

REFINING REMOTE OBSERVATION TECHNIQUES TO ESTIMATE PRODUCTIVITY OF BLACK-LEGGED KITTIWAKES *RISSA TRIDACTYLA* IN RESURRECTION BAY, GULF OF ALASKA

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ABSTRACT

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Monitoring the reproductive performance of seabirds can be challenging, as many species nest in remote locations and can be difficult to observe consistently. Using cameras for seabird monitoring in remote locations is an emerging method. Determining the monitoring frequency and type of equipment best suited for individual species, locations, and objectives is an important consideration due to different seabird reproductive strategies. To refine remote observation techniques for cliff-nesting seabirds, we tested a different observation methods on Black-legged Kittiwakes *Rissa tridactyla* in Resurrection Bay in the northern Gulf of Alaska. Kittiwakes were monitored during the breeding seasons (May–August) of 2013–2015 using remote video and still images. Our first objective was to determine if estimates of productivity changed with observation frequency; we used observations at one-, four-, and seven-day intervals. Our second objective was to assess the appropriate observation frequency for identifying important reproductive events (e.g., phenology). For this objective, we used a finer scale of observation frequency: one- to seven-day intervals. Our third objective was to identify if estimates of individual nest success differed between video and still-image methods. Results indicated that observation frequency significantly influenced estimates of productivity and reproductive phenology. We also found that estimates of individual nest success were comparable between video and still-image methods of monitoring. The results of this study demonstrate that remote camera methods of observing a cliff-nesting seabird were suitable for monitoring reproductive ecology and aspects of ecological interest, and that comparable estimates of productivity can be obtained through both still-image and video methods.

Key words: *Rissa tridactyla*, Black-legged Kittiwake, remote cameras, productivity methods, observation frequency, equipment methods

INTRODUCTION

Remote cameras have been used increasingly as a monitoring tool for observing wildlife. These techniques offer an opportunity to observe wildlife from afar with minimal disturbance to the animals, and they have been used successfully as an alternative to active on-site observation (Per Huffeldt & Merkel 2013). Time-lapse photography and videography 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 & Brewer 2000). Remote camera equipment can be especially useful for consistent and cost-efficient monitoring of wildlife in remote locations (Lorentzen *et al.* 2012, Per Huffeldt & Merkel 2013, Southwell & Emmerson 2015). Cliff-nesting seabirds, such as the Black-legged Kittiwake *Rissa tridactyla*, are good candidates for monitoring via remote camera methods because minimal equipment vastly improves nest visibility and increases the sample size that can be monitored.

Historically, monitoring the reproductive ecology of kittiwakes has been conducted using binoculars or still-image photography from boat-based surveys or land-based observations (Roberts & Hatch 1993, Walsh *et al.* 1995, Shultz *et al.* 2009). In previous studies, the frequency of observation for reproductive ecology has varied from daily to twice annually (Gill & Hatch 2002, Buck *et al.* 2007, Byrd *et al.* 2008b). Twice-annual observation methods

typically involve recording still images or conducting live counts of nests at the beginning of the breeding season, after nests are established, and again at the end of the breeding season prior to the fledging of chicks. Using this method, productivity is defined as the total number of hatchlings per nest and is calculated from images collected during the time periods mentioned previously (Suryan & Irons 2001, Buck *et al.* 2007). Another method to assess productivity involves conducting live or still-image observations at pre-established plot sites several times per week. Using this approach, productivity is calculated by determining the number of fledglings produced per nest attempt (Walsh *et al.* 1995, Regehr & Montevecchi 1997, Byrd *et al.* 2008b, AMNWR 2019). The definition of a “fledgling” is not standardized and varies depending on project design; a chick can be considered a fledgling once it has been observed flying or when it reaches a specific age, such as the average fledge age of 40 days old (Gill & Hatch 2002). The frequency of observation also varies across studies, but an interval of three to five days has commonly been used (Hunt Jr. *et al.* 1986, Hatch & Hatch 1988, Regehr & Montevecchi 1997, Coulson & Fairweather 2001, Frederiksen *et al.* 2013, AMNWR 2019). More frequent observation allows for more detailed data on the phenology of reproductive events, such as the number of hatchlings or the timing of incubation. Even more detail can be obtained through daily observation of breeding kittiwakes (Gill *et al.* 2002, Jodice *et al.* 2002, Leclaire *et al.* 2010); however, daily access to colonies can be challenging, especially in remote locations.

To our knowledge, the effect of observation frequency on productivity estimates has not been studied in seabirds, but an effect has been shown for other avian species. A study monitoring colony-nesting Griffon Vultures *Gyps fulvus* investigated the effect of observation frequency on population and productivity estimates, and it found that higher monitoring frequency increased the accuracy of detection of breeding pairs (Martínez *et al.* 1997). Multiple observations per 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, making it an unfeasible method for some study sites or projects (Per Huffeldt & Merkel 2013). Using remote camera methods such as time-lapse photography or remotely operated video-cameras could be an effective alternative to live on-site observation.

Remote monitoring methods can obtain high-frequency data with minimal effort while simultaneously enabling researchers to permanently record observations for later review. Video and still-image methods of remote observation have been used with great success in studies to monitor terrestrial bird species that nest in nest-boxes, and, in some cases, these methods have been found to exceed other monitoring techniques for tracking predations events, recording adult presence, and calculating productivity (McQuillen & Brewer 2000, Pierce & Pobprasert 2007). Using these techniques to monitor the reproductive ecology of seabirds is still a relatively novel concept and remote camera methods must be adapted for each habitat and species to obtain target data. Time-lapse photography is the most common remote method in published literature for monitoring seabirds (Zador & Piatt 1999, Lorentzen *et al.* 2012, Per Huffeldt & Merkel 2013, Southwell & Emmerson 2015). It has been successfully used to monitor breeding success and colony attendance of Common Murres *Uria aalge* and Thick-billed Murres *U. lomvia*, providing the data to assess ecological links between breeding seabirds and environmental trends (Zador & Piatt 1999, Per Huffeldt & Merkel 2013). Time-lapse photography has also been used successfully to monitor breeding success of Adelie Penguins *Pygoscelis adeliae* in Antarctica (Southwell & 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 & Pobprasert 2007, Wanless *et al.* 2007).

