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Rabies in Virginia, 1989-2003: With particular attention to animals, geographic distribution, and virus variant

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Virginia Commonwealth University

Rabies in Virginia, 1989-2003:
With particular attention to animals, geographic distribution, and virus variant

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PMCH 691 – MPH Research Project

Virginia Commonwealth University
Medical College of Virginia Campus
School of Medicine

Department of Preventive Medicine and Community Health

Master of Public Health Program

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07/2004

Submission Statement
for the MPH Research Project

This MPH Research Project report is submitted in partial fulfillment of the requirements for a Master of Public Health degree from Virginia Commonwealth University's School of Medicine. I agree that this research project report be made available for circulation in accordance with the program's policies and regulations pertaining to documents of this type. I also understand that I must receive approval from my Faculty Advisor in order to copy from or publish this document, or submit to a funding agency. I understand that any copying from or publication of this document for potential financial gain is not allowed unless permission is granted by my Faculty Advisor or (in the absence of my Faculty Advisor) the Director of the MPH Program.

____

Student Signature – William A. Holzgrefe

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Date – 8/2/2004

Project Agreement Form
for the MPH Research Project

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Number of semester hours (3-6): 3 Semester: 2 Year: 2004

Please complete the following outline. **Do not exceed 2 pages (A-H).**

A. PROJECT TITLE:
Rabies in Virginia, 1989-2003: With particular attention to animals, geographic distribution, and virus variant.

B. PURPOSE (state hypothesis/research question):
To describe the progress of the raccoon rabies epizootic in Virginia during the period 1989-2003.

C. SPECIFIC OBJECTIVES (list major aims of the study):
The period under study has not been extensively described in the literature. This study will undertake to determine what the status of the previously documented epizootic of rabies is at present, and what the available data will permit insofar as an estimation of the impact of the disease on wild animals, domesticated animals, and humans. The study will also attempt to document the geographic distribution of animal cases of the disease, and to determine whether the raccoon-associated strain of the disease has penetrated the entirety of the Commonwealth. Additional aims are to examine which animals or animal species pose the greatest risk to human populations, and to consider whether this has changed over time.

D. DESCRIPTION OF METHODS

D.1. Identify source(s) of data (eg, existing data set, data collection plans, etc): The data sets that are being proposed for use already exist; the animal data is held by the Virginia Department of Health (use would be subject to their permission/provision of the data and removal of potential identifiers) and by the Virginia Division of Consolidated Laboratory Services. Human data (population by ZIP code or county) is available from the U.S. Census Bureau. Population data for domestic livestock are available from the U.S. Department of Agriculture.

D.2. State the type of study design (eg, cross-sectional, cohort, case-control, intervention, etc): The study would be a descriptive correlational study, and will probably contain a significant GIS content.

D.3. Describe the study population and sample size: The study population will consist of wild and domestic animals submitted (typically postmortem) for testing for rabies, on which testing was performed and valid results obtained. The human population of Virginia will be used for a population density-based comparison. For example, the animal population saw 542 reported, laboratory confirmed cases in 2003 *(total submissions not available). Due to the low numbers, several years of reporting data will probably have to be used, with the measures extending as far back as the data will permit, which is known to be to 2000 in the case of viral typing data, and earlier (1989) for general testing results (also needed to establish trends).*

D.4. List variables to be included (If a qualitative study, describe types of information to be collected): Animals submitted for testing (limited to those most associated with human exposure, e.g. dogs and cats, as well as those described in the literature as reservoirs of the disease, e.g. raccoons and skunks), viral serotype (i.e., bat-associated rabies strain, raccoon rabies, etc.), known or suspected exposure of positive animals to humans and domestic animals (depending on availability of unlinked data), location of animal by county, as ZIP code information is unavailable, month of collection, human population by county, other variables to be opportunistically determined.

D.5. Describe methods to be used for data analysis (If a qualitative study, describe general approach to compiling the information collected): The descriptive component will be comprised of listing and examining summary data for submissions and positives during the period under study. Analysis will be simplistic, using rates of positivity in submitted animals and for whole populations where possible (i.e. in livestock), visual tests for trends, and chi square tests for significant differences between selected criteria. The GIS program-derived maps used will focus on distribution of cases, both alone and in the context of populations (human and livestock), and will undertake to graphically demonstrate the progress of the disease spread during the study period.

E. ANTICIPATED RESULTS:

It is expected that the geographic distribution of viral types will have shifted over time, with the possible exception of bat-associated rabies; whether this is significant will need to be determined. Additionally, it is expected that there will be a positive correlation between the detection of rabid wild animals and the density of the human population. Different classes of animals, particularly domestic livestock, are expected to be more frequently rabid in areas of low population density.

F. SIGNIFICANCE OF PROJECT TO PUBLIC HEALTH:

A preliminary survey of the literature indicates that there has not been a study of this type undertaken in Virginia, or in the US (or, if it has, it has not reached the public domain – there are informal reports of a potentially similar study from Massachusetts being in preparation). The results could be useful for purposes of resource allocation and program development and assessment on the part of the public health establishment. It can also be useful at the level of the general public to raise awareness in (geographic and possibly other types of) populations that are at elevated risk from rabies, and enhance actions (e.g. pet and livestock vaccination) at that level.

G. IRB Status:

1) Do you plan to collect data through direct intervention or interaction with human subjects? ___yes _X_no

2) Will you have access to any existing identifiable private information? ___yes _X_no

If you answered "no" to both of the questions above, IRB review is not required.
If you answered "yes" to either one of these questions, your proposed study must be reviewed by the VCU Institutional Review Board (IRB). Please contact Dr. Turf or Dr. Buzzard for assistance with this procedure.

Please indicate your IRB status:
___ to be submitted (targeted date___________)
___ submitted (date of submission _____________; VCU IRB # ________)
___ IRB exempt review approved (date____________)
___ IRB expedited review approved (date____________)
_X_ IRB approval not required

H. PROPOSED SCHEDULE: Start Date: 5/17/2004 End Date: 6/30/2004

I. INDICATE WHICH OF THE FOLLOWING AREAS OF PUBLIC HEALTH KNOWLEDGE WILL BE DEMONSTRATED:

1. Biostatistics – collection, storage, retrieval, analysis and interpretation of health data; design and analysis of health-related surveys and experiments; and concepts and practice of statistical data analysis. X yes ___no (if yes, briefly describe): The project will require the analysis of a potentially large data set, using several different variables. Statistical analysis software usage will be necessary.

2. Epidemiology – distributions and determinants of disease, disabilities and death in human populations; the characteristics and dynamics of human populations; and the natural history of disease and the biologic basis of health. _X_yes ___no (if yes, briefly describe): The disease being studied (rabies) is a zoonotic disease impacting humans, and if not promptly treated, is invariably fatal. While rabies deaths are uncommon in the US, Virginia has had two deaths from the disease in the past decade. This study will examine the distribution of the disease in the animal population relative to the human population at risk.

3. Environmental Health Sciences – environmental factors including biological, physical and chemical factors which affect the health of a community. X yes ___no (if yes, briefly describe): Rabies is usually classed as an environmental health issue.

4. Health Services Administration – planning, organization, administration, management, evaluation and policy analysis of health programs. ___yes _X_no (if yes, briefly describe):

5. Social/Behavioral Sciences – concepts and methods of social and behavioral sciences relevant to the identification and the solution of public health problems. ___yes _X_no (if yes, briefly describe):

Preceptor: Name: C. M. G. Buttery Title: Professor

Address: [redacted]

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Field of expertise: Public Health, Geographic Information Systems

Faculty Advisor: Name: Paul E. Mazmanian

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SIGNATURES:

Student: ____________________ Date: __________

Preceptor: ____Date:______________

Faculty Advisor: ____Date:______________

MPH Program Director: ______________________________Date:____________________

MPH Program Coordinator: __________________________________Date:______________

MPH Research Project Approval Form

Rabies in Virginia, 1989-2003:
With particular attention to animals, geographic distribution, and virus variant

Submitted to the Graduate Faculty of the
Department of Preventive Medicine and Community Health
Virginia Commonwealth University

In partial fulfillment of the requirements for the degree of
Master of Public Health

Comments:

Approval signatures:

____
MPH Student – William A. Holzgrefe

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MPH Research Project Faculty Advisor – Paul E. Mazmanian

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MPH Program Director – I. Marilyn Buzzard

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MPH Program Coordinator – Karen P. Bryant

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ACKNOWLEDGEMENTS

This work would not have been possible without the assistance, guidance, aid and direction provided by many people. These include my preceptor, Dr. C. M. G. Buttery, whose general comments helped to give the project form and whose GIS software made a substantial portion of the project possible; my advisor, Dr. Paul Mazmanian, who was supportive when support was needed; Mrs. Lisa Anderson, without whom I would have been utterly lost in the wilderness of statistical analysis; Dr. Elizabeth Turf, who guided from near and far; Dr. Suzanne Jenkins, whose comments and help got the project off the ground; Ms. Jessie Hamlin, who (in conjunction with Dr. Jenkins) provided the primary data set used and answered my questions about it; and Sylvia Whaley and Donna Hawkins, who know more than I probably ever will about rabies in Virginia, and were kind enough to teach me a little about it when I was a very junior colleague of theirs. Gratitude must also be expressed for the faculty and especially the staff of the department of Preventive Medicine, for helping me to know where the path was, even if I wasn't always on it.

