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Comparing Sight-Resight Methods for Dog Populations: Analysis of 2015 and 2016 Rabies Vaccination Campaign Data from Haiti

Julie M. Cleaton

ABSTRACT

COMPARING SIGHT-RESIGHT METHODS FOR DOG POPULATIONS: ANALYSIS OF 2015 AND 2016 RABIES VACCINATION CAMPAIGN DATA FROM HAITI

By

JULIE MARIE CLEATON

21 APRIL 2017

INTRODUCTION: Sight-resight studies are performed to estimate population sizes, in this case dog populations in rabies endemic areas.

AIM: This study compares one- and two-day sight-resight methods with two-day as the standard to explore the feasibility and accuracy of the one-day method in different vaccination campaign strategies and dog population characteristics.

METHODS: 2015 household survey data and sight-resight data are analyzed to find the percentage of free roaming and confined dogs in the community and use those to adjust the population estimate formulas. 2016 sight-resight data are analyzed as a two-day campaign and as if it had been a one-day campaign. In a sensitivity analysis, confidence intervals are explored in relation to vaccination coverage.

RESULTS: Before missed mark and proportion free-roaming corrections, the one-day method results in slightly underestimated population estimates to the two-day method when the vaccination campaign is central point, overestimated when door-to-door, and far underestimated when capture, vaccinate, release. After corrections door-to-door estimates were accurate whereas central point and capture, vaccinate, release estimates substantially underestimated population sizes.

DISCUSSION: Results suggest that the one-day mark-resight method could be used to conserve resources depending on the vaccination method and estimated coverage.

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APPROVAL PAGE

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Author's Statement Page

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Introduction

1.1 Background

Rabies is a zoonotic disease caused by viruses of the genus *Lyssavirus*, and it is spread mainly through bites from infected mammals. In the United States the most common animal reservoirs are raccoons, bats, skunks, and foxes. Dog rabies has been eliminated in the US since 2007, and human cases are now very rare and occur mostly from bat contacts, travel, and organ transplants (Monroe et al, 2016). However dog rabies is still endemic in 122 countries with 78% of the world's dogs, and these are where most human rabies deaths occur (Wallace et al, 2017).

Although transmission is slow with R_0 estimates of 1.05 to 1.72, rabies has a large impact because of its high virulence (Hampson et al, 2009). The disease is preventable through pre- and post-exposure vaccinations, but once symptoms develop it is fatal in over 99% of cases, making it the most deadly infectious disease (Fooks et al, 2014). Rabies enters the peripheral nervous system and eventually reaches the central nervous system, causing encephalitis and organ failures. An estimated 59,000 people die from rabies worldwide every year, and the vast majority of those cases are caused by bites from rabid dogs (Hampson et al, 2015).

Haiti is one of the few countries in the Western Hemisphere where deaths still occur due to dog-mediated human rabies. There are an estimated 130 deaths each year in the country, although only 7 were documented in 2015 (Hampson et al, 2015; Wallace et al, 2016). Case detection is difficult for several reasons. A small percentage of bites are reported and treated, although this should improve as the integrated bite case management (IBCM) system has expanded. Other encephalitic conditions present in Haiti and a lack of diagnostic testing capabilities also contribute to the small number of confirmed cases (Wallace et al, 2016). Despite these limitations, dog-mediated human rabies is a known problem in the country and Haiti's Ministry of Agriculture, Natural Resources and Rural Development (MARNDR) has been working with the US Centers for Disease Control and Prevention (CDC), the Christian Veterinary Mission, and the Pan American Health Organization (PAHO) to improve the rabies situation there. Through a recent country-wide vaccination campaign Haiti has entered phase III of the global dog rabies elimination pathway (GDREP), meaning that they have built capacity and surveillance and are now working to sustain 70% vaccination for seven years (Wallace et al, 2017).

Post-exposure prophylaxis prevents rabies from developing in humans, but it is expensive and does not keep bites from occurring. The most effective long-term solution to prevent dog-mediated human rabies deaths is to vaccinate dogs against rabies. In order to eliminate rabies from dog populations, the World Health Organization (WHO) recommends vaccinating 70% of the dogs for seven years, and PAHO recommends 80% (WHO, 2013). To meet these goals and know that they have been met, an accurate count of the local dog population is necessary. There are a number of ways to do this including household surveys, censuses, sight-resight or mark-resight studies, and others.

1.2 Research Questions

The two studies surrounding the 2015 and 2016 vaccination campaigns were designed to address several research questions each. The first study was focused on collecting information about dog ownership in urban and rural communities and estimating the dog populations there. This information would then be used to estimate the dog population in all of Haiti. The research questions can be broken down as follows:

1. What is the population structure of dogs in Haiti?
2. What proportions are confined and free-roaming?
3. How do those proportions affect population estimates?
4. How can local dog population estimates be extrapolated to a country level?

The second study was focused on determining vaccination coverage by different campaign methods and again estimating the local dog populations. The data collected during this study could also be applied to a different estimation method used by rabies control groups, so questions arose about how the traditional and modified sight-resight studies compare.

1. Is a one-day method of estimating populations using the Lincoln-Petersen calculation comparable to a two-day method?
2. How does it vary by vaccination campaign type (central point, door-to-door, capture, vaccinate, release)?
3. How do vaccination coverage and proportion confined affect one-day estimate accuracy compared to two-day estimates?
4. What influences the width of confidence interval for the one-day method?

Review of the literature

2.1 Overview of population estimation methods and calculations

Population estimates have been conducted for hundreds of years, but large-scale censuses were challenging in both human and animal populations. To compensate for this, Pierre LaPlace used a variation of what is now referred to as the sight-resight method to estimate the population of France in 1802. Several towns had accurate birth and total population data, and a new birth registry provided an estimate of the births in the entire country. He then extrapolated the proportion of births per total town population to reach an estimate of about 28,000,000. His method was deemed more successful than a census attempted around the same time (Cochran, 1978). This basic calculation has since been adapted for use in wildlife populations, originally fish and now primarily mammals.

The calculation is now referred to as the Lincoln-Petersen or Petersen-Lincoln estimator, and the methods used are called capture-recapture, mark-resight, and sight-resight. Carl Petersen first brought this method into use in 1896 among fish populations by capturing and tagging fish to track their migration, then using that capture and recapture data to estimate population size. Frederick Lincoln used similar inputs from banded birds whose bands had been returned by hunters, thus Petersen and Lincoln were both foundational for population estimation in their respective fields (Chao et al, 2008). Douglas Chapman published another version of this estimator in 1951 to adjust for bias when there is a small number of recaptures. The following equations are the Lincoln-Petersen estimator, the Chapman modification, and a one-day vaccination campaign-based modification used by Mission Rabies and others. The Lincoln-Petersen and Chapman calculations have been compared and the results showed no significant difference between the estimates (Tenzin et al, 2015). The Chapman version is used in this study to account for bias.

$$Total\ population\ = \frac{day1\ count * day2\ count}{resights}$$

$$Total\ population\ = \frac{(day1\ count +\ 1) * (day2\ count +\ 1)}{(resights +\ 1)} - 1$$

$$Total\ population\ = \frac{(total\ vaccinated +\ 1) * (day1\ count +\ 1)}{(marked\ vaccinated\ day1 +\ 1)} - 1$$

These are not the only methods and calculations used to estimate population sizes. Censuses, surveys, longer sight-resight studies, logit-normal mixed effects models, Bayesian analyses, the CAPTURE program, Jolly-Seber for open populations, and more are potential ways to estimate animal populations (Seber, 1982). In small mammals the CAPTURE program and Lincoln-Petersen estimator were compared, and the estimator was found to be more useful except when trap response was a factor, which it is not in dog sight-resight studies (Menkens and Anderson, 1988). One study compared a mark-resight study to household and school surveys and found that the mark-resight study quickly and cheaply attained precise results while the surveys were more intensive and expensive (Sambo et al, 2017). Belo and colleagues (2015) reviewed free-ranging dog population estimation papers published since 1980, including several capture-recapture studies and census surveys. Most of the reviewed studies did not provide enough information about their methods and did not try to account for the limitations of their methods. The least problematic papers they reviewed used the Lincoln-Petersen estimator, but they did find a number of limitations that should be addressed to make the sight-resight methods more accurate and replicable. The authors suggested using the Beck photo method to avoid scaring dogs off, performing the campaign over a brief interval so as not to violate the closed population assumption or considering the population open; addressing heterogeneity of captures; accounting for mark loss in the Lincoln-Petersen estimation method; providing more details about routes, timing, and identification methods; providing uncertainty measures for parameter estimates; and reporting a better measure than density of dogs per total area (Belo et al, 2015). Another recent systematic review covered owned dog population estimates, which were primarily surveys. However most were in high-income countries, making them less relevant for Haiti (Downes et al, 2013).

One-day mark-resight studies have been conducted after vaccination campaigns, using the same calculation as the usual two-day studies but with different inputs. Instead of marking all dogs seen on the first day and counting those and the unmarked dogs on the second day, this method marks all dogs vaccinated and counts those and the unmarked dogs in the entire vaccinated area. While this might conserve resources, it also violates several assumptions of the Lincoln-Petersen estimator (Table 2, Table 1). The inputs for the two-day sight-resight method compared in this study are the numbers sighted and photographed on days one and two, where the photo functions as a mark. Dogs photographed or seen on both days are the resights in the above formulas.

