Trends in Common Raven Populations in the Mojave and Sonoran Deserts: 1968-2004

By

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Draft Report to
U.S. Fish and Wildlife Service
Ventura, CA 93003
Contract No: 814405M055

June 12, 2006

Executive Summary.—Predation by common ravens (*Corvus corax*) on juvenile desert tortoises (*Gopherus agassizii*), a threatened species in the deserts of the southwest United States, is one factor preventing the recovery of tortoise populations. The U.S. Fish and Wildlife Service (USFWS) and other agencies are embarking on efforts to reduce the effects of ravens on tortoise populations. To better understand raven population dynamics and the current level of threat ravens pose to tortoise populations, it is important characterize recent population trends in raven populations within tortoise range. Since 1968, the Breeding Bird Survey, managed by the USFWS and U.S. Geological Survey (USGS), have been collecting data on bird abundance throughout the United States, including in the deserts of the southwest. We performed an extensive analysis of those data to determine identify spatial and temporal variation in raven populations in the Mojave and Sonoran Deserts. We divided the deserts into four subregios: West Mojave, East Mojave, Colorado, and Sonoran Deserts and evaluated for trends among and within the subregions as well as evaluating more small-scale variation within subregions.

Subregions varied in raven abundance, dispersion, and population growth rates. Ravens were in the greatest abundance in the West Mojave Desert and were most widely dispersed throughout the area. The Sonoran and Colorado Deserts had the lowest numbers and the birds were more narrowly distributed. East Mojave raven numbers and distribution were intermediate but still relatively low. The West Mojave raven population has been increasing, perhaps at rates as high as 6% per year (795% over 37 years). The growth rate of the Sonoran Desert raven population is probably higher (1377%), but their overall abundance is much lower and they are not spreading nearly as much into the desert. Even within subregions, there is considerable variation. All of these differences likely reflect spatial variation in anthropogenic resources, to which ravens are tightly linked, and recent historical differences in colonization and distribution of ravens. Inconsistencies in coverage of BBS methods, particularly year-to-year coverage of routes, and high annual variation in raven abundance and number of stops with ravens make it difficult to track raven trends below the regional level using BBS data. These results suggest that management priorities could vary among subregions. The high numbers coupled with high dispersion of ravens in the West Mojave supports aggressive management at the local and regional scales. Whereas, areas with lower levels of dispersion (e.g., Sonoran and East Mojave Deserts) could probably benefit most by local-level management targeted at birds known to be preying on tortoises or areas where such predation might be particularly critical to tortoise recovery, and reducing raven use of specific human development sites. We recommend that long-term monitoring of raven populations associated with raven management programs not rely solely on BBS data. Rather, a combination of more frequent targeted surveys, nest use surveys, and indices of predation pressure would yield more reliable and useful results. Research comparing raven population dynamics in different subregions of the desert could yield important insights into how human activities facilitate the spread and growth of raven populations.

INTRODUCTION

The management of native predator species is fast becoming a more common tool for aiding the recovery of threatened and endangered animal populations. Subsidized predator populations, those that subsist and sometimes increase due to resource subsidies provided by humans (Soule et al. 1988), are an especially common cause for such actions. Resource managers need to know recent trends in subsidized predator population levels to determine the level of threat posed by the population, to identify appropriate management actions, and to monitor for the effects of predator management.

In the western United States, common ravens (*Corvus corax*) are one such subsidized predator that subsists on human effluence while also preying on threatened desert tortoises (*Gopherus agassizii*; Boarman 2003). In the Mojave Desert, they feed on refuse, drink irrigation water, nest on power towers, and roost in shade structures. Their use of human resource subsidies increases fledgling success and juvenile survivorship (Kristan et al. 2003, Webb et al. 2004). Hyperpredation and spillover predation are two processes by which predator populations, sustained by abundant food, prey on rare species. The elevated predator numbers, facilitated by human-provided subsidies, place increased predation pressure on desert tortoise populations near and away from human habitations (Kristan and Boarman 2003).

Raven population reduction is now the focus of management efforts to reduce their effects on desert tortoises and other threatened and endangered prey populations (Boarman 2003, U.S. Fish and Wildlife Service [USFWS] in prep.). Current efforts in California are focused on reducing the availability of human subsidized resources to help reduce the number of ravens that survive each year, thereby lowering the number of ravens that may prey on desert tortoises. These actions are predicated on the notion that raven population increases in recent years (Boarman and Berry 1995, Boarman 2003) have led to increased predation pressure on desert tortoises. A portion of the proposed management efforts includes the lethal removal of birds known to prey on tortoises. The USFWS requires that lethal removals not threaten the persistence of raven populations.

Regional raven populations have not been evaluated since 1995. At that time Boarman and Berry (1995) demonstrated that raven abundance increased in the Mojave and Colorado Deserts by over 1000% between 1968 and 1992. We report herein on an updated analysis of Breeding Bird Survey (BBS) data to provide the information necessary to complete plans and monitor the effectiveness of a proposed management program to reduce raven predation on desert tortoises in the Mojave and Colorado deserts of California. We report on a new and more in-depth analysis of 37 years of BBS data (1968-2004). We investigated how average raven numbers, distribution (measured by number of stops on which ravens were found), and annual trends in those numbers differed by subregions of the desert tortoise's range, and whether trends within subregions varied fundamentally at the local, route level.

METHODS

The BBS, originally started by the USFWS but now managed by U.S. Geological Survey, consists of approximately 2900 transects throughout the United States and Canada (http://www.mbr-pwrc.usgs.gov/bbs/genintro.html). Surveyed once each spring (if possible) by well qualified volunteers, each route follows a road 24.5 miles long. Stops are made every 0.5 mile where three-minute point counts are taken of all bird species seen or heard within 0.25 mile of the stop.

The BBS groups their routes into 99 physiographic strata, which represent a combination of physiographic and vegetation characteristics of the area (Robbins et al. 1986). We used all routes for the Mojave and Sonoran Desert strata as identified by the BBS (Fig. 1). We were interested in a finer-scale subregional grouping, specifically West Mojave, East Mojave, Colorado, and Sonoran Deserts, but BBS did not make these distinctions. We coded the data by subregion as follows. All Sonoran Desert routes were coded as Colorado Desert if they were in California and Sonoran Desert if they were in Arizona (Table 1, Fig. 1, Appendix A). In the Mojave Desert, we used a map of desert tortoise recovery units to identify whether a route occurred in West or East Mojave (Tracy et al. 2004). Because of the relatively small number of routes, we did not partition East Mojave into smaller subunits (e.g., northeast Mojave, etc.).

Statistical Analyses.— For overall annual trends, we used two methods: the route-regression models, developed by the BBS office (http://www.mbr-pwrc.usgs.gov/bbs/trendin.html), and linear regression (which we will refer to as "linear models" hereafter). Route regression is a method specifically developed for BBS data analysis and is considered the technique most appropriate for the data. However, it is generally applied to large regions and requires a greater number of routes than were available for it to be applied rigorously to a sub-regional analysis. In contrast, linear models (such as regression, ANOVA, and ANCOVA) are simpler, but do not explicitly account for all of the complexities of BBS data, including the complication of spatial and temporal autocorrelation. To determine the relative contributions of individual routes, regions, and subregions to raven population patterns, we generated a series of ANOVA and ANCOVA models using total number of ravens per route and total number of stops with ravens per route as the dependent variables. Given that neither approach could be applied without qualification to this data set, we employed both techniques, but consider the results to be valuable primarily as a guide to additional, more intensive study.

For all linear models we set alpha at 0.05, but used extreme caution when interpreting the results because of low homoscedasticity. Transformations did not improve the situation, so we present here the results from non-transformed data to make the interpretation more straightforward. We therefore refer to all results as trends, even when the probability level was below alpha.

Effect of Subregion—To test if subregions differed in overall raven numbers counted on surveys, we conducted one-way ANOVAs on the mean number of ravens counted per route and the mean number of stops per route on which ravens were observed, with routes categorized by subregion (West Mojave, East Mojave, Sonoran, and Colorado deserts).

We summarized the differences among subregions by classifying routes as having either "high" or "low" numbers of ravens and numbers of stops with raven detections. As a cutoff, we chose the number that most closely divided the routes into equal groups, which for number of stops was ≤ 3, and for number of ravens was ≤ 5. The proportion of routes in each subregion that had a "high" number of stops with raven detections and total ravens detected was then tabulated.

Effect of Year (Annual Population Trends).—We tested for region-wide population trends using two methods. The route-regression models, developed by the BBS office, were generated for various year spans beginning with 1968 (18, 12, 9, 7, 6, 5, 4, 3, and 2). The BBS office (http://www.mbr-pwrc.usgs.gov/bbs/trendin.html) recommends a minimum of 14 data points (i.e., routes) to obtain a statistically significant result. Unfortunately, this was rarely obtained for the Mojave and Sonoran desert strata separately. Therefore, with one exception, we were forced to consider the results from analyses consisting of a suboptimal sample size, so the results are tenuous. We also conducted a linear regression to test for the effect of year on relative abundance estimates.

Effect of Route.— Human-subsidized resources are thought to influence raven population increases; human developments are patchily distributed throughout the desert southwest. Ravens may also decrease locally if the availability of these subsidies decreases due to land use changes. We expect that new populations of ravens will be established by spreading out from already established areas. Consequently, as ravens expand through the desert, we expect that proximity to and distribution of human-subsidized resources that benefit ravens will influence their abundances in a site-specific way, and raven abundance among routes are expected to vary substantially within a subregion. The relative strength of variation among subregions compared to among routes within subregions, can shed light on whether raven population management can be effective at the subregion level or it should only be implemented at the regional level. To determine at what scale the greatest amount of variation occured, we considered routes separately and nested routes within subregions in an ANOVA to measure the relative variation in raven numbers among routes within subregions, and among subregions.