Remote monitoring methods have the potential to supplement or even replace many *in situ* techniques used to study cliff-nesting seabirds, but estimates of reproductive phenology could vary across sampling frequencies and types of monitoring equipment. Determining the effects of observation frequency and equipment type on productivity estimates for cliff-nesting seabirds will provide further guidance for the design of studies using remote camera technology. The objectives of this study were to (1) demonstrate the efficacy of using remote camera technology to monitor the reproductive health of a cliff-nesting seabird, the Black-legged Kittiwake, (2) determine the effect of observation frequency on estimates of productivity, (3) investigate the effect of observation frequency on reproductive phenology, and (4) identify if individual nest success differed significantly between video and still-image methods of monitoring.

STUDY AREA AND METHODS

Efficacy of using remote camera technology to monitor a cliff-nesting seabird

The remote camera used to monitor kittiwakes was positioned 1.5 km north of Cape Resurrection (59.8827°N, 149.2932°W) in Resurrection Bay near Seward, Alaska (Fig. 1). The camera was situated opposite a sub-colony of nesting kittiwakes that was divided into two study locations: island and mainland. The camera was located approximately 78 m (\pm 11 m) from the island location and ~118 m (\pm 8 m) from the mainland location (Fig. 2). Cameras were equipped with 12x–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. Audio and video signals from the



Fig. 1. Location of the remote video camera system at Cape Resurrection near Seward, Alaska. The remote camera system is located approximately 25 km south-southeast of Seward.

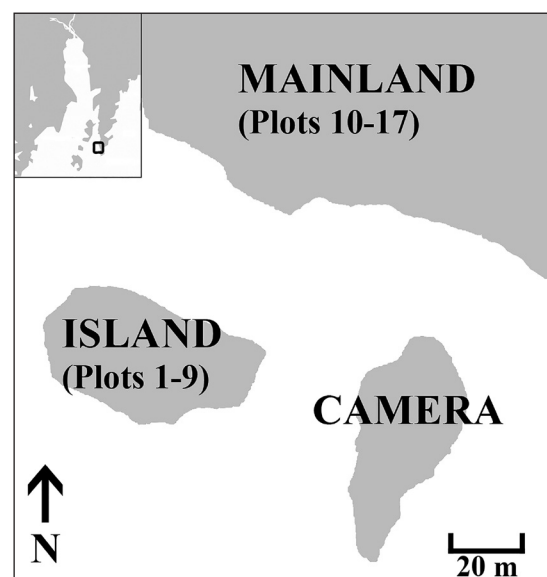


Fig. 2. Close-up view of the study site at Cape Resurrection. The remote video camera system was located east of island plots 1–9 and southeast of mainland plots 10–17.

camera were transmitted from the signal tower located on site to the operation site at the Alaska SeaLife Center by way of a repeater on Chiswell Island (Maniscalco *et al.* 2006). The camera was operated remotely using a computer system at the Alaska SeaLife Center in Seward, which was 25 km north of the study site.

The sub-colony consisted of ~2000 breeding pairs of kittiwakes, 14% of the entire breeding population that nests around Cape Resurrection (Hollmén unpubl. data). Seventeen plots, approximately 4 m × 3 m in size, were randomly selected to represent the sub-colony. Plots 1–9 were located on the island (Fig. 3A) and plots 10–17 were located on the mainland (Fig. 3B). The number of locations monitored within each plot ranged from six to 16, for a total of 149 locations. Plots and locations were based on natural markers and were marked in photo reference sheets for clarification of specific locations (see Fig. 4 for an illustration of Plot 9 and monitored nests). 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 (in the morning and afternoon) during 2013 and 2015. A second morning observation was monitored in 2014 for another study (Table 1). The target monitoring schedule was met for most of the field season, with about 10% to 20% of target observations missed due to weather, technological issues, and staffing problems; most of the missing days were due to lack of staff. Weather prevented observation only six times (2% of total possible observations) throughout the observation period. Observations began in the second or third week of May and ended in the last week of August (14 May–29 August 2013; 06 May–31 August 2014; 11 May–25 August 2015), encompassing the entire

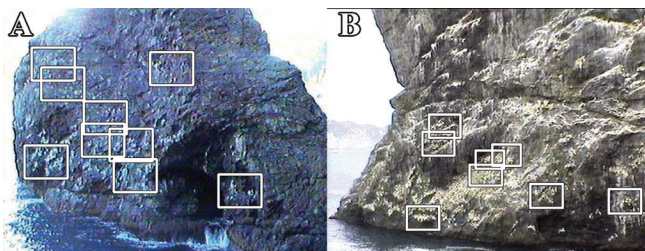


Fig. 3. View of island plots 1–9 (A) and mainland plots 10–17 (B), as seen by the remote video camera system. Plots are indicated by white rectangles. Images grabbed from camera monitoring system.