Assumption	**1-day method**	**2-day method**
Closed population	Y	Y
Marked/unmarked same mortality	Y short-term, N long-term	Y
No mark loss	N (wax)	Y (photo), N (wax)
No mark identification error	N (wax)	Y (photo), N (wax)
Marked animals randomly mixed in population	N	Y
Marked/unmarked equal subjectivity to sampling	N	Y

Table 2.1 Lincoln-Petersen assumptions met by the one- and two-day sight-resight methods. Y indicates that the assumption is met, N that it is or can be violated.

Resources/inputs	1-day method	2-day method
Day of marking/vaccinating	Y	Y
First day of counting	Y	Y
Second day of counting	N	Y
Large proportion of marked dogs in area must be counted	Y	N
KAP Survey for % confined	N	Y
Accurate human population for dog count	N	Y
Accurate human population for H:D ratio	Y	Y

Table 2.2 Sight-resight resources required for one- and two-day methods.

The accuracy of these dog enumeration methods is unclear because the true free-roaming population sizes remain unknown. However, when comparing population estimates to vaccination coverage it is generally possible to tell when estimates are very far off; for example if coverage is estimated at 110% then the population estimate was too low. The Lincoln-Petersen estimator has been evaluated in ungulates, and the accuracy depended on the proportion of the total population that had been marked. The standard error was not influenced by this proportion. The Lincoln-Petersen method frequently over-estimated a well-known white-tailed deer population even when 68% of the population was marked, and other ungulates required 45% and 75% marking for accurate estimates (McCullough and Hirth, 1988).

Methods

3.1 2015 Sight-resight study design

Haiti is politically divided into 10 departments, which are further subdivided into 144 communes. Twelve communes were randomly selected for the 2015 sight-resight (SRS) surveys and fourteen for rapid dog counting surveys. SRS surveys were conducted in conjunction with a national governmental rabies vaccination program. Therefore, the nearest government-sponsored campaign to the randomly selected sites were chosen for the final SRS locations. Rapid surveys were not held in conjunction with government programs and were conducted at the randomly chosen sites. Surveys were conducted between July 2014 and April 2015. All dog surveys were recorded using a GoPro video camera to validate dog counts and dog identification. Communities that were selected for this study were objectively assigned a rural-urban status based on human population within the lowest governmental political unit, section communal. Designations were assigned as:

Urban: >=30,000

Semi: >15,000 - <30,000

Rural: <=15,000

SRS and rapid surveys were conducted between 2 pm and 5 pm. Distances covered varied due to condition of roads, accessibility of the community, and number of dogs sighted. GPS units were used to record the track covered by the surveyors and a GPS location was taken for each dog sighted.

SRS surveys were held in conjunction with government-sponsored rabies vaccination campaigns. The primary vaccination method is a fixed-point location with verbal outreach to nearby community members. If dog turnout is low, some door-to-door efforts are undertaken by vaccinators. In all cases, dogs were presented to the vaccinators by an owner; no active capture-vaccinate-release efforts were undertaken. On the first day of the three-day SRS study a knowledge, attitude, and practices (KAP) survey was conducted at the vaccination sites to gain an understanding of the health of the dogs and their confinement status (Schildecker; see Appendix I for survey questionnaire). Every vaccinated dog was marked with a temporary collar and a temporary wax ID on the hindquarters. On day two a team of surveyors walked a pre-selected route through the community, centered near the main fixed-point vaccination location. Dog counters had standardized data recording sheets and filmed the route and all dogs sighted. On day three the dog counting team walked the same route as the previous day. Upon completion of the counting activities, data sheets and GoPro video was used to visually match dogs on day two and day three. Dogs sighted on both days were considered as 're-sighted.' Data recorded included the presence of a vaccination collar, unique wax ID, other collar, confinement status, physical markings and wounds, body condition score, and presence of a communal food source (i.e. garbage pile, street vendor).

Three population estimations were used to compare the resulting predicted dog populations from the SRS data. A site-specific Chapman calculation was conducted in which each site had a specific population attributed to it. A second calculation was made in which the Chapman method was conducted at the site-specific level and for each community and owned dogs. This enables the specific estimation of free-roaming dogs in a community, which is integral to mass canine vaccination program planning. The final method involved all components of the second method, with the addition of a correction factor to account for the owned population of dogs never allowed to roam freely, and therefore not eligible for counting by the SRS methodology.

For each site there was a known proportion of owned dogs which were reportedly never allowed to roam freely in the communities (information collected during KAP study component). Therefore, to account for these dogs that were not eligible to be counted during this survey, a population correction method was employed. For this correction, a conservative assumption was made that all dogs sighted behind a household wall during the SRS were never allowed to roam freely within the community; an assumption that is biased towards the null and likely to result in a lower total dog population estimation. The correction was applied only to sites for which the SRS percentage of owned dogs observed behind walls was lower than the reported percentage of 'always confined' dogs from the KAP survey (n = 10). A site-specific corrected owned dog population was calculated by summing the total non-walled, owned dogs and then dividing by the inverse of the KAP percentage 'never.' The Chapman estimates for owned and community dogs were summed to establish the total estimated dog population for the surveyed area. Dog populations are presented in absolute terms as well as the relative function, "humans per dog." Data are presented as aggregate for each community type: urban, semi-urban, and rural.

3.2 2015 Rapid Count Population Survey

To further boost confidence and representativeness of this data, an additional 13 sites were surveyed using a rapid counting method. A standardized data collection form was used to count each dog, track its confinement status, presence of a collar, presence of wounds, and body condition score. Rapid counts are known to underestimate the true dog population; therefore a data correction method was applied to rapid count data in an attempt to gather a more reliable dog count.

To correct for the undercounting of the rapid method, an assumption was made that the SRS population estimation was 'true'. A human:dog ratio (H:D ratio) was calculated using SRS data for each community type; urban, semi-urban, and rural. These stratified SRS H:D ratios were compared to similarly aggregated, stratified H:D ratios calculated from the rapid survey data. Rapid surveys, which systematically under-count dog populations, resulted in a high H:D ratio. The rapid H:D ratio was compared against the SRS H:D ratio and the fold increase for each aggregated community type was applied to the site-specific rapid counts to come to a 'true' dog population within that community.

$$\text{Stratified Rapid Count} = \text{Rapid}_{\text{observed}} * [(\text{Human Pop}_{\text{Rapid}} / \text{Dog Pop}_{\text{Rapid}}) / (\text{Human Pop}_{\text{SRS}} / \text{Dog Pop}_{\text{SRS}})]$$

$$\text{SRS Count} = \text{Community}_{Chap} + [(\text{Owned}_{Chap} - (\text{Owned}_{\text{Chap}} * \%\text{Obs}_{\text{Non-Walled}})) / (1 - \%\text{KAP}_{\text{Always Confined}})]$$

$$\text{Owned SRS Adjusted with Partial Boost} = (\text{Owned}_{ChapAC} + \text{Owned}_{ChapFR}) / [1 - (\%\text{KAP}_{\text{Always Confined}} - (\%\text{Obs}_{\text{Walled}} / 2))]$$

$$\text{Owned SRS Adjusted with Full Boost} = (\text{Owned}_{ChapAC} + \text{Owned}_{ChapFR}) / (1 - \%\text{KAP}_{\text{Always Confined}})$$

3.3 2015 Data Analysis

In total 12 SRS sites were completed: five rural communities, three semi-urban, and four urban communities. An additional 14 rapid surveys were completed: five rural, four semi-urban, and five urban. Data from the standardized collection forms were entered into Microsoft Access.

Data cleaning and analysis was conducted in SAS version 9.3. Dogs were considered to be owned if they were seen within the gates of a property, tied by rope while on a property, or were free-roaming but had a collar or other evidence of rabies vaccination. Dogs that were free-roaming and had no indication of ownership (i.e. a collar or vaccination mark) were considered to be community dogs for the purposes of this study. Univariate analysis comparing characteristics of dogs was conducted between rural-urban community types. Cochran chi-square statistics of association were used to show statistical significance between variables. SRS data were collected in conjunction with government-sponsored rabies vaccination campaigns, during which dogs were recorded to have the presence of a vaccination collar or wax ID. These data were used to calculate the vaccination coverage within the community as well as within the street dog population.

The four population estimation methods were compared against each other both in terms of H:D ratio as well as national dog populations when the H:D ratio is applied to the Haitian national population of 10,500,000. Further refinement of the national dog population was achieved by applying community-type stratified H:D ratios to the proportion of the Haitian population residing in the respective community. Stratified H:D ratios were applied to Haiti base map data at the section communal level to develop detailed maps which predict the population of dogs.

3.4 2016 SRS methods

The 2016 vaccination campaign study set out to compare three different vaccination strategies: central point (CP), door-to-door plus oral vaccinations (DD + ORV), and central point plus capture-vaccinate-release (CP + CVR). Central point, or fixed point, vaccinations occur in one location and dogs are brought there by their owners. Free-roaming dogs are less likely to be reached by this strategy. Door-to-door vaccination requires more work on the vaccinator's part and still may not reach many free-roaming dogs, but they are more likely to reach dogs that are difficult to handle or whose owners were unaware of a central point campaign. Dogs that were difficult to handle in the DD group were offered an oral vaccine. Capture, vaccinate, and release campaigns target free-roaming dogs that would not be brought to the concurrent CP campaign. CVR is the most labor intensive but reaches the dogs at the highest risk for rabies.