Combined Effects.—We tested whether considering each route individually explained the data better than the one that treated routes within subregions collectively. We also allowed the regression line for counts at each route over time to have a different slope by allowing year and route to interact, but removed subregion from the model. This model therefore allowed every route to have a different change over time, which would be necessary if routes within subregions did not exhibit similar patterns of change. Routes with fewer than 5 years of surveys were removed for this analysis to reduce the chances of spurious results from small numbers of observations.

Models that allowed change in raven numbers to differ between subregions could represent a case in which the same rate of change in raven numbers occurred among subregions but with different overall abundances (subregion and year without an interaction), or a case in which different rates of change occurred for each subregion (region, year, and the interaction between them). However, these models did not account for the smaller-scaled, site-specific variability among routes. For example, if ravens have been colonizing different areas over time, then the process of colonization and population growth may have different starting dates for each route. Including route as a factor in the model would represent this process by allowing a series of parallel lines (one for each route) with different intercepts to be fit to the data. To test for this, we analyzed a model that took route-level variation into account by including year, subregion, and route nested within subregion.

Finally to better understand patterns within subregions, we split the data into different subregions, and examined differences among routes under the assumption that they all exhibited the same rates of change, but with different starting dates (that is, we included year and route with no interaction). Although subsetting the data has the disadvantage of reducing the sample size, the model structure is simplified, and easier to interpret.

RESULTS

Effect of Subregion.—We conducted a one-way ANOVA of total ravens per route by subregion (West Mojave, East Mojave, Sonoran Desert, Colorado Desert) (Table 2). Routes in the West Mojave on average had more than twice the number of ravens than the next closest subregion (East Mojave), and nearly three times as many as Sonoran Desert over the 37-year study period. Similarly, ravens were observed at twice as many stops within routes in the West Mojave than the East Mojave, and nearly three times as many stops in the West Mojave than in the Sonoran and Colorado Deserts.

When we classified routes as having either "high" or "low" numbers of ravens, or numbers of stops with raven detections, a similar pattern emerged (Table 3). More routes had high numbers of ravens in the West Mojave followed by the East Mojave, Sonoran, and Colorado. Similarly, more stops on routes with ravens were found in the West Mojave than East Mojave, fewer still in the Sonoran, with the lowest level of distribution being in the Colorado Desert.

Effect of Year (Annual Population Trends).—The route-regression method yielded few significant results (although the sample sizes were almost always too low; $n = 7\text{-}10$). In the Mojave and Sonoran Deserts combined, there was a significant increase in relative raven abundance of 1.9% per year ($p = 0.0003$, $n = 56$) over the 37-year period, which is equivalent to a 21% increase over 10 years, and 100% increase over the 37 years. In the Mojave, there tended to be an increase of 14-42% per year in the late 1970s followed by a decrease of 13-18% per year somewhere between 1999 and 2004 (probably between 2001 and 2002), but the sample sizes were too low to yield any certainty ($n = 6\text{-}10$), and the routes often varied from year to year. The routes containing fewer ravens were generally recorded more in later years (Table 1, Appendix B, C).

The linear regression method revealed a small, negative change in total ravens over time (Table 4). The tiny R^2 (<0.01) suggests that, although statistically significant, the pattern is very slight. The number of stops with ravens did not significantly change over time ($F_{1, 480} = 0.63$, $p = 0.426$).

Effect of Route.--Subregions had a much larger F-value than did routes within a subregion, indicating that although there was significant variation in number of ravens among routes within a subregion, large differences among subregions were also present (Table 5a, Fig. 1). The West Mojave had a greater abundance of ravens overall, although not all routes had large raven numbers (Appendix B). Similarly, the West Mojave has more stops with ravens than the other subregions, even when variability among routes is addressed (Table 5b, Fig. 2, Appendix C).

Combined Effects.— The model consisting of route, year, and their interaction was significant for all three effects (Table 6). The site-specificity of changes in raven abundance can be seen by the wide range in slopes among routes (Appendix B), from a 2 raven per year increase for Lenwood to a 0.74 raven per year decrease for Tecopa. The total number of ravens increased significantly in the entire study area over time, by 0.4 ravens per year, which was an increase of approximately 4.3% per year, or 375% over 37 years (Table 7). When variability in the timing of increases is accounted for by including route in the model (nested within subregion), the differential in predicted number of ravens in the West Mojave becomes even greater than the East Mojave. A similar pattern was seen in the number of stops with ravens. There was a significant increase in raven numbers over time, at a rate of 0.2 more stops per year, or approximately 3.8% per year, or 297% over 37 years. Although the model that allowed each route to have a different slope had the greatest R^2 (0.66, Table 6), the large R^2 of this model (0.55) was also high, indicating that substantial similarities in patterns of increase among routes within subregions. In a separate model, there was no significant change over time in total number of ravens (effect test for year: $t = 0.14$, $p = 0.88$) or number of stops with ravens (effect test for year: $t = 1.91$, $p = 0.057$) when only subregion is taken into account. None of the interactions was significant.

When analyzing the effects of year and route within each subregion separately, all models were significant ($p< 0.05$) with the exception of number of ravens in the Colorado Desert ($p > 0.10$). West Mojave showed the most rapid absolute increases in ravens and number of stops, the other subregions showed less increases in raven numbers (Table 8). The West Mojave also showed a high increase in number of stops with ravens, which was intermediate in the East Mojave and Colorado Deserts and negligible in the Sonoran Deserts.

DISCUSSION

Differences in rates and timings of spread of ravens among subregions, and among routes within subregions, can both help identify areas that have the greatest raven populations, and can help identify potential natural limiting factors for raven population growth. Breeding bird survey data were used for this analysis simply because they are the only data available that provide the needed information to address these questions. However, caution must be used when interpreting the results of BBS data, as there are many known sources of uncontrolled variation within the data set. For example, there is high variation among years along each route, and considerable inconsistency among years in which transects are surveyed. Also, observer bias is frequently a significant factor, and most BBS analyses go to great lengths to control for observer bias. Not only is there variation among individuals in their ability to see (or hear), identify, and count species, but a marked year-to-year improvement in individuals' abilities. As suggested to us by Bruce Perterjohn (USGS BBS Office, pers. comm.), we believe this not an issue for raven surveys because they are large, highly visible birds in the open desert environment, and, being the only large black bird in the area, cannot be confused with any other species.

BBS experts recommend that a minimum of 14 routes are necessary to yield valid estimates of changes in bird population sizes, which, if followed, would limit use of BBS data to regional analyses. Route regression approaches were designed specifically for use with BBS data, and are able to account for many of the known sources of error provided that sufficient data are available. Traditional linear models are simpler in structure, and by omitting parameters that control for various sources of error in the BBS, they can be applied to smaller data sets. When sample sizes permit their use, route regressions are superior analytical methods for BBS data compared to traditional linear models. We had the additional difficulty that the residuals from the regression analyses showed that we violated the homogeneity of variance assumption, and transformations failed to fix the problem. Although the BBS is the only data set currently available to address whether the rates and timings of raven increases have differed among subregions, if we strictly adhered to standard statistical criteria we would be unable to use these data. We present the results of this analysis with the caveat that the patterns uncovered should be considered to be suggestive but not confirmatory, as an encouragement to conducting more reliable research to explain the subregional differences we detected. In other words, these results should be viewed as hypotheses requiring further investigation before being accepted as fact.

Subregional differences.—The total number and distribution of ravens varied by subregion. Routes in the West Mojave had two to three times the number of ravens as the other subregions. The West Mojave also had the greatest number of stops with ravens, which shows that ravens are not only more abundant where they occur, but they are more evenly distributed spatially within the West Mojave than in other subregions. Colorado Desert sites had the fewest ravens and the fewest stops with ravens, suggesting that comparisons between Colorado Desert and West Mojave Desert raven populations might be fruitful for understanding potential limiting factors for rave n populations.

Change over time.—The change in raven populations over time depended strongly on which analysis we used, because of the peculiarities of the data set. According to the BBS's route regression method, raven populations increased nearly 2% per year in the Mojave and Sonoran Deserts combined over the 37-year study period. We were unable to reduce this trend with statistical certainty to specific regions or time frames, but an interesting, non-significant trend emerged: there may have been a leveling off of the increases in the last four years. Unfortunately, the sample sizes (n = 6-10) were too low to yield any certainty. The changes may be caused by different routes surveyed or inconsistencies among years in which routes were surveyed. By analyzing data separately for each subregion, we found increases in raven abundance of 795% (which is equivalent to a 6% annual increase) in the West Mojave, but very little in the East Mojave Desert (Table 8).

One of the dominant patterns in the data is that timing of increases, and rates of change once increases begin, are highly site-specific. Combined with this heterogeneity among the routes and subregions, the uneven coverage of routes over time can lead to some very misleading results. For example, the linear regression method revealed a small, negative change in total ravens over time in the Mojave and Sonoran Deserts combined over the entire 37-year period when differences among routes or subregions were not accounted for (Table 4). The tiny R^2 (<0.01) suggests that, although statistically significant, the pattern is very slight, but even a slight decline would be a very surprising result to desert biologists. However, the apparent decline was due to an increase in later years of the study in relative number of routes surveyed in areas that had few ravens. For example, in recent years routes have been added in the Sonoran Desert, where raven abundance is lower (Tables 2 & 3), and routes have not been surveyed in the West Mojave where abundance is higher (Table 1). Analysis by subregion helps to prevent this change in coverage from producing a spurious regional decrease in raven numbers.

