et al. 2008).

Structural characteristics and location of a nest site within a colony can play a key role in influencing individual nest success. Structural protection, such as overhangs or nest height above water, has been found to provide shelter from both biological threats, such as larger species of gulls, and physical elements, such as heavy precipitation (Olsthoorn and Nelson 1990, Regehr and Montevecchi 1997, Regehr et al. 1998). Nesting on cliff faces provides some measure of protection from many land-based predators but kittiwake chicks and eggs can still be predated by aerial predators, particularly during years of poor resource availability for the predators, making nest site location on the cliff face an important part of individual nest success (Regehr and Montevecchi 1997). Nests located on the upper sections of a colony in Canada were more likely to be targeted by gulls in the genus *Larus* than nests located lower down the cliff face (Massaro et al. 2001). Steep cliff structure and rocky projections over or beside nest areas provided protection from predation and increased chick survival (Regehr et al. 1998). Some evidence also suggests that overhangs above the nest, in the absence of predation, provide protection from heavy precipitation (Olsthoorn and Nelson 1990). Colony density and location within the colony have also been found to be positively correlated with individual nest success (Regehr et al. 1998, Kildaw 1999, Massaro et al. 2001). A study utilizing artificial nest ledges at St. Paul Island, Alaska, found that colony density was more important than physical characteristics of a nest site and that kittiwakes would choose reduced quality nest sites (devoid of structural protection) to be located in a high density location (Kildaw 1999).

Behavioral patterns of breeding birds may also affect annual productivity. Adults nesting closer to the center of the colony have been found to be more experienced, higher quality breeding adults (Regehr et al. 1998). These individuals have also been found to express more aggressive behavior prior to incubation, presumably to defend territory from potential usurpers or ward off birds attempting to steal nesting material (Tinbergen 1959, Nickerson 2000). Kittiwakes typically try to maintain a constant presence at the nest site, particularly during the incubation and early brooding periods, to chase off any adults intending to take over prime locations or protect chicks from predators (Roberts and Hatch 1993). Parental absence during the early brooding period, leaving chicks open to predation and weather, has been found to be an indication of poor resource availability (Roberts and Hatch 1993, Cadiou and Monnat 1996, Massaro et al. 2001). A study observing kittiwake behavior in a colony on Middleton Island, Alaska, found that kittiwakes tried to keep adult absence from the nest to a minimum, indicating that kittiwakes (during early chick rearing) try to maintain attendance of at least one adult at the nest at all times. Because absence of adults from the nest were often preceded by unsuccessful (no food reward) begging by the chick, it was believed absences of both parents were indicative of poor resource availability (Roberts and Hatch 1993). Average timing of laying and clutch size can also be an indication of poor resource availability (Regehr and Montevecchi 1997). Annual reproductive success and the timing associated with important reproductive behaviors, such as hatching, can also change in conjunction with oceanographic patterns (Agler et al. 1999, Gill et al. 2002, Piatt and Sydeman 2007, Byrd et al. 2008, Sydeman et al. 2012).

Responses of most seabirds to shifts in oceanographic conditions are primarily indirect, due to prey resources shifting in response to sea surface temperature (SST) or sea ice cover (SIC) (Frederiksen et al. 2004, 2007; Byrd et al. 2008, Sydeman et al. 2012, Hatch 2013). Kittiwakes in a North Sea colony were observed to initiate the breeding season earlier in years of more mild winters and warmer winter SST (Frederiksen et al. 2004). Warm winter SST and SIC also encouraged kittiwakes nesting on the Pribilof Islands in the Bering Sea to begin the breeding season earlier than in cooler years. In contrast, however, Common Murres (*Uria aalge*) and Thick-billed Murres (*Uria lomvia*) typically did not show strong correlations between breeding behavior and changing SST or SIC. Reasons for the differences among species were hypothesized to be related to prey availability. Considering deep-diving murres and surface-feeding kittiwakes sample different zones of the water column, it could be assumed that prey occurring in the upper reaches of the water column is more greatly affected by changes in winter SST and SIC (Byrd et al. 2008). Changes in weather may have direct effects on seabird colonies as well. Increases in air temperature could negatively affect the physiological health of breeding pairs while a change in rates of precipitation could influence breeding success (Sydeman et al. 2012). Kittiwake nests are constructed of mud and vegetation, so high rates of precipitation could cause increased nest loss while unseasonably low precipitation could increase overall success (Baird et al. 2009). Understanding the relationship between local environmental conditions and reproductive health of breeding populations of seabirds is an essential component in detecting when anomalous changes in the local environment is reflected in reproductive behavior.

To summarize, developing techniques that can identify and monitor factors that influence reproductive success of target colonies is becoming increasingly important as global temperatures rise and anthropogenic influence encroaches on habitats (Piatt and Sydeman 2007, Sydeman et al. 2012). Remote camera techniques could provide the ability to both determine the factors that most influence productivity and provide the equipment to maintain a long-term monitoring station to detect changes in the reproductive behavior of breeding colonies that signify a change in the local environment. The goal of this study was to identify environmental and behavioral factors that influence productivity of a sub-colony of kittiwakes in Resurrection Bay near the northern Gulf of Alaska using remote camera techniques. The specific objectives were to 1) determine the effect of nest characteristics on individual nest success; 2) identify if individual behavior of breeding adults during the incubation period influenced hatch success; 3) determine if loss (nest, egg, and chick) events were influenced by seasonal weather patterns; and 4) investigate if annual productivity and sea surface temperature over a short time period were correlated.

2.2 METHODS

2.2.1 Estimating Productivity from Monitoring Data

The study site and monitoring protocol for productivity used for this study is described in Chapter 1. In addition to daily observations recorded for 2013-2015, 3 more years of observation were included for this study. Observations were conducted once a day in the morning every 3-4 days in 2010-2012. Because videos were recorded daily from 2013-2015 and every 3-4 days from 2010-2012, the scale of productivity estimates was inconsistent due to the time gaps in observation between the 2 recording periods. Decreased observation may affect estimates of initial hatch dates, potentially altering the age of the chick when it was last seen and, by proxy, possibly altering estimates of productivity. A chick was considered fledged once it had reached 40 days of age, because observation of first flight was not feasible for this study design (Gill et al. 2002, Gill and Hatch 2002). To address the discrepancy in sampling effort between the 2 periods of observation (2010-2012 and 2013-2015) and identify if a correction factor was needed to make the data sets comparable, the 2014-2015 dataset was reduced from daily to 2, 3, 4, 5, 6, and 7-day intervals to reflect observation conducted in 2010-2012 (R Core Team 2015). If mean productivity for reduced intervals differed by 0.1 fledglings per nest attempt to daily intervals, different fledge ages (39, 38, 37, 36, 35, and 34) would be applied to each reduced interval to identify a fledge age that minimized the difference in productivity between daily observations and reduced intervals. The adjusted fledge age with the least difference between daily observations and reduced data sets would be used as a correction factor on the 2010-2012 data to make it more statistically comparable to the 2013-2015 data set. Productivity was considered to be the number of fledglings produced per nest attempt. All analyses were conducted in R (R Core Team 2015).

2.2.2 Effects of Nest Characteristics on Nest Success

Number of chicks produced per individual nest site per year was the response variable used to determine if nest characteristics influenced individual nest success during 2010-2015. Physical parameters were analyzed using a combination of video observations and onsite images taken with a high-resolution DSLR camera (Canon® EOS Digital Rebel XSi, Canon USA, Lake Success, NY). Images taken using the DSLR camera were paired with images taken from the remote cameras and analyzed in Adobe Photoshop CS3 for detailed nest characteristics. Target physical characteristics of each nest were nest height from the water, presence of an overhang, number of vertical walls adjacent to nest, and mainland or island location. A biological nest site characteristic, average number of visible nests (in remote camera image), was also included in the analysis. Nest height was calculated using a combination of a range finder and ImageJ (Abramoff et al. 2004). From the ranges collected at the study site, height from the high tideline to the nest was calculated by taking the square root of the squared distance to the high tideline from the boat subtracted from the squared distance from the boat to the predetermined nest site (Pythagorean Theorem). This height was used as a measurement scale in ImageJ to measure the height above the high tideline of all other locations monitored for reproductive behaviors. Presence of an overhang was classified as Type 1, directly over the nest within 2 body lengths that shaded at least 80% of the nest, or Type 2, more than 2 body lengths above the nest and covering multiple nests. Type 1 overhangs were hypothesized to provide protection from both predators and precipitation while Type 2 could provide some shelter from rain, but less so from predators. Number of vertical walls adjacent to the nest was determined by walls immediately adjacent to a nest that were higher than an incubating bird. If the adjacent wall had a slope of less than 60° it was not considered a vertical wall. Average number of visible nests within the camera view was calculated by averaging the number of nests in videos recorded on 3 different days once nests have been established (first-second week of June). Mainland and island locations were approximately south facing with the island location south of the mainland location (Figure 1.2).