After two days implementing each of these strategies and marking the vaccinated dogs with collars and wax, two-day sight-resight studies were conducted at all 5 sites for a total of 15 studies. Two SRS workers walked the same path each day around the vaccinated area, recording each dog and its demographic and vaccination information while photographing the dogs. On the second day the teams recorded whether they remembered the dog from the day before, calling it a resight. The photographs and information sheets were used to confirm those resights and come up with final population estimates. The photos from one CP site were unavailable, so in that case only the results from the field forms were reported and that site was excluded from the matched dogs. The Lincoln-Petersen-Chapman calculation discussed above was used to estimate the number of dogs along each track based on the numbers sighted and resighted. Matched dogs' data were analyzed to determine the final number vaccinated and to examine vaccination collar loss and wax mark loss or misidentification. Collar and mark loss were calculated using SAS 9.3. To estimate collar loss from vaccination to the next day of SRS counting, the number with collars was subtracted from the number with marks. To estimate collar loss from the first day of counting to the second day, the number with collars on day two was subtracted from the number with collars on day one. These numbers were divided by the number of matched dogs vaccinated and eligible to have a collar each day to get the percent collar loss per day. To estimate mark misidentification, the number of matched dogs marked or collared on the second day but not the first was divided by the number of eligible vaccinated dogs. The number of dogs vaccinated was increased by 13.7% to account for collar loss.

To determine the local dog population estimates and human to dog ratios, the GPS data of the SRS tracks were imported into Garmin Basecamp to edit out driving components and determine track length. The edited tracks were then exported to Google Earth and transposed over the most recent images of Haiti where houses were visible (twelve from February 2016 or October 2015, four from 2010). The rooftops along each track were counted and multiplied by 6.2, the average number of people per household, resulting in human population estimates for each track. These estimates were divided by the estimated number of dogs along each track to get the H:D ratio. A 25% boost was applied to the Chapman estimates to account for confined dogs ineligible for counting, and then the H:D ratios were applied to the approximate human population of the urban and rural areas to get the approximate number of dogs in each zone.

3.5 2016 one-day and two-day comparison methods

To treat the two-day study as a one-day study, only the number vaccinated and the proportion of counted dogs vaccinated on the first day were included in the Lincoln-Petersen calculations, as opposed to sighted and resighted numbers. The two-day study results were treated as the gold standard for comparison. To compare by vaccination method, estimates from all four urban sites were summed for each campaign type and averaged. The one rural site was not a large enough sample to be analyzed here. The two-day SRS estimates from each zone were subtracted from the one-day estimates. The difference was divided by the two-day estimate to determine percent differences based on both averages and sums of the two-day and one-day results.

In order to explore how the vaccination coverage and proportion of the dog population that is confined affect the one-day estimates, tables were created in Microsoft Excel for each vaccination method. The point estimates for vaccination coverage for free-roaming and confined dogs by each vaccination method were drawn from CDC expert opinion, and low and high estimates for these are 50% and 150% of the point estimate up to a maximum of 95% coverage. Coverage of confined dogs in a CP or DD campaign was said to be 80% and 40% among roaming dogs, and in a CVR campaign 20% and 70%. It was assumed that the true dog population is 3,356, the number estimated by the two-day method for all four urban areas, that 30% of that area was walked, and that the vaccination coverages described above are correct. Those numbers were then used to calculate the projected numbers of dogs vaccinated, sighted, and marked among the sighted dogs. The results were graphed to illustrate how accurate the estimates are to the two-day method as proportion confined increases.

3.6 Sensitivity analysis methods

The influences of vaccination coverage and the proportion of vaccinated dogs resighted on the confidence intervals of the point population estimates are investigated in this sensitivity analysis. Nine scenarios are used as examples to demonstrate the effects of those factors: when vaccination coverage is 20%, 50%, and 80% in small (250), medium (500), and large (1000) dog populations. The percentage walked scales from 5% to 100% of the area vaccinated. The formula used to calculate the variances is below, and 1.965 multiplied by the square roots of the variances was subtracted from and added to the point estimates to get the low and high bands of the confidence intervals (Adams, 1951).

$$\frac{(Total\,vax\; + \;1)\; * \;(Sighted\; + \;1)\; * \;(Total\,vax\; - \;Marked)\; * \;(Sighted\; - \;Marked)}{(Marked\; + \;1)\; * \;(Marked\; + \;1)\; * \;(Marked\; + \;2)}$$

Results

4.1 2015 dog population structure

According to the knowledge, attitudes, and practices survey, about 70% of dogs in urban and semi-urban sites are allowed to roam freely at some point and about 30% are always confined (Table 4.1). On the ground teams observed 81% and 60% roaming in urban and semi-urban sites during the sight-resight study, confirming the KAP survey results. In rural areas 62% of owned dogs were allowed to roam, and 38% were observed roaming freely. Overall vaccination coverage was 46% according to the SRS study (Table 4.2). It was higher among adult dogs and dogs who are at least sometimes confined.

Characteristics of Dogs Sighted During a Dog Population Survey by Community-type, Haiti 2014-2015

		Urban		Semi		Rural		Total
		n	%	n	%	n	%	n
Community	**Number Sites (SRS and Rapid)**	13	50.0%	6	23.1%	7	26.9%	26
	Total Observed Dogs	879	59.5%	341	23.1%	257	17.4%	1,477
	Total Estimated Dogs	4,182	74.7%	1,147	20.5%	266	4.8%	5,595
	Estimated Owned Dogs	*1,940*	*46.4%*	*898*	*78.3%*	*223*	*83.8%*	*3,061*
	Estimated Community Dogs	*2242*	*53.6%*	*249*	*21.7%*	*43*	*16.2%*	*2,534*
	Estimated Human:Dog	8.2		7.6		59.1		9.3
	Average Body Condition Score (1 - 9)	3.3		3.1		3.7		3
	Sighted at Food Location *(% of observed dogs)*	36	4.1%	0	0.0%	8	3.1%	44
Gender	**Male (Total)**	368	41.9%	133	39.0%	113	44.0%	614
	In-tact	*318*	*86.4%*	*112*	*84.2%*	*109*	*96.5%*	*539*
	Neutered	*50*	*13.6%*	*21*	*15.8%*	*4*	*3.5%*	*75*
	Female (Total)	395	44.9%	163	47.8%	95	37.0%	653
	Lactating	*133*	*33.7%*	*75*	*46.0%*	*21*	*22.1%*	*229*
	Non-Lactating	*262*	*66.3%*	*88*	*54.0%*	*74*	*77.9%*	*424*
	Missing	116	13.2%	45	13.2%	49	19.1%	210
	Total	*879*	*100.0%*	*341*	*100.0%*	*257*	*100.0%*	*1,477*
Age	**Juvenile**	109	12.4%	58	17.0%	50	19.5%	217
	Adult	737	83.8%	264	77.4%	204	79.4%	1,205
	Missing	33	3.8%	19	5.6%	3	1.2%	55
	Total	*879*	*100.0%*	*341*	*100.0%*	*257*	*100.0%*	*1,477*
Confinement	**KAP: Dogs Always Confined (%)**	29%		31%		38%		
	KAP: Dogs Allowed to Roam (%)	71%		69%		62%		
	Running loose	710	80.8%	206	60.4%	108	42.0%	1,024
	Walked on leash	3	0.3%	1	0.3%	0	0.0%	4
	Tied on a property	100	11.4%	100	29.3%	42	16.3%	242
	Behind a wall	66	7.5%	34	10.0%	107	41.6%	207
	Total	*879*	*100.0%*	*341*	*100.0%*	*257*	*100.0%*	*1,477*

Table 4.1 Characteristics of dogs sighted during a dog population survey by community-type

Effects of Animal's Gender, Age, Confinement Status and Community-type on Rabies Vaccination Coverage, Haiti 2014/2015												
		Urban			Semi			Rural			Total	
			n	%		n	%		n	%	N(vax)	% total population
	Number sites		6			7			2		15	100.0%
	Dogs sighted		648			287			46		981	100.0%
	Dogs with vaccination ID		252	38.9%		172	59.9%		27	58.7%	451	46.0%
		Total	Vaccinated	Percent	Total	Vaccinated	Percent	Total	Vaccinated	Percent		
Gender	Male	323	136	42.1%	137	84	61.3%	23	13	56.5%	233	48.2%
	Female	281	98	34.9%	110	70	63.6%	17	11	64.7%	179	43.9%
	Missing	44	18	40.9%	40	18	45.0%	6	3	50.0%	39	43.3%
											P-value: 0.37	
Age	Juvenile	81	21	25.9%	43	23	53.5%	14	3	21.4%	47	34.1%
	Adult	541	220	40.7%	227	137	60.4%	32	24	75.0%	381	47.6%
	Missing	27	11	40.7%	17	12	70.6%	0	0	-	23	52.3%
											P-value: 0.008	
Confinement	Running loose	524	187	35.7%	176	108	61.4%	14	7	50.0%	302	42.3%
	Walked on leash	3	2	66.7%	1	1	100.0%	0	0	-	3	75.0%
	Tied on a property	65	39	60.0%	83	42	50.6%	0	0	-	81	54.7%
	Behind a wall	56	24	42.9%	27	21	77.8%	32	20	62.5%	65	56.5%
											P-value: 0.002	

Table 4.2 Effects of animal's gender, age, confinement status and community-type on rabies vaccination coverage.