ABSTRACT

Objectives: The description of the raccoon rabies epizootic in Virginia over fifteen years (1989-2003).
Methods: Using simple statistical methods and a geographic information system (GIS)-based approach, and fifteen years worth of animal surveillance data, the progress of this epizootic has been charted in terms of the geographic spread of the disease, the major animal species affected by the disease and its spread, and the exposure and risk to humans and livestock animals presented by the expansion of the geographic range.
Results: The resulting descriptive study illustrates the eastward expansion of the epizootic, the mushrooming of the disease in the northern region of the state, and the rates of rabid animal submissions for every health district and selected important animal species. Human exposures to rabid animals are mapped and compared to human population densities. Strong seasonal trends in human and livestock exposures to rabid animals are illustrated, with animal exposures predominating in the spring and autumn, while human exposures peak in the summer; also shown is the possible emergence of new strains of rabies virus and the possible extinction of the previously dominant strain.
Conclusions: Some potentially positive developments have been found, such as substantially increasing levels of bat submissions across time, which may signify greater public awareness of the disease. Serious deficiencies in the monitoring system are discussed, centering on the accuracy and comparability of the data collected, and suggestions for improvement are offered. While several potentially interesting new areas of study are put forward, the standard approach to rabies control (pet vaccination and control, education of at-risk populations, orally vaccinating wild animals) is not found to be in need of significant modification, aside from the specifics of the approach being tailored to better meet local conditions.

INTRODUCTION

There are few diseases with histories as long, as wide-ranging, and as fundamentally horrifying as rabies. As recent events have demonstrated

[1,2], rabies is not merely a disease of the past or of the third world, remaining a current problem in the United States with conservative costs in the range of hundreds of millions of dollars annually[3]. With the trend of human populations towards greater land use and higher population densities, the risks to humans and to livestock and companion animals from rabies is almost assured to increase. Because of this danger, it is necessary to undertake examinations of how and why rabies spreads, and in particular what sorts of animal populations are involved, and how and what sorts of relationships they have with their surrounding environment, including human and domestic animal populations. As will be reviewed, studies of this nature have already been conducted, and continue to be conducted; the situation relevant to this undertaking is not a static one, and so the knowledge in the field needs to be advanced as much as possible to aid in the response to the disease.

The disease of rabies has been known to human populations for millennia, taking its name from either Sanskrit or Latin[4], and being known to the Babylonians of 4,000 years ago[4] and the ancient Greeks[5]. While the history of the disease is better documented in Europe, with the form most often affecting humans coming from canines (dogs and wolves)[5], it cannot be assumed that the New World was entirely free of the disease, there being anecdotal accounts of similar conditions amongst natives in the Pacific Northwest and records of vampire bats being associated with illness[3]. In any event, rabies of the terrestrial form was definitely present in British-colonized North America, almost certainly as a result of the importation of dogs and red foxes for sport purposes[3].

Any mammal can, theoretically, become infected with the rabies virus[6], though the number of species that are significant in terms of acting as reservoirs and as sources of infection for humans and domestic animals is limited. In North America, the principal species are mainly foxes, skunks, and raccoons, as well as bats, which follow different patterns of exposure and infection from those of terrestrial mammals[3, 4]. Other mammals, including dogs, cats, horses and cows can act as hosts[3,4,7], though these are typically incidental and often dead-end contacts. Bats differ from terrestrial rabies carriers in the patterns associated with their detection and the infrequency with which bat-associated rabies strains are detected in non-bat species[3,8,9]; as such, bat rabies is not a threat to animal populations, but does present a substantial exposure risk to humans in North America[3]. Recognizing the difference between the different viral variants plays a role in mapping the epidemiology and epizootiology of the disease.

Rabies the virus is an enveloped RNA virus of the family Rhabdoviridae and genus *Lyssavirus*, and possesses the now-classical bullet shape[4,6,10]. It is introduced typically by means of a bite, with other methods (such as aerosol or corneal transplant) being very rare[4,6,10]; the nature of the virus is to move itself along peripheral nerves to the central nervous system, and also to the salivary glands[4,6,10]. In the CNS it causes severe damage without directly causing cell death[10], a somewhat surprising find. Most importantly, it is uniformly fatal if interventions are not made, and the disease progresses to the symptomatic stage[3,4,6,10]. While there have been some survivors of symptomatic rabies, these patients all received either pre- or post-exposure prophylaxis[4,10], and at least half (total n=6) suffered permanent, severe neurological sequelae[10]. Clearly, rabies is not a minor or inconsequential disease. Fortunately, preventative measures have been available for humans since the 1880s[4,5,10], and attention has been paid to domestic animals in the United States since the 1920s[3], greatly reducing the occurrence of rabies in non-wildlife animals. Vaccines are also available for animals, though the effectiveness can vary for unknown reasons[11].

Testing for rabies typically involves one or more of several different methods. Some, such as examining for Negri bodies or inoculating mice, have long histories but are considered outmoded and seldom used today[5,12,13]; the current gold standard in testing is the use of direct immunoflourescent antibody (DFA or IFA) testing[8,9,12,13,14,15], though molecular biology-based techniques are becoming more common[16]. The standard procedure in Virginia is for the head of a suspected animal, or occasionally the whole carcass (in the case of bats, normally the whole carcass), to be submitted for IFA testing, followed, in the event of a positive result, by monoclonal antibody (mAb) testing[17]. Monoclonal antibody testing was developed in order to examine the link between different virus strains and host organisms (e.g. between the variant associated with raccoons and animals infected with that variant)[8,9], and is also useful for determining a geographic range of the virus[13]. The method is not perfect, however, and some variants of the virus that are different may appear to be the same when studied with mAbs[16], though it is widely accepted as being suitable for surveillance and investigative work.

As has been noted[3], the primary wild reservoir of rabies infection in the United States is the raccoon (*Procyon lotor*). This is a recent change, the shift from rabies being most often found in skunks to most often found in raccoons having started in the early

1980s and reaching fruition in 1989[3,12]. The reason for this is the well-documented introduction of raccoon rabies into the West Virginia-Virginia border region in 1977, whereupon the disease spread to eventually encompass areas from North Carolina to New England, and some parts of Canada, by the turn of the last century[3,13,15,18,19,20].

Rabies has been an issue in Virginia, to varying degrees, for decades[5,21]. Before the advent of the raccoon epizootic, most laboratory detected cases of rabies in the state were in foxes (gray and red)[21]. The study by Carey, Giles, and McLean[21] appears to be the first study combining both past rabies activity and a prediction of how a new epizootic would progress in the state. While they did base the model on an epidemic begun the in mountains, the model did not predict with complete accuracy the course taken by the raccoon epizootic, indicating instead a relatively contained spread along the valleys of the mountains leaving the piedmont and tidewater regions virtually unscathed. Of course, this model expected previous experience to hold, not accounting for the importation of a new strain with different characteristics, and as such it is still a remarkable piece of modeling.

The earliest full-scale descriptive study of the raccoon rabies epizootic was that of Jenkins and Winkler[15], which covered not only Virginia but also West Virginia, Maryland, and Pennsylvania. It is a very thorough study of the early years of the epizootic, and its usefulness is only somewhat diminished by its age and the limits of technical sophistication. The study by Smith et al.[13] on the antigenic properties of the raccoon epizootic dovetails with the study by Jenkins and Winkler, demonstrating with a high level of certainty that the epizootic was not a locally originating, *de novo* phenomenon, but one directly linked to the ongoing raccoon epizootic in the farther southeastern U.S.