Spread of a population expanding its range into new locations or new habitats can be thought of as a two-stage process, with first a colonization of a new area followed by an increase in abundance. Expansions are contagious, in the sense that new populations will generally be founded by immigrants from existing, nearby populations. We expect under these circumstances for different subregions of the desert to have started this process at different times, and to be in different degrees of completion. Even if the subregions are equally good raven habitat, we may still find subregional differences due to these differences in timing. For example, if the West Mojave has the greatest number of ravens because it was colonized first, then the East Mojave may have fewer ravens simply because it has more recently been colonized. Subregional differences would need to be considered in this case to improve the estimate of rate of change, but would not necessarily imply that subregions with more ravens are better raven habitat. If this were the case, however, we would expect that rates of change among subregions would be the same, or if differences did occur that subregions with more ravens would have lower rates of change if they are reaching carrying capacity. In fact, we found the West Mojave has both the greatest number of ravens and a rapid rate of change in raven numbers and numbers of stops. The East Mojave is also increasing in numbers of stops, but not in numbers of ravens. This may mean either that ravens are spreading through the East Mojave Desert, but have not yet started to rapidly increase in population size, or that ravens can disperse into the area but are not able to increase in abundance. The Colorado Desert had the smallest sample sizes, and thus the relatively rapid increase in abundance observed was not significant. The Sonoran Desert was increasing slowly both in numbers of stops and rapidly in abundance of ravens. This heterogeneity among subregions in the characteristics of their raven expansion suggest that the subregions differ in their suitability for ravens, and it may be fruitful to study raven population dyna mics among subregions to improve our understanding of the reasons for these differences.

We were not able to use linear regression to formally test for a change in direction or intensity of the trends at a particular point in time, in part, because we did not have sufficient data for a purely exploratory analysis, and did not have an *a-priori* hypothesis for when to look for a change in rate. However, the residual plots did not show evidence of nonlinearities which would have led us to suspect that a straight line is a poor representation of the data.

Small-scale, site specific variation.—There was a high level of variation among routes both among and within subregions. The differences among routes were caused by both differences in timing (revealed by the inclusion of "route" as a factor in our models) and differences in rates of change (revealed by the "route x year" interactions). This is not surprising, because the desert is not uniformly high-quality habitat for ravens, and their populations tend to cluster around human developments and the resources they receive from them. Routes that are near anthropogenic sources of food and water are expected to experience rapid raven population growth, whereas more remote routes should generally lack large numbers of ravens, even within the populous West Mojave Subregional differences were still detectable, however, even when this site specificity was accounted for.

Management Recommendations.— Although much of the variation in raven numbers is site-specific, the subregional differences in raven population growth suggests that management needs to focus at both the local and the regional level. Furthermore, ravens are both more numerous and more widely dispersed in the West Mojave than in other subregions, suggesting that anthropogenic resources are also more widely dispersed there. Consequently, the West Mojave subregion may require a broader multi -scale management effort than other subregions where more localized efforts may be sufficient to control raven populations. We recommend that, particularly in the West Mojave Desert, management focus both on localized measures such as targeted removal of known offenders (birds known by evidence to prey on tortoises) and aggressive removal of even relatively minor sources of human-subsidized food and water; and regional methods such as reduction of garbage availability at landfills and perhaps broader removal of birds (Boarman 2003). In the Colorado, Sonoran, and East Mojave Deserts, efforts should be focused more at specific locations where predation is known or suspected of occurring or affecting tortoise recovery. Regional-level management may be wise for all subregions, but may not need to be as aggressive at this point in time for the Sonoran, Colorado, and East Mojave subregions.

Monitoring and Research Recommendations.—We recommend that the BBS surveys not be relied upon solely to determine the effectiveness of or need for raven management in the Mojave and Sonoran Deserts. There is too much variation and too little consistency in coverage of routes. Instead, the best approach would be a multifaceted one with the following components, in roughly descending order of importance:

1. Subregional road surveys;

2. Point counts at selected human subsidized resource sites, randomly selected non-resource sites, and other sites of specific interest to the raven management program;

3. Use of an index of change in predation pressure, such as styrotorts (Styrofoam tortoises; Kristan and Boarman 2003) placed randomly throughout the areas of interest; and

4. Surveys of raven nests and predation activity during the breeding season.

Before developing detailed designs of the surveys, a thorough analysis should be conducted of existing data to determine the optimal timing, best methods, and minimum adequate sample sizes to ensure a cost effective, scientifically credible program is implemented. Some experimentation with styrotorts, or some other index of predation pressure, is warranted to understand the limits of the method and to determine the frequency and timing of deployment. Whereas it is essential to measure the effect of raven management on tortoise populations, such monitoring is costly and difficult to accomplish, due to the challenges of working with juvenile desert tortoises in the wild. We believe this aim can be most practically attained by monitoring predation pressure (Item 3, above) plus evaluating long-term results of line distance sampling being conducted by the Desert Tortoise Recovery Office of the USFWS.

Differences among subregions in the characteristics of their raven population expansions may be in part due to differences in suitability of the subregions for raven habitation. Comparative studies of the population dynamics of ravens in subregions that are experiencing the greatest and least increase in ravens could help focus management actions on the areas that are most at risk of experiencing raven population increases in the future.

Summary.—Common raven populations clearly have increased in the Mojave and Sonoran Deserts over the past 37 years. Subregions vary in raven abundance, dispersion, and population growth rates, with the West Mojave Desert having the most ravens and experiencing the large increases. Even within subregions, there is considerable variation. All of these differences likely reflect spatial variation in anthropogenic resources and recent historical differences in colonization and distribution of ravens. Inconsistencies in coverage of BBS methods, particularly year-to-year coverage of routes, and high annual variation in raven abundance and number of stops with ravens make it difficult to track raven trends below the regional level using BBS data. We recommend that long-term monitoring of raven populations associated with raven management programs not rely solely on BBS data. Rather, a combination of more frequent targeted surveys, nest use surveys, and indices of predation pressure would yield more reliable and useful results.

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Table 1. Official BBS routes included in our analysis, the desert subregion we assigned to each (CD = Colorado Desert, SD = Sonoran Desert, EM = East Mojave Desert, and WM = West Mojave Desert), and the total number of routes surveyed per year. Years each route was surveyed are represented by an 'X.' Refer to Figures A and B for location of each route.

Region	Route	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	Total years
CD	ANZA BORREGO	X	X	X	X	X	X	X					X																			X		X			X		11
	BLYTHE												X																								X		2
	CADIZ																					X			X														2
	COACHELLA CN						X		X		X									X	X	X												X					7
	COTTONWOOD								X	X				X	X					X	X				X	X	X	X	X	X	X				X		X	X	16
	ESSEX																						X		X		X	X	X										5
	FLYNN																					X	X			X	X	X	X	X									7
	GLAMIS										X																		X										2
	HAVASU LAKE						X					X																									X		3
	IMPERIAL DAM																									X													1
	IRON MTNS																																	X					1
	PARKER DAM						X		X																												X		3
SD	AJO	X								X			X											X					X		X		X	X	X				9
	ALAMO RES.																										X	X	X	X	X	X		X	X	X	X		10
	ARABY																														X				X				2
	BATES WELL																												X								X		2
	CABEZA PRIETA																													X			X				X	X	4
	CASA GRANDE																						X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	15
	CATUS FOREST																								X		X			X	X	X	X	X	X	X		X	10
	CIBOLA LAKE																										X		X				X						3
	COOLIDGE														X		X		X																				3
	CUTTER																									X	X		X	X	X	X	X	X					8

	FLORENCE			X	X	X	X	X	X	X												X																	8
	GILA BEND																												X				X	X			X		4
	HOPE																							X	X	X	X	X		X							X	X	8
	LAGUNA	X																				X																X	3
	LUKEVILLE								X	X		X	X	X	X																								6
	NEW RIVER										X															X	X	X	X	X		X	X	X	X	X	X	X	13
	ORGAN PIPE																							X	X	X		X									X		5
	PALO VERDE																														X		X			X	X		4
	PISINIMO																									X	X												2
	QUARTZSITE															X			X		X	X	X								X				X				7
	RED ROCK																									X	X				X	X	X	X	X				7
	RIVIERA																									X	X			X	X	X					X	X	7
	WIKIEUPP																									X	X	X	X		X	X		X	X	X		X	10
EM	BEATTY																				X	X	X	X	X	X	X	X	X	X	X								11
	CIMA						X				X	X		X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X							21
	IVANPAH																						X					X	X	X	X	X	X	X	X	X	X	X	12
	JEAN LAKE									X													X		X	X	X	X	X		X	X	X		X	X			12
	NELSON																																	X					1
	OATMAN																					X				X	X		X	X	X	X	X	X	X			X	11
	SQUAW PEAK	X																																					1
	TECOPA													X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X							19
	TRONA										X																		X		X								3
	VAL OF FIRE																		X	X	X	X	X	X	X	X	X	X	X		X			X	X				14
	VALLEY WELLS																						X				X	X	X	X								X	6
	WALKER CAN		X		X	X			X		X		X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	30
	WILLOW BEACH																						X	X		X	X	X	X	X	X								8
	WLLWLBCH 2																																			X			1
WM	BARSTOW		X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X							X	X	X	X							23
	CALIF CITY										X	X	X	X															X	X	X								7
	FT IRWIN								X			X	X	X	X	X																							6
	GOLDSTONE																			X	X	X			X	X	X	X	X	X	X	X		X	X		X	X	15

INYOKERN									X	X												X	X	X	X	X	X	X	X	X	X	X	X	X		X		16
JOSHUA TREE			X			X	X	X	X	X	X		X	X					X	X	X			X				X	X	X	X	X	X		X			20
LENWOOD								X			X	X	X	X	X	X	X	X							X	X	X	X										13
LUCERNE VAL							X				X										X	X		X	X	X	X	X	X	X	X	X						13
WILLOW SPGS	X	X	X	X	X	X	X	X						X																								9
TOTAL	**5**	**4**	**5**	**4**	**5**	**9**	**6**	**11**	**8**	**10**	**9**	**9**	**10**	**11**	**7**	**6**	**5**	**8**	**9**	**11**	**15**	**15**	**11**	**16**	**23**	**27**	**22**	**31**	**24**	**28**	**20**	**17**	**20**	**17**	**11**	**19**	**14**		**482**

Table 2. One-way ANOVA of total ravens by region (West Mojave, East Mojave, Sonorant Desert, Colorado Desert).

a) Mean number of ravens per route (R^2 = 0.16).