Nest success was modeled using a Poisson regression as a function of nest characteristics ("lme4" package in R; Bates et al. 2014, R Core Team 2015). Overhang and mainland/island were treated as categorical fixed effects; nest height, number of walls, and number of visible nests were treated as continuous fixed effects; and location was treated as a random effect. Model predictors were centralized in preparation for model averaging using the "arm" package in R on the global model (Grueber et al. 2011, Gelman and Su 2015, R Core Team 2015). Using the "MuMIn" package, a full submodel set was generated from the standardized global model (Barton 2015, R Core Team 2015). The top models were selected for averaging using a ΔAIC_c cutoff value of 2 (Grueber et al. 2011).

2.2.3 Effect of Behavior on Hatch Success

I analyzed video footage from 2013-2014 to determine if adult behavior influenced hatch success. Fourteen nests in 2 plots, one on the island and one on the mainland, were monitored to assess activity budgets and chosen based on nest visibility for behavioral observations (Figure 2.1). In 2013, behavioral observations were recorded every 3-4 days at 10:00 am or 6:00 pm for 20 minute intervals. Timing of observation was alternated between morning and evening. In 2014, more time was available for behavioral monitoring and each plot was recorded daily for one hour periods. Timing of recording for each plot would switch each day, with one plot recorded at 10:00 am and the other recorded at 5:00 pm.

Videos were reviewed using focal-animal sampling (Altmann 1974). Behaviors were recorded using Behavioral Observation Research Interactive Software (BORIS) (Friard and

Gamba 2015). Target behaviors were adult presence during the nesting period (May), time spent incubating during the incubation period (June-July), aggression during the nesting period (May), and aggression during the incubation period (June-July). Percent presence of adults during the incubation period was excluded from the model due to correlation with percent time spent incubating. An out of view "behavior" was also included for time periods when interference caused complete loss of view of subjects. Behavior states were classified as presence/absence, incubation, brooding, and out of view. Aggression was assigned as a behavior point, where the behavior was classified as an instantaneous event (Altmann 1974). Aggression was recorded as each aggressive move an individual made toward another bird. Behaviors considered aggressive included both open- and closed-mouth jabs and physical attacks (Tinbergen 1959). Point behaviors were calculated as average number of aggression events per reproductive period. Videos were reviewed up until each subject had either failed or hatched a chick successfully. A time budget analysis was produced for each observation using BORIS. Since behavioral observations were conducted more frequently for longer time periods in 2014 than 2013, years were analyzed separately.

Hatching success was modeled as a function of nesting period and incubation period using a generalized linear model (GLM) with a binomial error distribution. The binary response variable was hatch success (1 = successful, 0 = unsuccessful). Birds that did not initiate incubation of an egg were not included in the analysis. A standardized GLM for 2014 was run with all target variables with no significant results (Grueber et al. 2011, Gelman and Su 2015, R Core Team 2015).

2.2.4 Effect of Weather on Loss Events

Total loss per day per type of loss (nest, egg, and chick) from 2014-2015 was recorded to determine if loss events were influenced by seasonal variation in weather patterns. Weather data were collected using a weather station installed at the study site. A Vantage Vue® weather station and WeatherLink USB data logger from Davis Instruments (Davis Instruments Corp., Hayward, CA) were purchased and installed at the study site on April 29, 2014. Target weather patterns of interest recorded were air temperature, wind speed/direction, and precipitation. The weather station was programmed to record every hour to minimize visits to the colony for download of data from the logger while still recording a frequent measure of weather at the colony. Recorded data were downloaded every 2.5 months. Data included for the analysis were from May-August for the breeding seasons of 2014 and 2015. Three different analyses were run for determining the effect of seasonal weather patterns on the 3 types of loss. Losses included all losses except for nests lost after the nest was classified as successful or if a chick was lost earlier and the nest was lost late in August.

Given the single subject repeated measures design (repeated measures of loss of the same colony over time), the assumption of independence was expected to be violated and a high rate of zeroes was anticipated. Initial data exploration revealed potential lag in weather effects on loss (e.g. weather event occurs on one date and loss occurs the following date). Losses and target weather variables were averaged over 3-day periods in an attempt to address the issue of independence and account for the lag in weather effects on loss. Losses were rounded to the nearest integer to run a zero-inflated general linearized model (ZIP) with a Poisson distribution using the "pscl" package in R (Jackman 2015, R Core Team 2015). Each type of loss was evaluated using a separate regression. Predictor variables were centralized using the "arm" package (Grueber et al. 2011, Gelman and Su 2015, R Core Team 2015). Automated model selection was conducted using the "MuMIn" package (Barton 2015, R Core Team 2015). Top models were chosen based on a ΔAIC_c value of less than 2 (Grueber et al. 2011). Model averaging was conducted using model averaging functions in the "MuMIn" package (Barton 2015, R Core Team 2015).

2.2.5 Relationship between Sea Surface Temperatures and Annual Productivity

Annual productivity of the study colony for 2010-2014 was used to determine if productivity was correlated with SST. Annual SST data was downloaded online from the long-term oceanographic time series GAK1, located just outside of Resurrection Bay (59°50.7'N, 149°28.0'W) (Weingartner et al. 2013). SST was averaged over the kittiwake's breeding (April-August) and pre-breeding seasons (September-March) (Baird et al. 2009, Wolf et al. 2010) based on previous studies indicating that winter SST could play an important role in kittiwake breeding success (Frederiksen et al. 2007, Byrd et al. 2008). Due to the small sample size and expected non-normality of data, non-parametric Spearman rank correlation was used for analysis (R Core Team 2015).

2.3 RESULTS

2.3.1 Estimating Productivity from Different Monitoring Frequencies

Estimates of productivity between 3-5 day and daily observation frequencies differed by more than 0.1 fledglings per nest attempt. Observation intervals for the 2010-2012 recording period ranged from 3-5 days, and the Monte Carlo simulation indicated that 38 days of age was an appropriate correction for 3-day intervals while 37 days of age was an appropriate correction for 4-day intervals (see Figure 2.2 for 2014). As both 3- and 4-day intervals were present in all 3 years of the 2010-2012 dataset and the full dataset of 2013-2015 included twice-daily observations, 37 days was used as the correction factor. Based on this correction factor, productivity was calculated for 2010-2012 by classifying a chick as a fledgling once it had reached 37 days of age. Productivity was calculated for 2013-2015 using 40 days of age.

Productivity and total hatchlings and fledglings fluctuated throughout all 6 years (Figure 2.2Figure). Productivity ranged from 0.015-0.442 while total fledglings ranged from 2-69 (Figure 2.3). The mean fledge date ranged from August 8-15 over the 6 year time period (Table 2.1). The correction factor described previously only affected productivity and total fledglings (as the correction factor only adjusts the age of what is considered a fledgling) and, as a result, total hatchlings and nest attempts are likely underestimated for 2010-2012 due to the reduced sampling frequency for that time period (Figure 2.3). Mean dates of nest, incubation, and hatch initiation may also be off for 2010-2012 due to the reduced sampling frequency (Table 2.1).

2.3.2 Effects of Nest Characteristics on Nest Success

Nest height, overhang, walls adjacent to the nest, and mainland/island location remained the same throughout all years of observation. Locations where a nest was not created in any year of observation were eliminated from this analysis. Number of visible nests within view changed very little between years, between 0.5-4.5 nests per location. Nest height ranged from 0.96-17.71 m above the high tide line, with most nests occurring between 5 m and 12 m above the high tide line. Fourteen locations (9.5% of total) had a Type 1 overhang and 7 locations (4.7% of total) had a Type 2 overhang. Thirty-three locations (22.4% of total) had more than one wall adjacent to the nest. Of these 33 locations, 29 locations had 2 walls and 4 locations had 3 walls. Nests were approximately evenly divided between mainland and island locations, with 71 locations on the mainland and 76 locations on the island.

The full model indicated that mainland/island (z=4.8, p<0.001) and nest height (z=2.7, p=0.02) had significant influences on the number of fledglings produced per nest. The summary output of the model averaging resulted in an averaging of 5 models (Table 2.2). Model averaging indicated that mainland/island location and nest height above water were the most important predictors for success, with Type 1 overhang having 83% relative importance to these 2 factors (Table 2.2). Mainland/island importance was a significant factor influencing nest success in all years but nest height seemed to vary in importance between years (Figure 2.4).

