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Responses of black vultures to population management at Dutch Gap, Virginia

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The Center for Conservation Biology

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Cover Photo: Black Vultures that were tagged and released in October 2007 *by Ray Fernald.*

The Center for Conservation Biology is an organization dedicated to discovering innovative solutions to environmental problems that are both scientifically sound and practical within today's social context. Our philosophy has been to use a general systems approach to locate critical information needs and to plot a deliberate course of action to reach what we believe are essential information endpoints.

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EXECUTIVE SUMMARY

Black Vultures (*Coragyps atratus*) have caused property damage at Dutch Gap by perching, defecating, and removing rubber materials from vehicles, equipment, and buildings. Damage was concentrated at the electrical generating station of Dominion Virginia Power and at a public boat ramp, operated by Chesterfield County, Virginia, Department of Parks and Recreation, adjacent to the power plant. Initial efforts to reduce this damage began in 2000 when USDA Wildlife Services provided technical assistance to Dominion. Since then, management efforts have included culling vultures on several occasions to reduce damage; however, monitoring was not completed to document effectiveness of these interventions on reducing damage or to assess the effects on the vulture population.

Beginning in October of 2007, USDA Wildlife Services (WS), Virginia Department of Game and Inland Fisheries (VGIF), and the Center for Conservation Biology (CCB) worked to develop a management plan to reduce damage by Black Vultures at Dutch Gap while simultaneously gathering data on vulture responses to proposed hazing activities. This adaptive approach allowed for active management of the damage problem while simultaneously gathering data on the vulture population at Dutch Gap. The management approach included monitoring numbers of vultures that used the site beginning in October 2007, tagging 100 Black Vultures so their movements could be tracked over time, and then implementing a hazing program to reduce or eliminate vulture use of this location. CCB tagged 100 vultures in October 2007 with the help of WS and VGIF. In November 2007, WS and VGIF used pyrotechnic devices to haze all vultures from the Dutch Gap area during an intensive program that lasted for 2 weeks. In January 2008, the management plan was extended to include a nearby neighborhood, Rivers Bend, because vultures began using that location and causing damage to homes and buildings. Since then, WS and VGIF have hazed vultures to reinforce the management plan whenever they returned to locations where damage had been recorded. Throughout this project, Dominion retained responsibility to haze vultures at their power plant. WS and VGIF monitored the number of vultures using Dutch Gap and Rivers Bend through February 2009. Throughout this project, reports of tagged vultures were collected by project partners and the general public to provide data on movements of Black Vultures.

This report describes the detailed analyses and results of the vulture monitoring. In particular, we report on changes in vulture numbers at the managed site (Dutch Gap and Rivers Bend) and movements of tagged vultures from this managed site to the broader surrounding landscape.

The number of Black Vultures observed at Dutch Gap decreased by 86% following the initial intensive hazing. Immediately after intensive hazing at Dutch Gap, vultures were not hazed on the north side of the James River to prevent disturbance to a pair of Bald Eagles in that area. The number of vultures at Dutch Gap remained low until hazing began at Rivers Bend in January 2008. At that time, vultures returned to Dutch Gap and remained on the north side of the James River through the end of the project. Thus, the north side of the James River became a *defacto* "refuge" for vultures. During intensive hazing at Rivers Bend, vulture numbers at the managed site increased as vultures moved to the refuge area at Dutch Gap. During periods of reinforcement hazing, vulture numbers appeared to increase slightly (3%) although movement away from Dutch Gap increased by 3% and movement to Dutch Gap decreased by 2%. Throughout the entire project period of 71 weeks, vulture numbers at Dutch Gap decreased by 4% per week.

The number of Black Vultures at the managed site and movement of tagged vultures changed seasonally. Vulture numbers were greatest during fall (July 5 through Dec. 21) and decreased by 36% during winter (Dec 21 to Mar 7). During the breeding season (Mar 7 to Jul 4), vulture numbers were 4% lower than during the fall. Movement rates away from Dutch Gap were lowest during fall, greatest during the breeding season, and intermediate during winter. Likewise, movement rates to Dutch Gap were lowest during fall, greatest during the breeding season, and intermediate during winter. These movement patterns suggest turnover of individual vultures at Dutch Gap is lowest during fall when vulture numbers at Dutch Gap were greatest.

Combining data on the number of vultures observed at Dutch Gap/Rivers Bend and the rates they moved away from and toward this managed site allowed us to estimate the number of vultures that use Dutch Gap during the project period. We estimated that an average of 924 vultures (with 95% confidence limit of 2018) used Dutch Gap from October 2007 through January 2009, with an average of 75 counted weekly at Dutch Gap during this time period.

Observations of tagged vultures provide some evidence of where vultures that used Dutch Gap at some point in time move. Individual Black Vultures moved up to 95 miles from Dutch Gap to other locations (including Virginia Beach, Charlottesville, and Lynchburg, VA). Most observations of tagged vultures were from the greater Richmond-Petersburg metropolitan area. Since inception of this project, WS, VGIF, and CCB were notified of additional areas where vultures were damaging property. The pattern of damage at new sites combined with continued risk of electrical flashovers at transmission towers on the North side of James River highlights the potential that vultures displaced from Dutch Gap may be responsible for damage in other locations. Additional research to understand movement among damage sites over a broader area is needed.

Overall, the management approach to reduce damage caused by Black Vultures appeared to be effective at Dutch Gap. Reports of damage decreased dramatically as vulture numbers decreased and individual vultures moved away from the managed site. Vulture numbers at the boat ramp and the power plant have decreased to near zero, thus reducing opportunities for vultures to damage property at these locations. Risk of flashovers on transmission towers may also be reduced if this risk decreases as the number of vultures declines. However, this approach has affectively addressed damaged at only one locality, without addressing damage that occurs throughout Virginia.

BACKGROUND

Black Vulture (*Coragyps atratus*) populations in Virginia have grown in size recently and have become problematic in some situations (Lowney 1999). Vultures congregate at the Dutch Gap Boating Access and the adjacent Dutch Gap Power Plant operated by Dominion, which are located along the James River about 10 miles south of Richmond, Virginia (Figure 1). Black Vultures loaf (perch during the daytime) on emissions stacks and roost (perch over night) on other structures at the power plant. Vulture excrement, which accumulates at loaf and roost sites, must be cleaned at substantial cost to Dominion. The vultures also congregate at the parking area of the boat ramp where they loaf on parked vehicles and tear rubber from windshields, wiper blades, and other parts of vehicles. Black vultures have also entered vehicles and torn upholstery and defecated causing substantial damage to vehicle interiors.