4.2 2015 estimation results

Based on the sight-resight study alone with no corrections, the human to dog ratio is estimated to be 10.9 (Table 4.3). After stratifying the population into owned and loosely owned dogs, the ratio comes down to 10.2. After stratifying and correcting for always confined dogs that would not be seen in an SRS study, the ratio becomes 8.9 with a total country estimate of almost 1.2

million. After including the corrected rapid counts, the ratio comes back up a little to 9.2 and the country estimate 1.1 million (Figure 4.1).

Comparison of Dog Population Estimation Calculation Methodology using Sight-Resight Population Data, Haiti 2014/2015									
	Site-Specific Chapman Estimation			**Site-Specific, Stratified Chapman**			**Site-Specific, Stratified Chapman with Confinement Correction**		
				Community Dogs		*Owned Dogs*	*Community Dogs*		*Owned Dogs*
		N		N		*N*	N		N
Day 1 Count		553		219		334	219		334
Day 2 Count		562		270		292	270		292
Dogs Re-sighted		134		49		85	49		85
Total Unique Dogs		981		440		541	440		541
	Low	Mean	High	Low	Mean	High	Low	Mean	High
Total Estimated Dogs	1,403	2,805	4,208	897	2,980	5,065	1,066	3,426	5,726
Human Population		30,486			30,486			30,486	
Human : Dog Ratio	21.7	10.9	7.2	34.0	10.2	6.0	28.6	8.9	5.3
Haitian Dog Population									
Total Estimated Dogs	483,222	966,099	1,449,321	308,945	1,026,373	1,744,489	367,152	1,179,984	1,972,151

Table 4.3 Comparison of dog population estimation calculation methodology using sight-resight population data. Final estimated dog population does not include 'rapid survey' sites and is not adjusted for urban/rural Haitian populations. The population-adjusted dog population, 1,165,763, is presented in Figure 4.1.

Comparison of Dog Populations Stratified by Urban-Rural Community and Survey Method, Haiti 2014/2015									
	CORRECTED SIGHT-RESIGHT COUNTS				**CORRECTED RAPID COUNTS**				***Total***
	Urban	**Semi**	**Rural**	**SRS Total**	**Urban**	**Semi**	**Rural**	**Rapid Total**	
Number Sites	6	4	2	12	7	2	5	14	***26***
Human Population	21,571	5,603	3,312	30,486	12,636	3,107	12,434	28,177	***58,663***
Human Population Density (People / km2)	1,524	858	594	1,161	1,028	719	806	868	***922***
Community Dogs (N)	1500	160	9	1,669	742	61	179	982	***2,651***
Street Dogs (N)	2,185	624	47	2,856	1,291	238	924	2,453	***5,309***
Dogs Always Confined (N)	449	113	9	571	257	43	173	473	***1,044***
Total Dogs (N)	2,634	737	56	3,427	1,548	281	1,097	2,926	***6,353***
Community Dog H:D	14.4	35.0	368.0	18.3	17.0	50.9	69.5	28.7	22.1
Street Dogs H:D	9.9	9.0	70.5	10.7	9.8	13.1	13.5	11.5	11.0
Confined Dog H:D	48.0	49.6	368.0	53.4	49.2	72.3	71.9	59.6	56.2
TOTAL H:D	8.2	7.6	59.1	8.9	8.2	11.1	11.3	9.6	9.2

Table 4.4 Comparison of dog populations stratified by urban-rural community and survey method.

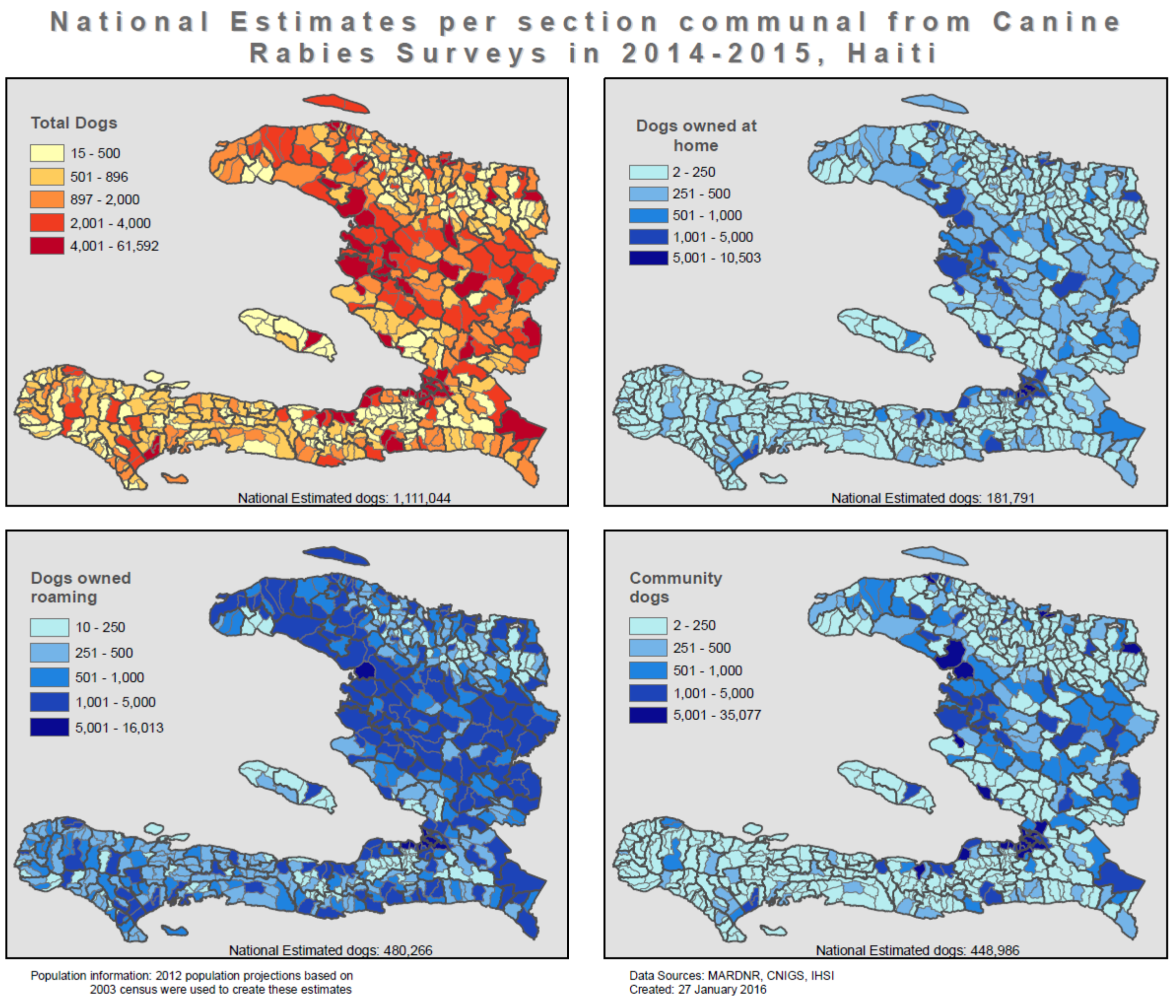

Figure 4.1 Haiti dog population estimates per section communal.

4.3 2016 one-day and two-day comparison results

Without adjusting for dogs whose marks or collars had not been seen or dogs who were ineligible for sighting, the one-day method appears similar to the two-day SRS method when the vaccination campaign was conducted as central or fixed point. It underestimated the two-day method by about 10% (Table 4.5). With a capture, vaccinate, release campaign the one-day method underestimated by about 25%, it overestimated by about 50% in a door-to-door campaign.

After correcting for missed marks by increasing the resights by 9%, CP is still the campaign type for which this method is most similar to the two-day estimate, but it underestimates by about 20%. CVR is underestimated by about 30%, and DD is still overestimated by about 40%. Correcting for sighting ineligibility does not affect CVR estimates because the dogs targeted are all free-roaming, but CP becomes even further under underestimated at about 40% off. DD on the other hand becomes accurate to the two-day method after making both corrections. This pattern goes contrary to the expectation that CVR estimates would be most accurate, due to the vaccinated population and dogs eligible for sighting being the same groups.

Campaign type	Correction	Averaged % Difference	Total % Difference
CP (including CVR-CP)	-	-9%	-13%
	Missed mark correction	-16%	-20%
	Eligibility for sighting correction	-34%	-37%
	Both corrections	-39%	-42%
CVR	-	-23%	-25%
	Missed mark correction	-29%	-31%
	Eligibility for sighting correction	-23%	-25%
	Both corrections	-29%	-31%
DD	-	56%	43%
	Missed mark correction	44%	32%
	Eligibility for sighting correction	12%	3%

	Both corrections	4%	-5%

Table 4.5 Percent differences between the one-day and two-day estimates.

When vaccination coverage is low for central point campaigns, as it was in this instance, the one-day estimate will underestimate compared to the two-day estimate. When vaccination coverage is medium or high, this method is expected to overestimate the population especially in areas with a higher proportion of confined dogs. At 29% confined and a low vaccination coverage, the one-day estimate is expected to be 34% below the two-day estimate, which is close to the percent difference after correcting for dogs ineligible for sighting of about 35% (Figure 4.2).

When the vaccination method is capture-vaccinate-release, the success of the campaign is not a large influence on the accuracy of the one-day estimates. Instead the driving factor is the proportion confined; as this increases the one-day method increasingly underestimates the population size (Figure 4.3). At 29% confined it is predicted that the one-day method underestimates by about 20%, and in this case they underestimated by 25% before the missed mark correction and 30% after.