2.3.3 Effect of Behavior on Hatch Success

Observations were collected from the first day of behavioral observation recording until all nests either hatched a chick or failed. Dates of collection were from May 22-July 12 in 2013 and May 15-July 11 in 2014. A total of 14 morning observations and 11 evening observations were reviewed for 2013. A total of 37 morning observations and 33 evening observations were reviewed for 2014. Twelve out of 95 observations (12.6%) experienced enough interference that accurate observation of target behaviors was impossible and an "out of view" behavior was used. The maximum time that birds were out of view was 37% of total observation time, but the average was 2.16% for all observations. Most out of view observations occurred in 2014.

Hatch success for locations that attempted incubation varied between 2013 and 2014. The 2013 breeding season had to be excluded from the overall analysis due to the 100% hatch success for that year. The 2 years could also not be combined into one analysis due to the more frequent and longer observation periods in 2014, creating a discrepancy in sampling frequency. The more frequent observation in 2014 made the data more robust and increased the detectability of uncommon events, such as aggressive interactions, and comparison to 2013 would have been inaccurate. Six out of 12 nests (50%) that initiated incubation in 2014 successfully hatched a chick. State behaviors were averaged as percent time over each reproductive period.

2.3.4 Effect of Weather on Loss Events

The Vantage Vue® weather station operated from 2014-2015 with only one incidence of technological failure resulting in loss of data. In 2015, 24 days of data were missed from May 27-June 19 due to technical difficulties with the recording module. Average temperate was 11.8 °C (SD = 2.7) for 2014 and 13.3 °C (SD = 3.0) for 2015. Average precipitation was 0.30 mm (SD = 0.91) for 2014 and 0.25 mm (SD = 0.79) for 2015. Average wind speeds were 1.27 m/s (SD = 1.21) for 2014 and 1.12 m/s (SD = 1.08) for 2015.

Regression models for chick loss did not reveal any significant results. However, average wind had a significant effect on egg loss (z=-2.8, p=0.004) and nest loss (z=2.8, p=0.005). The degree of nest loss seemed to increase with increasing wind speeds (see Figure 2.2 for 2014). Model averaging found that average wind was the most important predictor of nest loss, with average rain accounting for 27% of variance (Table 2.3). Top model selection resulted in only one model for egg loss, with average temperature and average wind as the 2 factors that explained the majority of variation in egg loss.

2.3.5 Relationship between Sea Surface Temperatures and Annual Productivity

Average SST prior to the breeding season for 2010-2014 were 6.15 °C (SD = 1.77), 6.81 °C (SD = 2.37), 5.46 °C (SD = 3.04), 7.29 °C (SD = 2.61), and 7.28 °C (SD = 2.42). Average SST during the breeding season for 2010-2014 were 6.40 °C (SD = 2.38), 7.07 °C (SD = 3.06), 4.70 °C (SD = 0.83), 5.88 °C (SD = 2.66), and 7.56 °C (SD = 3.18). Spearman rank correlations found a non-significant relationship between annual productivity and pre-breeding-season SST (r_s = 0.8, p=0.13) and breeding season SST (r_s = 0.6, p=0.35).

2.4 DISCUSSION

Remote camera methods were successfully used to monitor and identify factors influencing productivity of a colony of Black-legged Kittiwakes from 2010-2015. Productivity between daily observations (2013-2015) and every 3-5 day observations (2010-2012) differed by 0.1 fledglings per nest attempt and a correction factor was needed to make the data sets comparable. Thirty-seven days of age was found to be a good correction for 3-5 day observation frequencies and was applied to the 2010-2012 dataset to perform analyses to determine factors influencing reproductive success. Nest height above water and nest location (mainland or island) were the most important predictors of individual nest success. Variation in behavior of breeding adults did not influence hatch success. Average wind speed significantly influenced egg and nest loss events. Pre-breeding and breeding season SST was not correlated with annual productivity.

2.4.1 Estimating Productivity from Different Monitoring Frequencies

The results from the fledgling age correction calculations suggested that a correction factor was needed, and that a good estimate for this dataset was to subtract $n - 1$ (n = observation interval) days from 40 days of age to correct for decreased frequency of observation. The protocol for determining if a chick is fledged can vary with project design but is usually determined by observation of first flight or, in the case of this project, using a pre-determined age that a chick must reach before it is considered a fledgling (Gill et al. 2002). Pre-determining an age at which a chick is considered a fledgling provides an alternative for situations when actual chick flight cannot be observed (i.e. very frequent or continuous observation is not feasible). The average fledge age, however, is based on daily observation and may underestimate productivity for studies that monitor less frequently, as indicated in the results of this study. The 2 observation frequencies used here, daily and every 3-4 days, are the 2 most common observation frequencies for kittiwake productivity, making a correction factor for that interval potentially relevant to other studies (Hunt Jr. et al. 1986, Hatch and Hatch 1988, Regehr et al. 1998, Coulson and Fairweather 2001, Jodice et al. 2002, Gill et al. 2002, Degeorges et al. 2010). There was overlap in confidence intervals of the same observation frequency between different fledge ages, indicating that, while the correction factor chosen for the analyses was the closest in comparison to the original dataset, other fledge ages could potentially have been used for the analyses to similar effect.

The correction factor chosen for this study may not be directly applicable to all study designs. The dataset was based on daily 30-second back-captures of study subjects, a relatively short period of time with respect to studies that use live observation, but could be useful for photographic surveys. The methods described above for identifying a correction factor could prove to be a valuable framework for other studies with different sampling frequencies, particularly in the instance of remote observation.

2.4.2 Effects of Nest Characteristics on Nest Success

Nest height above the water and nest location (island vs. mainland) were the most important factors to influence individual nest success, with overhangs directly over the nest within 2 body lengths having mild importance. Physical characteristics of a nest site thus had a more significant impact on individual nest success than biological characteristics (e.g. nest density), contrary to some previous studies in which nest density was more important (Kildaw 1999, Massaro et al. 2001). Nests located in high-density areas of the colony are less susceptible to predation (Massaro et al. 2001). Nest density was not a significant predictor of individual nest success in my study, indicating that predation may not play a significant role in influencing individual nest success for this study colony. Depredation of eggs or chicks was not observed in any live or video observations in all 6 years of observation, further supporting the inference that predators may not be a great influence at this study site (Tanedo, unpubl obs).

A greater influence of physical nest characteristics indicates that individual nest success may be more heavily influenced by weather patterns than predation. The importance of nest height may be linked to storm surge events, when the tide was high and wave action was intense (Tanedo, unpubl obs). Entire plots were lost during these time periods, eradicating a good portion of lower elevation nests that were preparing to fledge a chick. Despite consistent loss throughout all 6 years, birds returned to nest in these exact locations every year. It is important to note that, while nest height had a significant influence on individual nest success, it may be more important in some years than others and could depend on the timing and strength of weather patterns.

Location (mainland or island) significantly influenced productivity, potentially due to weather patterns as well. The island location consistently produced fewer chicks (with the exception of 2012) and experienced greater loss each year than the mainland locations, despite both locations having a comparable number of monitored nests. The mainland location also contained Plot 17, the plot with the lowest elevation and the most consistent failure for all 6 years due to getting washed out by wave action. Both mainland and island locations are oriented in the same south-facing direction, but the island location is just south of the mainland. This configuration and the significance of island and mainland locations on individual nest success may indicate some kind of buffering factor for mainland locations. The results of this analysis suggest that weather patterns play a bigger role in influencing individual nest success than biological factors such as predation. The effect of predation, however, was not investigated for this project and could play a greater role than indicated in this analysis.

2.4.3 Effect of Behavior on Hatch Success

Analysis of the behavioral data collected did not reveal any significant predictors of individual nest success. Percent time incubating versus participation in other activities did not significantly change hatch success, nor did presence of the adult influence hatch success of birds that initiated incubation. Most adults were present the majority of time during the nest creation period and maintained a constant presence during the incubation period. Exceptions to this pattern were individuals who had experienced nest or egg loss. Adults who lost an egg or nest were more likely to leave the nest site unattended. Birds that had created a nest but did not initiate incubation were also more likely to leave the nest unattended, but generally maintained a frequent presence. These individuals were also observed actively defending the location as well as fighting off birds that attempted to steal nesting material, regardless of nest state. Aggression was not observed to have any significant influence on hatchability, but may have an impact on overall success. Since only one nest in the analysis was successful in 2014, a conclusive analysis concerning the effect of any behavioral activity on overall success could not be run.