Previous management of vultures to alleviate damage at Dutch Gap included daytime hazing and population reductions by culling vultures. These efforts reduced damage over short-time frames, but complaints of vulture damage resumed after18 months to 2 years in each case. The number of Black Vultures at Dutch Gap increased from about 50 immediately after culling to 300-400 individuals at the end of these time intervals and the intensity of damage returned to levels deemed excessive to Dominion and the general public that used the boat ramp. These increases cannot be explained by reproduction of 50 vultures that remained at Dutch Gap based on population models for this species (Blackwell et al. 2007), and therefore, must include movement of vultures to the site from a much wider regional population. One potential source of vultures could be from other roosts located in the landscape surrounding Dutch Gap.

Biologists with Virginia Department of Game and Inland Fisheries (VGIF) and the Center for Conservation Biology (CCB) did not observe any satellite roosts during an initial flight on 29 October 2007 over Dutch Gap and the surrounding landscape. This flight covered a 10 x 10-km area centered on Dutch Gap, and should have included 90% of the area used Black Vultures from a roost site (Coleman and Fraser 1989). Early monitoring at Dutch Gap by U.S.D.A. Wildlife Services (WS), VGIF, and CCB indicated that vultures move to and from loafing areas at Dutch Gap to roost at or immediately adjacent to Dutch Gap. Thus, any interaction of Black Vultures at this site must have been with vulture roosts spread over a much wider area than initially thought.

Proposed management designed to alleviate vulture damage included, culling birds at Dutch Gap or hazing the night roost and daytime loafing areas to disperse birds to one or more alternate roost sites. Data was not collected to determine how vultures responded to past culling. In 2005, 20 Black Vultures were marked with patagial tags. Of these marked birds, 3 were culled and 2 were observed regularly at Dutch Gap in October 2007. The other 15 vultures had not been observed, indicating 1) they might have been migrating at the time they were captured and tagged or 2) they might have responded to the culling and left the area. These 2 alternatives have much different implications for Dutch Gap. The first indicates that potentially many more vultures used Dutch Gap than were observed at any time. The second scenario implies that vultures may have responded to management actions and avoided using Dutch Gap over a long-time frame, thus management may have been more effective than originally thought. We also do not know how vultures respond to hazing at roosts. If vultures are displaced from the night roost at Dutch Gap, they might continue to return to the site during daytime to loaf and damage may continue. Therefore, our objective is to determine how the vulture population at Dutch Gap will respond to management actions through population monitoring.

Beginning in October 2007, VGIF, WS and CCB began working collaboratively to develop an approach to reduce damage caused by Black Vultures at Dutch Gap. The approach included intensive hazing over a 2-week period at Dutch Gap to prevent vultures from roosting and loafing in the area. In conjunction with management actions, vultures would be monitored in 2 ways. First, numbers of vultures that used Dutch Gap were counted prior to and after initiating hazing. Second, 100 Black vultures were tagged with numbered patagial tags and movements of these tagged birds would be monitored by recording their presence at Dutch Gap and other areas. The specific objectives of monitoring were to determine 1) how vultures responded numerically to hazing management and 2) how vulture movement was influenced by hazing. Additionally, we wanted to describe 3) daily and seasonal patterns of vulture use of Dutch Gap.

METHODS

This study was completed over the time period of October 2007 to February 2009 near Chester, Virginia with a primary focus at Dutch Gap, Virginia (Figure 1). For the purposes of this report, Dutch Gap refers to the Dutch Gap boat ramp maintained by Chesterfield County, Department of

Parks and Recreation and the Dominion power generating station located along the James River. The study area was expanded to include the Rivers Bend community in January 2008.

In November 2007, USDA Wildlife Services (WS) assembled a walk-in trap and baited it with beaver and dear carcasses so that vultures could be captured. Vultures appeared to be wary of the trap initially. On 18 November 2007, we used a rocket net to capture 7 Black Vultures feeding on a deer carcass placed outside of the trap. Once these live vultures were put inside the trap, additional vultures readily entered the trap. By the following day, we placed cattle ear tags on the patagium of 100 vultures and released them (Avery et al. 2006, Sweeney et al. 1985,

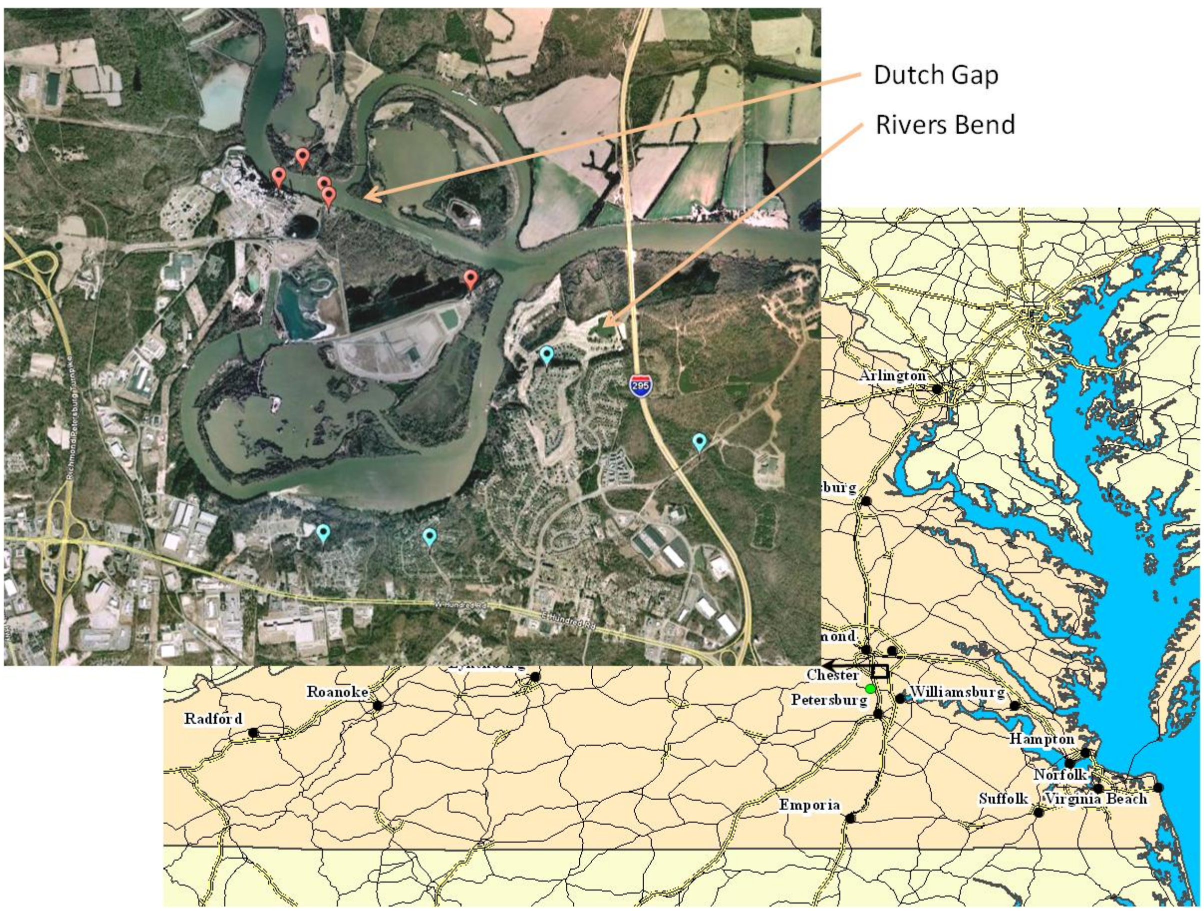

Figure 1. Studies of Black Vultures were completed from October 2007 to February 2009 at 5 sites at Dutch Gap (orange) and 4 sites at Rivers Bend (aqua), located near Chester, Virginia.