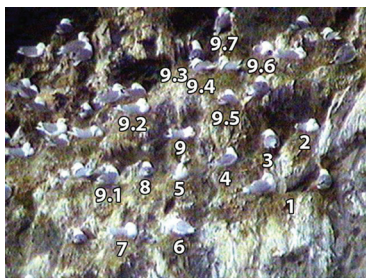


Fig. 4. View of Plot 9 with monitored study sites marked in white, as seen by the remote video camera when zoomed in. Images grabbed from camera monitoring system.

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 Monday–Friday and evening observations Sunday–Monday. A second observer recorded evening observations from Tuesday to Saturday (9% of all observations recorded). Review of the recordings for target reproductive behaviors was conducted by SAT. This research was conducted in compliance with the University of Alaska Fairbanks Institutional Animal Care and Use Committee (Observational Research Protocol#: 580845-1).

Estimating productivity from remote observation data

Target reproductive indices and behaviors included presence of a nest, number of nest attempts, number of adults/chicks, incubation behavior, and brooding behavior. The first nest attempt was defined as the first observation of nesting material (e.g. mud and vegetation) being used for construction at the nest location. A nest was considered lost if > 50% of the original nesting material was gone. If a nest was lost and rebuilt, the rebuild day was recorded as a second nest attempt (AMNWR 2019). Incubation was determined using specific behavioral cues, such as shifting an egg (video) or a specific posture indicative of incubation (video/still image). Brooding behavior was determined in a similar manner, using specific behavioral movement (video) or postures (video/still image) to determine if a bird was brooding over a chick that was only a few days old. The target behaviors most utilized for identifying a bird brooding over a chick were drooping wings combined with a bird hovering over the nest. A chick was considered lost if it permanently disappeared from view for the rest of the season prior to fledging or if it was not observed every day after the minimum fledge date (i.e., prior to reaching fledging age). A minimum fledge date was established for this project because fledged chicks were observed occupying failed sites (i.e., sites where a pair that had lost a nest, egg, or chick) and chicks in early August should be readily visible on the nest at this age, regardless of whether the adult is on the nest. 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 & Hatch 2002) from the minimum observed hatch date from any year. The earliest identified hatch date observed during the entire project was 25 June. The minimum fledge date was calculated by adding 40 days from the minimum hatch date, and it was determined to be 06 August.

TABLE 1
Total observations of Black-legged Kittiwake nests collected in Resurrection Bay, Alaska, by year and time

Year	Time	Observations	Total Observations
2013	10h00	61	85
	18h00	59	
2014	07h30	66	105
	09h30	84	
2015	16h30	76	89
	09h30	68	
	16h30	71	

Productivity was calculated as the number of fledglings produced per nest attempt. Total nest attempts were calculated by tallying the total number of 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 two-chick nests, the second chick's age was calculated from the first observed hatch date to the last day two chicks were seen on the nest. Chicks were considered fledged once they had reached 40 days of age.

Effect of observation frequency on estimates of productivity

Observations recorded from the video data were systematically reduced from the daily dataset to simulate target observation intervals. Target observation intervals for the “decreased observation” condition were four days and seven days (the “productivity interval” dataset); these were chosen to reflect the range of observation frequencies commonly used in other studies (Coulson & Fairweather 2001, Gill & Hatch 2002, Byrd *et al.* 2008b). A target interval of two times per year (once in June and once in August, referred to as the “twice annual” dataset), an observation frequency commonly used in other studies (Suryan & Irons 2001, Buck *et al.* 2007), was also included in the analysis. To subsample observations for the productivity interval datasets, an interval start date was randomly selected from the first five observations of each month. To maintain consistency across all three years, only morning observations were used for the analysis (for 2014, the 09h30 observation was used). Twice annual datasets were created by randomly selecting a single day during 15–24 June (approximately mid-incubation for total nest count) and a single day during 04–14 August (approximately late chick-rearing for total chick count). We summed nests and chicks to calculate productivity. To produce the dataset (representing daily observations) that would be used as the control for both analyses (productivity interval and twice annual), a subsample of the daily dataset was created by randomly removing between zero and three days within the time periods of important reproductive events (early hatch dates in July and fledging periods in August). Productivity was then calculated from the new dataset.

Effect of observation frequency on estimates of reproductive phenology

The methods used to create the interval datasets for calculating the effect of observation frequency on productivity were also used to determine the effect of observation frequency on reproductive phenology. Target intervals were increased to include two- to seven-day intervals (“phenology interval” dataset) because we needed a

finer scale to identify when mean dates of important reproductive events changed relative to observation frequency. The twice annual dataset was excluded from this analysis because reproductive phenology cannot be calculated from just two dates. From each sample dataset, dates were calculated for mean nest building, incubation, and hatch initiation.

Effect of monitoring equipment on estimates of nest success

Productivity was calculated from still images using the above methods. Individual nest success (i.e., the number of fledglings produced per nest) was calculated for each nest for each equipment type and year. The response variable used for the analysis was individual nest success; possible responses were zero, one, or two fledglings produced per nest.

Data analysis

Effect of observation frequency on productivity

The productivity interval datasets (4-d and 7-d) were run in a Monte Carlo simulation with 1000 repetitions. The subsample of the daily dataset was also 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 productivity interval dataset. The daily dataset and twice annual dataset were normally distributed, so repeated measures ANOVA was chosen to determine if there was a significant difference between means ($\alpha = 0.05$) (R Core Team 2015). We conducted a Friedman's test, which is used to test for differences between groups and is tolerant of non-normal data and data with unequal variance, to determine if a significant difference existed between the daily dataset and each productivity interval ($\alpha = 0.05$, R Core Team 2015). If the Friedman's test was significant, post-hoc comparisons between each pair of intervals were explored to identify significant relationships (Galili 2010, R Core Team 2015).