The effect of adult behavior on the hatch success of an individual nest was based on 12 nesting individuals in one year, a relatively small sample size. I found no significant effects of adult behavior on hatch success but recommend that further data is needed to determine whether adult behavior may influence hatch success at my study site. Adult behavior can change from year to year for several reasons, one of which is food availability. Adults are more likely to leave the nest unattended during poor food resource years, leaving chicks open to predation or weather events (Roberts and Hatch 1993). Increasing the number of subjects and variety of locations within the sub-colony that are monitored could also give a better understanding of how aggression influences hatch success, as one study has indicated that more aggressive, successful individuals nest in the high-density locations (Nickerson 2000). Extending analysis to adult behavior during the brooding period would also lead to better understanding of importance of adult presence through the chick rearing period, when adult presence may be influenced by availability of food resources (Roberts and Hatch 1993, Regehr and Montevecchi 1997).

2.4.4 Effect of Weather on Loss Events

The effect of weather changes on losses experienced by breeding kittiwakes varied among types of loss. Analysis of seasonal weather effects did not reveal any significant predictors of chick loss. Egg loss significantly decreased with increasing average wind speed. Conversely, nest loss increased with increasing average wind speed. Nest loss at higher wind speeds is a logical result, considering that kittiwake nests are composed of mud and grass material and are constructed on a very narrow ledge (Baird et al. 2009). When a nest is lost, all contents within the nest bowl, such as eggs or chicks, are usually lost as well, indicating that chick and egg loss, when coupled with nest loss, were also significantly influenced by high average wind speed. Comparatively, just egg loss was significantly less during periods of greater average wind speed, potentially due to adults restricting movement away from the nest during high wind events. Loss of an egg could be caused by multiple reasons, such as nest loss or predation (Regehr and Montevecchi 1997).

Loss of an egg due to predation for this particular study site seems unlikely for multiple reasons. As mentioned previously, nest density, a measure of protection from predators, was not found to be an important factor influencing individual nest success. Windy conditions also increased the range of nests that could be attacked by increasing the maneuverability of large gull species (Massaro et al. 2001). Predation of eggs and chicks was also not directly observed through video recordings in any of the 6 years of productivity observation or any of the behavioral videos in 2014-2015, though predation potentially occurred outside time periods of observation. I recommend further observation and potential incorporation of behavioral observation to determine the reason behind decreased egg loss under windy conditions.

Analysis of seasonal weather patterns on different types of loss indicated some interesting results that warrant further investigation. Average temperature, while an insignificant factor in all models of loss, was included in the final model of egg loss as a predictor of relative importance. Continued data collection may emphasize the importance of other weather factors and shape a better understanding of how this colony is influenced by seasonal weather patterns. Final results of this analysis conclude that, for the breeding seasons of 2014 and 2015, average wind speeds had an important influence on nest and egg loss.

2.4.5 Relationship between Sea Surface Temperatures and Annual Productivity

Pre-breeding and breeding season SST were not significantly correlated with annual estimates of productivity for the Cape Resurrection kittiwake colony. The majority of studies investigating the effect of SST on annual productivity conclude that cooler SST prior to the breeding season is correlated with higher success, which is mainly attributed to shifts in availability of preferred prey (Frederiksen et al. 2007, Hatch 2013).

Kittiwakes prey on a variety of different forage fish and small invertebrates depending on region or time of year, but Pacific Capelin (*Mallotus villosus*), Pacific Sand Lance (*Ammodytes hexapterus*), and occasionally Pacific Herring (*Clupea pallasii*) are typically the preferred prey for Pacific kittiwakes (Baird et al. 2009, Hatch 2013). Forage fish generally prey on zooplankton, particularly during their larval stages, and rely on the timing and abundance of zooplankton for recruitment (Anderson and Piatt 1999). During cooler regimes, peak abundance of *Neocalanus* species occurs later, usually in late spring, following the spring bloom of phytoplankton (Mackas et al. 1998, Anderson and Piatt 1999, Anthony et al. 2000). Species favoring cooler climates, such as capelin, rely on the later timing of abundant zooplankton to support late spring, early summer spawning (Anderson and Piatt 1999, Brown 2002, Spies 2007). Warmer SST associated with warm regimes initiates earlier spring phytoplankton blooms, causing a shift in the timing and duration of the peak abundance of zooplankton (Mackas et al. 1998). Decoupling peak abundance of prey and timing of spawning for late spring spawners decreases recruitment and reduces overall fitness of those species, reducing their quality as prey items (Anderson and Piatt 1999, Anthony et al. 2000, Brown 2002). Early abundance of zooplankton also supports earlier spawners, such as Walleye Pollock (*Theragra chalcogramma*) and Pacific Cod (*Gadus macrocephalus*), increasing recruitment of lower quality prey species for breeding seabirds (Anderson and Piatt 1999, Romano et al. 2006). Increased recruitment of pollock and cod could also put further strain on forage fish favored by seabirds, as larger pollock and cod tend to feed on the same composition of forage fish (Anderson and Piatt 1999).

SST did not have a significant relationship with annual productivity for this colony of seabirds. The lack of relationship could be due to the sample size; 5 years of data were used for this analysis, a relatively small sample size to make any conclusive statements on the effect of SST on annual estimates of productivity for this dataset. The relationship between SST and productivity of seabirds, however, can also be complex and expected predictions, such as warmer SST negatively affecting seabird productivity, may not always hold. Seabird diet quality and composition can vary between regions and seasons and the processes negatively affecting forage fish availability in some areas could have little effect in other areas (Anthony et al. 2000, Baird et al. 2009, Hatch 2013). In summary, throughout 5 years of observation, the Cape Resurrection kittiwake colony exhibited good years of productivity under a range of environmental conditions.

2.5 CONCLUSION

Remote monitoring methods were successful in identifying the factors that most influence kittiwake productivity in Resurrection Bay in the northern GOA. Physical nest characteristics, such as nest height above water, were found to have a stronger influence over individual nest success than the biological characteristic, local nest density. Nest loss increased with increasing wind speeds, simultaneously indicating that egg and chick loss could also be negatively influenced by increasing wind speeds. Annual oceanographic variation did not reveal any strongly significant results from the 6 years of productivity data collected from this particular colony, though I found a weak positive relationship between SST and annual productivity. Determining the effect of individual variation in behavior of adults during the incubation period did not reveal any significant results. Based on these results, I conclude that individual and annual success of the Cape Resurrection kittiwake colony was found to be influenced by several physical characteristics, including nest height, mainland vs. island location, and high wind events.

2.6 FIGURES

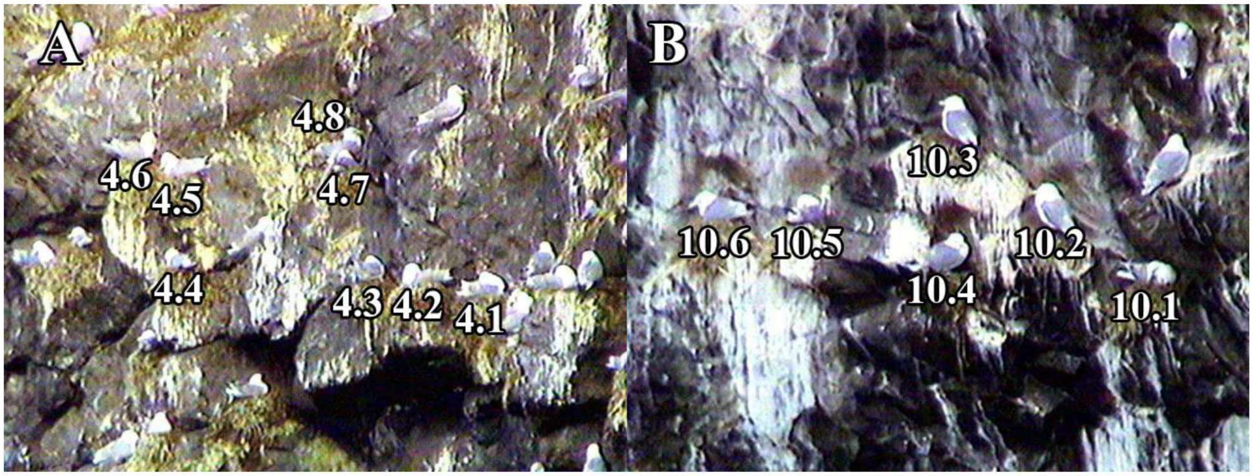

Figure 2.1: Island behavioral plot, Plot 4 (A) and mainland behavioral plot, Plot 10 (B).