When the vaccination method is door-to-door, again the success of the campaign is not the biggest influence on the one-day estimate accuracy. Dog confinement plays a larger role; this method increasingly overestimates as the percent confined goes up (Figure 4.4). The predicted estimates for about 29% confined lie between the corrected and uncorrected actual estimates. The one-day method generally overestimates in DD campaigns because there will be a lower proportion of vaccinated and marked dogs among the countable free-roaming population, thereby inflating the population estimate.

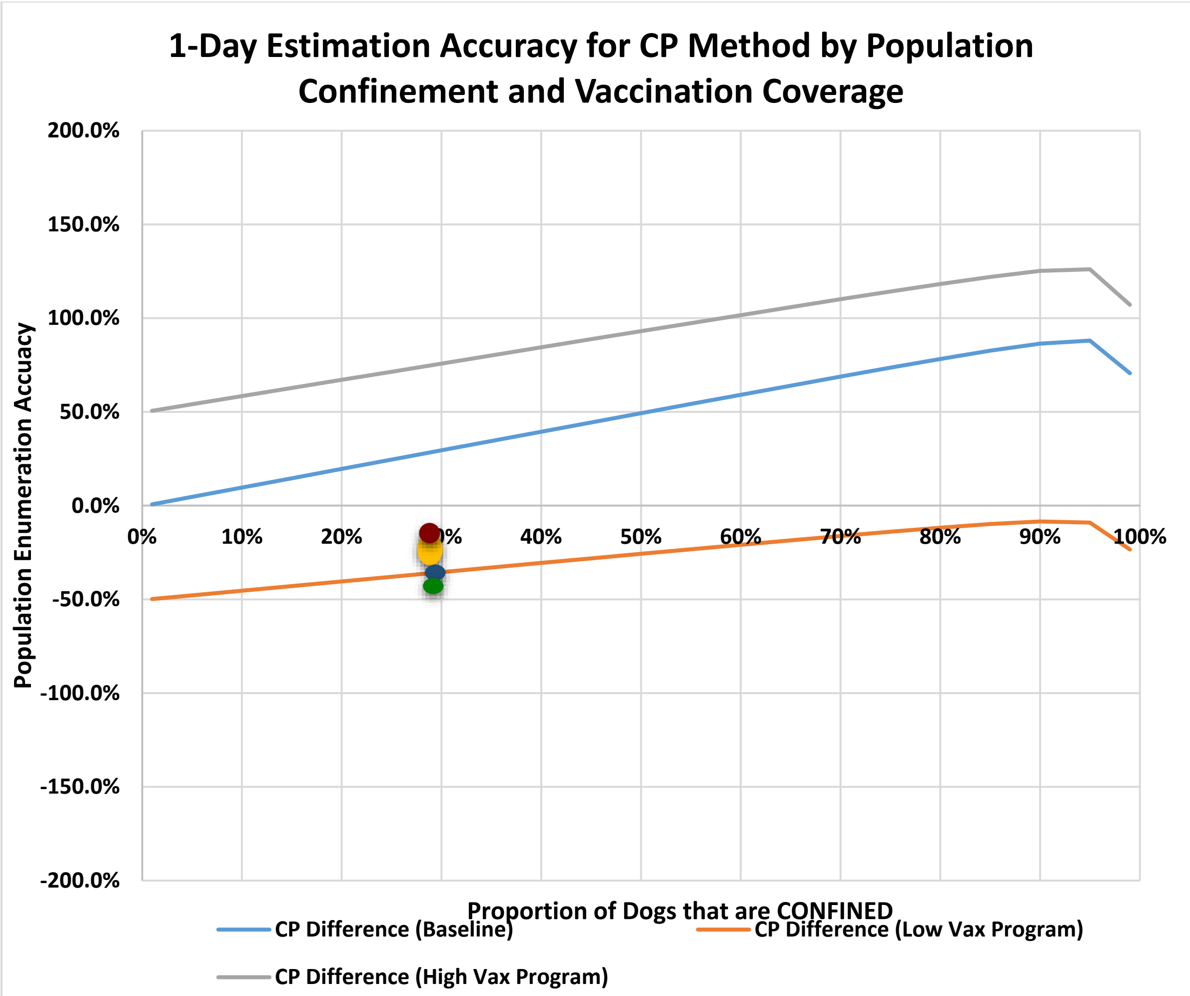

Figure 4.2 One-day estimation accuracy for central point campaigns. The colored dots indicate approximately where the actual one-day estimates fell compared to the two-day estimate when about 29% of the dog population was confined. The red dot is the uncorrected estimate, yellow is missed mark corrected, blue is free-roaming proportion corrected, and green is corrected for both.

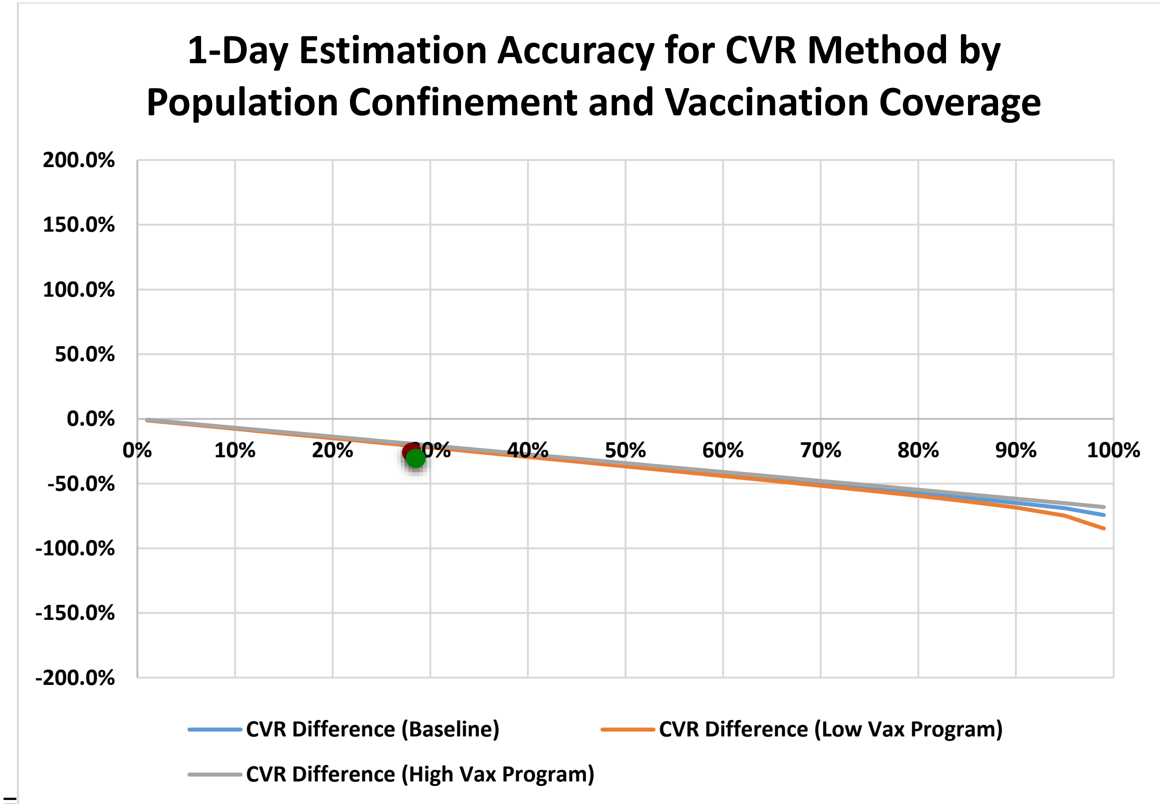

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Figure 4.3 One-day estimation accuracy for capture, vaccinate, release campaigns. The colored dots indicate approximately where the actual one-day estimates fell compared to the two-day estimate when about 29% of the dog population was confined. The red dot is the uncorrected estimate, yellow is missed mark corrected, blue is free-roaming proportion corrected, and green is corrected for both.