Effect of observation on reproductive phenology

The phenology interval datasets (two- to seven-day intervals) were run in a Monte Carlo simulation with 1000 repetitions. The Monte Carlo simulation of the daily dataset described above was also used for this analysis. The Friedman's test was used as described above to determine if a significant difference existed between

TABLE 2

Mean dates (and standard deviation (SD) in days) of reproductive events for Black-legged Kittiwakes at Cape Resurrection. All dates and times were used to calculate mean dates of initiation of reproductive events

Year	Mean Dates of Initiation			
	Nest	Incubation	Hatch	Fledge
2013	19 May (6.21)	03 Jun (4.73)	05 Jul (4.80)	15 Aug (4.00)
2014	25 May (3.96)	05 Jun (5.26)	07 Jul (4.57)	15 Aug (3.46)
2015	24 May (4.89)	02 Jun (5.03)	05 Jul (4.50)	14 Aug (3.56)

TABLE 3

A comparison of differences between the type of monitoring equipment (still image vs. video methods) used to determine total nests, chicks, and fledglings produced by Black-legged Kittiwakes at Cape Resurrection, 2013–2015

Year	Equipment Type	Total Nests	Total Chicks	Total Fledglings
2013	Still image	149	123	47
	Video	149	125	55
2014	Still image	156	121	63
	Video	156	128	69
2015	Still image	156	104	56
	Video	156	105	63

data collected daily and data collected at different time intervals (phenology interval dataset) ($\alpha = 0.05$, R Core Team 2015).

Effect of monitoring equipment on estimates of nest success

A generalized linear mixed-effects model (GLMM) was used to model nest success as a function of year and equipment type. The model was run with a negative binomial distribution with location as a random effect using the “glmmADMB” package in R (Warton 2005, Fournier *et al.* 2012, Skaug *et al.* 2014, R Core Team 2015).

RESULTS

Efficacy of using remote camera technology to monitor a cliff-nesting seabird

Overall, video and still-image recordings were of consistent, usable quality. Using the remote video camera to collect observations was simple, and it enabled the monitoring of many cliff-nesting seabirds at a distance. During the project, very few days of possible observations were missed due to low battery power, caused by failure of the solar panels to properly charge batteries during inclement weather. There were, however, some minor disadvantages to using this remote camera technology. Image quality was excellent most of the time, but unusually sunny days (e.g., cloudless days, which are uncommon in Resurrection Bay) were more likely to experience interference (i.e., static across the image). Glare on sunny days could also hinder review of observations because study subjects were overexposed and whited out, which made it challenging to identify bird behavior. These two issues were largely based on the design of this camera system and where the camera was facing at the time of recording. The interference mentioned previously was due to the sun overcharging the batteries through the solar panel, which caused some electrical interference. The glare from the sun could be mitigated by altering the recording period for when the sun would be least likely to be hitting the location enough to interfere with observation. Our system design also required active control by staff to collect video or still images. While providing a dynamic ability to monitor multiple areas, it limited the number of video/still images collected to when staff were available to record. Compared to active on-site observation, however, using the remote video camera system required significantly less staff effort and time to collect observational data.

Estimating productivity from remote observation data

The daily dataset with both morning and afternoon recordings was analyzed for estimates of productivity and reproductive phenology. Across all years and all observations, the mean nest initiation dates were in the 19–25 May range (Table 2). Mean egg-laying dates were in the 02–05 June range with mean hatch dates approximately 32–33 d later, from 05–07 July (Table 2). Mean fledge dates were similar among all years, 14–15 August (Table 2). The mean age of fledglings (chicks that reached the age of 40 d) at the time they were last observed was 44 d for all three years. Nests that were considered to have failed due to a missing date of observation after the minimum fledge date, but that had a consistent fledgling presence (i.e., at least three consecutive days) accounted for 36% (2013), 17% (2014), and 38% (2015) of total chick loss during August (fledging month). Total nest attempts among years ranged from 149 to 156 (Fig. 5). Total number of hatchlings ranged from 105 to 128, with 55–69 of those hatchlings becoming fledglings (Fig. 5). Two-chick nests consisted of 19%–25% of the total nests that hatched a chick, with 46%–65% of those nests successfully fledging both chicks.

Effect of observation frequency on estimates of productivity

Estimates of productivity decreased as much as 0.1 fledglings produced per nest between intervals, and estimates dropped with reduced observation frequency (Fig. 6). This decrease in productivity differed between years, with estimates of productivity decreasing more in 2014 than in 2013 or 2015 (Fig. 6). Productivity estimates derived from the daily dataset and the productivity interval dataset were significantly different (Friedman’s test: $X^2 = 6$, $P = 0.049$). Post-hoc comparisons indicated a significant difference between the daily dataset and the seven-day interval ($P = 0.038$), with lower productivity in the less frequent monitoring schedule. Productivity estimates derived from the daily dataset were significantly lower than those calculated from the twice annual dataset (repeated measures ANOVA: $F = 36.79$, $P = 0.026$).