Wallace et al. 1980). Each vulture was tagged on both wings with a uniquely numbered orange tag. Within 1 week of tagging vultures, the trap and remains of bait animals were removed from the site.

Beginning in October 2007, monitoring surveys were completed by VGIF and WS at 5 sites at Dutch Gap (Figure 1). In January 2008, the monitoring survey was expanded to include 4 sites located along a route through the Rivers Bend community. Monitoring surveys were scheduled randomly during one morning and one afternoon each week. Morning and afternoon surveys were completed on different days when possible. During each survey, a biologist counted the number of Black Vultures perched or flying at each monitoring site and scanned perched vultures to identify any that were individually tagged.

From 27 November to 11 December 2007, biologists from WS, VGIF, and personnel from Dominion implemented an intensive hazing program to disperse all vultures from Dutch Gap. This effort included firing multiple types of pyrotechnic devices in the direction of vultures at the 5 sites of Dutch Gap throughout the day to prevent all vultures from using the site. Vulture effigies were also hung at sites where vulture damage occurred (Avery et al. 2002). Hazing efforts were concentrated in the morning as vultures moved from roost sites to loafing areas at Dutch Gap and in the evening when vultures were moving to roost locations at Dutch Gap. The intensive hazing at Dutch Gap ended prior to 15 December 2007 because a pair of Bald Eagles (H*aliaeetus leucocephalus*) constructed a new nest on transmission towers in the vicinity where vultures were loafing and roosting on the north side of Dutch Gap. After 15 December 2007, vultures were hazed only at locations south of the James River at Dutch Gap.

An additional intensive hazing program was implemented at the Rivers Bend community from 7–25 January 2008 when Black and Turkey Vultures (*Cathartes aura*) began roosting in this neighborhood and loafing on houses and community buildings at that site. Other hazing efforts were applied as needed whenever vultures were observed at Dutch Gap or Rivers Bend during monitoring surveys or if agencies received complaints from the public at these locations. This reinforcement hazing included use of pyrotechnic devices, paintball guns, lethal take of individual vultures to reinforce hazing, and hanging of real and plastic vulture effigies at the managed site.

We were interested in the influence of several factors on the number of vultures using Dutch Gap and Rivers Bend over time. Use of managed locations was measured as the number of vultures perched at each site and as changes in survival or movement of vultures. The factors of interest were (1) intensive hazing at Dutch Gap, (2) intensive hazing at Rivers Bend, (3) reinforcement hazing at either site, (4) season, and (5) trend over the time that management was implemented. We defined season as breeding, fall, and winter. Breeding extended from the average date that vultures were expected to lay eggs (7 March) to the average date of fledging (4 July) given the latitude of Dutch Gap (Buckley 1999, Jackson 1983). Fall ended on the first day of winter (21 December) and winter was the remaining part of the year.

Vulture monitoring

We used an information theoretic approach in data analysis (Burnham and Anderson 2001, Burnham and Anderson 2002) based upon a model set that included combinations of factors that we were interested in *a priori* and other factors known to influence vulture behavior. We fit models to datasets using 2 methods. First, we analyzed the number of vultures counted during monitoring surveys using general linear models (Proc GENMOD, SAS Institute Inc., Cary, NC, USA). We used repeated measures to account for autocorrelation (AR[1]) in counts from one survey to the next and general estimating equations to generate model estimates. Estimates of model fit to the data were compared using QICu (Pan 2001). We included effects of intensive or reinforcement hazing when such hazing was completed at a monitoring site during the interval since the last survey to reflect the order that monitoring and hazing occurred at each location. When vultures were observed at a location, they were counted first and then hazed, so any response by vultures would be recorded in next monitoring survey. When analyzing data, we excluded the Dominion plant site from analysis because we have no detailed records of when vultures were hazed.

Mark-resight analysis

The second type of analysis that we employed was from resighting data of tagged vultures. These data were analyzed in Program MARK (White and Burnham 1999). We used multi-strata models to estimate apparent survival, resight probabilities, and movement rates among strata (Brownie et al. 1993). We included one stratum to define the managed locations (combined Dutch Gap and Rivers Bend sites) and another stratum (outside) to include all areas (both observed and unobserved locations) outside of the managed site (Figure 2). We estimate apparent survival because permanent emigration outside of the study area cannot be separated from death. That is, a marked individual that is never observed again could have either died or left the area and never returned. Thus, true survival rates for vultures are expected to be greater than apparent survival rates, especially if we find evidence that hazing decreases apparent survival. It is more likely that hazing will increase permanent emigration rates than death rates. We included the outside stratum so we could estimate rates that vultures move away from Dutch Gap in response to hazing efforts.

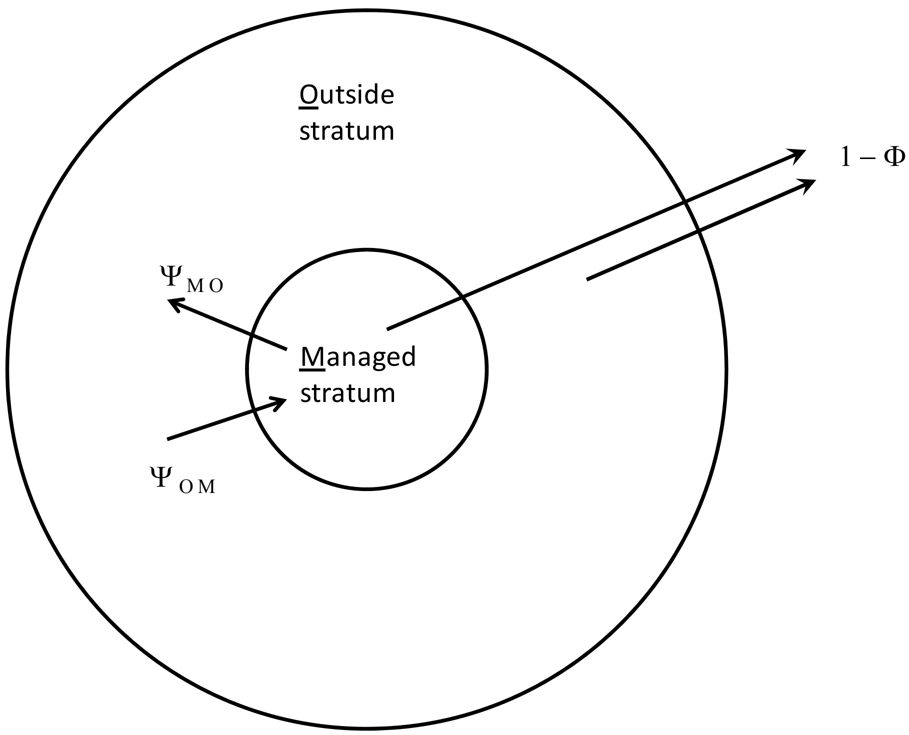

Figure 2. Analysis of mark-resight data collected at Dutch Gap, Virginia from October 2007 to February 2009 was analyzed using multistrata models. Strata included the combined managed site of Dutch Gap and Rivers Bend and the outside stratum. Movement rates (Ψ) included estimates of movement between each stratum. Permanent emigration from both strata were captured in estimates of apparent survival (Φ) or its complement, apparent death (1- Φ).