On the local level, the study by Hubbard[15] provides a look at the early stages of the epizootic from the point of view of those most closely involved in the recognition and response to the emerging situation. While it has been superseded by the larger scale studies done subsequently, it is still a useful record of early response that is probably typical of the better-prepared health departments (and the "skunky odor" mentioned therein is still associated with rabid raccoons[22]). Later studies, such as those of Jenkins, Perry, and Winkler[23], Torrence, Jenkins, and Glickman[18], and Jones et al.[24] cover broader areas, conceptually and geographically. The work of Jenkins, Perry, and Winkler[23] covers raccoon rabies as a whole, using the epizootic in the mid-Atlantic region as its central case study. Given its unavoidable technical limitations (e.g. the impossibility of trapping and testing every raccoon in the study area), it is a thorough and useful study of how rabies tends to spread in the population, and what the condition of rabies was in the late 1980s, in a geographic, environmental, ecological and epizootiological sense.

Taking a narrower approach, Torrence, Jenkins, and Glickman[18] examine raccoon rabies in Virginia only, with the resulting work being not unreasonably described as the definitive study of rabies in Virginia over the defined period (1984-89). This does, however, illustrate a deficiency in the literature, namely the lack of studies focusing on Virginia in the past fifteen years. As the front wave of the epizootic has moved, so has the focus[20,25,26], with Virginia seemingly an afterthought. All study has not ceased, however, as demonstrated by the paper of Jones et al.[24]. This work focuses instead on factors that play a role in the spread and maintenance of rabies in Virginia (as well as Maryland and Pennsylvania), particularly human populations and the local environment.

The focus on associated features, rather than on primarily (or exclusively) the virus and its principal host(s), and on mathematical modeling, are characteristic of rabies research over the last decade, and even before. Examples of this include Carey, Giles, and McLean[21], Källén, Arcuri, and Murray[27], Murray, Stanley, and Brown[28], Smith and Wilkinson[29], Curtis[30], Anthony et al.[31], and Lucey et al.[26]. Perhaps the most limiting aspect of these is that several (Källén et al., Murray et al., Smith and Wilkinson) are focused on rabies in foxes in Great Britain and Europe, making them examples of technique rather than instructive references for a raccoon epizootic. Of the remainder, Curtis focuses on the technical aspects of using geographic information systems (GIS), though he does offer the interesting observation that the number of samples submitted was negatively correlated with distance from the testing facility[30], a possible relationship to keep in mind when evaluating the representativeness of data. Anthony et al. on the other hand look at measures of raccoon population in an urban context; their conclusion is that submissions are reflective of the true raccoon population[31]. Whether this is the case outside of urban areas is unknown, and may indeed be unknowable barring the introduction of a means to conduct a wildlife census for a realistic investment of resources financial and otherwise.

The paper of Lucey et al.[26] is rather interesting in that it maps the introduction and dissemination of raccoon rabies over a defined territory, and uses this information to assess the impact of natural barriers on the flow of the disease. Ideally, this sort of analysis should be possible with any epizootic disease, but the realities of surveillance make that nearly impossible. As such, this is still an example of the form GIS-enhanced surveillance of zoonotic diseases could take in the future.

Given the state of the literature described above, it therefore follows that there is a need for a comprehensive evaluation of the state of rabies in the Commonwealth. The present study will undertake to describe and illustrate the progress of the rabies epizootic over the period 1989-2003, with attention to several issues, related to varying degrees. One is whether the relationship between cases of rabies and the human population follows that described by previous research, namely, a pattern of more cases in suburbs, with fewer in highly urbanized and very rural regions. Another is whether, given the limitations of the available data sets, it is possible to determine the spread of the raccoon variant of the virus in Virginia versus the previously established skunk variant. Has the introduction changed, or (given the limitations of the available data) appear to have changed, the distribution of host species, and if it has, has it impacted the human population, either through livestock or companion animal exposure, or directly? At the most basic level, has the epizootic changed since the late 1980s? Answering these questions, or determining what is needed in order to answer them, would assist in evaluating the success of the state's rabies monitoring and control programs, and aid in formulating improvements in the response to this epizootic.

OBJECTIVES

The period under study (1989-2003) has not been previously described in detail in the relevant literature. In addressing this gap, this study undertakes to provide as comprehensive a descriptive study as is feasible with the available resources, and based primarily on surveillance records. Several questions are also expected to be answered. These questions are related to what extent it is possible to infer (the data not being suitable for a formal risk assessment) the level of risk assumed by humans and livestock animals as a result of the epizootic of raccoon rabies in Virginia, and what if any factors identifiable from the available data influence this informal estimation of risk. To the extent possible, use will be made of geographic information systems to illustrate possible relationships spatially and, where applicable, temporally. Particular attention will be paid to examining whether there has been a change in the range of host species (sometimes referred to as “spillover”).

METHODS

The data sets used in this study were as follows. Submission form information on each animal submitted for rabies testing from 1989 to 2003 was entered into a database maintained by the Virginia Department of Health, Office of Epidemiology's Division of Zoonotic and Environmental Epidemiology, which was subsequently provided in spreadsheet (Microsoft Excel, Microsoft Corp.) format. Data on monoclonal antibody testing results was recorded and maintained by the Virginia Department of General Services, Division of Consolidated Laboratory Services' Immunology and Virology Group, also in Excel format. Human population data for each county and city in Virginia for 1990 and 2000 was obtained from the U.S. Census Bureau[1], and information on the livestock population of the state at the county level for 1987, 1992, 1997, and 2002 were obtained from the U.S. Department of Agriculture, National Agricultural Statistics Service[2]. The rabies submissions used two forms, one of greater length that asked questions regarding the habitat the animal was found in (e.g. commercial, agricultural, etc.), when it was found, and what suspicious signs the animal had (e.g. aggressive, wobbly, etc.). The shorter form omits these fields and was introduced after 1997. Both record the animal type, the county where it was found, date, whether humans or other animals were exposed, and other categories. The outcome of the IFA test[8,9,12-15] is also recorded (fields for alternative diagnostic procedure outcomes are included but omitted from this analysis); results reported as nonspecific, unsatisfactory, or otherwise uncertain were counted as submissions and otherwise excluded from the analysis. The records of

[1] 1990 - Copied from html into Excel format. 2000 – Downloaded in comma separated value format and converted to Excel.

[2] 1997, 2002 – Downloaded in comma separated value format and converted to Excel. 1987, 1992 – Copied from html into Excel format.

monoclonal antibody testing note the species of animal tested, location the animal was submitted from, and the type and subtype (where applicable) of the virus type found. Matching the mAb result to the VDH submission record is imprecise due to the nonstandardized nature of the recorded sample numbers; however, this is not a major barrier to analysis. The human and animal census data both have documented deficiencies[32,33], of the two the limitations of the animal census are more pronounced. The animal census is limited in two major respects, one being that the chances of missing small farming operations combined with nonresponders could mean there is a substantial undercount rate (in 2002, the nonresponse level was 12%[33]); the other is that data is frequently withheld in accordance with federal privacy laws (where reporting how many livestock are in a locality might enable the deduction of an individual's holdings). Given these two issues, the census is still the only and best way of establishing a base population for livestock animals. No data is available for companion animal populations.

The two statistical computer programs used were Excel and SPSS (versions 11 and 12, SPSS Inc.). Summary statistics including some rates were compiled in SPSS using the CROSSTAB functionality. These were compiled by species tested, submitting locality, test outcome, and year. Examination of several variables (e.g. human exposure) prompted the use of combined annual data sets, i.e., where there were too few occurrences during one year, several years were combined to look for trends. These included calculations of rates using SPSS and Excel. Seasonal variations were graphed in Excel, with output from the SPSS CROSSTAB function providing the numbers used. Mapmaking was done using AtlasGIS (v3.2, ESRI Inc.), with a boundary file of Virginia designating all counties and the major cities (several smaller cities are omitted from the program, for example Danville and Williamsburg; these minor cities and towns report few or no cases of rabies over the study period, so that their omission does not have an appreciable impact on the plotting of cases). Files created in the standard Excel format were converted to Dbase IV format for mapping purposes. Ranges of numbers, here representing human or animal populations, are indicated by coloring of the defined region and are noted in the key of the map; individual cases are plotted as points in an overlay, where applicable. Individual point overlays are not representative of the exact location where the plotted case occurred, owing to the lack of accurate spatial coordinates associated with each case. Instead, they are plotted randomly within ten or fifteen miles (to scale) of the geographic center of the specified area. Maps were not created for each year, instead using individual years only at the starting time point (1989), midpoint (1996), and ending time point (2003) for overall snapshots of rabies cases, with groupings of data, typically four years, representing the intervening time periods for other areas of examination.