ANOVA

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
region	3	12189.609	4063.20	29.9943	<.0001
Error	478	64752.615	135.47		
C. Total	481	76942.224			

Means for ANOVA

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
Sonoran Desert	150	6.1600	0.9503	4.293	8.027
Colorado Desert	60	5.2500	1.5026	2.298	8.202
East Mojave	150	7.3000	0.9503	5.433	9.167
West Mojave	122	17.9508	1.0537	15.880	20.021

b) Mean number of stops per route containing ravens (R^2 = 0.21).

ANOVA

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
region	3	2870.180	956.727	43.1879	<.0001
Error	478	10588.959	22.153		
C. Total	481	13459.139			

Means for ANOVA

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
Sonoran Desert	150	3.70000	0.38430	2.9449	4.455
Colorado Desert	60	3.15000	0.60763	1.9560	4.344
East Mojave	150	4.52000	0.38430	3.7649	5.275
West Mojave	122	9.46721	0.42612	8.6299	10.305

Table 3. Differences among subregions when classified as having either "high" or "low" numbers of ravens, or numbers of stops with raven detections.

		Proportion with high:	
Region	N	Ravens	Stops
Sonoran Desert	150	0.41	0.39
Colorado Desert	60	0.37	0.28
East Mojave	150	0.57	0.53
West Mojave	122	0.70	0.72

Table 4. Regression analysis of total ravens per route by year in the Mojave and Sonoran Deserts combined. Model $R^2 < 0.01$.

ANOVA

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Model	1	622.773	622.773	3.9168	0.0484
Error	480	76319.451	158.999		
C. Total	481	76942.224			

Parameter Estimate

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	249.70549	121.43	2.06	0.0403
Year	-0.120739	0.061007	-1.98	0.0484

Table 5a. One-way ANOVA for total number of ravens with routes treated as main effects and nested within regions to account for the variation among routes that was explained by subregional differences in raven numbers. $R^2 = 0.50$

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Model	58	7903.553	136.268	10.3754	<.0001
Error	423	5555.586	13.134		
C. Total	481	13459.139			

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Subregion	3	3	2915.5588	73.9965	<.0001
Route[Subregion]	55	55	5033.3728	6.9680	<.0001

Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean
Sonoran Desert	3.366534	0.35516308	3.70000
Colorado Desert	2.535354	0.66205780	3.15000
East Mojave	4.019767	0.52914755	4.52000
West Mojave	10.044895	0.35951394	9.46721

Table 5b. One-way ANOVA for total number stops per route with ravens with routes treated as main effects and nested within regions to account for the variation among routes that was explained by subregional differences in raven numbers. $R^2 = 0.59$

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Model	58	38407.879	662.205	7.2692	<.0001
Error	423	38534.345	91.098		
C. Total	481	76942.224			

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Subregion	3	3	12888.320	47.1593	<.0001
Route[Subregion]	55	55	26218.270	5.2328	<.0001

Least Squares Means Table

Level	Least Sq Mean		Std Error	Mean
Sonoran Desert	5.602086		0.9353774	6.1600
Colorado Desert	4.064683		1.7436325	5.2500
East Mojave	6.250591		1.3935926	7.3000
West Mojave	19.539684		0.9468360	17.9508

Table 6. ANOVA model for total number of ravens with year and route independent of region (R^2 = 0.66).

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Model	75	48792.232	650.563	9.0971	<.0001
Error	359	25673.179	71.513		
C. Total	434	74465.411			

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Route	37	37	30506.710	11.5294	<.0001
Year	1	1	1024.777	14.3299	0.0002
Route*Year	37	37	8660.484	3.2731	<.0001

Table 7a. Results of ANOVA of total number of ravens for model for effect of route, region, and year. $R^2 = 0.55$

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Model	59	42139.222	714.224	8.6602	<.0001
Error	422	34803.002	82.472		
C. Total	481	76942.224			

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Year	1	1	3731.343	45.2440	<.0001
Subregion	3	3	16271.718	65.7670	<.0001
Route[Subregion]	55	55	29946.957	6.6022	<.0001

Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean
Sonoran Desert	4.232683	0.9129788	6.1600
Colorado Desert	4.711137	1.6618078	5.2500
East Mojave	5.682936	1.3286543	7.3000
West Mojave	21.519062	0.9477360	17.9508

Table 7b. Results of ANOVA of number of stops ravens for model for effect of route, region, and year. $R^2 = 0.66$

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Model	59	8890.735	150.690	13.9198	<.0001
Error	422	4568.404	10.826		
C. Total	481	13459.139			

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Year	1	1	987.1816	91.1895	<.0001
Subregion	3	3	3778.7880	116.3534	<.0001
Route[Subregion]	55	55	5940.1874	9.9767	<.0001

Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean
Sonoran Desert	2.662170	0.33077646	3.70000
Colorado Desert	2.867863	0.60208069	3.15000
East Mojave	3.727789	0.48137765	4.52000
West Mojave	11.063005	0.34336918	9.46721

Table 8. Summary of effect of year on variation in numbers of ravens and numbers of stops with ravens within each subregion. The value represents the change in number of ravens and number of stops with ravens per year (% change over 37 years).

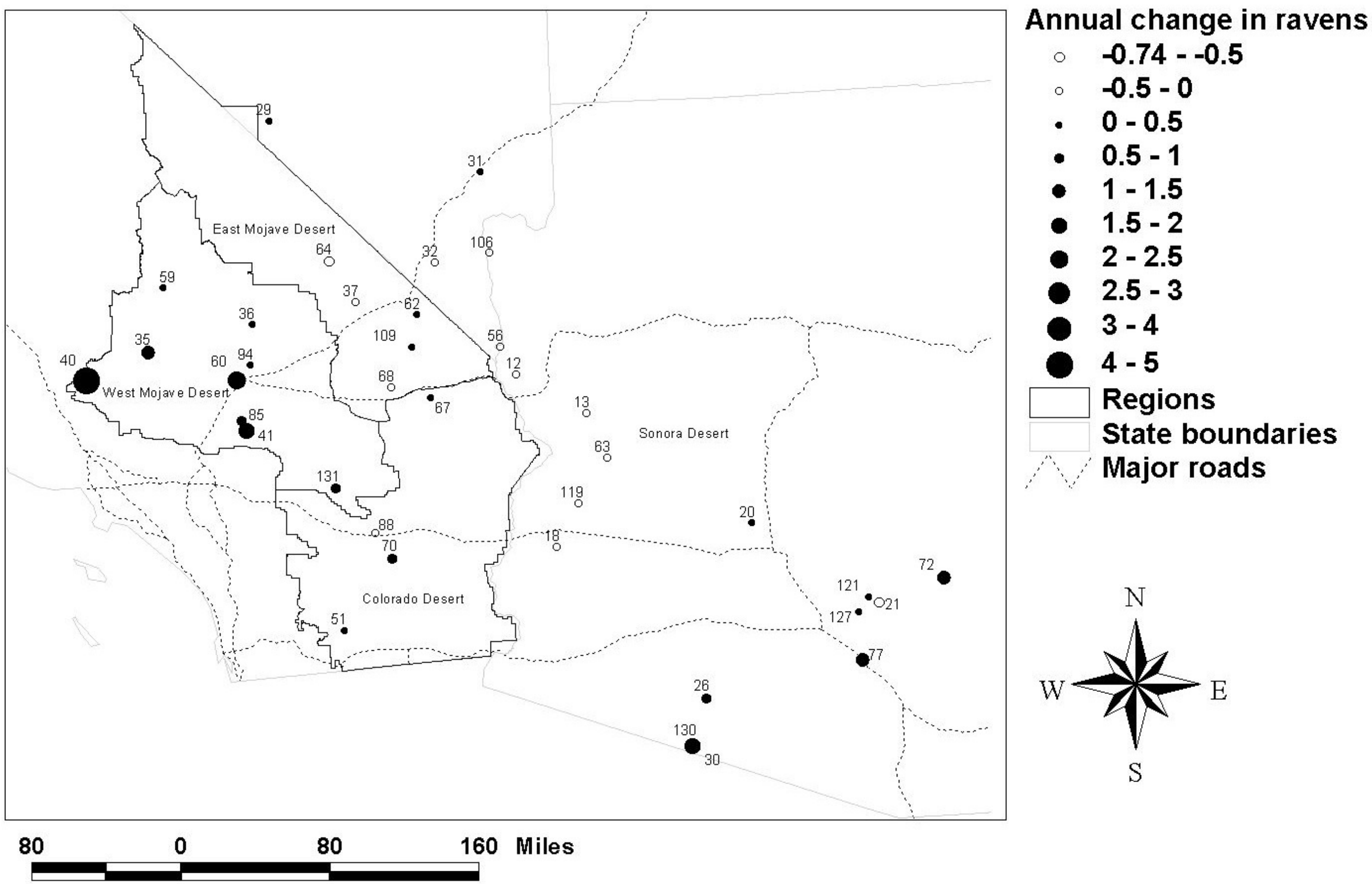
	Change over time			
Subregion	Ravens		Stops	
Sonoran Desert	0.38	(1377%)	0.07	(136%)
Colorado Desert	0.21*	(762%)	0.13	(486%)
East Mojave	0.09	(78%)	0.16	(588%)
West Mojave	0.88	(795%)	0.39	(431%)