We incorporated separate estimates of survival and movement probabilities for hatch year and after hatch year vultures in all models because vulture demographics differ by age (Blackwell et al. 2007). Further, we allowed resight probabilities to differ by strata because observations of tagged vultures in each were obtained in very different manners. At managed locations, tagged vultures were identified through monitoring surveys. Observations of tagged vultures in the outside stratum were obtained opportunistically by project partners and through observations provided by the general public. We summarized observations of tagged vultures by calendar month for each stratum.

We developed a model set to determine the influence of hazing and trapping vultures during tagging on apparent survival and movement rates. All models included age effects on survival and movement, and strata effects on resight probability and movement. The model set included all combinations of models with hazing and trapping effects on survival and hazing, trapping, and season effects on movement. Whenever hazing or season was included in a model, all levels were included. Also, when modeling hazing or trapping effects on movement, we allowed effects to influence both movement away from and movement to Dutch Gap. For example, hazing was intended to increase movement away from Dutch Gap, but could have also resulted in decreased movement to Dutch Gap from the outside stratum. The model set included combinations of factors (Table 1) to develop 32 models. We used model averaging to determine estimates of apparent survival, resight probabilities, and movement rates from all models (Buckland et al. 1997). We also calculated effect sizes from the averaged estimates and used the delta method to estimate SEs (Powell 2007).

Population size

The number of vultures that use Dutch Gap over time is likely greater than the number counted in any given time period. If the population is stable over time, the number of immigrants (those moving from the outside stratum to the managed stratum) is equal to the number of emigrants (those moving from the managed stratum to the outside stratum). Thus, we can estimate the number in the outside stratum based upon the number counted in the managed stratum as:

$$N_O = e * N_M / i$$

where N_O is the number in the outside stratum, N_M = the number in the managed stratum, e = emigration rate, and i = immigration rate. Permanent emigrants are individuals that leave the study area without returning throughout the duration of the study. Given that estimated survival is 0.781 for HY and 0.875-0.906 for AHY vultures (Blackwell et al. 2007), permanent emigration was calculated as the difference between these rates and estimates of apparent survival. Thus, the number of permanent emigrants can be estimated as N_M * (survival – apparent survival). We calculated the total number of vultures in our study area as the sum of the number of permanent emigrants for each month plus the average number of vultures at Dutch Gap and in the outside stratum for the duration of the study. To estimate the number (and SE) of vultures that use Dutch Gap, we ran a Monte Carlo simulation with 10,000 trials (Buckland 1984, Williams et al. 2002:737). In each trial, we drew a random estimate, given the mean and SE reported for each parameter used to calculate population size, and estimated the size of the vulture population. We then used the average of all trials as the best estimate of population size, and calculated confidence intervals (percentile based) following Buckland (1984).

Vulture mapping

Throughout this study, project partners and the general public observed and reported locations of tagged vultures. These reports provided a measure of the geographic distribution for vultures tagged at Dutch Gap. We mapped locations of tagged vultures and calculated 95% and 50% fixed-kernel and minimum-convex-polygon home ranges to illustrate the geographic distribution of tagged vultures (Kernohan et al. 2001, Nooge and Eichenlaub 1997).

RESULTS

Vulture Monitoring

Of the 32 models developed to determine the influence of hazing on number of vultures counted at Dutch Gap, we found support in the data for 2 models (Table 1). These models differed by a QICu value of 4.0. The best model included effects of intensive hazing, reinforcement hazing, season, and week. The second best model was the same except reinforcement hazing was not included. No support was found for an effect of trapping to tag vultures on the number of vultures counted at Dutch Gap. Surveys completed in the afternoon, winter, breeding season and following intensive hazing at Dutch Gap recorded lower numbers of vultures than at other times (Table 2, Figure 3). Surveys at Dutch Gap and during intensive hazing at Rivers Bend and reinforcement hazing were associated with increased numbers of vultures counted. The antilog of beta estimates from our linear models were interpreted as the multiplicative factor by which counts change (e.g., $e^{-0.34} = 0.71$; afternoon surveys have 0.71 times the number of vultures than during morning surveys).

Mark-resight analysis

Of the 32 models developed for analysis, we found support in the data for 12 models (AIC $\omega >$ 0.01; Table 3). Of these models, the top 2 models were redundant because the Δ AICc value = 2.01, indicating these models differed by including a trap effect on apparent survival (Burnham and Anderson 2002:173). Otherwise, absolute fit of these models to the data (deviance) are nearly equal. To determine the relative importance of effects included in the model set, we can compare effect weights, which are calculated as the sum of AICc ω for models that include those effects (Burnham and Anderson 2002:167). Weights for effects on apparent survival have little support with less than 15% of the support in the data for haze or trap effects. In contrast, season, haze, and trap effects on movement from Dutch Gap to the outside stratum had considerable support in the data (weights $\geq$ 75%).

Parameter estimates and effect sizes were calculated from model averaged parameter estimates (Buckland et al. 1997) (Table 4). Apparent survival was greater for hatch-year (HY) than after-hatch-year (AHY) vultures, likely reflecting lower rates of permanent emigration for younger birds. In all cases, SEs for effect sizes on apparent survival were very high. Resight probabilities for the 2 strata differed, with the probability of observing a tagged vulture during surveys at Dutch Gap and Rivers Bend in a given month equal to 1.0. Movement rates for HY vultures appeared to be the same as for AHY vultures. Movement away from Dutch Gap was lowest during fall and increased during winter and breeding seasons. Likewise, movement from the outside stratum to Dutch Gap was lowest during fall and increased during winter and breeding seasons. These results suggest that cycling to and from the Dutch Gap area was lowest in fall, moderate in winter, and highest during the breeding season. All types of hazing did not alter movement rates as expected. The expected pattern of increased movement from Dutch Gap to the outside stratum was observed only for reinforcement hazing, but not for intensive hazing at Dutch Gap or Rivers Bend. When considering movement from the outside stratum to Dutch Gap, the expected pattern of decreases associated with hazing was observed for intensive hazing at Rivers Bend and reinforcement hazing but not for intensive hazing at Dutch Gap.