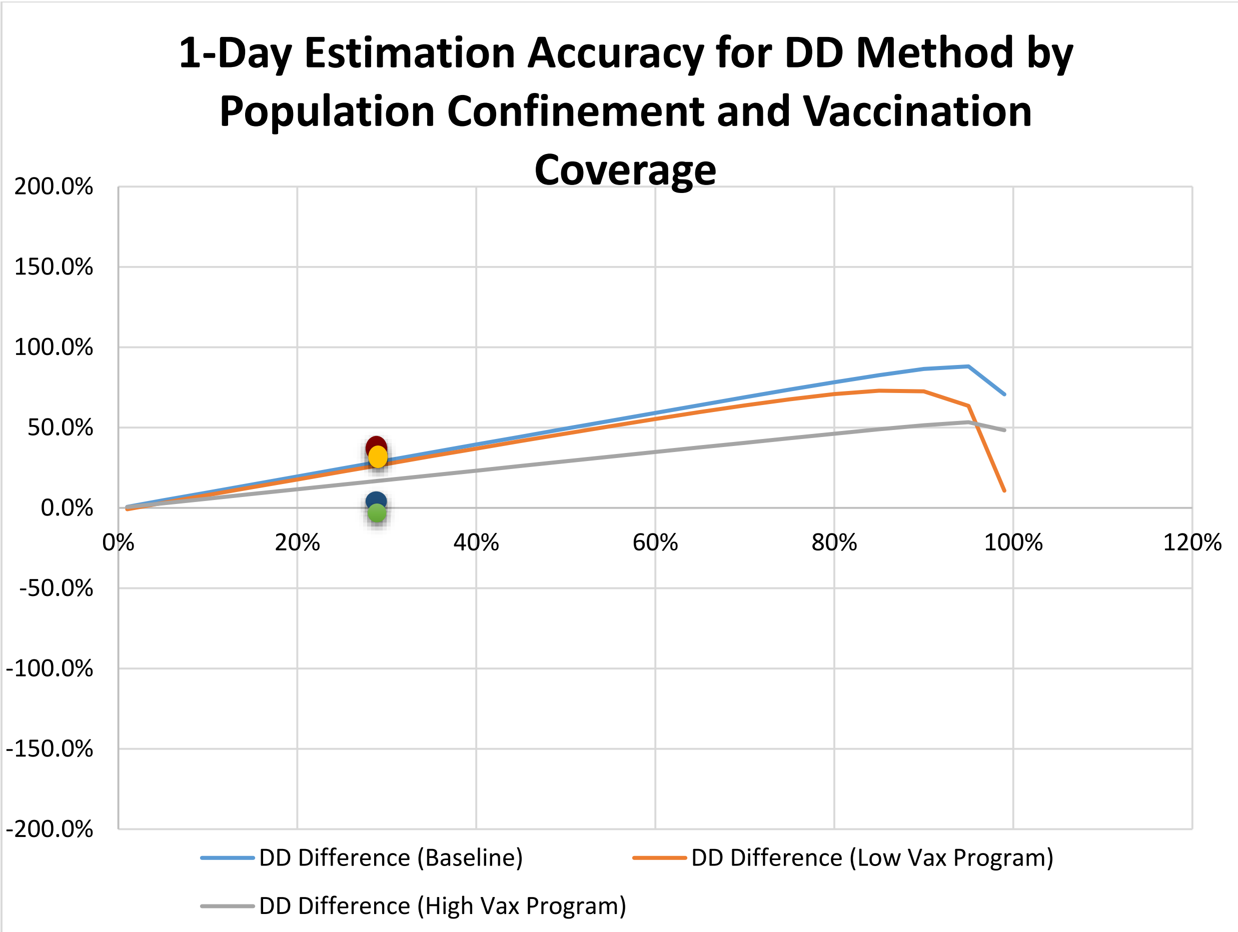

Figure 4.4 One-day estimation accuracy for door-to-door campaigns. The colored dots indicate approximately where the actual one-day estimates fell compared to the two-day estimate when about 29% of the dog population was confined. The red dot is the uncorrected estimate, yellow is missed mark corrected, blue is free-roaming proportion corrected, and green is corrected for both.

4.4 2016 sensitivity analysis results

The two-day SRS method does not require walking as much of the vaccinated area as the one-day method in order to get a tight confidence interval. When coverage is low and the dog population is small, counters should walk about 60% of the area for a two-day study (Figure 4.9). This is still preferable to the same situation in a one-day study, where the entire area could be walked but the confidence interval spans would still be over 200% of the vaccinated dogs, and over 100% even with a larger population (Figure 4.10). When coverage is moderate, walking up to 20% of the area should be sufficient for a two-day study, whereas a one-day study would need to walk 70% to get the same confidence interval spans (Figures 4.7, 4.8). When coverage is high, both one-day and two-day studies can get tight confidence intervals with low proportions walked. Two-day studies require less than 10%, and 20% should be enough for one-day studies (Figures 4.5, 4.6).

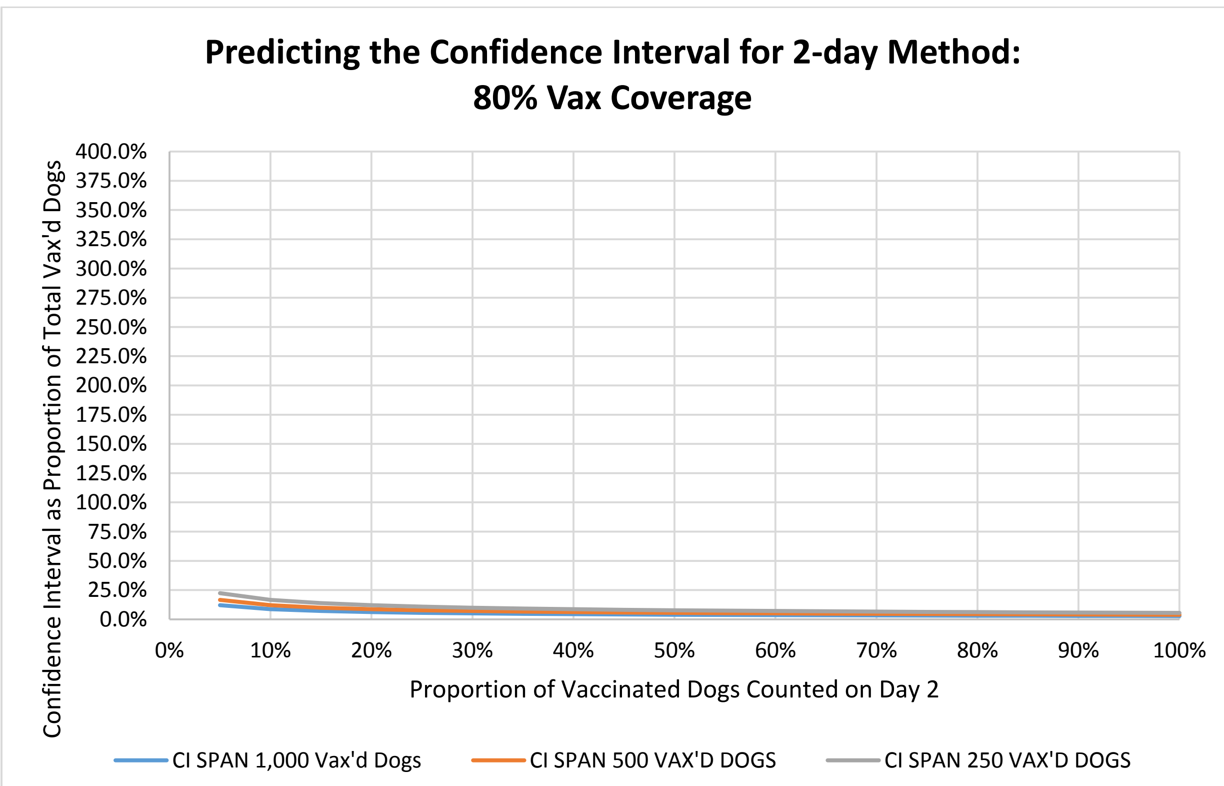

Figure 4.5 High coverage two-day method confidence intervals.

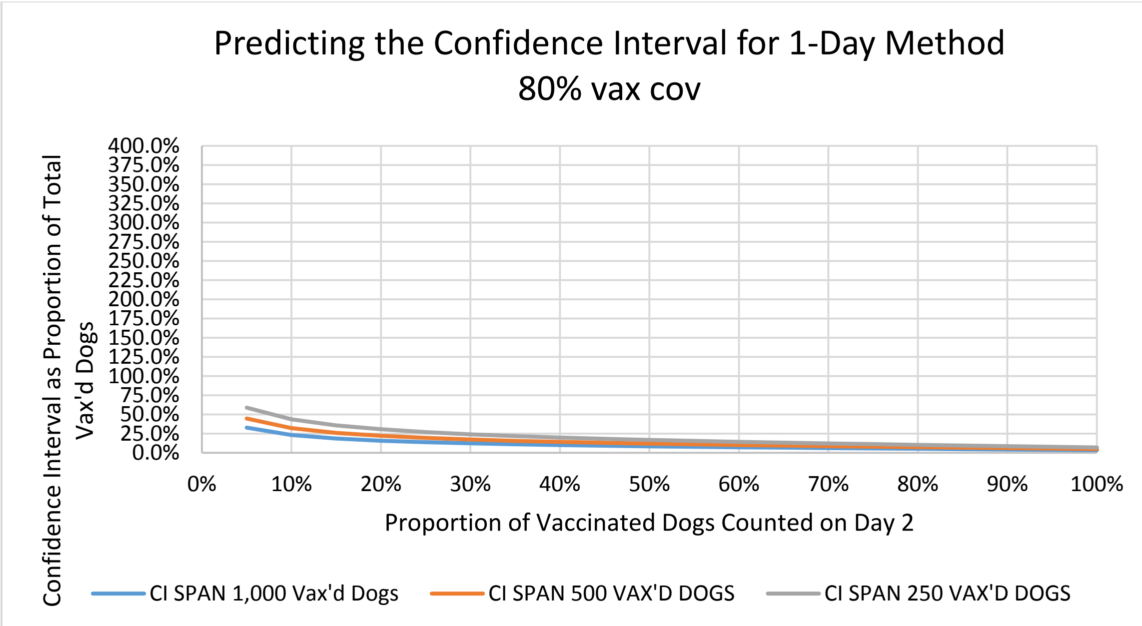

Figure 4.6 High coverage one-day method confidence intervals.