* not significant

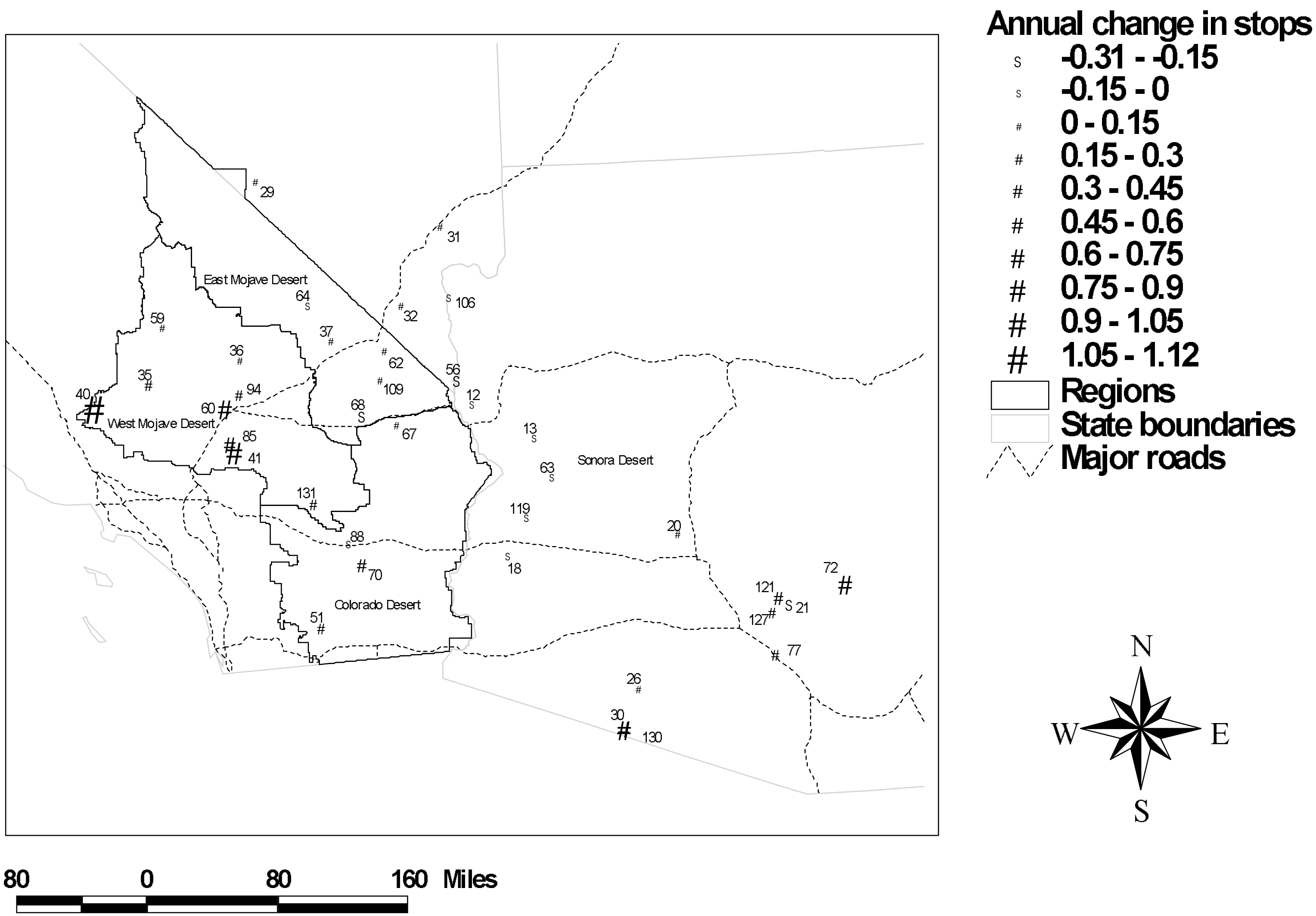
Figure 1. Map showing all routes included in survey indicating direction and intensity of average annual changes in number of ravens on each route by size and type of symbol. Key to route numbers appears in Appendix A.

Figure 2. Map showing all routes included in survey indicating direction and intensity of average annual changes in number of stops at which ravens were observed on each route by size and type of symbol.

Changes in raven numbers over time



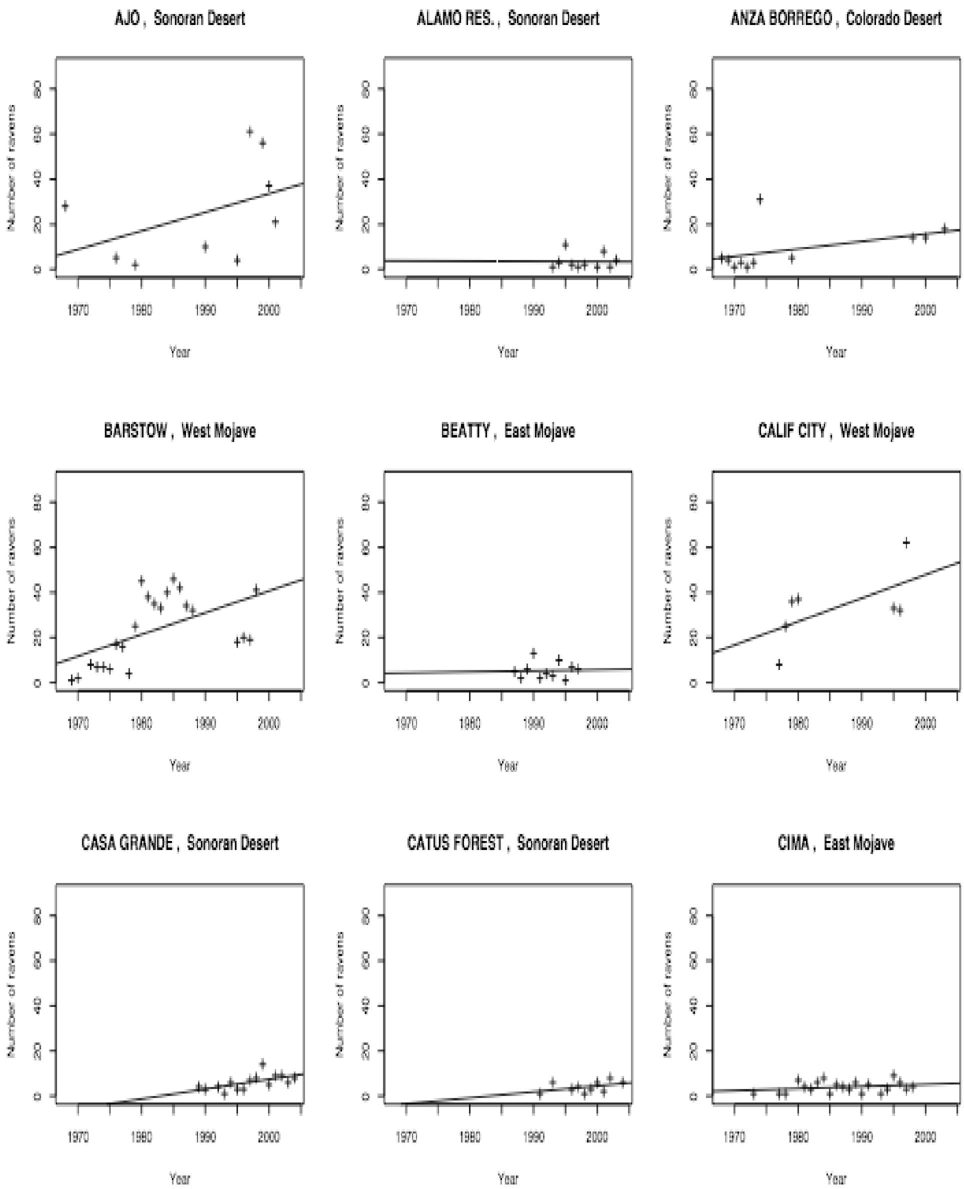
Changes in number of stops with raven detections over time