Table 1. Table of model results for analysis of the number of vultures counted at Dutch Gap, Virginia from October 2007 to February 2009.

Model effects[a]									Model Rank	Δ QICu	Model likelihood	QICu ω
DG	PM	DGIH	RBIH	RH	Wi	Br		Week	1	0.0	1.000	0.883
DG	PM	DGIH	RBIH		Wi	Br		Week	2	4.0	0.132	0.117
DG	PM						Trap	Week	3	682.1	0.000	0.000
DG	PM			RH			Trap	Week	4	739.6	0.000	0.000
DG	PM	DGIH	RBIH	RH	Wi	Br	Trap	Week	5	832.2	0.000	0.000
DG	PM	DGIH	RBIH		Wi	Br	Trap	Week	6	841.4	0.000	0.000
DG	PM	DGIH	RBIH					Week	7	1229.4	0.000	0.000
DG	PM	DGIH	RBIH	RH				Week	8	1262.3	0.000	0.000
DG	PM			RH	Wi	Br	Trap	Week	9	1470.8	0.000	0.000
DG	PM				Wi	Br	Trap	Week	10	1510.0	0.000	0.000
DG	PM							Week	11	1577.6	0.000	0.000
DG	PM			RH				Week	12	1613.4	0.000	0.000
DG	PM	DGIH	RBIH				Trap	Week	13	1892.1	0.000	0.000
DG	PM	DGIH	RBIH	RH			Trap	Week	14	1926.6	0.000	0.000
DG	PM			RH	Wi	Br		Week	15	2805.3	0.000	0.000
DG	PM				Wi	Br		Week	16	2865.3	0.000	0.000
DG	PM	DGIH	RBIH		Wi	Br			17	27657.0	0.000	0.000
DG	PM	DGIH	RBIH	RH	Wi	Br			18	27827.0	0.000	0.000
DG	PM	DGIH	RBIH		Wi	Br	Trap		19	28817.5	0.000	0.000
DG	PM	DGIH	RBIH	RH	Wi	Br	Trap		20	28974.9	0.000	0.000
DG	PM				Wi	Br			21	30181.5	0.000	0.000
DG	PM			RH	Wi	Br			22	30361.0	0.000	0.000
DG	PM				Wi	Br	Trap		23	30410.9	0.000	0.000
DG	PM			RH	Wi	Br	Trap		24	30582.1	0.000	0.000
DG	PM								25	32936.0	0.000	0.000

Table 1. Continued.

Model effects						Model Rank	Δ QICu	Model likelihood	QICu ω
DG	PM			RH		26	32975.8	0.000	0.000
DG	PM				Trap	27	33031.3	0.000	0.000
DG	PM			RH	Trap	28	33067.9	0.000	0.000
DG	PM	DGIH	RBIH			29	35173.9	0.000	0.000
DG	PM	DGIH	RBIH	RH		30	35209.3	0.000	0.000
DG	PM	DGIH	RBIH		Trap	31	35465.5	0.000	0.000
DG	PM	DGIH	RBIH	RH	Trap	32	35495.7	0.000	0.000

[a]Model effects included Dutch Gap (DG), afternoon surveys (PM), intensive hazing at Dutch Gap (DGIH), intensive hazing at Rivers Bend (RBIH), reinforcement hazing (RH), winter (Wi), breeding season (Br), trapping (Trap), and a time effect (Week).

Table 2. Beta estimates (SE) for effects that describe the number of vultures counted at Dutch Gap, Virginia from October 2007 to November 2009. Estimates are included for the top 2 models and the model averages.

Model	1		2		Model averaged		Relative effect sizes	
Intercept	-1.45	(1.156)	-1.45	(1.148)	-1.45	(1.155)	0.23	(0.315)
Dutch Gap	5.93	(0.821)	5.93	(0.791)	5.93	(0.818)	376.15	(0.441)
Afternoon	-0.34	(0.444)	-0.35	(0.448)	-0.34	(0.444)	0.71	(0.641)
Dutch Gap intensive hazing	-1.94	(0.716)	-1.95	(0.739)	-1.94	(0.719)	0.14	(0.487)
Rivers Bend intensive hazing	1.14	(0.885)	1.14	(0.89)	1.14	(0.886)	3.13	(0.412)
Reinforcement hazing	0.03	(0.669)	-	-	0.03	(0.629)	1.03	(0.533)
Winter	-0.44	(0.538)	-0.44	(0.554)	-0.44	(0.54)	0.64	(0.583)
Breeding	-0.06	(0.529)	-0.05	(0.532)	-0.06	(0.529)	0.94	(0.589)
Week	-0.04	(0.017)	-0.04	(0.017)	-0.04	(0.017)	0.96	(0.983)