RESULTS

During the period of study, a total of 53742 animals were submitted for rabies testing in Virginia, an average of 3583 per year. Table 1 lists the annual submissions broken down by species; raccoon, skunk and fox are included for obvious reasons, as are bats, all given their known association with rabies. Cats and dogs are included because their nature as domesticated animals can result in greater exposures, even when feral. Similarly, bovine and equine rabies cases indicate a direct threat to humans by their nature as domesticated animals. As the table indicates, animals outside of these eight are frequently submitted (mean 788/year) but seldom rabid (mean 16/year); this category includes any and all mammals, ranging from mice to a tiger. The submission trend indicates greater numbers of bats being tested throughout the time period, while other species fluctuate or remain nearly the same. The numbers of positive submissions remain nearly the same through the years, a trend which is borne out in the rates of infection among submitted animals (Table 2). Here, the rates remain similar, increasing somewhat among foxes and raccoons, and declining in bats. Of particular note are the infection rates in submitted raccoons and skunks, the former reaching 46% by 1994 and remaining above 40% for the remainder of the survey period, while skunks had positive rates above fifty percent and mostly above sixty.

Submissions by species for the study period are given for each health district (Table 3). This table indicates the geographic distribution of rabies cases and submissions, and provides a view of localized trends. Most districts submit approximately the same amounts of different animal types, and have approximately the same rates of positivity. The districts that depart from this are of note, with the Crater district submitting more than double its nearest competitor, while others (e.g. Lenowisco, Mount Rogers, Western Tidewater) submitted far fewer than the mean of 1535 submissions. Table 4 lists the rates of positive infection among animals submitted for testing by each health district by year. This is a crude means of indirectly estimating the chances of an animal from these areas being positive, and looking for a change over time. Most localities maintain existing rates, with some fluctuation; however, there are a handful of places (e.g. Danville, Eastern Shore, Norfolk, etc.) that start with little or no rabies activity at the start of the survey period and progress to light, moderate, or even severe levels by comparison, such as the Eastern Shore, with no cases through 1993 to finally settle at 34.5% in 2003, the highest rate in the state for that year. This change is examined using maps below.

Tables five and six look at exposures associated with cases. In Table 5, human exposures are listed by species. As expected, the rates of rabies cases associated with one or more known or suspected human exposures is highest among raccoons, foxes and particularly skunks. The rates in other species are rather low, with only the rates in cows and horses being perhaps surprisingly high. Table 6 summarizes rabies cases with a known or suspected exposure to one or more domestic animals (e.g. cat, dog, cow). Here the rates are higher than for human exposures, with only foxes showing slightly reduced levels. The exposures given in Table 5 are restated in Table 7, as a function of the reporting health district.

Tables 8 and 9 list the results of mAb testing, with annual totals for the available years given in Table 8, and the unusual results are localized in Table 9. Bat virus types were excluded from Table 9 due to the excessively fragmentary nature of the records, which rendered less than a third of the test results interpretable with an acceptable level of confidence.

The figures are intended to supplement and enhance the information presented in the tables. In Figure 1, the fifteen years of submissions are presented, allowing for comparison between years and between the overall submissions and overall positives. The trend for most of the survey period is towards more submissions, and towards more positives, albeit less dramatically. Figure 2 follows these trends for raccoons, skunks, and foxes, while Figure 3 covers bats separately, as bat rabies is seldom associated with terrestrial rabies.

Figures 4 and 5 present submissions and positives, respectively, in the proportions they represent. For example, cats are the most frequently tested animal, but make up a very small proportion of those that are actually rabid.

Figure 6 tracks total annual submissions by month. Through the progression of figures, it is possible to discern a weak bimodality in the occurrence of positives, the first typically occurring around the period of March through May, and the second around September or October. Overall submissions tend to peak during the summer months.

Individual species levels are traced in Figure 7, which looks at the monthly submissions and positives for raccoons, skunks, and foxes on an annual basis. Any trend here is more difficult to spot, due to the lower numbers of submissions and positives. In the later years (Figs. 7f through 7o) it is sometimes possible to discern a bimodal pattern in both positives and total submissions, although this is not consistent. Figure 8 shows the trends associated with bat submissions. Starting around 1996 (Fig. 8h) the number of bat submissions increases dramatically during the summer, while the number of positives remains approximately where it was at the beginning of the study period.

Figures 9 and 10 examine rabies in raccoons and skunks in three year groups, in an effort to detect trends across years. The raccoon comparison yields little, while the skunk comparison appears to indicate well-defined peaks of activity in the spring and summer.

Human exposures to rabid animals (i.e., rabies-positive animals that had an associated, documented exposure) are graphed by month in groups of three years in Figure 11. There does not appear to be a consistent trend in human exposure based on these figures, except perhaps during the summer months. Figure 12 graphs both human and animal exposures to rabid animals, using instead three years combined together. Here the results are clearer, with human exposures occurring more often during the summer, and animal exposures more frequently during the spring and fall. This is carried forward to the entire study period in Figure 13, which also shows the summer peak for humans and spring and fall peaks for animals. Figure 14 presents this slightly differently, using seasons (meteorologically defined) instead of months. The effect is similar.

The maps directly convey and contextualize the information in the tables. As mentioned in the previous section, the placement of individual cases is not exact, and serves primarily to establish a visual context to aid in the detection of patterns. Maps 1 through 3 give yearly snapshots, with Map 1 juxtaposing the number of rabid animals in 1989 with the human population according to the 1990 Census, Map 2 combining the rabid animal collections for 1996 with the population in 2000, and Map 3 comparing rabies positives with the 2000 human population. The specified decennial Censuses have been used because they are the most thorough count of the human population, and given the trend towards higher populations, it is probably less inaccurate to set 1996 rabies cases alongside the 2000 human population than it is to set it against 1990 human population. These examples demonstrate both spreading geographical range (Map 1 vs. Map 2), and a possible plateauing effect (Map 2 vs. Map 3). Map 4 traces rabies in the three main species (raccoons, skunks, and foxes) in four year groupings (three years in the case of the final set), which provides a view of which animals dominate positive counts in different regions of the state over time. For example, in Maps 4a-4c, the number of rabid skunks increases and the area of greatest concentration shifts, particularly from 4b to 4c, moving from the area of Rockingham/Augusta to Northern Virginia and the Interstate 95 corridor. At the same time, the range of rabid raccoons moves both east and west, becoming appearing on the Eastern Shore and moving west of the north-south axis that runs through approximately Radford, which had been the province of skunks and foxes. While it is not a perfect comparison, Map 4d would seem to indicate both a reduction in overall numbers, which is probably due to only three years being used, and to a slight rollback in range in the southwestern corner of the state.

Map 5 illustrates human exposures to rabid animals, overlaying this on the most relevant set of Census-derived human population ranges. The exposures are collapsed into three year sets, as the numbers involved are somewhat small, and this follows what was done for Fig. 12. Through the time series, it is possible to discern an association between the size of the human population and the number of exposures. As populations grow, exposures increase, although the increase is, for the most part, not dramatic. Rural areas also show an increase in exposures as the time period moves forward. As may be expected, Map 6 indicates that the majority of livestock rabies cases occur in areas with higher populations of those animals. Since the annual number of cases for both cows and horses is less than ten, all reports of infection for the study period have been combined together and compared to the most recent livestock census (2002). The areas with the most positive reports also have somewhat higher numbers of human exposures (Map 5) and positive wild animal reports (Map 4).

Map 7 displays the data from monoclonal antibody testing. Each type of rabies virus is depicted on a different map, with the occurrence of each type of rabies plotted in a different color by year. Map 7a depicts the raccoon B strain, which, with occurrences in only two localities, reduces the utility of the map (the "new" raccoon strain has been detected in Fredericksburg only, which is one of the independent cities not included in the boundary file used in making the map). The same may be said of Map 7b, showing skunk rabies virus. Detected only in Scott County (and once in Bristol, also not included in the boundary file), the geographic context is more relevant when compared to the main rabies strain, raccoon A (Map 7d). The raccoon A strain is found across the state, mirroring the overall reporting of cases. Also shown is the bat strain, which shows a tendency towards being detected in more heavily populated suburban/urban areas (Map 7c).

DISCUSSION

In examining the data and the results given here, there is an overarching feature that influences the amount of credit and level of confidence due them, and that is representativeness. The primary purpose of Virginia's rabies testing program is to provide diagnostic information of use to clinicians, a situation that has been acknowledged infrequently in the relevant literature[15,18,19,23], rendering surveillance the secondary objective. As a result, the submitted samples tend to be of two types, those associated with human or domestic animal contact and therefore requiring analysis for purposes of prophylaxis, and those that are submitted for surveillance purposes. This introduces what could and may indeed be a crippling bias into the results, since there is no systematic, formalized way in which the acquisition, collection, and disposition of specimens is conducted. Although this issue has been noted before[12,15], there have not been any procedures put in place to improve the situation that have been made public. Ultimately, there are systemic issues relating to available funding, manpower, and priority that restrict what can be done. Bearing this in mind, the collection or "front" end is where the most information can be gathered, and sometimes is not.