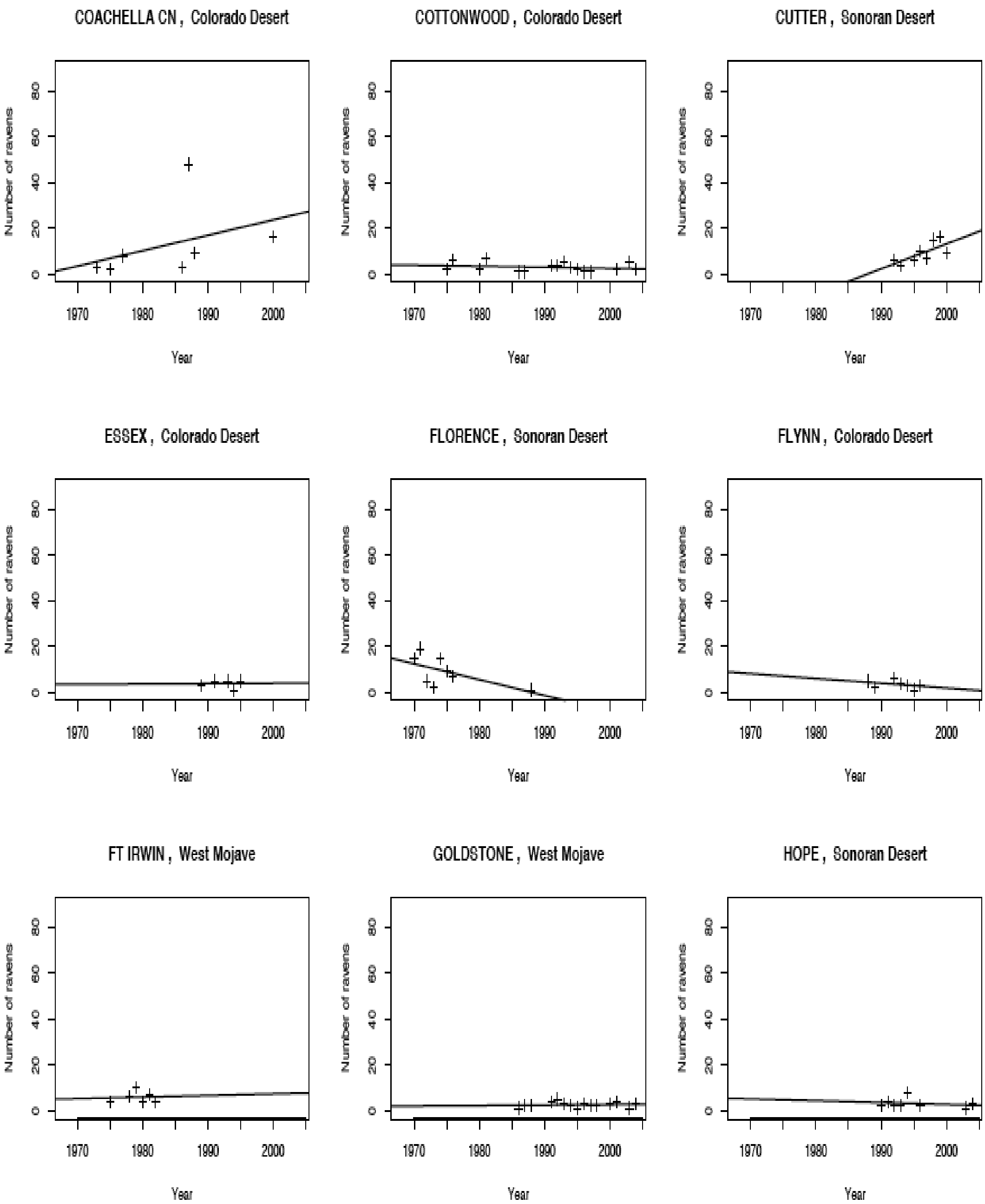


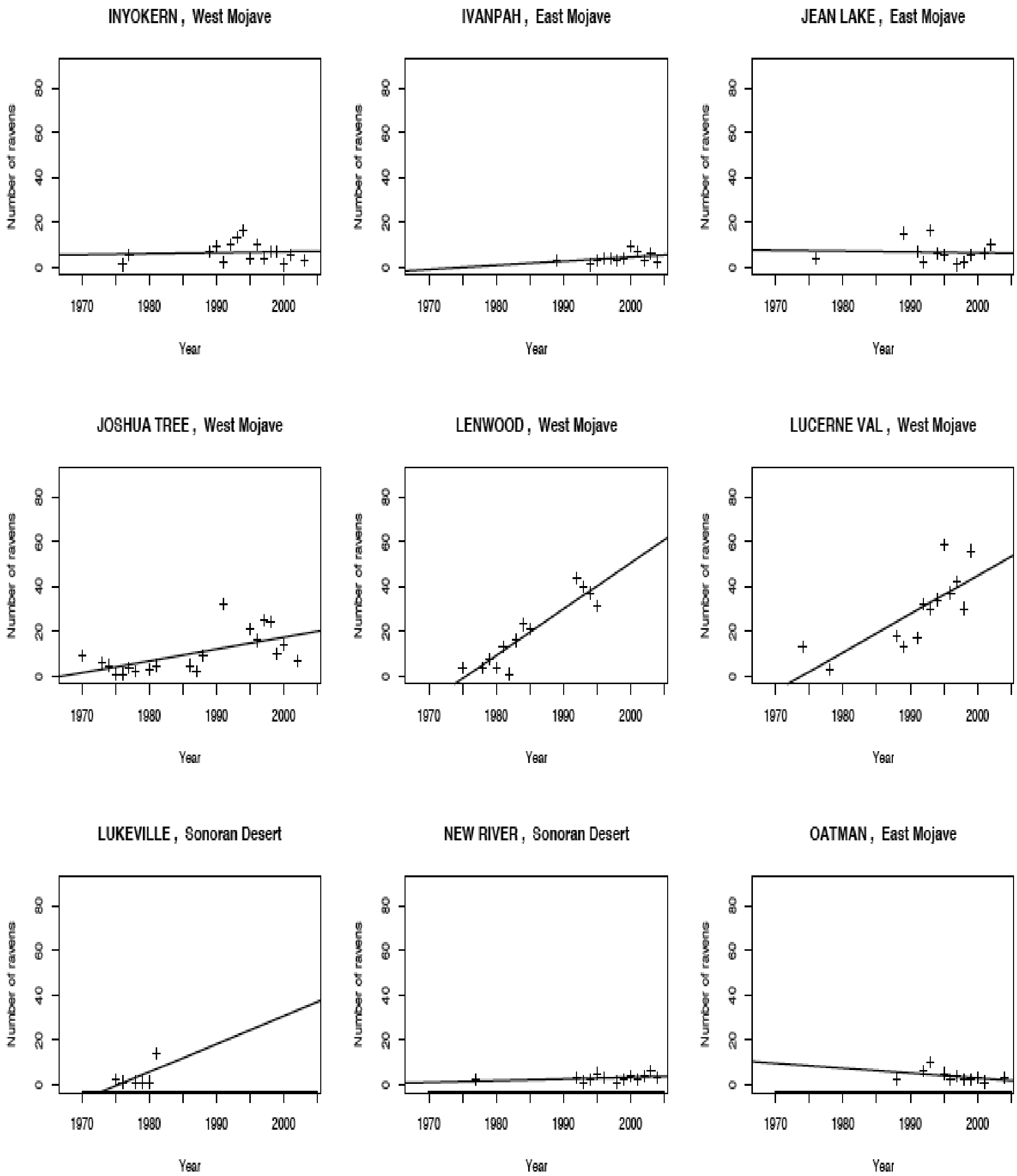
Appendix A. Route names and official BBS route numbers as represented in Figures 1 & 2. See Table 1 for subregion and years each route was surveyed.

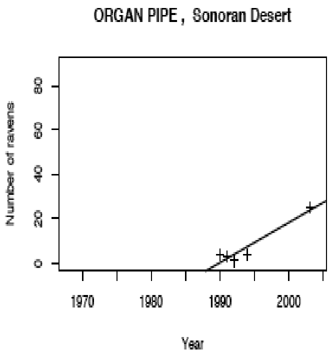
Route name	Route number		
		ALAMO RES.	63
		TRONA	63
SQUAW PEAK	6	TECOPA	64
WALKER CAN	11	ESSEX	67
OATMAN	12	FLYNN	68
WIKIEUPP	13	CIBOLA LAKE	68
QUARTZSITE	18	IRON MTNS	69
QUARTZSITE	19	GILA BEND	69
NEW RIVER	20	PALO VERDE	70
FLORENCE	21	COACHELLA CN	70
LAGUNA	24	CUTTER	72
AJO	26	ARABY	74
COOLIDGE	27	PISINIMO	76
BEATTY	29	RED ROCK	77
LUKEVILLE	30	CABEZA PRIETA	80
VAL OF FIRE	31	LUCERNE VAL	85
JEAN LAKE	32	HAVASU LAKE	86
NELSON	33	COTTONWOOD	88
CALIF CITY	35	BLYTHE	90
GOLDSTONE	36	IMPERIAL DAM	93
VALLEY WELLS	37	FT IRWIN	94
WILLOW SPGS	40	WILLOW BEACH	106
BARSTOW	41	CIMA	109
CADIZ	43	HOPE	119
PARKER DAM	44	CASA GRANDE	121
GLAMIS	48	CATUS FOREST	127
ANZA BORREGO	51	ORGAN PIPE	130
RIVIERA	56	JOSHUA TREE	131
INYOKERN	59	BATES WELL	176
LENWOOD	60	WLLWLBCH 2	206
IVANPAH	62		

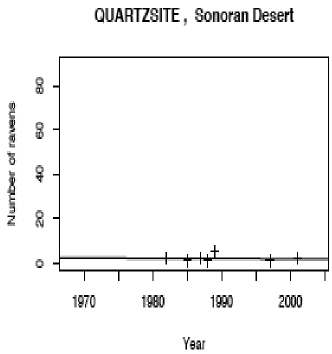
Appendix B. Graphs showing number of ravens per year for each route separately.

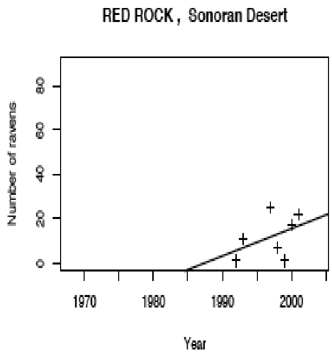


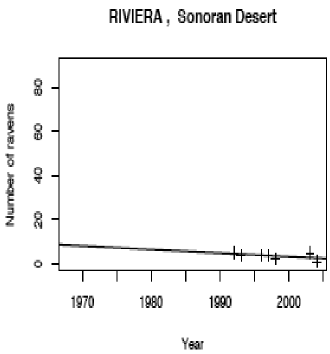

COACHELLA CN , Colorado Desert
COTTONWOOD , Colorado Desert
CUTTER , Sonoran Desert
ESSEX , Colorado Desert
FLORENCE , Sonoran Desert
FLYNN , Colorado Desert
FT IRWIN , West Mojave
GOLDSTONE , West Mojave
HOPE , Sonoran Desert
Number of ravens
0
20
40
60
80
1970
1980
1990
2000
Year

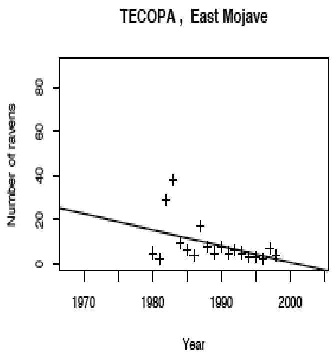

INYOKERN , West Mojave
IVANPAH , East Mojave
JEAN LAKE , East Mojave
JOSHUA TREE , West Mojave
LENWOOD , West Mojave
LUCERNE VAL , West Mojave
LUKEVILLE , Sonoran Desert
NEW RIVER , Sonoran Desert
OATMAN , East Mojave
Number of ravens
0
20
40
60
80
Year
1970
1980
1990
2000

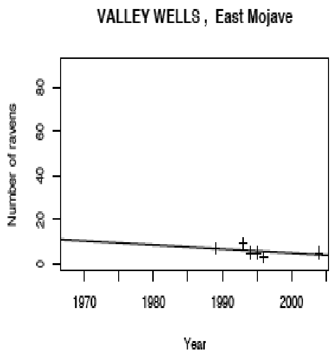

ORGAN PIPE , Sonoran Desert
Number of ravens
0 20 40 60 80
1970 1980 1990 2000
Year