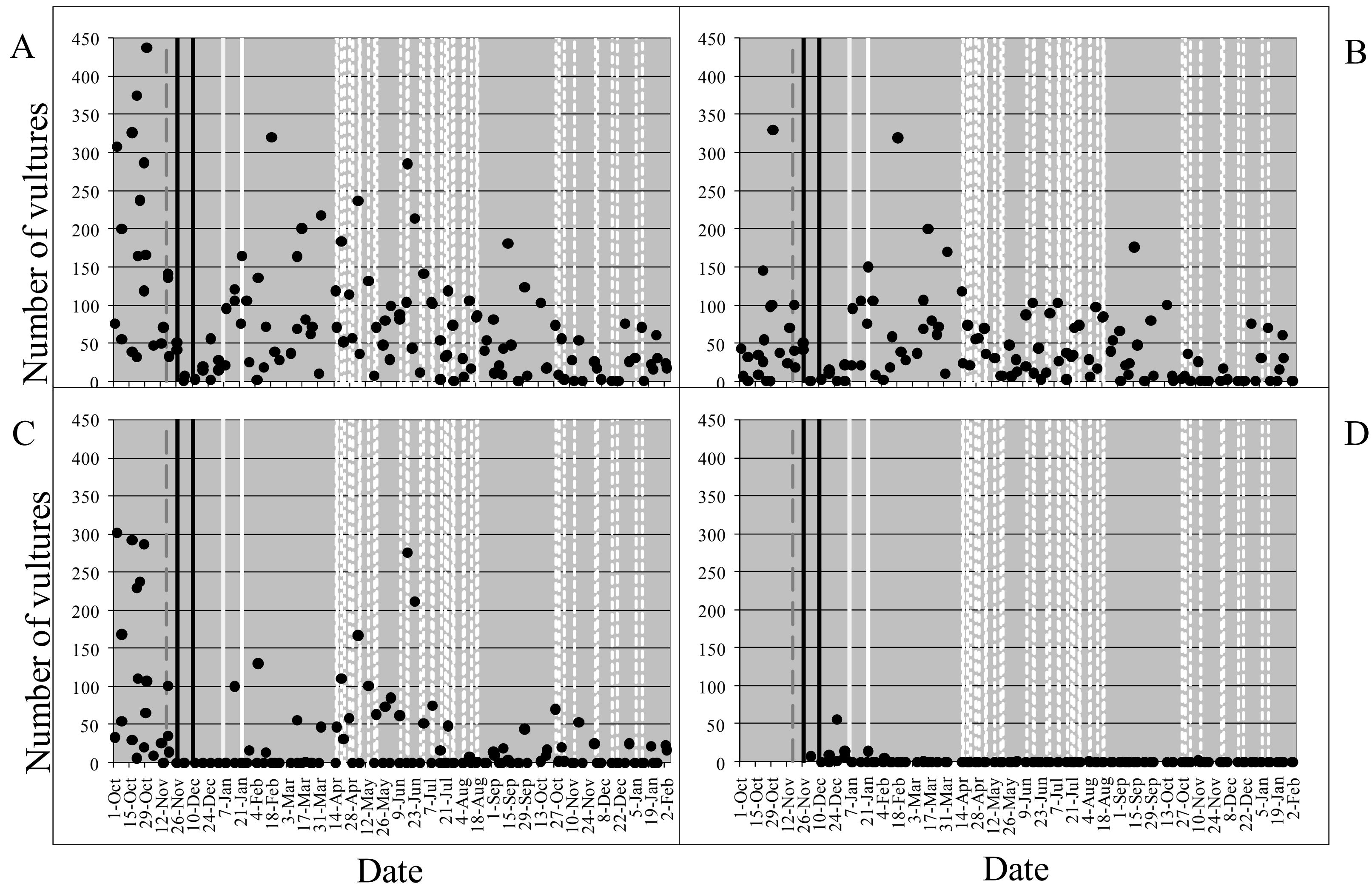

Figure 3. The number of Black Vultures counted from October 2007 to February 2009 at Dutch Gap and Rivers Bend combined (A), north side of the James River at Dutch Gap (B), south side of the James River at Dutch Gap (C), and at Rivers Bend (D). Vertical lines represent timing of vulture trapping (gray dashed), intensive hazing at Dutch Gap (solid black), intensive hazing at Rivers Bend (solid white), and reinforcement hazing (dashed white).

Table 3. Model results from mark-recapture analysis of black vultures tagged at Dutch Gap, VA in November 2007 and resighted through February 2009.

Model Rank	phi			p	psi				ΔAICc	AICc ω	Model Likelihood	Number of Parameters	Deviance
1	Age			Strata	Age	Season	Haze	Trap	0.00	0.556	1.000	16	534.99
2[a]	Age		Trap	Strata	Age	Season	Haze	Trap	2.01		0.366	17	534.73
3	Age			Strata	Age		Haze	Trap	2.32	0.127	0.313	14	541.80
4	Age			Strata	Age	Season		Trap	3.78	0.062	0.151	10	552.03
5	Age		Trap	Strata	Age		Haze	Trap	3.86	0.059	0.145	15	541.10
6	Age		Trap	Strata	Age	Season		Trap	4.60	0.041	0.100	11	550.69
7	Age	Haze		Strata	Age	Season	Haze	Trap	4.75	0.038	0.093	19	532.87
8	Age	Haze		Strata	Age	Season		Trap	5.98	0.020	0.050	13	547.68
9	Age	Haze		Strata	Age		Haze	Trap	6.20	0.018	0.045	17	538.92
10	Age			Strata	Age		Haze		6.85	0.013	0.033	13	548.55
11	Age	Haze	Trap	Strata	Age	Season	Haze	Trap	6.89	0.013	0.032	20	532.68
12	Age	Haze	Trap	Strata	Age	Season		Trap	7.25	0.011	0.027	14	546.73
13	Age	Haze	Trap	Strata	Age		Haze	Trap	8.01	0.007	0.018	18	538.43
14	Age		Trap	Strata	Age			Trap	8.26	0.007	0.016	9	558.67
15	Age			Strata	Age			Trap	8.34	0.006	0.016	8	560.89
16	Age			Strata	Age	Season	Haze		8.80	0.005	0.012	15	546.04
17	Age		Trap	Strata	Age		Haze		8.95	0.005	0.011	14	548.42
18	Age	Haze		Strata	Age			Trap	9.36	0.004	0.009	11	555.45
19	Age	Haze	Trap	Strata	Age			Trap	9.98	0.003	0.007	12	553.88
20	Age	Haze		Strata	Age		Haze		10.69	0.002	0.005	16	545.68
21	Age		Trap	Strata	Age	Season	Haze		11.04	0.002	0.004	16	546.02
22	Age	Haze	Trap	Strata	Age		Haze		12.93	0.001	0.002	17	545.64
23	Age	Haze		Strata	Age	Season	Haze		13.15	0.001	0.001	18	543.58

Table 3. Continued.

Model Rank	phi			p	psi				ΔAICc	AICc ω	Model Likelihood	Number of Parameters	Deviance
24	Age	Haze	Trap	Strata	Age	Season	Haze		15.46	0.000	0.000	19	543.58
25	Age	Haze	Trap	Strata	Age	Season			19.83	0.000	0.000	13	561.53
26	Age			Strata	Age				21.53	0.000	0.000	7	576.20
27	Age	Haze		Strata	Age				23.17	0.000	0.000	10	571.43
28	Age		Trap	Strata	Age				23.43	0.000	0.000	8	575.98
29	Age	Haze	Trap	Strata	Age				24.00	0.000	0.000	11	570.08
30	Age			Strata	Age	Season			25.78	0.000	0.000	9	576.18
31	Age	Haze		Strata	Age	Season			26.62	0.000	0.000	12	570.51
32	Age		Trap	Strata	Age	Season			27.65	0.000	0.000	10	575.90
Effect ω		0.12	0.15			0.75	0.85	0.97					

[a]AICc ω were adjusted to reflect that model 2 is redundant to model 1.

Table 4. Parameter estimates and effect sizes from analysis of mark-resight data for Black Vultures from Dutch Gap, VA 2007-2009.

Apparent Survival					
Age[a]	None	DGIH[b]	RBIH[c]	RH[d]	Trap
AHY	0.40 (0.079)	0.47 (0.207)	0.47 (0.212)	0.36 (0.143)	0.54 (0.415)
HY	0.46 (0.158)	0.53 (0.227)	0.53 (0.232)	0.42 (0.205)	0.60 (0.37)
Effect sizes		0.07 (0.199)	0.07 (0.204)	-0.04 (0.121)	0.14 (0.434)
Resight probability	Managed stratum	1.00 (0.004)		Outside strata	0.08 (0.013)

Table 4. Continued.