The non-standardized approach affects this analysis in several ways. The aforementioned systemic bias is one. Another is the lack of any means to ensure that the guidelines that are in place are followed. Determining what constitutes an exposure is usually left up to the environmental health or animal control officer responding to a report of a suspicious animal; while there is certainly a place for wide latitude in constituting an exposure[3], and indeed protecting the health of persons or animals possibly exposed should be the highest priority, the impairment of the ability of researchers to study standardized and accurate data can have effects that reverberate back to the "front end", negatively affecting community health and safety. Unfortunately, this dissonance between two competing yet complementary needs is unlikely to be solved in the near future[34].

The third manner in which the minimalist approach to data collection harms research and planning is of particular relevance to this project. The lack of location information more specific than the county or city level hinders efforts to examine in detail relationships between human and domesticated animal populations, local environmental features, wild animals, and rabies. As others have demonstrated[12,19,23,24,26,31], the local environment impacts both the spread of rabies, and the chances of humans coming into contact with infected animals. With the crudity of the geographic locators currently in use, it is not possible to draw more than the most general of conclusions about where cases and exposures occur, save by poring over the paper submission records, a tedious process indeed when there are an average of over three thousand submissions annually, and one outside the scope of this study. In the future it will presumably be easier to record and store information as precisely as possible using the Global Positioning System, thereby making localization of specimen collection possible to within meters. This would make the output from the use of GIS resources more precise and thus more useful than is possible at present.

An additional issue arises in how to define outcomes in cases where the result of testing is inconclusive, or the specimen is unacceptable for testing. In this study, these cases have been removed from consideration due to this uncertainty, although this has not always been the case in prior studies[18]; while the impact of this adjustment is arguably minimal, it may perhaps be helpful to have a consistent way of dealing with these cases. At present, deciding whether to treat the case as potentially rabid "just to be sure" is made on an essentially case by case basis[35], where having clear and consistent direction in how to handle these occurrences would provide a basis for recoding these specimens into either positive or negative categories. Whether that would be a valid measure is debatable, however the option to debate and consider it is certainly one that would be preferable to have as opposed to the current situation.

The final issue to be addressed in terms of collection and recording of data is that of recording accuracy. The principal data set evinced a small though troubling tendency towards error, in such fields as species and date; while the number of noticeable errors declined in later annual data sets (unfortunately not to zero, e.g. a collection date of 9/25/2005 in the table for 2002), this issue casts some shadow over all analyses done using the set, since there is often no way of knowing whether there has been a mistake somewhere in the data entry process without examining the original submission form. As well, if the forms themselves are in error, then there is essentially no way to catch and correct a mistake unless it is glaringly obvious. A related issue, though not truly an error, is the matter of "leftover" submissions, which occur when a sample collected in one year is analyzed in a subsequent year, and therefore included in that later year's records. The numbers involved are small (<1% of annual average), and in this study they were treated as being part of the annual set in which they were originally listed; they were excluded only from the monthly analyses. The occurrence of these types of records declines to almost nil after 1997, suggesting a relationship to the change in procedures that happened during that time.

Because of these factors, it is quite possible that fluctuations in rates and total numbers on a yearly and even seasonal basis do not reflect the true state of the animal population at large. This should be borne in mind when considering changes across time, and it is essential that this be considered in all discussions of rabies in wild animal populations.

So, given that the data and the means used to collect it have a variety of flaws, it is still important to acknowledge that this is, and is likely to remain, the only source for information on wildlife and domestic animal rabies on a large, regional- or state-level scale. While the conclusions that can be drawn from it are limited and perhaps somewhat inaccurate, they are still valuable.

What conclusions can be reached from this data and these analyses? The most obvious is that the range of the epizootic has expanded and moved eastward. While this partially disagrees with previous projections[21,36], it is logical in that the primary agent of spread of the disease is now raccoons, and raccoons prefer to live in areas, such as suburbs, with a significant human presence[19,24,31]; the eastern Piedmont and Tidewater regions are the state's second most populous region, after the northern part where the epizootic has been firmly established for twenty years. The Eastern Shore, though significantly less heavily populated than the Tidewater, has also seen an explosion of cases since the mid-1990s. Because of this, areas not previously considered to be especially at risk for animal to human or significant animal to animal transmission now are, a situation to which the involved health departments have had to respond and adapt. It is possible that with improved surveillance this movement could have been detected early enough to prepare, even if preventing it was not a viable option. Interestingly, these newly affected areas have seen only mild levels of human exposure to rabid animals, such as on the Eastern Shore and in Norfolk, a result that could indicate a satisfactory level of public attention and adherence to recommendations from the public health establishment, or could reflect something else, such as a sparse human population, in the case of the Eastern Shore.

Another notable aspect is that the raccoon strain of the disease has supplanted the previously enzootic skunk form of the virus. Since 1999, there has been only one case of skunk adapted rabies found in the state. Although it is not possible to be certain due to a lack of complete records, it is not unreasonable to infer that the shift occurred throughout the late 1980s and early 1990s, perhaps gaining speed in the middle of the last decade, with the enzootic skunk form being confined to ever more isolated pockets until finally being overrun by 2000. This is not unexpected, as the raccoon strain appears to be better adapted to causing infection in a wide array of mammals (as opposed to the skunk variant, which does not always cause disease in other animals, e.g. raccoons)[37], but it is interesting to consider this from an epidemiologic point of view. One of the practical consequences of the change is that as a result of the greater ease with which this variant of the virus infects susceptible animals there is likely to be an increase in the overall numbers of rabid animals and in the number of human and domestic animal exposures, which is a reflection of increased health risk. And indeed this is the case, with the numbers of rabies cases rising through the early 1990s and reaching a plateau during the middle of the decade.

Related to this, it is also of interest to note that there are or have been three different kinds of raccoon-associated rabies virus present in the state. The principal type is known as raccoon A, and is the type primarily responsible for the epizootic. There has also been detected in this state raccoon B virus, on a limited but geographically diverse basis. In addition, a new strain of raccoon-associated virus has been detected twice (confirmed by the CDC both times), once in 1999 and once in 2000, both times in Fredericksburg (Table 9). While there does not appear to be an functional difference between the three, and the literature empty of studies of the new strain, their detection serves as an excellent argument in favor of maintaining and even expanding testing for rabies virus types, as it is impossible to know when a new strain might appear, potentially more virulent than the current one.

What else could explain the upward trend in rates? Aside from the previous explanations of expanding range and changing disease ecology, only changing human population dynamics offers a plausible reason. With increasing suburban sprawl, the preferred range for raccoons is vastly increased, and species previously found far from civilization now have homes and subdivisions in their habitats, both of which combine with a rising tide of human population to create many more circumstances for interaction between all three. The result is greater transmission of the virus to other wild and domestic animals, greater contact between rabid or potentially rabid animals and humans, and more opportunities for said animals to be caught, killed, and tested. If one were to assume, most probably correctly, that the rates found here are higher than they are in the general animal population, and to further assume that the true rate is perhaps half or less of what it is in the sample population, then one is still left with the rather unsettling thought that one in twenty or thirty wild animals is carrying rabies. While this is almost certainly not the case, it can still be reasonably decided that rabies is not a minor concern where wild animals are involved.

Among the rates of infected animals, one species stands out, the skunk. In every year surveyed, the rate of rabid skunks never dropped below fifty percent. It may be hypothesized that this is a function of the generally human-avoidant nature of skunks; they tend to come into contact with humans only during winter, or when sick[12]. Thus is it expected that the numbers where skunks are concerned would show more bias than other animals. However, this does not necessarily mean that even more than usual, contact with skunks should be considered an exposure to rabies; slightly less than half of skunks reported to have been exposed to humans were rabid (48%), while those without an exposure were more often rabid (71%). Compared to raccoons (23% rabid with exposure to 48% rabid and without) and foxes (28% to 21%), however, any encounter with a skunk is more likely to be with a rabid one, though the rate of positive exposures for foxes is also higher than positive non-exposure cases, this difference being smaller and essentially marginal. (Bats, as mentioned previously, are not so easily reduced to statistics. While there would seem to be less of a probability of a bat being rabid in the event of a human contact [5% vs.7%], the nature of exposures to bats renders this almost meaningless.) Exposures to animals are quite different, however. Among rabid skunks in this study, there is an exposure to another animal almost three-quarters of the time (74%) compared to rabid skunks with no exposure to another animal (40%); this is also true of raccoons (52% vs. 26%) and foxes (27% vs. 17%).