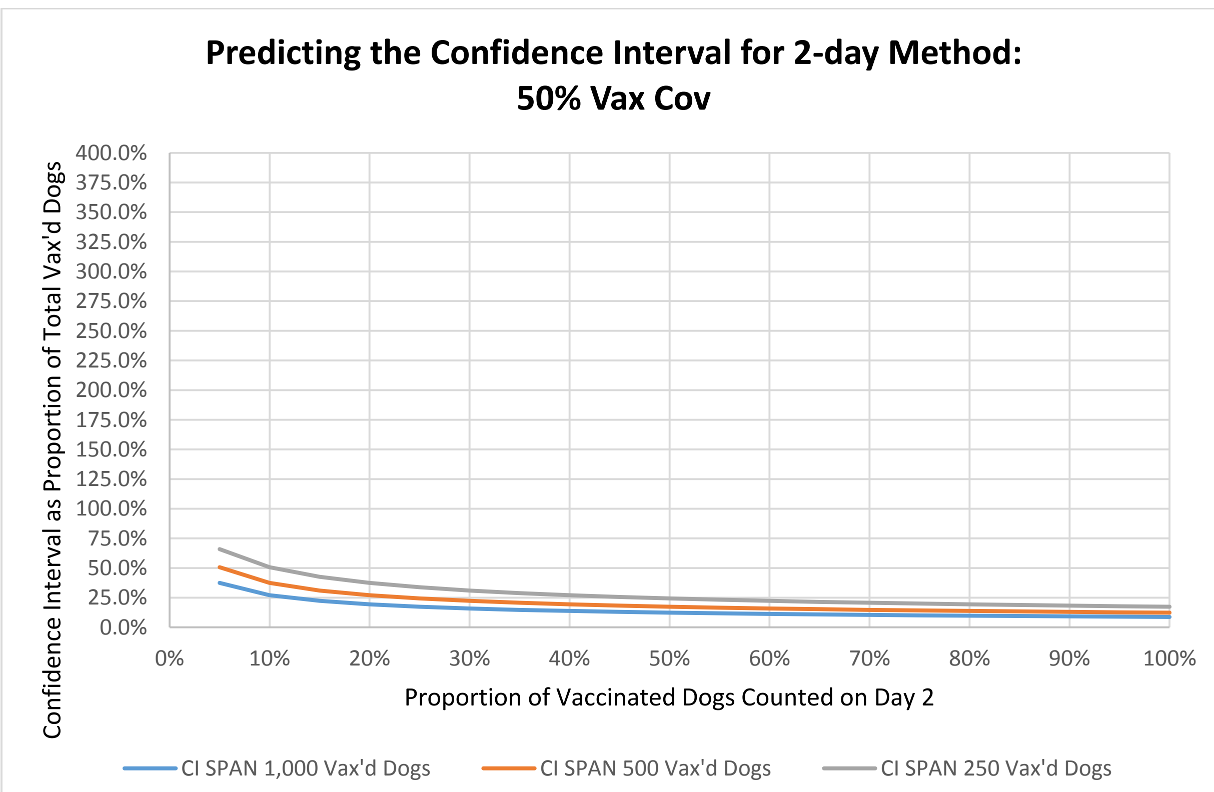

Figure 4.7 Medium coverage two-day method confidence intervals.

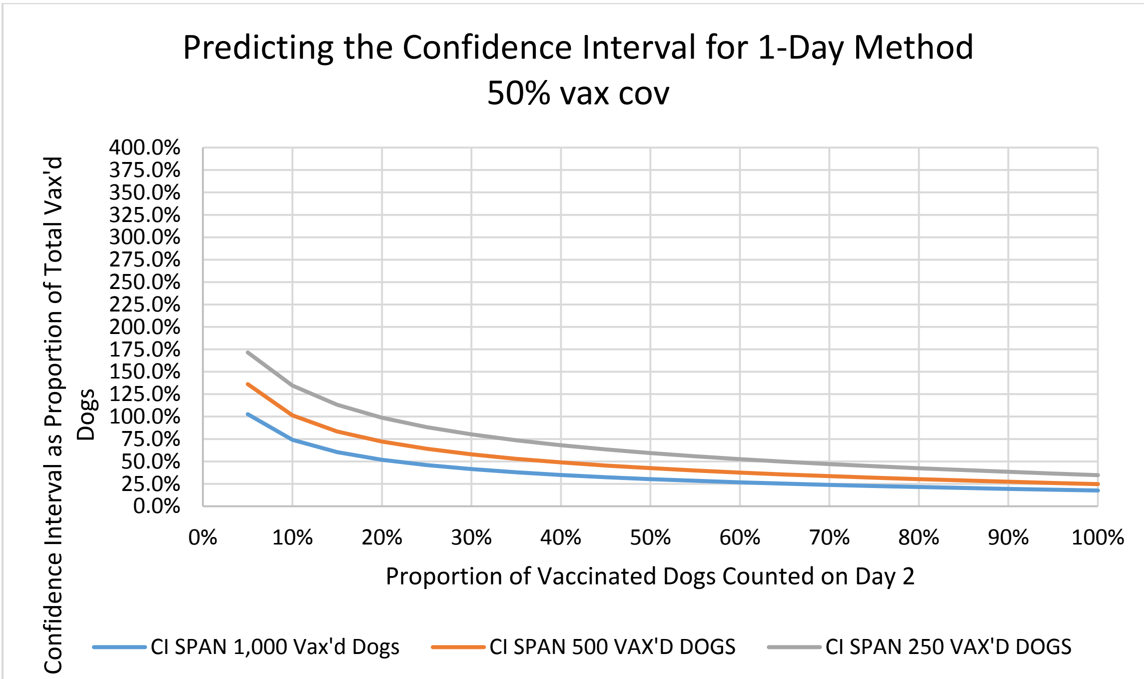

Figure 4.8 Medium coverage one-day method confidence intervals.

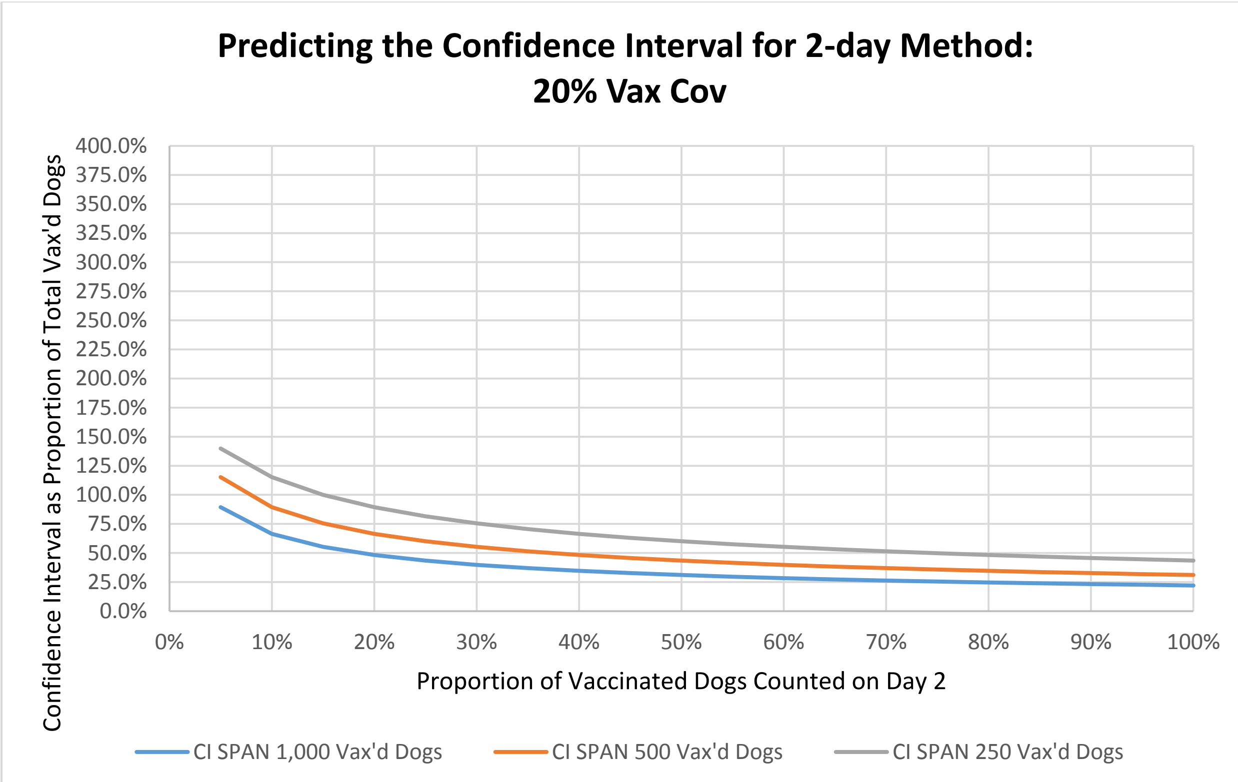

Figure 4.9 Low coverage two-day method confidence intervals.