Effect of observation frequency on reproductive phenology

Mean initiation dates for nesting, incubation, and hatch that were determined by different sampling intervals (every two to seven

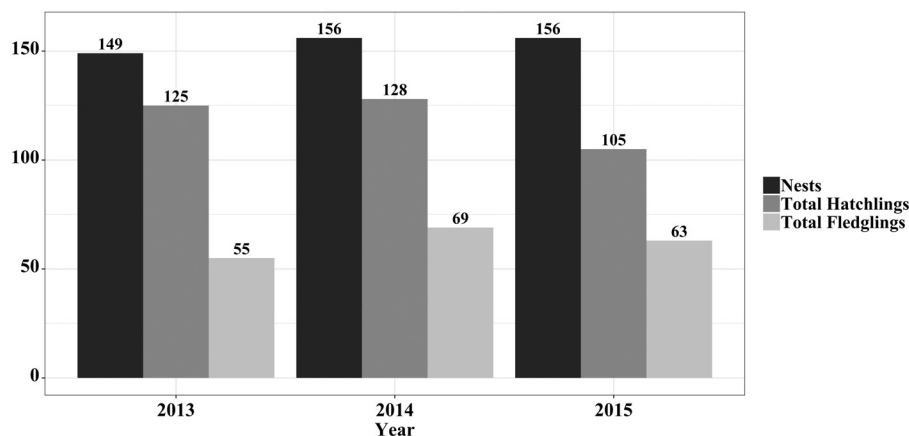


Fig. 5. Total nests, hatchlings, and fledglings for Black-legged Kittiwakes at Cape Resurrection, 2013–2015. All dates and times were used to calculate this data.

days) were one to three days later than mean dates determined from daily sampling; later dates were associated with decreased observation frequency. This effect remained similar in all years, with mean detection of nest, incubation, or hatch occurring later with decreased observation frequency (Fig. 7). We found a significant difference in the dates of mean nest initiation (Friedman's test: $X^2 = 16.06$, $P = 0.013$), incubation initiation (Friedman's test: $X^2 = 18$, $P = 0.006$), and hatch initiation (Friedman's test: $X^2 = 17.928$, $P = 0.006$) between different sampling intervals. Post-hoc comparisons for nest initiation dates did not indicate which interval pairs were significantly different. Post-hoc tests for incubation and hatch initiation, however, revealed a significant difference between daily sampling and seven-day observation intervals ($P = 0.012$ for both).

Type of monitoring equipment

Nest initiation, incubation initiation, and hatching initiation varied from one to three days in mean date, based on equipment type (Table 4). The average fledge date did not differ between still image and video methods (Table 4). Nest attempts were the same for both observation methods, while the difference in total hatchlings ranged from one to seven, depending on method (Table 3). Productivity estimates calculated from video observations were 0.369 (2013), 0.442 (2014), and 0.404 (2015). Productivity estimates from still-image observations were 0.315 (2013), 0.404 (2014), and 0.359 (2015). Variation in productivity estimates between video and still-image methods of observation were not significantly different (GLMM; $z = 1.12$, $P = 0.264$).

DISCUSSION

Efficacy of using remote camera technology to monitor a cliff-nesting seabird

We found remote camera methods to be useful for monitoring reproductive performance of kittiwakes at our study site in the Gulf of Alaska. Investigators must balance staff time, funding, and various other logistics with the research objective when designing monitoring projects. Using remote camera technology significantly reduced the amount of staff time required to meet the objectives. The remote cameras were operated from an office and required no more time to operate than starting up a computer, which reduced the

need to travel to study sites or maintain semi-permanent camps. The number of observations required to meet target objectives were also collected by a single observer for most of the project. Data collection and analysis by a single observer is not usually feasible for remote colonial species, which require frequent observation to monitor reproductive ecology and often prompt investigators to hire multiple individuals. The use of remote camera technology enabled data collection and analysis by a single observer. Furthermore, collecting data using remote camera technology created permanent records of observations, providing opportunities to revisit visual records for clarification, train personnel, or note additional behaviors to record for future projects. Overall, the remote camera system was a reliable and useful method for monitoring kittiwake productivity.

Effect of observation frequency on productivity

Observation frequency significantly influenced estimates of productivity, with a downward trend in productivity associated with decreased observation frequency. Post-hoc comparisons between the productivity interval datasets and the daily datasets revealed a significant difference between the daily dataset and the seven-day interval. Decreased observation frequency, such as on a seven-day interval, increased the chance of inaccurately determining the timing of dates important for calculating productivity. This, in turn, can decrease productivity estimates. Hatch dates are incredibly important for determining productivity, as a chick is considered fledged after some number of days post hatch (40 d for this study). An egg that hatches just after a seven-day check won't be discovered until seven days later, moving the estimated fledge date up by seven days. Chicks that fail to reach their estimated fledge date are recorded as failed, and this can influence estimates of productivity. Estimates of productivity are a common response variable that can be used to detect changes in the local environment, so the ability to reliably identify when changes happen is critical (Frederiksen *et al.* 2007, Piatt *et al.* 2007, Byrd *et al.* 2008a, Zador *et al.* 2013). As a result, we do not recommend observations at intervals longer than four days when monitoring ledge-nesting seabirds such as kittiwakes.

In our study, twice-annual observations significantly overestimated productivity when compared to daily observations. Productivity for twice-annual observations was calculated by counting every chick seen as a fledgling during late chick-rearing, as was done in other studies (Suryan & Irons 2001, Buck *et al.* 2007). Total

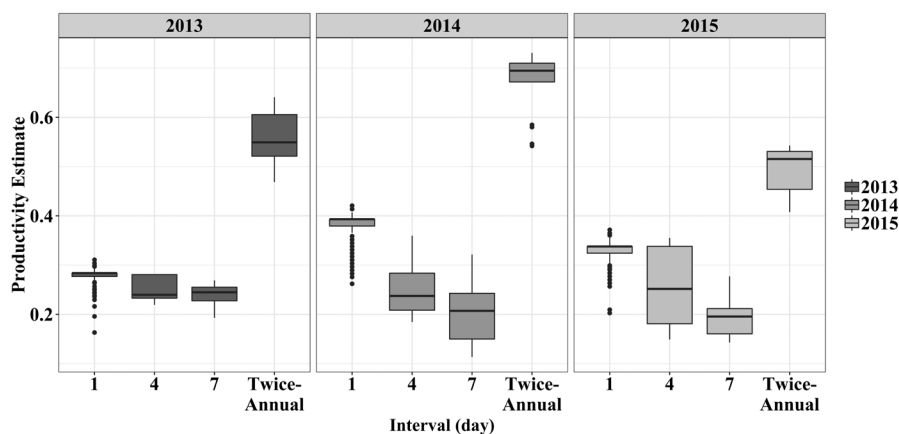


Fig. 6. Mean estimates of productivity with standard deviation for Black-legged Kittiwakes at Cape Resurrection, 2013–2015, for each monitoring interval tested.