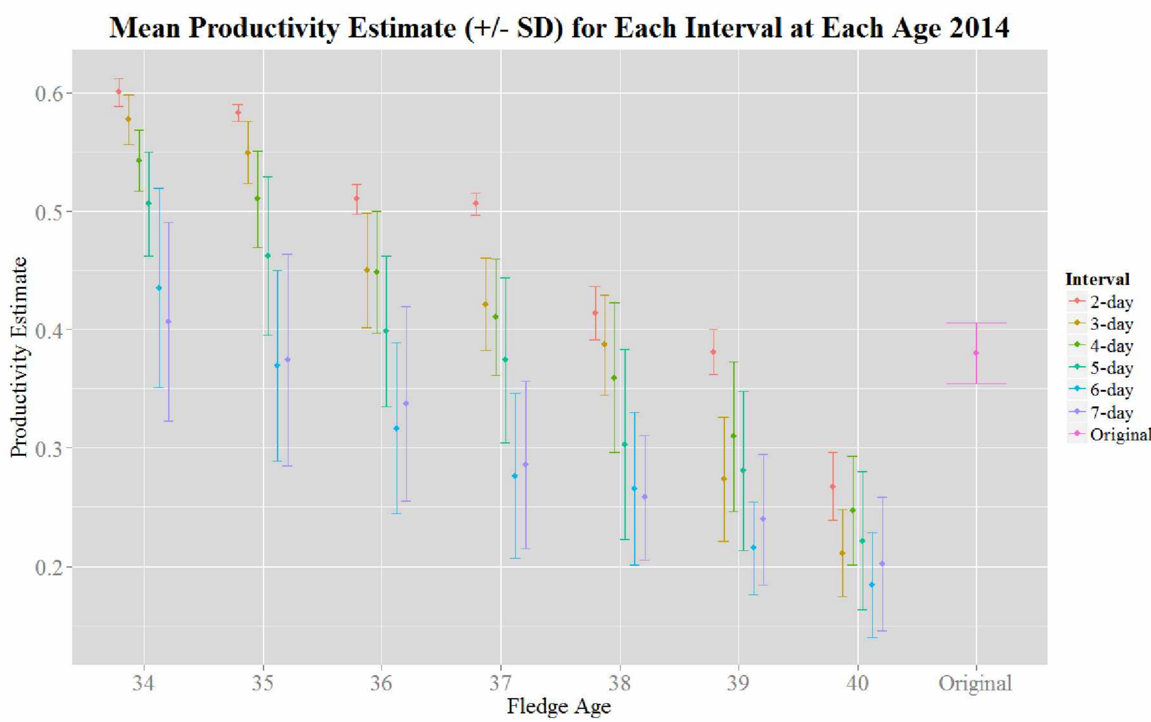

Figure 2.2: Fledgling age correction calculation for 2014.

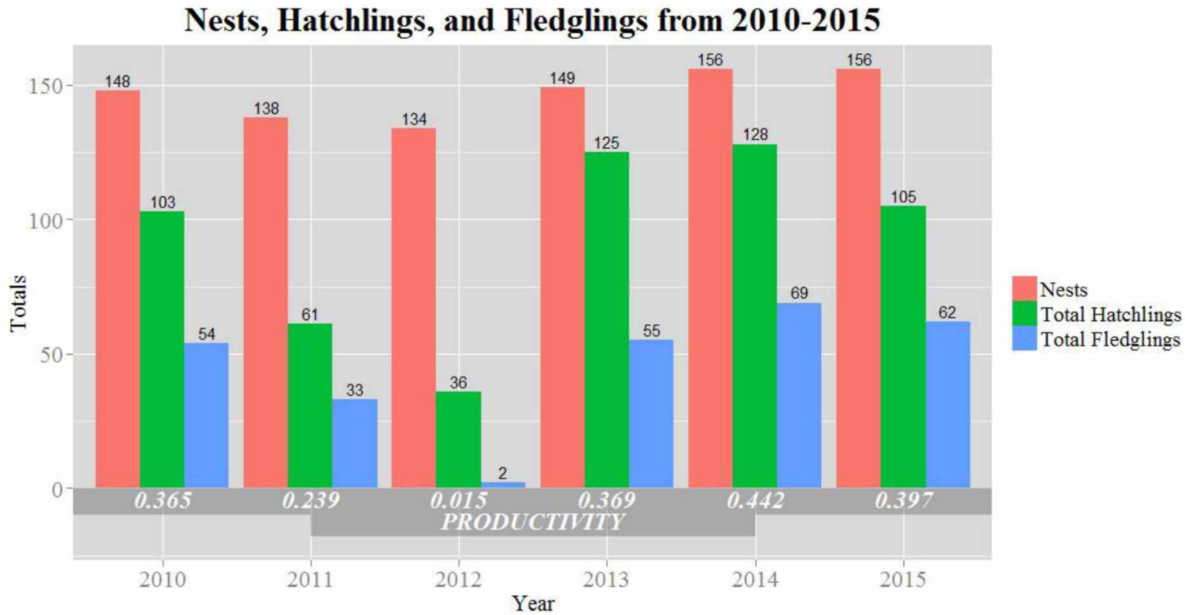

Figure 2.3: Total nests, hatchlings, fledglings, and estimates of productivity for 2010-2015.

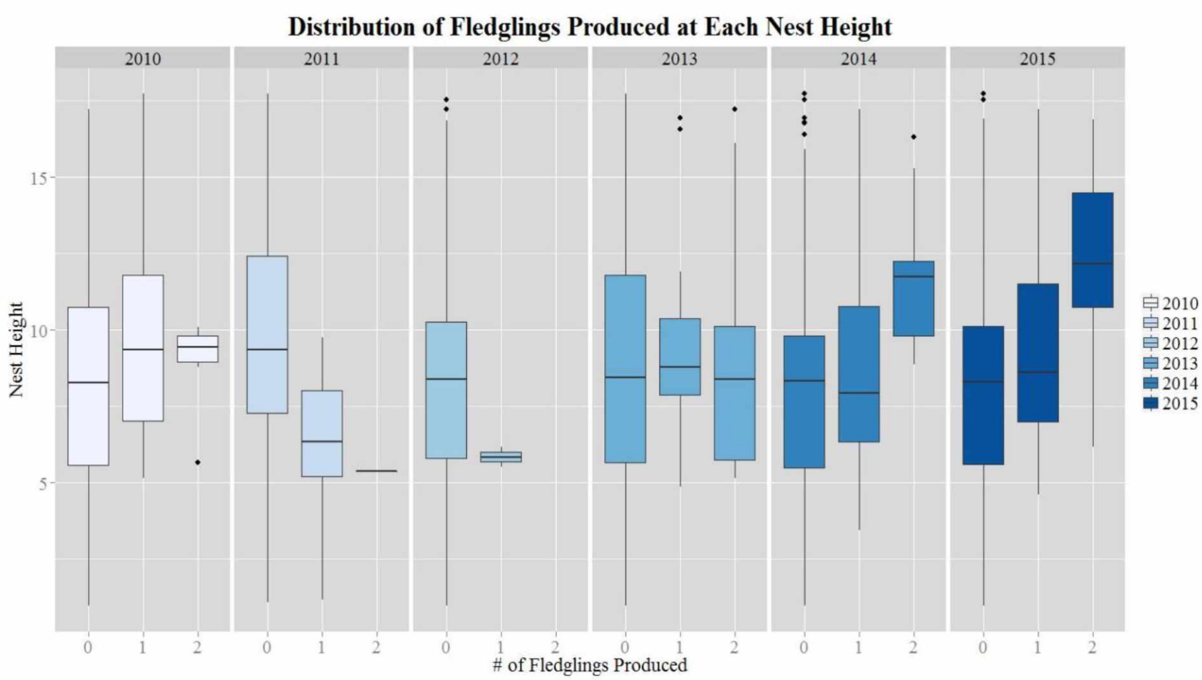

Figure 2.4: Boxplots of total fledglings produced per year with regard to nest height.