Towards the other end of the spectrum of accuracy is the measurement of rabies in domestic animal populations. While there is little formal study of rabies in domestic animals outside of compilations of raw numbers and case reports[7], given the nature of domestic animal herds it is unlikely that many cases go undetected; otherwise, there would be much higher incidence of rabies in persons associated with raising cattle and horses, and packing meat, where there appears to be none (to be sure, if humans in these potentially high-risk occupations get and maintain artificial immunity to rabies, then unreported exposures without resulting disease could be common; this is perhaps a question that could benefit from greater study). The numbers here are quite low; cows had a total of 98 rabies cases over the study period, while horses had 27; using the 1987 populations for these animals as the starting point, the cumulative incidence over the study period is 6.5/100,000 for cows, and 56/100,000 for horses (bearing in mind that the population numbers are imprecise, and this is a very crude estimation). Goats, sheep, and donkeys had six or fewer during this period. As Map 6 demonstrates, most cases occurred in areas with larger populations of bovine and equine livestock. This is expected for the simple reason that the presence of more animals in an area tends to generate more potential exposures for a larger susceptible population. For the most part, concern for rabid livestock animals should be directed towards the western part of the state, in the form of programs to enhance awareness on the part of the agricultural sector most at risk. While the numbers of rabies cases in domestic livestock animals is quite low, their position as working, food, and recreational animals poses a unique case, where rabies has the potential to affect large numbers of people in the form of a point source. As noted, this has been documented before[7], although there have not been any known human cases associated with such exposures. Determining whether vaccination, either of humans or of livestock, is cost-effective is left to another study.

Companion animals are a difficult category to make definitive statements about. The problem lies in feral populations. When the case information is reported, there is a category for whether the animal is a “Pet”, “Stray”, or “Wild”. Leaving aside the more perplexing cases (can bats be pets? Can raccoons?), it can be difficult to differentiate between a stray cat and a wild/feral one. The situation is similar for dogs. So while one can say that the cumulative rate of rabies infection for pet cats tested is 1.8%, the rate for strays 2.6%, and wild 3.2%, what does this really mean? With little certainty as to whether the cats really were pets, strays, or feral, it is impossible to make recommendations with a reasonable expectation of accuracy. Examining rabies in companion animals would be a useful exercise with manifold potential benefits, but the questionable nature of the data makes it a procedure fraught with problems, and most likely a waste of effort. Again, the problem of being able to rely upon the data is an issue.

Previous studies have noted patterns of a seasonal and yearly range for both skunk and raccoon rabies variants[12,15,18,23,31], and though the seasonal peaks reported vary somewhat, the yearly patterns follow two or three year cycles. This study found that there appears to be seasonal variation in the total number of positive cases. This is best illustrated in Figures 13 and 14. Additionally, in looking at the relevant figures (Figs. 6, 7), a pattern of spring and fall increases can be faintly detected. This is more pronounced in positive cases that have human or animal exposures associated with them, being best demonstrated in Figs. 12-14. Here there is a single clear peak in human exposures during the summer, and a bimodal pattern in animal exposures during the spring and fall. The most likely explanation for the human peak is that with warmer weather comes enhanced opportunity for contact with rabid animals. The animal exposure pattern may be related to the pattern of rabies in the wild, with greater numbers of rabid animals leading to greater numbers of exposures. Certainly, the much higher total numbers of animal exposures are probably due to a combination of animals spending more time outdoors (if they are domesticated) and territorial and range issues. A more precise assessment would require an animal behaviorist, putting it outside the scope of this study.

As is often the case[3], bats present an interesting counterpoint to terrestrial rabies. With an average of fifteen rabid bats per year, they are not a major constituent of rabies reports, at least according to the numbers. Since bats are considered to be among the more dangerous and even insidious carriers of rabies[3,4], however, it is important not to underestimate them. Given the trends in bat submissions, it appears that this is not happening. Figure 8 provides a graphical representation of bat submissions and positives, and starting around 1996 (Fig. 8h), the submission rates for bats begin to trend upwards. Interestingly, the number of positives stays about the same, hardly echoing the dramatic change in submissions. One reason for this may be improved public awareness of the role bats play in rabies transmission, leading to more submissions; while the association of bats with rabies has been known for decades[3], it is not impossible to reasonably conclude that perhaps the general public has been unaware of this change. If so, then certainly this would be considered a victory for the public health establishment, albeit a belated one.

The GIS portion of this study yields some interesting results, although it is of somewhat reduced utility owing to limitations both of the data sets used and the technical capabilities of the software employed. The lack of precise geospatial data is particularly troublesome. Even so, the maps show the mushrooming of rabies during the middle of the 1990s, particularly in the northern and eastern part of the state. In particular, the lack of much activity involving skunks in the eastern Tidewater area, while the rest of the heavily affected areas saw considerable skunk involvement, is noteworthy. Whether this is a result of there not being many skunks in the area, or of the characteristics of the local skunk or human populations, is not known, and may be worthy of additional study. In addition, the low levels at which rabies, particularly associated with raccoons, appears to be infiltrating the far southwestern corner of the state may indicate that there is either a significant physical barrier, or the ongoing efforts to produce a vaccinated animal buffer there and in surrounding states[38] are having an effect on the penetration of the disease. Whether this is a result of either of these two possibilities, or whether there are other factors at play, will probably require a field study to determine definitively. Such an undertaking would be advisable, since if there is a human-associated or –controllable factor involved, finding out what it is could have an effect on rabies control elsewhere.

Human exposures to rabid animals do not appear to follow a geographic trend, with the only associations being with higher population and greater numbers of rabies reports. As with the livestock, this is an expected development. However, it is somewhat unexpected that the numbers of exposures in the eastern Tidewater and Eastern Shore are as few as they are, given the high numbers of reports and the large human population. This may be attributable to demographic factors or to rabies awareness programs, or it could stem from reporting variances, and may be deserving of further study.

There does not appear to be a geographic trend in rabies virus types, inasmuch as can be determined from the available data, aside from the expansion of the range of raccoon A. The non-raccoon A rabies types are too infrequently reported to be able to establish a geographic range or association with certainty, though of course it appears, and could be guessed, that the two non-A types of raccoon rabies are more common in the north and the Eastern Shore, possibly having moved southwards, if not having arisen locally in the case of the “new” raccoon strain. The skunk strain would seem to be confined to the southwestern part of the state, if it is still in circulation at all, and its detection fits with the absence, or near absence, of the state’s dominant raccoon strain in that area. It is probably not possible to determine whether the skunk strain is still in circulation in Virginia by relying on standard surveillance submissions, and should a stakeholder decide to attempt to determine this, a field study of the trap and test variety would almost certainly have to be employed.

Can possible factors influencing the level of risk imposed on humans and livestock be identified from the data used and examined in this study? Yes, although they are not groundbreaking. As may seem obvious, the more people there are in a given location, or the more livestock there are in a given location, the greater the chances of exposure to rabid animals, if the disease is also present in the wildlife at that location. However, neither the human population nor the level of rabies seems to be a determining factor in the sense that areas with low population can have low exposure levels or high ones, areas with high population can have high exposure levels or exposure levels lower than may be expected (e.g. Virginia Beach), and areas with many rabid animals can have relatively few exposures (e.g. the Eastern Shore). The local situation, such as sparsely populated and rural, probably plays a significant role. In addition, seasonality is a component of risk, both to humans and to livestock, and this in turn is a reflection of cultural practices (summer vacations, farming, etc.). The interplay between these factors is complex, and is deserving of further study. Again, the constraints of the data collection method appear, and any comparison between areas must be mindful of local sampling variation.

The overall relatively low rates of rabies found in cats, dogs, and other domestic animals may be attributable to public action at the behest of public health authorities. Requirements for pet vaccination, for maintaining and adhering to fencing and leashing ordinances and laws, and even spaying and neutering can help to reduce the occurrence of and potential exposure to rabies in both animals and humans. This is not to say that there is not room for improvement. Feral cats can and do harbor rabies, as well as other diseases of humans and animals, and for this reason it continues to be important that pets (including dogs) not meant to be bred be neutered. Likewise, vaccination requirements should be rigorously enforced; annual or biannual vaccination is cheaper and easier than post-exposure prophylaxis, and less traumatic than putting down a family pet so that it can be tested. Vaccinating livestock animals should be considered as well, at least in areas identified as being more at risk of rabies introduction into livestock. This is perhaps more economical for horses, given their potential market value and the fact that there are fewer of them than there are of cattle.