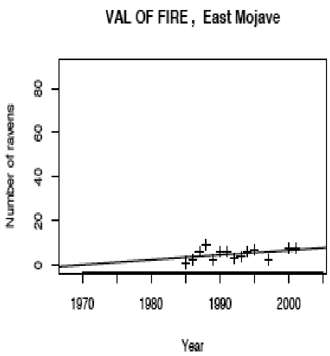

QUARTZSITE , Sonoran Desert
Number of ravens
0 20 40 60 80
1970 1980 1990 2000
Year

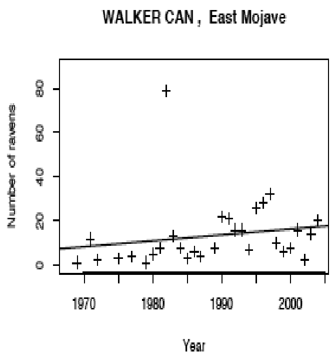

RED ROCK , Sonoran Desert
Number of ravens
0 20 40 60 80
1970 1980 1990 2000
Year

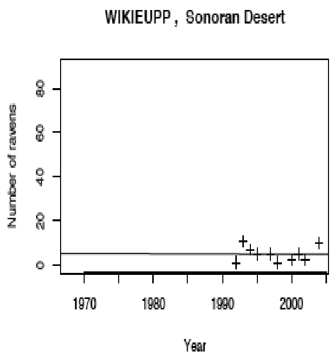

RIVIERA , Sonoran Desert
Number of ravens
0 20 40 60 80
1970 1980 1990 2000
Year

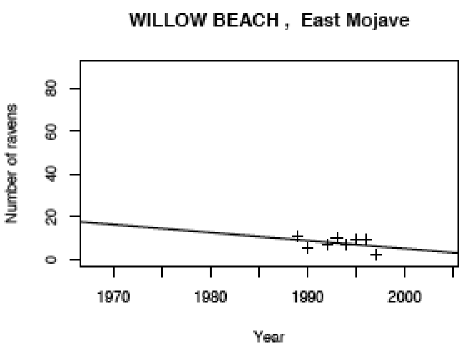

TECOPA , East Mojave
Number of ravens
0 20 40 60 80
1970 1980 1990 2000
Year

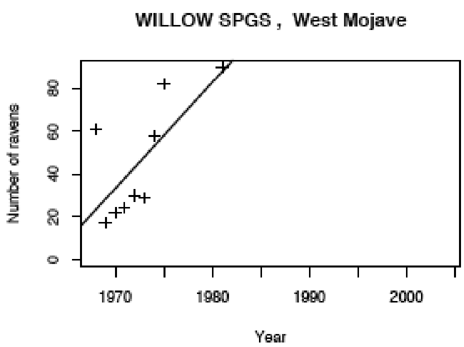

VALLEY WELLS , East Mojave
Number of ravens
0 20 40 60 80
1970 1980 1990 2000
Year


VAL OF FIRE , East Mojave
Number of ravens
0 20 40 60 80
1970 1980 1990 2000
Year

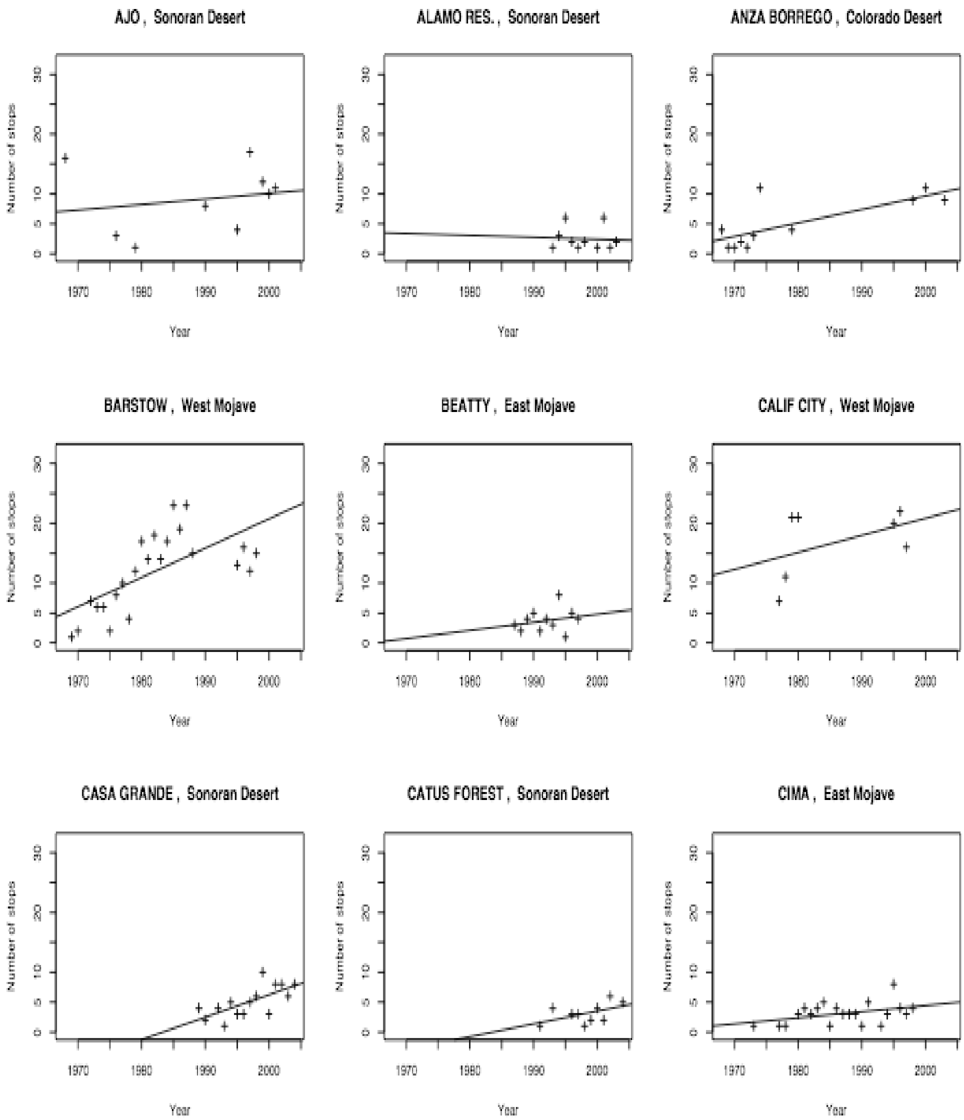

WALKER CAN , East Mojave
Number of ravens
0 20 40 60 80
1970 1980 1990 2000
Year

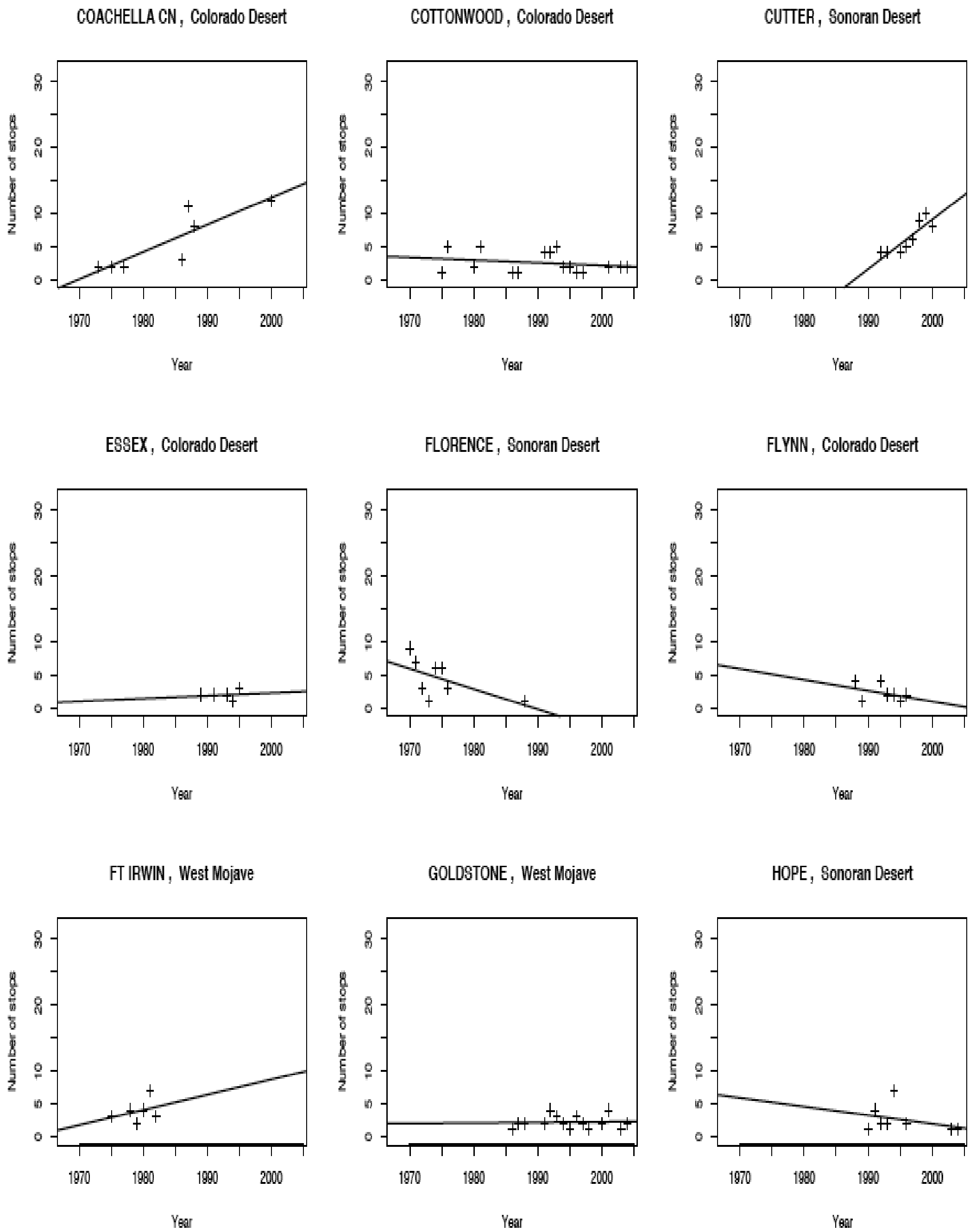

WIKIEUPP , Sonoran Desert
Number of ravens
0 20 40 60 80
1970 1980 1990 2000
Year