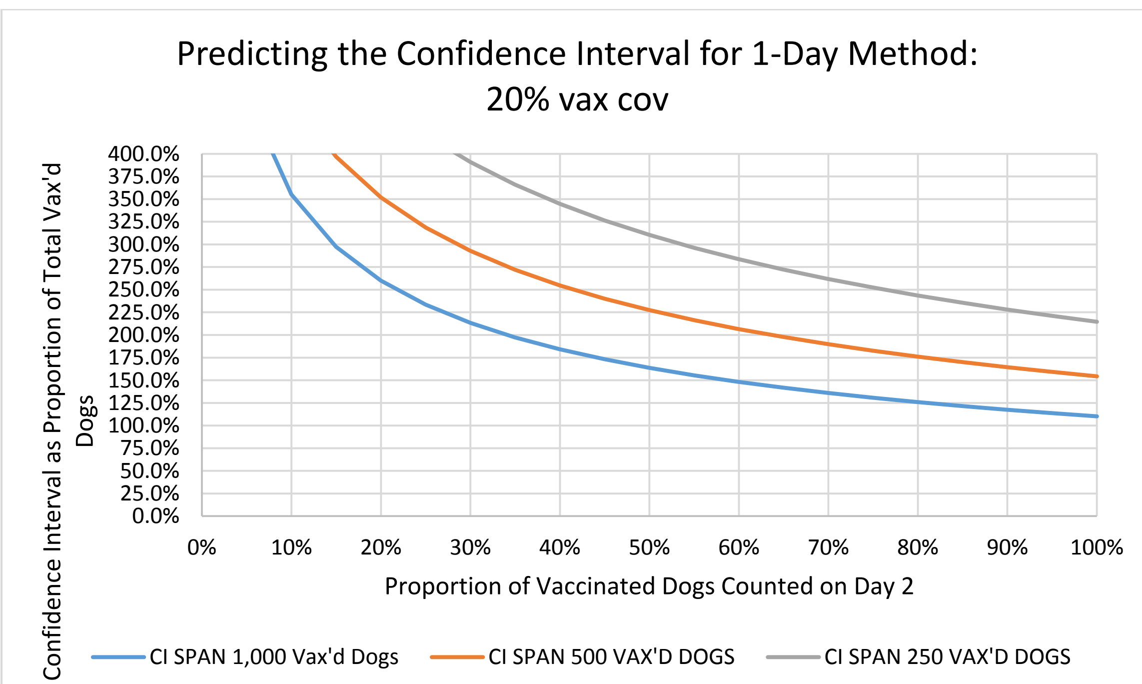

Figure 4.10 Low coverage one-day method confidence intervals.

Discussion and Conclusion

5.1 Discussion of research questions

Through the 2015 KAP survey, sight-resight study, and rapid counts, it was possible to determine Haitian dogs' population structure and confinement proportions. That information could then be used to enhance the local population estimates by compensating for dogs that were ineligible for the SRS study because they do not roam in the community. This boost to the Lincoln-Petersen estimates makes up for the heterogeneity in detection between different types of dogs and provides a higher, more conservative dog population. This is essential for rabies control so that vaccination campaigns do not fail from low vaccine stocks or artificially high coverage appearances. The country-wide estimates increased by about 200,000 dogs after the boost, and more than doubled the original guess by Haiti at how many dogs they had (500,000). With an approximate total of 1.1 million dogs and densities in each section communal, there is hope that the next vaccination campaigns can improve coverage and bring Haiti from a Phase II to a Phase III country in the GDREP (Wallace et al, 2017).

Through the 2016 sight-resight studies it was possible to analyze the data as if the study had been conducted in both two-day and one-day methods. Rabies control organizations have been using the one-day method after door-to-door campaigns despite the fact that it violates several assumptions of the Lincoln-Petersen estimator (Table 2.1). Using the two-day method results as the gold standard, the one-day results without adjustments over- and underestimated depending on the type of vaccination campaign. CP and CVR areas were underestimated and only got further off after corrections, and DD overestimated and became accurate after corrections. Because of data collection issues the DD sites were probably undercounted, so that result is less reliable than those for CP and CVR. Overestimates are expected for DD sites with the one-day method because the dogs visible for counting are mostly different from the dogs vaccinated, leading to a low number of resights and therefore large population estimates. For the same reason overestimates are expected for CP sites when the vaccination campaign has at least moderate success. CVR sites should get the most accurate estimates for free-roaming coverage because the vaccinated and visible populations are the same, but their total dog populations will be underestimated if confined dogs are not accounted for in some way. The percent differences from this study could be applied to one-day estimates to make them accurate to the two-day method, but these results are likely Haiti-specific so other areas should perform their own studies first if they plan to use the one-day method.

Vaccination coverage has a much larger influence on one-day estimates than two-day estimates. Low coverage can lead to inaccurate estimates and uselessly broad confidence intervals, whereas two-day estimates experience those effects to a much lesser degree making them still useful. The proportion of dogs that are confined also affects one-day estimates by decreasing accuracy in most scenarios, while it is simple in the two-day method to add a boost for those confined dogs because of the 2015 KAP survey. The one-day method always requires that data collectors walk until they have seen a larger proportion of dogs than the two-day method requires in order to get a tight enough confidence interval. 20-100% of the area may be necessary depending on how successful the vaccination campaign was for a one-day study, while two-day estimates only need 5-60% of vaccinated dogs counted.

5.2 Limitations and areas for further study

The 2015 study sampled a large number of dogs from different areas and cross-referenced the field observations with household survey results. This robust design allowed for country-wide extrapolation of results, but a weakness is that the human population data used for the human to dog ratios were calculated through an untested method because recent census data were not available. Another potential issue is that for both 2015 and 2016, SRS studies were conducted in the afternoon. A study in Bhutan found that there were 17% more sights in morning counts, so these afternoon counts may underestimate the population (Tenzin et al, 2015).

In the 2016 study, one-day and two-day methods are compared as if the two-day method is accurate, but the true population remains unknown. If many dogs were counted and released into a closed area for these studies then the methods could truly be compared, but unfortunately this is not practical or affordable. The two-day results are also based on seeing only 6% of all the vaccinated dogs, so this is as wide as the confidence intervals get for the two-day method. Point estimates may not be reliable comparisons for the one-day results. Excluding the results from rural areas also limits applicability of these findings, so SRS studies over large and diverse areas would be helpful to compare these methods.

Future research should investigate the feasibility of these two methods as well as comparing accuracy in other settings. Economic assessments could be performed for the required inputs in each method, for example two days of labor for a shorter time versus one day for a longer time. The Lincoln-Petersen estimator used here could also be compared to other methods and programs, such as Bayesian analysis and the CAPTURE program (Gsell et al, 2012).

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Appendix I – English version of 2015 KAP survey

Dog Ownership Characteristics Among Persons Attending a Government Canine Rabies Vaccination Clinic

1. What is your age? ___________

2. What is your gender? _________

3. Where do you live?
    a. Street ________________________________
    b. Commune ____________________________
    c. Department ___________________________

4. How many people live with you, in your household? ________________

5. Are you the primary care taker for your dogs?
    d. Yes
    e. No
    f. Unknown

6. How many dogs are you getting vaccinated today? ________________

7. How many dogs belong to your household? ____________________

8. Of the dogs belonging to your household, how many:
    g. Stay on your property at all times ___________
    h. Roam the street unsupervised sometimes _____________
    i. Roam the street unsupervised at all times _____________

9. What level of care do you provide for your dog(s)? Mark all that apply.
    a. None
    b. Food
    c. Water
    d. Shelter
    e. Veterinary Care
    f. Other: (free response)
    g. Declined to answer

10. If any of your dog(s) have **never** been vaccinated for rabies, what is the reason?
    a. Dog is too young (number _______)
    b. No money to buy vaccine (number _______)
    c. No vaccine available from veterinarians (number _______)
    d. No vaccine available from government (number _______)

e. No need to vaccinate (number _______)
f. Other (free response): (number _______)
g. Declined to answer

11. For any dogs that died **in the past year**, what was the cause of death? **Indicate frequency of each.**
    a. Hit by Car ____________
    b. Poisoned __________
    c. Disease/illness ____________
    d. Other: free response ________
    e. I don't know ________
    f. Declined to answer

12. **In the past year**, have you ever owned a dog that **died** after displaying **at least two** of the following symptoms? **If yes, how many?**
    Hypersalivation, Aggressiveness, Biting people or animals, Difficulty walking, Change in the dog's voice
    a. Yes, **number** __________
    b. No
    c. I don't know

13. Do you provide care for any dogs that you do **NOT** own? Mark all that apply.
    a. None
    b. Food
    c. Water
    d. Shelter
    e. Veterinary Care
    f. Other: (free response)
    g. Declined to answer

14. **In the past year**, have you or anyone in your household been bitten by a dog? Mark all that apply.
    a. No
    b. Yes, me
    c. Yes, an adult family member (indicate number if more than one) __________
    d. Yes, my child (indicate number if more than one) __________
    e. Declined to answer

15. Do you know anyone who has **ever** died from a disease caused by the bite of a dog?
    a. No

b. Yes: Gender: _____ Age: ___________ Year of Death: ___________
c. Yes: Gender: _____ Age: ___________ Year of Death: ___________
d. Yes: Gender: _____ Age: ___________ Year of Death: ___________
e. Yes: Gender: _____ Age: ___________ Year of Death: ___________
f. Yes: Gender: _____ Age: ___________ Year of Death: ___________

16. Do you know anyone who has **ever** died from a disease called 'rabies'?
    a. No
    b. Yes: Gender: _____ Age: ___________ Year of Death: ___________
    c. Yes: Gender: _____ Age: ___________ Year of Death: ___________
    d. Yes: Gender: _____ Age: ___________ Year of Death: ___________
    e. Yes: Gender: _____ Age: ___________ Year of Death: ___________
    f. Yes: Gender: _____ Age: ___________ Year of Death: ___________