nests were counted instead of total nest attempts; this did not account for nest loss events and resulted in increased estimates of productivity. Chicks can also be lost after the fledgling count survey. Estimates of productivity for twice-annual observations were a little over 1.5× greater than productivity calculated using more frequent observation methods at this study site. These findings reiterate the need to use caution when comparing estimates of productivity between locations that may have used different observation methods. Comparing estimates of productivity between a colony that used twice-annual observation methods to a colony that used age-based methods could insinuate that the first colony had significantly higher productivity when this could just be the result of using different methods to estimate productivity. Based on these results, we recommend considering the methods used to calculate productivity when determining the relationships between colonies on both local and regional scales.

Twice-annual observations make obtaining a productivity estimate for a large number of nest sites more feasible, with minimal staff involvement and time spent conducting observations. However, we feel that improved technology is making remote monitoring more economical and easier to operate, offering novel opportunities for colony observation. The remote-sensing technology also provides permanent records, creating an archive for re-analysis, training, and exploration of the data in new ways. We suggest that remote camera technology can provide an alternative to costly on-site monitoring of cliff-nesting seabirds, produce precise estimates of productivity, and enable detection of important reproductive events.

Effect of observation frequency on reproductive phenology

Decreased observation frequency significantly delayed detection of nest, incubation, and hatch initiation. With decreased observation frequency, these dates were detected one to three days later than that detected by daily observations, with the discrepancy increasing with greater intervals between observation periods. Sampling at seven-day intervals was not frequent enough to detect the same mean dates for important breeding phenology as were detected from daily sampling. Many of these events (nest, incubation, and hatch initiation) occurred between sampling periods and were summarily recorded one to seven days after the actual date, causing the mean dates of initiation to be later. The ability to precisely detect when birds are initiating nests, eggs, or hatch timing is important for identifying when birds may be responding to changes in their environment. Research has shown that some seabird species alter the timing of their breeding season by as little as 0.5–0.8 d (Byrd *et al.* 2008b) relative to sea surface temperatures (Frederiksen *et al.* 2004, Byrd *et al.* 2008b, Shultz *et al.* 2009). Such small alterations to their breeding strategy could be lost when observation frequencies are spaced too infrequently.

Accurately detecting these dates is also important for accurately estimating productivity, as hatch dates are a vital part of calculating when a chick is considered fledged. While some chicks may hang around the nest site beyond the set fledge age of 40 days, this may not always be the case. In fact, data from the daily dataset indicated that fledglings generally maintained a presence at the nest until ~44 days of age, approximately four days beyond when they were

TABLE 4
Mean dates (and SD in days) of reproductive events for Black-legged Kittiwakes at Cape Resurrection for still image and video methods of observation, 2013–2015

Year	Equipment Type	Mean Dates of Initiation			
		Nest	Incubation	Hatch	Fledge
2013	Still image	22 May (5.91)	03 Jun (4.96)	06 Jul (5.10)	15 Aug (4.27)
	Video	19 May (6.21)	03 Jun (4.73)	05 Jul (4.80)	15 Aug (4.00)
2014	Still image	27 May (3.41)	07 Jun (5.12)	07 Jul (5.02)	15 Aug (3.52)
	Video	25 May (3.96)	05 Jun (5.26)	07 Jul (7.57)	15 Aug (3.46)
2015	Still image	24 May (4.91)	03 Jun (4.81)	06 Jul (4.57)	14 Aug (3.41)
	Video	24 May (4.89)	02 Jun (5.03)	05 Jul (4.50)	14 Aug (3.56)

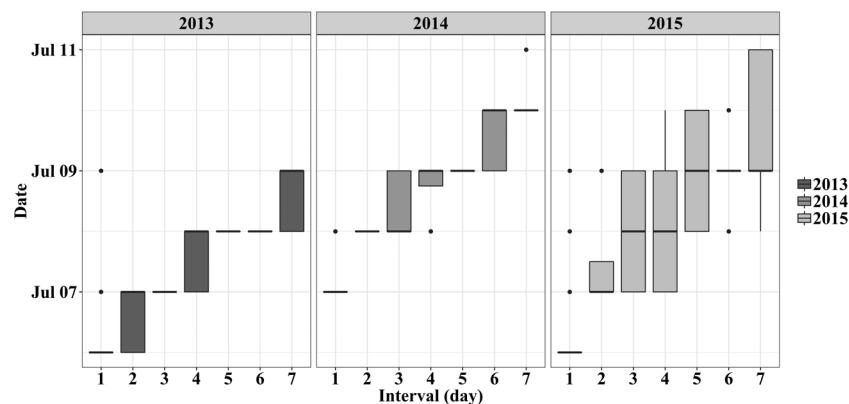


Fig. 7. Mean hatch initiation for Black-legged Kittiwakes at Cape Resurrection, 2013–2015, for each monitoring interval tested.

officially considered a fledgling for this project. An observer monitoring at a five-day interval could potentially mark fledglings as failed. This parallels what we found from the previous analysis, where we tested how estimates of productivity were affected by observation frequency.