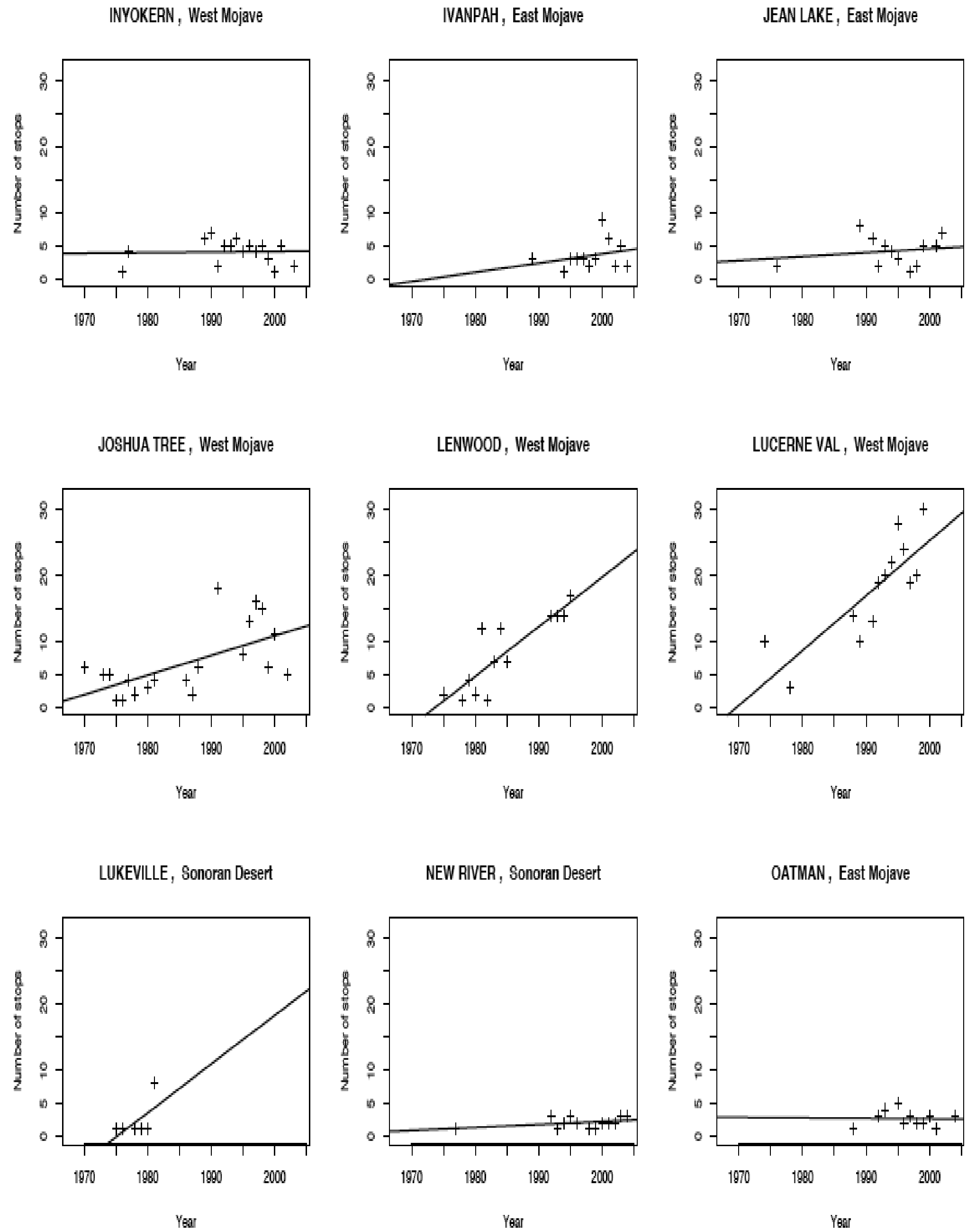

WILLOW BEACH , East Mojave
Number of ravens
0 20 40 60 80
1970 1980 1990 2000
Year

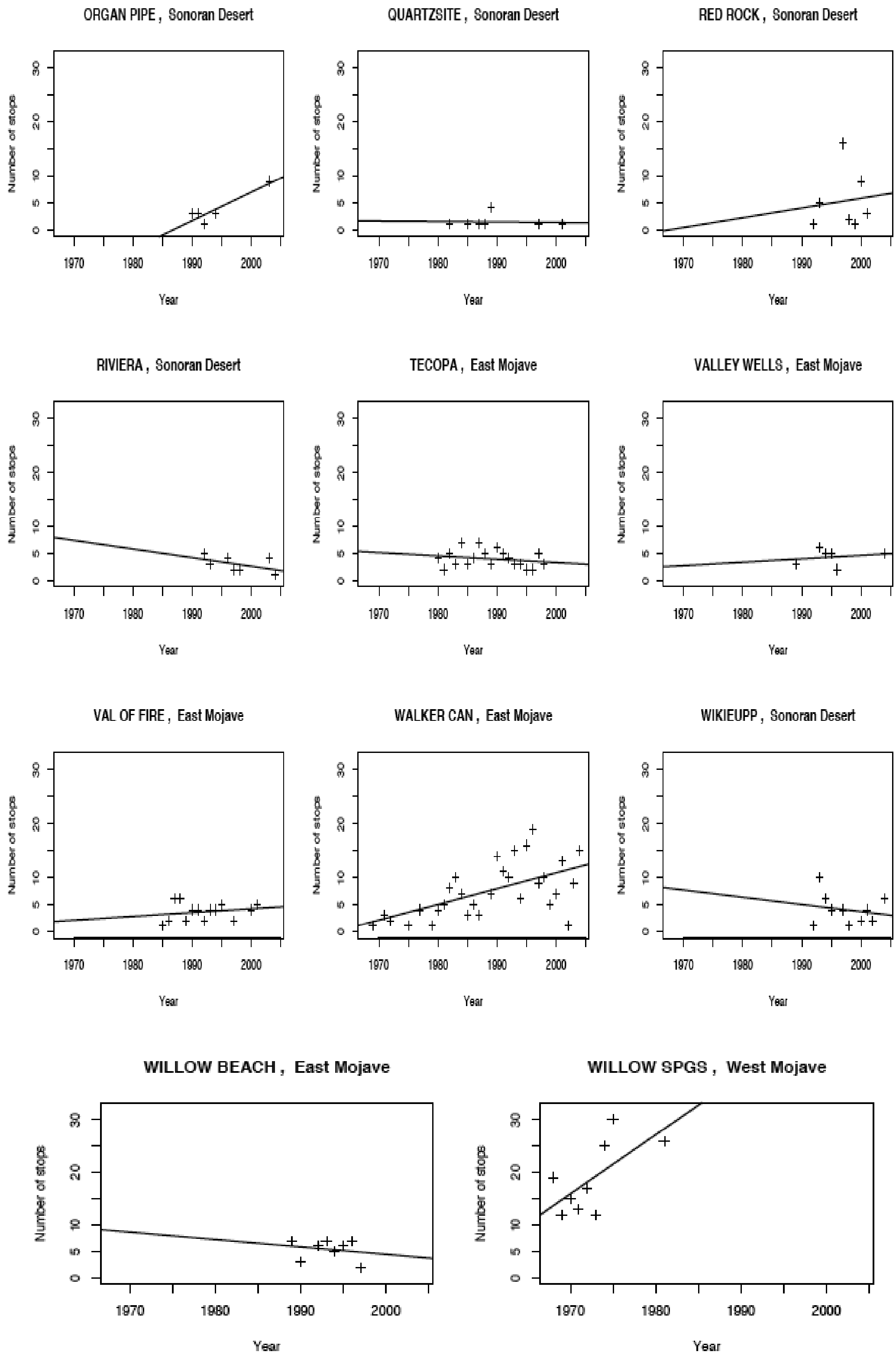

WILLOW SPGS , West Mojave
Number of ravens
0 20 40 60 80
1970 1980 1990 2000
Year

Appendix C. Graphs showing number of stops on which ravens were observed per year for each route separately.




COACHELLA CN , Colorado Desert
COTTONWOOD , Colorado Desert
CUTTER , Sonoran Desert
ESSEX , Colorado Desert
FLORENCE , Sonoran Desert
FLYNN , Colorado Desert
FT IRWIN , West Mojave
GOLDSTONE , West Mojave
HOPE , Sonoran Desert
Number of stops
0
5
10
20
30
1970
1980
1990
2000
Year


INYOKERN , West Mojave
IVANPAH , East Mojave
JEAN LAKE , East Mojave
JOSHUA TREE , West Mojave
LENWOOD , West Mojave
LUCERNE VAL , West Mojave
LUKEVILLE , Sonoran Desert
NEW RIVER , Sonoran Desert
OATMAN , East Mojave
Number of stops
0
5
10
20
30
Year
1970
1980
1990
2000


ORGAN PIPE , Sonoran Desert
QUARTZSITE , Sonoran Desert
RED ROCK , Sonoran Desert
RIVIERA , Sonoran Desert
TECOPA , East Mojave
VALLEY WELLS , East Mojave
VAL OF FIRE , East Mojave
WALKER CAN , East Mojave
WIKIEUPP , Sonoran Desert
WILLOW BEACH , East Mojave
WILLOW SPGS , West Mojave
Number of stops
Year
0
5
10
20
30
1970
1980
1990
2000