Movement		Managed stratum to outside stratum				
Age	Season		DGIH	RBIH	RH	Trap
AHY	Fall	0.53 (0.16)			0.56 (0.156)	0.90 (0.032)
AHY	Winter	0.66 (0.112)	0.36 (0.202)	0.71 (0.098)	0.69 (0.108)	0.94 (0.037)
AHY	Breed	0.71 (0.106)	0.00 (0)	0.00 (0)	0.74 (0.083)	
HY	Fall	0.52 (0.161)			0.55 (0.161)	0.90 (0.039)
HY	Winter	0.65 (0.118)	0.35 (0.2)	0.70 (0.105)	0.68 (0.118)	0.93 (0.043)
HY	Breed	0.70 (0.113)	0.00 (0)	0.00 (0)	0.73 (0.095)	
		Effect sizes				
	Breed	Winter	DGIH	RBIH	RH	Trap
	0.18 (0.137)	0.13 (0.126)	-0.30 (0.223)	-0.35 (0.229)	0.03 (0.145)	0.37 (0.165)
Movement		Outside stratum to managed stratum				
Age	Season		DGIH	RBIH	RH	Trap
AHY	Fall	0.06 (0.029)			0.04 (0.019)	0.06 (0.029)
AHY	Winter	0.09 (0.028)	0.18 (0.054)	0.07 (0.033)	0.06 (0.027)	
AHY	Breed	0.11 (0.034)			0.08 (0.026)	
HY	Fall	0.06 (0.029)			0.04 (0.019)	0.06 (0.029)
HY	Winter	0.09 (0.031)	0.17 (0.061)	0.07 (0.034)	0.06 (0.028)	
HY	Breed	0.11 (0.039)			0.07 (0.029)	
		Effect sizes				
	Breed	Winter	DGIH	RBIH	RH	Trap
	0.06 (0.042)	0.03 (0.033)	0.09 (0.06)	-0.02 (0.038)	-0.02 (0.02)	

[a] Vulture ages include hatch year (HY) and after hatch year (AHY).
[b]Intensive hazing at Dutch Gap (DGIH)
[c]Intensive hazing at Rivers Bend (RBIH)
[d]Reinforcement hazing (RH).

Population size

The average size of the population of Black Vultures that moved through Dutch Gap throughout the duration of our study as 924 (95% CI [-45, 2018]). Numbers of vultures that used Dutch Gap declined throughout the project although confidence intervals for projected numbers were large for some months (Figure 4). Variation in numbers that cycled through Dutch Gap was related to differences in numbers of vultures counted each month and differences in movement rates between strata. For example, vulture numbers counted during monitoring were highest during late summer/fall, which was reflected as larger estimates of the number of vultures cycling through the study area during these time periods.

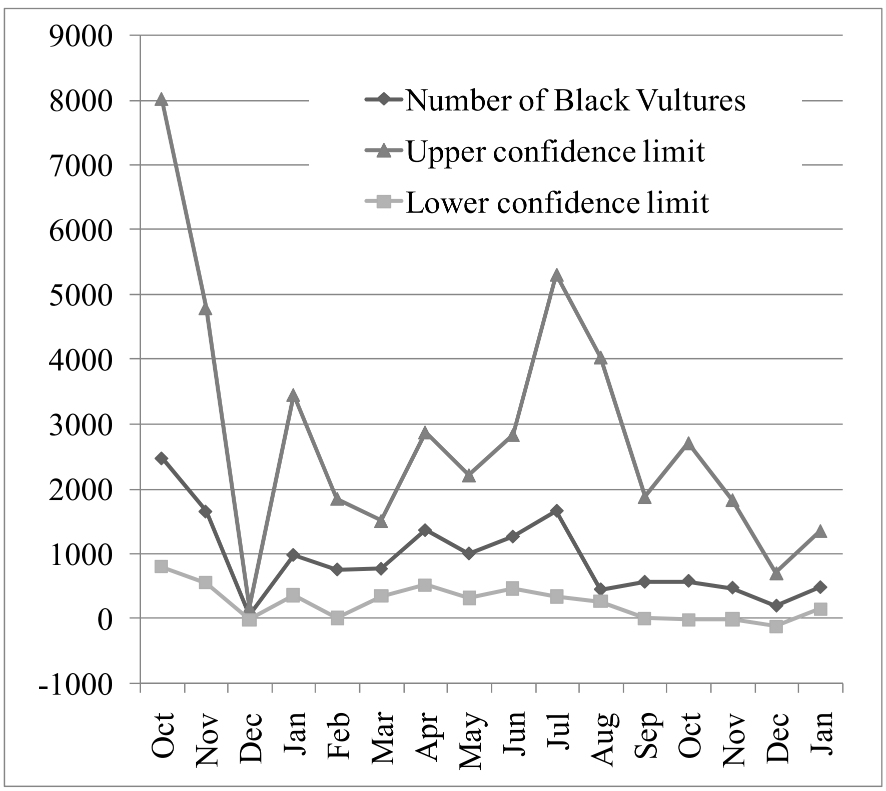

Figure 4. Monthly estimates of the number of Black Vultures that moved through Dutch Gap, Virginia from October 2007 to February 2009. Estimates were from a Monte Carlo simulation based on measured demographics from the period of the study.