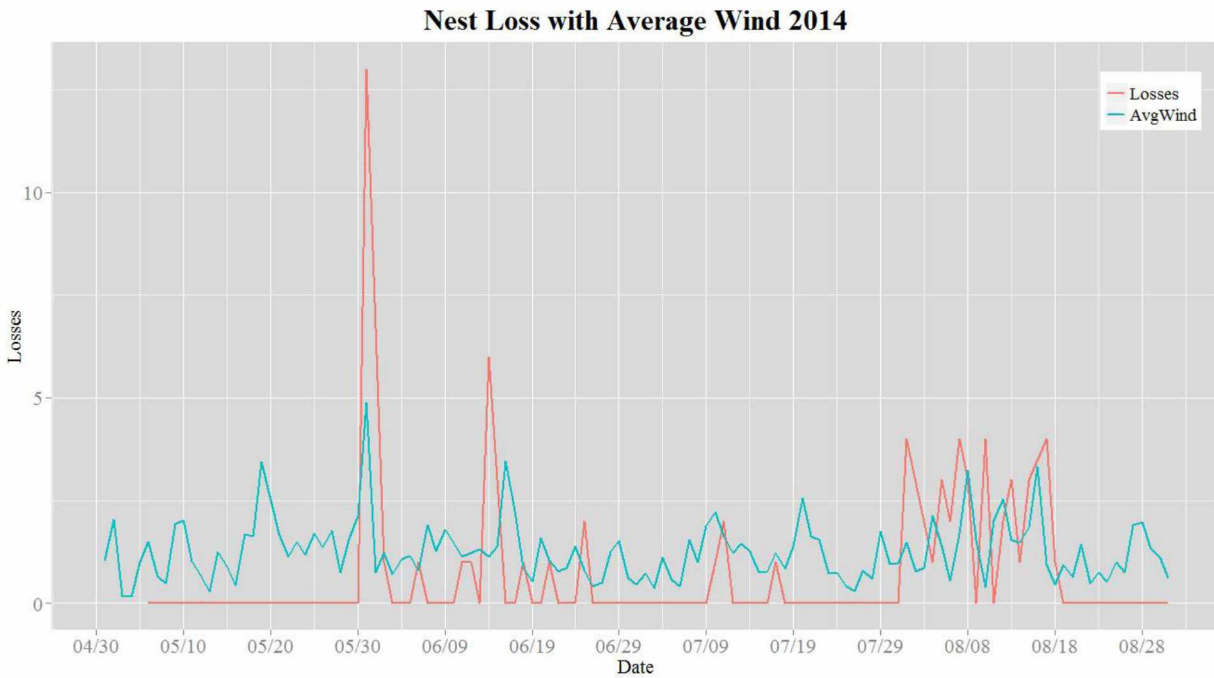

Figure 2.5: Nest loss and average wind speed per day in 2014.

2.7 TABLES

Table 2.1: Mean dates of nest, incubation, hatch, and fledge initiation dates with standard deviation (SD) for 2010-2015.

Year	Nest		Incubation		Hatch		Fledge	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
2010	05/27	3.49	06/06	5.70	07/07	5.13	08/10	2.81
2011	05/29	4.11	06/11	5.80	07/11	5.23	08/15	3.33
2012	05/24	4.69	06/07	7.00	07/08	6.55	08/08	2.70
2013	05/19	6.21	06/03	4.73	07/05	4.80	08/15	4.00
2014	05/25	3.96	06/05	5.26	07/07	4.57	08/15	3.46
2015	05/24	4.89	06/02	5.03	07/05	4.50	08/14	3.56

Table 2.2: Summary results of nest characteristics regression after model averaging.

Parameter	Estimate	Unconditional SE	Confidence Interval	Relative Importance
(Intercept)	-1.130	0.073	(-1.273, -0.987)	
c.MI[1]	0.574	0.137	(0.305, 0.843)	1.000
Overhang1[2]	-0.352	0.280	(-0.900, 0.197)	0.830
Overhang2	-0.930	0.514	(-1.937, 0.077)	"
Nest Height	0.397	0.147	(0.109, 0.686)	1.000
Visible Nests	0.199	0.116	(-0.028, 0.425)	0.640
Walls	-0.108	0.137	(-0.376, 0.161)	0.280

[1]Island was the reference category.
[2]Zero overhang was the reference category.

Table 2.3: Summary results of nest loss regression after model averaging.

Parameter	Estimate*	Unconditional SE	Confidence Interval	Relative Importance
(Intercept) (count)	-0.093	0.419	(-0.915, 0.730)	
AvgWind (count)	1.266	0.524	(0.239, 2.293)	1.000
AvgRain (count)	-0.096	0.226	(-0.963, 0.254)	0.270
(Intercept) (zero)	0.463	0.621	(-0.754, 1.679)	
AvgWind (zero)	-1.196	0.970	(-3.100, 0.705)	1.000
AvgRain (zero)	-0.356	0.836	(-3.565, 0.941)	0.270

*Standardized

2.8 REFERENCES

Abramoff, M. D., P. J. Magalhaes, and S. J. Ram (2004). Image processing with ImageJ. Biophotonics International 11:36–42.

Agler, B. A., S. J. Kendall, D. B. Irons, and S. P. Klosiewski (1999). Declines in marine bird populations in Prince William Sound, Alaska coincident with a climatic regime shift. Waterbirds: The International Journal of Waterbird Biology 22:98–103.

Altmann, J. (1974). Observational study of behavior: sampling methods. Behaviour 49:227–267.

Anderson, P. J., and J. F. Piatt (1999). Community reorganisation in the Gulf of Alaska following ocean climate regime shift. Marine Ecology Progress Series 189:117–123. doi: 10.3354/meps189117

Anthony, J. A., D. D. Roby, and K. R. Turco (2000). Lipid content and energy density of forage fishes from the northern Gulf of Alaska. Journal of Experimental Marine Biology and Ecology 248:53–78. doi: 10.1016/S0022-0981(00)00159-3

Baird, P. H., S. A. Hatch, and G. J. Robertson (2009). Black-legged Kittiwake (*Rissa tridactyla*). *The Birds of North America Online (A. Poole, Ed.). Ithaca: Cornell Lab of Ornithology*. [Online.] Available at http://bna.birds.cornell.edu/bna/species/092. doi: 10.2173/bna.92

Barton, K. (2015). MuMIn: Multi-Model Inference. R package version 1.15.1.

Bates, D., M. Maechler, B. Bolker, and S. Walker (2014). lme4: Linear mixed-effects models using Eigen and S4.

Bluhm, B. A., A. V. Gebruk, R. Gradinger, R. R. Hopcroft, F. Huettmann, K. N. Kosobokova, B. I. Sirenko, and J. M. Weslawski (2011). Arctic marine biodiversity: An update of species richness and examples of biodiversity change. Oceanography 24:232–248. doi: 10.5670/oceanog.2011.75

Brown, E. D. (2002). Life history, distribution, and size structure of Pacific Capelin in Prince William Sound and the northern Gulf of Alaska. ICES Journal of Marine Science 59:983–996. doi: 10.1006/jmsc.2002.1281

Buck, C. L., K. M. O'Reilly, and S. D. Kildaw (2007). Interannual variability of Black-legged Kittiwake productivity is reflected in baseline plasma corticosterone. General and Comparative Endocrinology 150:430–436. doi: 10.1016/j.ygcen.2006.10.011

Byrd, G. V., W. J. Sydeman, H. M. Renner, and S. Minobe (2008). Responses of piscivorous seabirds at the Pribilof Islands to ocean climate. Deep Sea Research Part II: Topical Studies in Oceanography 55:1856–1867. doi: 10.1016/j.dsr2.2008.04.015

Cadiou, B., and J.-Y. Monnat (1996). Parental attendance and squatting in the Kittiwake *Rissa tridactyla* during the rearing period. Bird Study 43:164–171. doi: 10.1080/00063659609461009

Coulson, J. C., and J. A. Fairweather (2001). Reduced reproductive performance prior to death in the Black-legged Kittiwake : senescence or terminal illness? Journal of Avian Biology 32:146–152.

Degeorges, A., F. Helfenstein, É. Danchin, R. H. Wagner, and S. Leclaire (2010). Family size and sex-specific parental effort in Black-legged Kittiwakes. Behaviour 147:1841–1862. doi: 10.1163/000579510X538872

Frederiksen, M., M. Edwards, R. A. Mavor, and S. Wanless (2007). Regional and annual variation in Black-legged Kittiwake breeding productivity is related to sea surface temperature. Marine Ecology Progress Series 350:137–143. doi: 10.3354/meps07126

Frederiksen, M., M. P. Harris, F. Daunt, P. Rothery, and S. Wanless (2004). Scale-dependent climate signals drive breeding phenology of three seabird species. Global Change Biology 10:1214–1221. doi: 10.1111/j.1365-2486.2004.00794.x

Friard, O., and M. Gamba (2015). Behavioral Observation Research Interactive Software.