Options where wild animals are concerned are more limited. Several studies[15,18,23] have considered various methods, particularly trapping or otherwise removing raccoons, and found them to be costly and ineffective. The only method widely deemed worthwhile is vaccination. There have been deployments of the oral wildlife vaccine in Virginia[38,39,40], principally to help create a "barrier" of vaccinated animals so that the westward expansion of raccoon rabies into the Ohio Valley and beyond might be prevented. If continued and expanded, there is the possibility that vaccination might be able to eventually reverse the raccoon rabies epizootic, or at least push it into more isolated areas where it poses less of a threat to humans and other animals. There is also the possibility that technological improvements could make use of traditional trapping a more effective proposition, and a combined culling and vaccinating program has a certain attractiveness (in reducing the overall numbers of raccoons, and vaccinating the remainder, establishing herd immunity is potentially easier), but there are barriers to carrying such a program out, not the least of which is a real or perceived public opposition to lethal methods of animal control. At present, then, the only realistic means available to reduce the threat of rabies from wild animals are expanded use of oral vaccination, and continued public education campaigning. Targeting these campaigns to areas that have higher levels of human contact with rabid animals, such as the Central Shenandoah or Fairfax health districts, and to younger people, particularly elementary school-age children who may be more likely to interact with sick or "friendly" wild animals, certainly bear considering.

In addition to the issues discussed above, there are other factors that can and possibly do play a role in the spread of the disease. Weather is probably the most important, having been previously linked to the spread of the disease[19]. Examining variables such as this and local environmental features are beyond the scope of this study, but are deserving of consideration in future research.

CONCLUSION

The obvious conclusion from this study is two-fold. One, rabies, specifically raccoon variant rabies, has established itself throughout the Commonwealth of Virginia, in all regions and almost all localities. Two, that the current surveillance system in place is not designed to act primarily as a surveillance system but as a clinical diagnostic support program, leading to lowered reliability and utility of data gathered by it. Neither of these is a new determination. In that respect, this study is a confirmation and extension of previous research. Two aspects of surveillance that this study was undertaken to explore, Geographic Information System use and monoclonal antibody testing results, were reduced in their usefulness by imprecision in data collection in the first case and too short a data collection and testing period in the latter.

Interestingly, there does not appear to have been a change in the risk of exposure to rabid animals to humans, illustrated in Figures 11 and 12, even as the overall numbers of animal exposures increased during the study period. This would suggest that while additional steps need to be taken to reduce the domestic animal exposure levels, efforts directed towards humans seem to be effective at containment, so that it is possible to look for ways to push the contact rates down. In a similar vein, the relative amount of spillover from raccoons into the other animal species of greatest interest (skunks, foxes, cats, and dogs) appears to be nearly constant, so that, if this is truly the case in the animal population at large, there is no longer an expanding epizootic, but probably something closer to a steady state.

As mentioned previously, while there are reasons for satisfaction with the response of the public health establishment to this epizootic, there is also, as is so often the case, room for improvement. While the lack of demographic data included in the animal submission records makes it impossible to determine whether, for example, children are more or less likely to be exposed to a rabid animal, it is preferable to err on the side of caution where a disease as dangerous as rabies is concerned. Therefore, it makes sense to target educational efforts towards young children and other groups that may be at a higher risk for coming into contact with rabid animals, including but not limited to persons living in severely affected areas and hunters[15]. Likewise, continuation and improved enforcement of rules regarding companion animal vaccination and leashing/fencing will keep the occurrence of rabies and exposures to rabies in these animals low, and have the potential to push them lower.

There are still many areas in the study of rabies in Virginia that have yet to be extensively examined. Several opportunities for further research have already been mentioned. These include detailed field studies to examine the ecology of the disease in the eastern Tidewater and far southwestern areas, and explorations of the occurrence of the non-raccoon A strains of the virus. Other topics that may be useful to explore are those involving relationships, such as between the geography and seasonality of the disease, or the role of companion animals in the maintenance of the disease and in exposing humans to the disease. Some studies, such as the last, will have to await improvements in data collection methods.

This study has provided the first (albeit crude) estimation of risk for livestock populations. There has also been extensive attention paid to the systemic deficiencies of the current surveillance program. While these issues are not news to those involved with the program, it is unlikely that policymakers will address them without sufficient incentive to do so. Ways to improve this include adopting more advanced technology, something that is in process[41], but which may not go far enough. Although it is something of a cliché that improved technological tools can improve efficiency and accuracy, in this case there is a high probability of truth to the idea. By making use of off-the-shelf technology such as personal digital assistants, GPS, and wireless networking, it is possible to automate the process of collecting data while simultaneously improving accuracy and precision, and reducing the chance of human error at certain critical junctures, such as data entry. This may be possible to accomplish at the district level for relatively modest expenditures, which would have to include standardized training so that elements requiring human judgment are more standardized and regimented.

What benefits would this change bring? Besides making life easier for epidemiologists and researchers, an improvement in accuracy and comparability between regions would make it possible to present policymakers with options based more on reality than guesswork and conjecture, permitting a more focused and efficient response to changes in the disease environment. This may have the effect of making it possible to realistically attempt to reverse the tide of the rabies epizootic. While it is possible to start vaccinating raccoons and other animals[18], doing so blindly and haphazardly cannot be expected to produce positive long term results. Improvement in the situation is unlikely to happen until changes are made in and to the approach taken to the disease.

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TABLE 1. Annual totals for rabies submissions among select species.

Species		1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	Total
Bats (*All spp.*)	Positive	14	6	8	12	12	9	8	17	22	20	17	19	23	17	19	223
	Total[b]	160	118	117	111	108	116	129	246	323	353	455	457	592	429	448	4162
Cats	Positive	10	10	7	21	19	25	27	29	33	21	23	27	20	27	34	333
	Total	865	804	723	914	961	978	1095	1178	1207	948	960	1105	991	990	1072	14791
Dogs	Positive	1	1	2	7	4	4	4	5	2	4	4	7	4	4	6	59
	Total	500	448	448	467	615	653	641	612	624	589	621	657	601	581	572	8629
Foxes (*All spp.*)	Positive	15	11	13	23	23	17	21	38	46	48	42	50	34	56	48	485
	Total	137	102	163	174	106	99	124	172	245	171	171	152	139	153	131	2239
Raccoons	Positive	148	127	167	203	213	251	271	383	429	326	354	328	288	318	321	4127
	Total	510	398	421	601	572	546	623	899	957	749	753	648	706	759	663	9805
Skunks	Positive	58	41	51	77	94	105	114	124	142	112	127	126	116	147	92	1526
	Total	89	80	86	110	142	142	179	196	200	170	182	195	172	211	137	2291
Others[a]	Positive	14	5	5	19	22	17	14	16	16	18	14	17	17	23	22	239
	Total	805	780	586	802	673	698	794	921	927	829	928	811	869	750	650	11823
Total	Positive	260	201	253	362	387	428	459	612	690	549	581	574	502	592	542	6992
	Total	3066	2730	2544	3179	3177	3232	3585	4224	4483	3809	4070	4025	4070	3873	3673	53740

[a] – Includes all other mammals submitted for testing.
[b] – Includes all submissions including positives.

TABLE 2. Annual rates of infection among animals submitted for rabies testing (given per 1000 of specified species submissions).

Species	**1989**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**Total**
Bat	87.5	50.9	68.4	108.1	111.1	77.6	62.0	69.1	68.1	56.7	37.4	41.6	38.9	39.6	42.4	53.6
Cat	11.6	12.4	9.7	23.0	19.8	25.6	24.7	24.6	27.3	22.2	24.0	24.4	20.2	27.3	31.7	22.5
Dog	2.0	2.2	4.5	15.0	6.5	6.1	6.2	8.2	3.2	6.8	6.4	10.7	6.7	6.9	10.5	6.8
Fox	109.5	107.8	79.8	132.2	217.0	171.7	169.4	220.9	187.8	280.7	245.6	329.0	244.6	366.0	366.4	216.6
Raccoon	290.2	319.1	396.7	337.8	372.4	459.7	435.0	426.0	448.3	435.2	470.1	506.2	407.9	419.0	484.2	420.9
Skunk	651.7	512.5	593.0	700.0	662.0	739.4	636.9	632.7	710.0	658.8	697.8	646.2	674.4	696.7	671.5	666.1
Bovine	111.1	40.5	17.9	126.4	104.8	88.2	90.9	46.5	52.6	70.4	94.6	54.6	73.5	136.4	113.6	83.2
Equine	47.6	43.5	38.5	52.6	71.4	28.6	31.3	54.1	57.1	55.6	30.3	51.3	69.0	71.4	28.6	48.3
Other	7.1	1.5	6.0	8.7	15.2	12.5	7.4	12.5	11.3	15.2	7.3	16.7	13.0	17.1	20.3	11.3
Total	84.8	73.6	99.5	113.9	121.8	132.4	128.0	144.9	153.9	144.1	142.8	142.6	123.3	152.9	147.6	130.1