Remote camera technology offers a unique approach to monitoring frequently enough to detect important dates for tracking reproductive phenology while minimizing the need for staff time to both collect and review the data (when compared with active on-site observation). Based on the results of this objective, we recommend, for the purpose of monitoring the reproductive phenology of cliff-nesting seabirds, monitoring more frequently than seven-day intervals when using remote camera technology. To both minimize staff time needed while maximizing the precision of data collected, we would suggest monitoring at three- to five-day intervals, the same interval for sampling undertaken by other studies (Hunt Jr. *et al.* 1986, Hatch & Hatch 1988, Regehr & Montevecchi 1997, Coulson & Fairweather 2001, Byrd *et al.* 2008b, Shultz *et al.* 2009, AMNWR 2019).

Type of monitoring equipment

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 estimated an average of 0.04–0.05 fewer fledglings per nest attempt than video estimates, which we feel is a negligible difference in estimates of productivity. The difference found between methods was due to a lack of observation on important dates used for calculation of chick age. Mean hatch date differed by one day between methods, and this was mainly due to missed behavioral cues that were not caught with still-image observations but could be observed with video methods. Video observations provided an advantage for detecting young hatchlings, as birds with chicks that are only a few days old sometimes exhibit subtle behaviors that can only be detected by video observation or precise timing of imaging. Using still-image observation, we missed eight fledging dates that were detected by video because either the adult or the fledgling moved to allow positive identification. All other differences in productivity estimates were a due to a combination of missed hatch and fledge dates.

Demonstrating that still-image methods of observation do not differ significantly from video methods is a valuable finding, as remote operation of still-image equipment is easier and less expensive to maintain compared to remote video methods. Operating video cameras remotely can be logistically challenging, as indicated in this project: our video cameras used multiple repeater towers to transmit the signal from the office to the cameras. The ability to move a camera and record video from 25 km away is tremendously useful, but is costly to maintain, requires a bigger power source, and needs large memory resources. Still-image methods such as time-lapse photography often require less power to operate and do not depend on repeater towers. Eliminating the need for repeater towers could also decrease the frequency of failure due to battery limitations. A waterproof housing with a solar panel or wind generator and a car battery is enough to power a time-lapse camera through an entire breeding season. After installation, still-image time-lapse methods also do not require staff to collect observations, limiting total possible observations to the capacity of the battery and memory card. One of the disadvantages, however, is the inability to monitor a large area with a single piece of equipment. Time-lapse

photography is usually installed to monitor a fixed location (Per Hufferdelt & Merkel 2013, Southwell & Emmerson 2015). In the case of cliff-nesting seabirds, multiple cameras would be needed to cover the same monitoring area as covered in this project, as the locations face multiple directions and cover a large portion of a colony consisting of 2000 breeding pairs. Another consideration is that still-image equipment used to monitor cliff-nesting seabirds should have the ability to zoom in far enough to accurately identify target reproductive behaviors. Our monitoring location here, for example, was ~78–118 m away from the cameras, making fixed-lens still-image equipment (such as trail cameras) unsuitable for this project. A camera with a zoom lens would be appropriate, but, as mentioned previously, this could limit the number of subjects available for monitoring with one camera.

Our results indicate that still-image methods are comparable to video methods of remote camera monitoring when they are of the same quality. Video cameras that can be remotely operated, such as those used in this project, are tremendously useful for monitoring many individuals with one piece of equipment. This style, however, can be costly, and videos take up more digital space than still images. Time-lapse photography is generally more affordable, can be automated, and has a smaller digital footprint than video. However, time-lapse methods are limited to the number of subjects a single camera can reach. Based on these findings, we recommend that, if funding is available and if the environment permits such a setup, researchers use a remote video camera system for long-term monitoring projects for cliff-nesting seabirds, due to its ability to monitor many individuals with a single unit from a remote location.

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REFERENCES

- Alaska Maritime National Wildlife Refuge (AMNWR) 2019. *Standardized protocols for annual seabird monitoring camps at Aiktak, Buldir, Chowiet, St. George, St. Lazaria, and St. Paul islands, Cape Lisburne, and select intermittent sites in the Alaska Maritime National Wildlife Refuge in 2019*. Homer, USA: US Fish and Wildlife Service, Alaska Maritime National Wildlife Refuge.
- BUCK, C.L. O'REILLY, K.M. & KILDAW, S.D. 2007. Interannual variability of Black-legged Kittiwake productivity is reflected in baseline plasma corticosterone. *General and Comparative Endocrinology* 150: 430–436.
- BYRD, G.V., SCHMUTZ, J.A. & RENNER, H.M. 2008a. Contrasting population trends of piscivorous seabirds in the Pribilof Islands: A 30-year perspective. *Deep-Sea Research Part II* 55: 1846–1855.