Gelman, A., and Y.-S. Su (2015). arm: Data Analysis Using Regression and Multilevel/Hierarchical Models. R package version 1.8-6.

Gill, V. A., and S. A. Hatch (2002). Components of productivity in Black-legged Kittiwakes *Rissa tridactyla*: response to supplemental feeding. Journal of Avian Biology 33:113–126. doi: 10.1034/j.1600-048X.2002.330201.x

Gill, V. A., S. A. Hatch, and R. B. Lanctot (2002). Sensitivity of breeding parameters to food supply in Black-legged Kittiwakes *Rissa tridactyla*. Ibis 144:268–283. doi: 10.1046/j.1474-919X.2002.00043.x

Grueber, C. E., S. Nakagawa, R. J. Laws, and I. G. Jamieson (2011). Multimodel inference in ecology and evolution: Challenges and solutions. Journal of Evolutionary Biology 24:699–711. doi: 10.1111/j.1420-9101.2010.02210.x

Harley, C. D. G., A. R. Hughes, K. M. Hultgren, C. J. B. Sorte, C. S. Thornber, L. F. Rodriguez, L. Tomanek, and S. L. Williams (2006). The impacts of climate change in coastal marine systems. Ecology Letters 9:228–241. doi: 10.1111/j.1461-0248.2005.00871.x

Hatch, S. A. (2013). Kittiwake diets and chick production signal a 2008 regime shift in the Northeast Pacific. Marine Ecology Progress Series 477:271–284. doi: 10.3354/meps10161

Hatch, S. A., and M. A. Hatch (1988). Colony attendance and population monitoring of Black-legged Kittiwakes on the Semidi Islands, Alaska. The Condor 90:613–620.

Hunt Jr., G. L., Z. A. Eppley, and D. C. Schneider (1986). Reproductive performance of seabirds: The importance of population and colony size. The Auk 103:306–317.

Jackman, S. (2015). pscl: Classes and Methods for R Developed in the Political Science Computational Laboratory, Stanford University. Department of Political Science, Stanford University. Stanford, California. R package version 1.4.9.

Jodice, P. G. R., D. D. Roby, S. A. Hatch, V. A. Gill, R. B. Lanctot, and G. H. Visser (2002). Does food availability affect energy expenditure rates of nesting seabirds? A supplemental-feeding experiment with Black-legged Kittiwakes (*Rissa tridactyla*). Canadian Journal of Zoology 80:214–222. doi: 10.1139/Z01-221

Kildaw, S. D. (1999). Competitive displacement? An experimental assessment of nest site preferences of cliff-nesting gulls. Ecology 80:576–586.

Lorentzen, E., R. Choquet, and H. Steen (2012). Modelling state uncertainty with photo series data for the estimation of breeding success in a cliff-nesting seabird. Journal of Ornithology 152:S477–S483. doi: 10.1007/s10336-011-0723-0

Mackas, D. L., R. Goldblatt, and A. G. Lewis (1998). Interdecadal variation in developmental timing of *Neocalanus plumchrus* populations at Ocean Station P in the subarctic North Pacific. Canadian Journal of Fisheries and Aquatic Sciences 55:1878–1893.

Massaro, M., J. W. Chardine, and I. L. Jones (2001). Relationships between Black-legged Kittiwake nest-site characteristics and susceptibility to predation by large gulls. The Condor 103:793–801.

Nickerson, M. (2000). Behaviour of kittiwakes during the breeding seaosn: relationships with nest density and breeding success.

Olsthoorn, J. C. M., and J. B. Nelson (1990). The availability of breeding sites for some British seabirds. Bird Study 37:145–164. doi: 10.1080/00063659009477052

Per Huffeldt, N., and F. R. Merkel (2013). Remote time-lapse photography as a monitoring tool for colonial breeding seabirds : A case study using Thick-billed Murres (*Uria lomvia*). Waterbirds 36:330–341.

Piatt, J. F., and W. J. Sydeman (2007). Seabirds as indicators of marine ecosystems. Marine Ecology Progress Series 352:199–309. doi: 10.3354/meps07070

R Core Team (2015). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL http://www.R-project.org/.

Regehr, H. M., and W. A. Montevecchi (1997). Interactive effects of food shortage and predation on breeding failure of Black-legged Kittiwakes: Indirect effects of fisheries activities and implications for indicator species. Marine Ecology Progress Series 155:249–260. doi: 10.3354/meps155249

Regehr, H. M., M. S. Rodway, and W. A. Montevecchi (1998). Antipredator benefits of nest-site selection in Black-legged Kittiwakes. Canadian Journal of Zoology 76:910–915. doi: 10.1139/cjz-76-5-910

Roberts, B. D., and S. A. Hatch (1993). Behavioral Ecology of Black-legged Kittiwakes during Chick Rearing in a Failing Colony. The Condor 95:330–342.

Romano, M. D., J. F. Piatt, and D. D. Roby (2006). Testing the junk-food hypothesis on marine birds: Effects of prey type on growth and development. Waterbirds 29:407–414.

Southwell, C., and L. Emmerson (2015). Remotely-operating camera network expands Antarctic seabird observations of key breeding parameters for ecosystem monitoring and management. Journal for Nature Conservation 23:1–8. doi: 10.1016/j.jnc.2014.11.002

Spies, R. B. (2007). Long-term ecological change in the Northern Gulf of Alaska. 1st edition. Elsevier Science.

Springer, A. M., J. F. Piatt, and G. V. V. Vliet (1996). Sea birds as proxies of marine habitats and food webs in the western Aleutian Arc. Fisheries Oceanography 5:45–55.

Suryan, R. M., and D. B. Irons (2001). Colony and population dynamics of Black-legged Kittiwakes in a heterogeneous environment. The Auk 118:636–649.

Sydeman, W. J., S. A. Thompson, and A. S. Kitaysky (2012). Seabirds and climate change: roadmap for the future. Marine Ecology Progress Series 454:107–117. doi: 10.3354/meps09806

Tinbergen, N. (1959). Comparative studies of the behavior of gulls (*Laridae*): A progress report. Behaviour 15:1–70.

Weingartner, T., S. Danielson, and D. Leech (2013). Station GAK1: Northern Gulf of Alaska Temperature/Salinity Time Series. [Online.] Available at http://www.ims.uaf.edu/gak1/.

Wolf, S. G., M. A. Snyder, W. J. Sydeman, D. F. Doak, and D. A. Croll (2010). Predicting population consequences of ocean climate change for an ecosystem sentinel, the seabird Cassin’s Auklet. Global Change Biology 16:1923–1935. doi: 10.1111/j.1365-2486.2010.02194.x

CONCLUSION

Remote camera methods were found to be a useful tool for monitoring cliff-nesting seabirds. The remote cameras used in this study were reliable for collecting video/still image records and provided detailed visual access to a breeding cliff-nesting seabird, the black-legged kittiwake, for 6 years of observation. Throughout the multi-year observation period, video records collected using the remote camera technology were consistent in visual quality and demonstrated the ability of using this technology for long term studies. The permanent records of daily reproductive events provided by video and still image documentation allowed observers to review behaviors multiple times and generated an archive of images for future reference. Some types of behaviors, such as those indicating the presence of a newly hatched chick, happen in a brief amount of time and would be difficult to confirm without the ability to review recordings. Multiple reviews were helpful for verification of observations, such as sighting of a chick, and simplified the ability to study factors potentially influencing nest success, such as investigating aggression events. The remote camera technology also provided daily visual observation access to the colony, permitting the tracking of important reproductive events, such as nest initiation. Daily observation to collect the amount of detail obtained using remote camera technology would have been difficult to accomplish using boat based surveys and would have required considerably more boat and staff time to accomplish.

Remote camera systems offer an extensive number of advantages over other methods of observation, such as boat based surveys, but using this method of monitoring wildlife can sometimes be challenging. Understanding the limitations that remote camera systems have is an important aspect to consider for any study design involving these systems. Remote cameras are constrained by the limits of the power source and memory storage available for a particular unit. Systems relying on solar power to recharge battery banks, such as the remote camera system used in this study, can become limited or unable to operate during periods when inclement weather prevents the batteries from charging properly. Depending on the camera unit, such as the camera system used in this study, sunny days can also degrade image quality by interfering with signal transmission from the camera site to the site of operation. Some types of equipment, such as video systems that can be remotely operated from another location, can also be expensive to purchase and install. Despite the limitations, the remote camera system for this project provided a reliable dataset for analysis, with few instances where the drawbacks to remote camera technology interfered with data collection. To help further develop remote camera systems for monitoring cliff-nesting seabird productivity, this study refined observation techniques and used these techniques to identify factors that influence breeding success for kittiwakes in Resurrection Bay, Alaska.