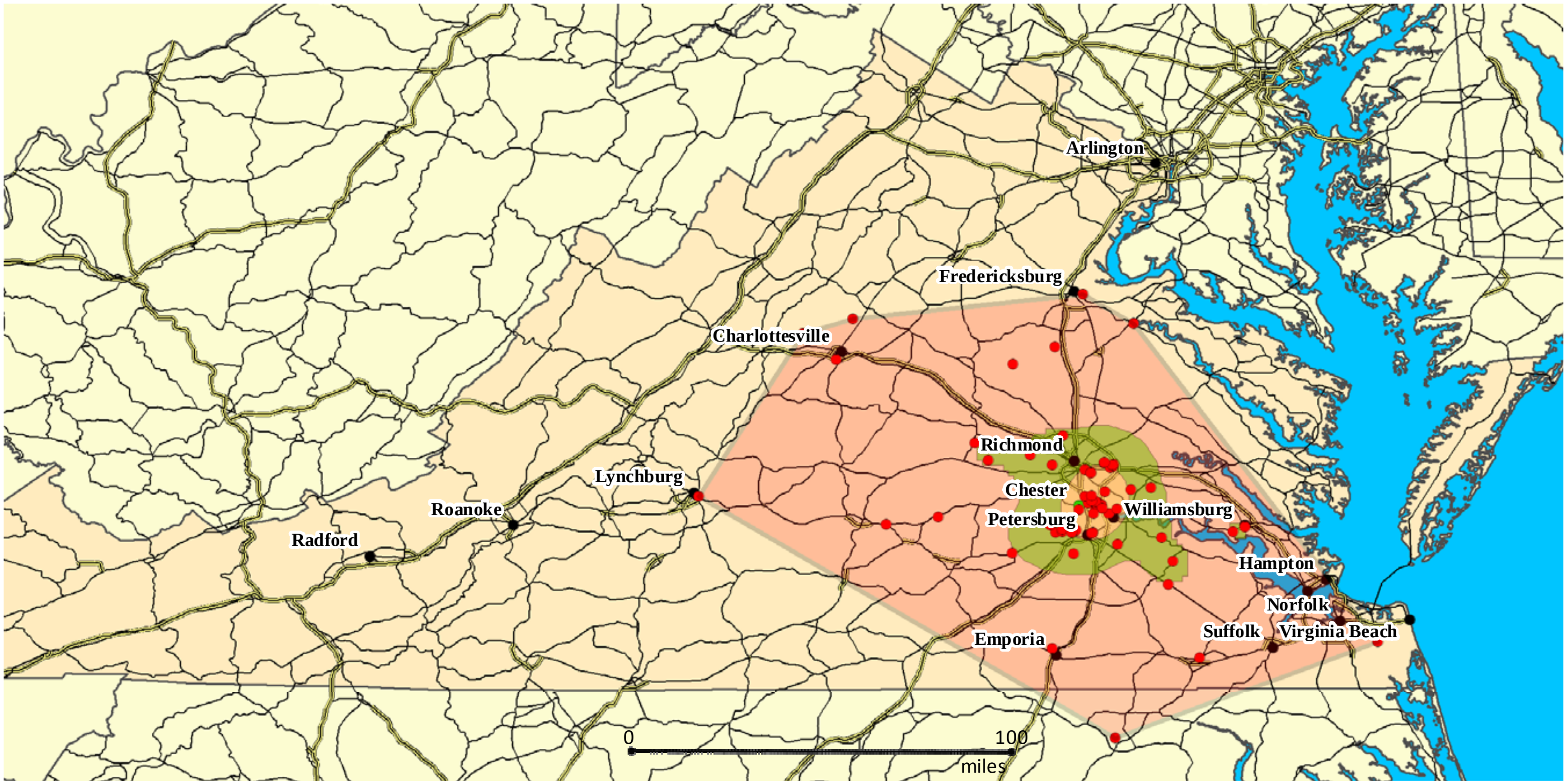

Figure 5. Locations (red dots) where Black Vultures that were tagged at Dutch Gap, Virginia were observed from October 2007 to February 2009. Shaded areas represent minimum convex polygon surrounding all locations (pink) and fixed kernel home ranges (95% green, 50% yellow). Vultures traveled straight line distances of up to 95 miles (Virginia Beach, Virginia).

Vulture mapping

Vultures that were tagged at Dutch Gap in 2005 and 2007 were observed over a wide portion of the state of Virginia from October 2007 to February 2009 (Figure 5). Individual vultures moved up to 95 miles in straight line distances from Dutch Gap. The 95% fixed kernel home range suggests that the majority of resightings of tagged vultures occurred in the greater Richmond-Petersburg metropolitan areas. The 50% fixed kernel home range is centered on Dutch Gap and includes southern Richmond to northern Petersburg.

DISCUSSION

Hazing was intended and expected to reduce the number of vultures at Dutch Gap by increasing movement away from this location. Numbers of vultures at Dutch Gap and Rivers Bend (the managed stratum) decreased over time (4% per week) and in association with intensive hazing at Dutch Gap (86% reduction). It seems likely that effects of hazing would have been more pronounced if the north side of the James River had not become a *defacto* refuge for vultures due to protection of the Bald Eagle nest. The number of vultures that remained at Dutch Gap from the time intensive hazing began there until it began at Rivers Bend decreased substantially. This decrease at Dutch Gap should have been associated with increased movement away from the managed stratum; however, movement rates changed in directions opposite of what we expected. Intensive hazing at Dutch Gap was associated with a large decrease in movement to the outside stratum because vultures were instead moving from Dutch Gap to Rivers Bend (i.e., movement was occurring within the managed stratum).

Likewise, intensive hazing at Rivers Bend also appeared to be associated with a decrease in the number of vultures at Rivers Bend; however, data analyses showed the opposite effect. The number of vultures counted increased during intensive hazing at Rivers Bend and movement away from Dutch Gap decreased. Again, these changes were associated with movement within the managed stratum, specifically to the north side of the James River at Dutch Gap, the refuge site.

Reinforcement hazing was the only hazing effect that produced expected results in terms of movement from the managed stratum to the outside stratum. However, we did not find a corresponding decrease in the number of vultures counted at Dutch Gap associated with reinforcement hazing. Biologists that implemented this hazing clearly know that when they hazed vultures that showed up along the south side of the James River, the vultures flew across the river to the refuge site.

Throughout the duration of this study, the number of vultures at Dutch Gap and Rivers Bend decreased. This steady decrease was not associated with a specific hazing effort in the model, but instead was steady over the entire 16 months of the composite program. Such declines contrast with previous efforts to reduce vulture damage through culling. In those cases, population reductions lasted 18-24 months until vulture damage resumed. Presumably, increases in vulture numbers would have occurred after 16 months. This is evidence that the hazing program changed dynamics of vultures in ways that are different from the culling program. This presumption should be confirmed through continued analysis of monitoring data as the hazing program continues at Dutch Gap.

We also found evidence that counts of Black Vultures and movement of vultures changed seasonally. Numbers were greatest during late summer and fall, and decreased in winter and during the breeding season. Movement rates away from the managed stratum also increased during winter and the breeding season. Movement to the managed stratum from the outside stratum also increased during winter and breeding seasons. With movement to and from the managed stratum increasing seasonally, the interpretation of changes becomes difficult because the absolute differences depend upon the number of vultures in both strata. Estimates of the number of vultures in the outside stratum provide little insight into seasonal changes because confidence intervals around monthly estimates are very large. However, the general trend of decreasing numbers of vultures at Dutch Gap and Rivers Bend throughout this study remains apparent.

The managed stratum in this study is the combined sites of Dutch Gap and Rivers Bend; however, the outside stratum is not defined. In fact, as modeled in the analysis of marked vultures, the outside stratum is only partially observable. Marked vultures can temporarily move to this stratum and remain unobserved, which decreases biases in survival estimates (Fujiwara and Caswell 2002). Questions remain about where vultures are moving to when they leave the managed stratum. More specifically, the research outlined here does not allow us to determine how the roost at Dutch Gap interacted with other roosts in the surrounding landscape. Observations of tagged vultures outside of the Dutch Gap/Rivers Bend areas were incidental to the design of the study, and had the potential to be influenced by coverage of the damage issue by Richmond and Petersburg media, the distribution of reported damaged caused by vultures, and/or other factors related to key habitat features such as abundance of road killed animals along dense road systems and habitat structure in suburban areas. Understanding these interactions and the distribution of vultures across the landscape requires continued focus at Dutch Gap, expansion of research to include neighboring roosts, and investigations into habitat and landscape features selected by Black Vultures.

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