- BYRD, G.V. SYDEMAN, W.J., RENNER, H.M. & MINOBE, S. 2008b. Responses of piscivorous seabirds at the Pribilof Islands to ocean climate. *Deep-Sea Research Part II* 55: 1856–1867.
- COULSON, J.C. & FAIRWEATHER, J.A. 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.
- LECLAIRE, S., HELFENSTEIN, F., DEGEORGES, A., WAGNER, R.H. & DANCHIN, É. 2010. Family size and sex-specific parental effort in black-legged kittiwakes. *Behaviour* 147: 1841–1862.
- FOURNIER, D.A., SKAUG, H.J., ANCHETA, J. ET AL. 2012. AD Model Builder: Using automatic differentiation for statistical inference of highly parameterized complex nonlinear models. *Optimization Methods and Software*. 27: 233–249.
- FREDERIKSEN, M., ANKER-NILSSEN, T., BEAUGRAND, G. & WANLESS, S. 2013. Climate, copepods and seabirds in the boreal Northeast Atlantic - current state and future outlook. *Global Change Biology* 19: 364–372.
- FREDERIKSEN, M., EDWARDS, M., MAVOR, R.A. & WANLESS, S. 2007. Regional and annual variation in Black-legged Kittiwake breeding productivity is related to sea surface temperature. *Marine Ecology Progress Series* 350: 137–143.
- FREDERIKSEN, M., HARRIS, M.P., DAUNT, F., ROTHERY, P. & WANLESS, S. 2004. Scale-dependent climate signals drive breeding phenology of three seabird species. *Global Change Biology* 10: 1214–1221.
- GALILI, T. 2010. *Post hoc analysis for Friedman's Test (R code)*. Tel Aviv, Israel: R-statistics blog. [Accessed at <http://www.r-statistics.com/2010/02/post-hoc-analysis-for-friedmans-test-r-code/> on 30 May 2019.]
- GILL, V.A. & HATCH, S.A. 2002. Components of productivity in Black-legged Kittiwakes *Rissa tridactyla*: Response to supplemental feeding. *Journal of Avian Biology* 33: 113–126.
- GILL, V.A. HATCH, S.A. & LANCTOT, R.B. 2002. Sensitivity of breeding parameters to food supply in Black-legged Kittiwakes *Rissa tridactyla*. *Ibis* 144: 268–283.
- HATCH, D.R., SCHWARTZBERG, M. & MUNDY, P.R. 1994. Estimation of Pacific Salmon escapement with a time-lapse video recording technique. *North American Journal of Fisheries Management* 14: 626–635.
- HATCH, S.A. & HATCH, M.A. 1988. Colony attendance and population monitoring of Black-Legged Kittiwakes on the Semidi Islands, Alaska. *The Condor* 90: 613–620.
- HUNT JR., G.L., EPPLEY, Z.A. & SCHNEIDER, D.C. 1986. Reproductive performance of seabirds: The importance of population and colony size. *The Auk* 103: 306–317.
- JODICE, P.G.R., ROBY, D.D., HATCH, S.A., GILL, V.A., LANCTOT, R.B. & VISSER, G.H. 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.
- LORENTZEN, E., CHOQUET, R. & STEEN, H. 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.
- MANISCALCO, J.M., PARKER, P. & ATKINSON, S. 2006. Interseasonal and interannual measures of maternal care among individual Steller Sea Lions (*Eumetopias jubatus*). *Journal of Mammalogy* 87: 304–311.
- MARTÍNEZ, F., RODRÍGUEZ, R.F. & BLANCO, G. 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. & BREWER, L.W. 2000. Methodological considerations for monitoring wild bird nests using video technology. *Journal of Field Ornithology* 71: 167–172.
- PER HUFFELDT, N. & MERKEL, F.R. 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., SYDEMAN, W.J. & WEISE, F. 2007. Seabirds as indicators of marine ecosystems. *Marine Ecology Progress Series* 352: 199–204.
- PIERCE, A.J. & POBPRASERT, K. 2007. A portable system for continuous monitoring of bird nests using digital video recorders. *Journal of Field Ornithology* 78: 322–328.
- R CORE TEAM. 2015. *R: A language and environment for statistical computing*. Vienna, Austria: R Foundation for Statistical Computing. [Available online at <http://www.R-project.org/>]
- REGEHR, H.M. & MONTEVECCHI, W.A. 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.
- ROBERTS, B.D. & HATCH, S.A. 1993. Behavioral ecology of Black-Legged Kittiwakes during chick rearing in a failing colony. *The Condor* 95: 330–342.
- SHULTZ, M.T., PIATT, J.F., HARDING, A.M.A., KETTLE, A.B. & VAN PELT, T.I. 2009. Timing of breeding and reproductive performance in murres and kittiwakes reflect mismatched seasonal prey dynamics. *Marine Ecology Progress Series* 393: 247–258.
- SKAUG, H.J., FOURNIER, D.A., NIELSEN, A., MAGNUSSON, A. & BOLKER, B. 2014. *Generalized Linear Mixed Models using AD Model Builder*. R package version 0.8.0. Gold Coast, Australia: rdrm.io
- SOUTHWELL, C. & EMMERSON, L. 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.
- SURYAN, R.M. & IRONS, D.B. 2001. Colony and population dynamics of Black-legged Kittiwakes in a heterogeneous environment. *The Auk* 118: 636–649.
- WALSH, P.M., HALLEY, D.J., HARRIS, M.P., DEL NEVO, A., SIM, I.M.W. & TASKER, M.L. 1995. *Seabird Monitoring Handbook for Britain and Ireland: A compilation of methods for survey and monitoring of breeding seabirds*. Peterborough, UK: JNCC/RSPB/ITE/Seabird Group.
- WANLESS, R.M., ANGEL, A., CUTHBERT, R.J., HILTON, G.M. & RYAN, P.G. 2007. Can predation by invasive mice drive seabird extinctions? *Biology Letters* 3: 241–244.
- WARTON, D.I. 2005. Many zeros does not mean zero inflation: Comparing goodness-of-fit of parametric models to multivariate abundance data. *Environmetrics* 16: 275–289.
- ZADOR, S.G., HUNT, G.L., JR., TENBRINK, T. & AYDIN, K. 2013. Combined seabird indices show lagged relationships between environmental conditions and breeding activity. *Marine Ecology Progress Series* 485: 245–258.
- ZADOR, S.G. & PIATT, J.F. 1999. Time-budgets of Common Murres at a declining and increasing colony in Alaska. *The Condor* 101: 149–152.