Objectives will vary among studies using remote camera technology and should be considered when selecting equipment and establishing an observation frequency. Predation events, for example, can occur at random and projects tracking these occurrences would benefit the most from motion-activated still image or video equipment. Frequent observation using still image equipment would be most appropriate for tracking diurnal occupancy of organisms in a fixed location. For monitoring cliff-nesting seabirds, breeding seasons can extend several months and tracking breeding success can become a balance of obtaining enough data to accurately calculate productivity and the battery life of camera equipment. To investigate the use of remote camera techniques for monitoring cliff-nesting seabirds, I investigated the effect of observation frequency and equipment type on estimates of productivity for kittiwakes. Decreasing observation frequency did not significantly influence estimates of productivity, but estimates did exhibit a general downward trend from daily observation to each decreased frequency of observation up to weekly observations. The decrease in productivity indicated that dates of important reproductive events, such as initial hatch date, were slightly different to that observed by daily observation as compared to each reduced interval of observation. Furthermore, decreased observation frequency could introduce uncertainty in other target response variables, such as the date of peak hatching, and should be considered in project design. In my study area, observations made twice a season (once in early June for total nests and once in early August for total fledglings) significantly overestimated productivity when compared to the daily estimate. This was due to the fact that productivity was calculated based on total nests in June and total fledglings observed in August, disregarding chick age since an accurate age could not be calculated without knowing the hatch dates of chicks. On the other hand, the type of remote camera observation used (video or still image) did not significantly influence estimates of productivity, making still image remote observation a good alternative to video observation if the project objective is to monitor estimates of productivity.

The same remote camera system was used to study factors that influence productivity for kittiwakes at my study site in the northern GOA. The importance of nest characteristics on individual nest success, studied for a period of 6 years, indicated that mainland vs. island locations and nest height above water were the most influential factors for this study site. Mainland nest locations consistently produced more fledglings per year than island locations while nests located nearer to the high tideline were more likely to experience failure. Individual variation in behavior of incubating adults did not have a significant effect on egg hatchability in one year of observation. Further observation of individual variation in behavior, however, is needed in order to reach a more conclusive understanding. When investigating seasonal variation in weather patterns, I found that increased wind speeds significantly increased nest loss. Nest bowl contents, including eggs and chicks, that were lost with the nest were also significantly influenced by increasing wind speeds. Chick loss, with the nest remaining intact, was not significantly influenced by any seasonal weather patterns, while egg loss, with the nest remaining intact, was significantly and positively influenced by increasing wind speeds. Analysis of the relationship between annual estimates of productivity and SST over 5 years of observation did not reveal a strong correlation between these 2 variables. The relationship between SST and productivity of seabirds, however, can be complex, particularly with regard to the effect of SST on the availability of forage fish. Continued observation of this colony for another 5 years and adding a method of tracking chick diet could offer a more detailed look at the relationship between SST and kittiwake productivity in Resurrection Bay.

Using remote camera technology was a useful alternative to boat based surveys for monitoring and identifying factors influencing productivity of Cape Resurrection kittiwakes in the northern GOA. Time-lapse photography with daily observation frequency is an excellent potential alternative to non-remote camera methods of observation if the objective of the study is monitoring estimates of productivity and tracking the occurrence of important reproductive events, such as peak nest initiation. Video methods of remote camera monitoring were also useful in determining the factors that influence individual and annual success of the Cape Resurrection kittiwake colony, and I found that success in this particular colony was primarily influenced by nest height above the high tideline, mainland vs. island location, and average wind speeds. Based on the results of this study, I recommend the use of remote camera technology for the purpose of studying cliff-nesting seabirds in remote locations and find it a useful tool for identifying and tracking factors that influence the breeding success of these populations over a multiyear time period.

Recommendations for future work include further exploration of remote camera technology and expanding the investigation of factors that influence estimates of productivity. Investigating the effect of duration of observation on the ability to detect target reproductive behaviors would be beneficial in determining if a 30-second observation is an appropriate length of time to detect target reproductive behaviors, or if increasing the observation period increases the detection rate of important reproductive behaviors, such as brooding. Testing other remote camera equipment types, such as trail cameras or high resolution DSLR cameras, at the Cape Resurrection kittiwake colony would further support the conclusions reached in this study by utilizing more readily available still image photography equipment. Exploring the influence of other factors, such as forage fish abundance and composition or predation events, on estimates of productivity would greatly improve understanding of the factors that influence estimates of productivity for the Cape Resurrection colony. The colony located at Cape Resurrection appeared resilient to anomalously warm ocean temperatures in the GOA during 2013-2015, maintaining 3 years of relatively good productivity under a range of different environmental variation. To conclude, recommendations for future work on seabird research would be to investigate reproductive health of other species within Resurrection Bay using techniques outlined in this study and compare results between species both within the bay as well as with colonies in nearby regions.

Appendix A: IACUC 2014 approval letter.

UAF UNIVERSITY OF ALASKA FAIRBANKS

(907) 474-7800
(907) 474-5993 fax
uaf-iacuc@alaska.edu
www.uaf.edu/iacuc

Institutional Animal Care and Use Committee

909 N Koyukuk Dr. Suite 212, P.O. Box 757270, Fairbanks, Alaska 99775-7270

March 13, 2014

To: Tuula Hollmen
Principal Investigator

From: University of Alaska Fairbanks IACUC

Re: [580845-1] Productivity of black-legged kittiwakes (Rissa tridactyla) in the Gulf of Alaska using remote observation techniques

The IACUC reviewed and approved the New Project referenced above by Designated Member Review.

Received:	March 10, 2014
Approval Date:	March 13, 2014
Initial Approval Date:	March 13, 2014
Expiration Date:	March 13, 2015

This action is included on the March 13, 2014 IACUC Agenda.

PI responsibilities:

- *Acquire and maintain all necessary permits and permissions prior to beginning work on this protocol. Failure to obtain or maintain valid permits is considered a violation of an IACUC protocol and could result in revocation of IACUC approval.*
- *Ensure the protocol is up-to-date and submit modifications to the IACUC when necessary (see form 006 "Significant changes requiring IACUC review" in the IRBNet Forms and Templates)*
- *Inform research personnel that only activities described in the approved IACUC protocol can be performed. Ensure personnel have been appropriately trained to perform their duties.*
- *Be aware of status of other packages in IRBNet; this approval only applies to this package and the documents it contains; it does not imply approval for other revisions or renewals you may have submitted to the IACUC previously.*
- *Ensure animal research personnel are aware of the reporting procedures on the following page.*

Appendix B: IACUC 2015 renewal letter.

(907) 474-7800
(907) 474-5993 fax
uaf-iacuc@alaska.edu
www.uaf.edu/iacuc

Institutional Animal Care and Use Committee
909 N Koyukuk Dr. Suite 212, P.O. Box 757270, Fairbanks, Alaska 99775-7270

March 24, 2015

To:	Tuula Hollmen Principal Investigator
From:	University of Alaska Fairbanks IACUC
Re:	[580845-2] Productivity of black-legged kittiwakes (Rissa tridactyla) in the Gulf of Alaska using remote observation techniques

The IACUC has reviewed the Progress Report by Designated Member Review and the Protocol has been approved for an additional year.

Received:	March 12, 2015
Initial Approval Date:	March 13, 2014
Effective Date:	March 13, 2015
Expiration Date:	March 13, 2016

This action is included on the April 9, 2015 IACUC Agenda.

PI responsibilities:

- *Acquire and maintain all necessary permits and permissions prior to beginning work on this protocol. Failure to obtain or maintain valid permits is considered a violation of an IACUC protocol and could result in revocation of IACUC approval.*
- *Ensure the protocol is up-to-date and submit modifications to the IACUC when necessary (see form 006 "Significant changes requiring IACUC review" in the IRBNet Forms and Templates)*
- *Inform research personnel that only activities described in the approved IACUC protocol can be performed. Ensure personnel have been appropriately trained to perform their duties.*
- *Be aware of status of other packages in IRBNet; this approval only applies to this package and the documents it contains; it does not imply approval for other revisions or renewals you may have submitted to the IACUC previously.*
- *Ensure animal research personnel are aware of the reporting procedures detailed in the form 005 "Reporting Concerns".*