TABLE 3. Total submissions by health district, for select species

	Bat		Cat		Dog		Fox		Raccoon		Skunk		Other		Total	
Health District	**Pos**	**Total**	**Pos**	**Total**	**Pos**	**Total**	**Pos**	**Total**	**Pos**	**Total**	**Pos**	**Total**	**Pos**	**Total**	**Pos**	**Total**
Alexandria	12	145	43	650	6	284	34	156	195	351	257	339	56	720	603	2645
Alleghany	11	144	19	805	5	365	42	175	258	413	166	238	19	433	520	2573
Arlington	10	200	26	606	1	338	25	97	163	297	83	113	6	463	314	2114
Central Shenandoah	4	70	22	412	0	190	34	146	153	256	57	73	17	408	287	1555
Central Virginia	4	129	10	412	3	243	17	89	137	280	91	122	8	245	270	1520
Chesapeake	11	173	2	415	1	193	0	16	68	242	2	7	0	218	84	1264
Chesterfield	4	86	4	654	0	259	3	10	72	237	0	0	3	241	86	1487
Crater	58	1103	19	1212	3	647	67	256	487	1048	78	153	16	1364	728	5783
Cumberland Plateau	7	175	15	503	0	185	39	253	261	523	47	105	10	406	379	2150
Danville	19	381	8	660	2	389	15	108	118	252	35	62	8	792	205	2644
Eastern Shore	3	85	5	275	1	161	10	29	41	118	40	55	6	183	106	906
Fairfax	3	146	14	528	4	374	14	100	149	382	119	178	9	494	312	2202
Hampton	4	29	1	262	2	185	4	56	24	134	35	61	4	161	74	888
Hanover	1	23	4	250	2	265	2	29	65	153	30	37	2	91	106	848
Henrico	1	70	4	426	4	378	5	47	90	262	28	40	4	227	136	1450
Lenowisco	4	28	0	95	2	134	0	27	0	36	11	21	1	65	18	406
Lord Fairfax	4	53	15	395	5	281	13	55	70	241	67	103	17	345	191	1473
Loudoun	5	109	9	630	1	304	11	59	82	258	59	117	15	397	182	1874
Mount Rogers	0	39	2	168	0	106	0	9	2	18	3	10	1	53	8	403
New River	13	192	8	563	3	335	10	37	116	334	15	35	2	627	167	2123
Norfolk	7	63	7	313	3	311	13	56	187	356	27	49	0	265	244	1413
Peninsula	8	124	10	492	0	280	20	74	127	278	66	106	8	371	239	1725
Piedmont	9	110	6	332	0	178	6	30	65	210	8	19	2	412	96	1291
Portsmouth	3	38	5	284	1	230	6	46	173	316	93	109	12	188	293	1211
Prince William	3	72	0	213	0	144	0	6	33	164	0	1	0	134	36	734
Rappahannock	1	17	10	156	3	134	15	52	64	121	42	48	2	93	137	621
Rappahannock Rapidan	1	23	3	465	0	177	10	28	41	142	0	0	0	246	55	1081
Richmond	1	46	6	233	1	144	15	36	307	448	7	9	1	108	338	1024
Roanoke	0	18	1	146	0	92	0	1	25	140	0	0	0	153	26	550
Southside	1	30	1	339	0	231	1	7	28	180	0	1	0	181	31	969
Thomas Jefferson	1	40	31	465	3	268	32	62	156	327	36	42	7	253	266	1457
Three Rivers	2	89	7	516	1	260	8	23	139	463	18	26	2	504	177	1881
Virginia Beach	2	36	7	242	2	155	3	35	97	237	6	10	1	213	118	928
West Piedmont	6	56	8	562	0	303	11	22	128	527	0	1	0	654	153	2125
Western Tidewater	0	17	0	104	0	116	0	7	5	59	0	0	0	102	5	405
Total	223	4159	332	14783	59	8639	485	2239	4126	9803	1526	2290	239	11810	6990	53723

TABLE 4. Annual rate of rabies infection by Health District (per 1000 animal submissions)

Total	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	Total
Alexandria	26.3	0	0	142.8	19.2	16.4	18.2	89.1	178.9	37.5	52.1	35.4	28.0	0	102.6	66.5
Alleghany	227.3	48.8	125	170.7	117.7	63.5	83.3	81.1	120.7	63.5	96.4	162.8	137	97.2	222.2	117
Arlington	53.3	27.4	14.7	22.5	17.2	45.9	58.3	93.8	58.8	65.9	61.7	33	24.4	101.1	139.3	57.8
Central Shenandoah	152.5	113	169.5	243.4	268.6	242.7	252.5	259.7	229.7	177.2	221.6	285.7	237.8	190.5	264.8	228
Central Virginia	0	0	51.9	16.1	112.2	153.9	136.4	183	173.3	165	118.2	135.9	113	211.3	194.2	141.7
Chesapeake	14.9	15.4	0	16.4	40.8	45.5	13.2	55.1	47.6	138.3	157.1	67.6	24.7	34.1	25.6	50.9
Chesterfield	71.7	54.2	16.1	17.2	90.9	112	75.2	157	151.9	59.3	93.8	65.6	92.9	34.5	76.5	78.7
Crater	155.6	330.5	175.8	161.3	76.9	137	155.2	163.8	118.6	138.9	166.7	181	161.3	195.4	25	172.7
Cumberland Plateau	105.3	606.1	588.2	0	0	697.7	746.3	142.9	117.7	57.7	23.3	52.6	122.8	131.3	64.8	83.3
Danville	0	0	0	32.3	0	0	102.3	213.5	238.1	171.9	132.1	82	133.3	133.9	53.6	125
Eastern Shore	0	0	0	0	0	377.8	396	500	185.6	222.2	280.5	504.4	271.7	216.2	345.2	330.1
Fairfax	39.2	30.4	79.2	118.9	79.9	153.8	105.9	143.2	187.5	133.7	181.1	142.9	92.2	153.9	104	125.9
Hampton	0	25.6	0	0	0	0	0	0	0	43.5	102	39.2	122.5	170.7	148.2	47.3
Hanover	67.4	0	109.1	100	159.7	95.2	103.5	186.4	195.8	172.9	182.5	139.1	132.5	171.9	140.5	138.6
Henrico	78.4	0	20	29.4	81.1	49.4	56.8	77.5	78.4	77.8	76.2	148.1	73.2	125	116.9	74.4
Lenowisco	69	0	40	52.6	45.5	43.5	0	0	40	0	133.3	31.3	35.7	93.8	27.8	44.3
Lord Fairfax	229.5	183	144.9	246.2	234.6	191.2	158.7	148.2	147.1	271.7	269	190.5	212.5	185.4	209.4	202.1
Loudoun	122.3	117.7	189.2	162.8	174.4	215	116.3	120.3	277	255.6	202.9	189.2	163	195.3	172.7	176.3
Mount Rogers	119.1	79.4	62.5	44.1	128.7	143.9	176.9	152	117.7	131.9	55.6	145.6	76.9	206.9	178.2	129.7
New River	11.8	25.3	100	146.3	215.2	107.9	71.9	138.9	70.5	108.5	123.4	143.9	86.3	69	81.8	97.1
Norfolk	0	0	0	0	0	0	0	0	0	0	0	26	83.3	144.7	114.6	32
Peninsula	104.3	53.4	181.2	58.8	30	57.7	41.7	53.1	92.9	96	77.5	181.2	130.8	93.5	123.7	94.1
Piedmont	287.9	239.6	163.9	40	213.3	296.9	303.4	269.7	289.5	234.4	272.7	190.5	221.3	273.7	212.1	242
Portsmouth	0	0	0	0	0	0	0	32.3	0	33.3	23.8	27	0	23.8	0	12.4
Prince William	17.7	16.7	51.6	89.7	20.4	96.8	92.4	98.2	114.5	84.3	127	120.2	58.8	105.3	149.1	77.5
Rappahannock	57.5	43.1	91.8	133.9	132.2	89.3	80.3	139.5	187.9	317.2	161.8	146.3	114.1	262.1	175.2	148.5
Rappahannock Rapidan	189.5	151.2	151.2	171.4	184.5	181.8	234	201.8	262.1	162.4	196.4	172.4	173.9	138.3	157.9	184.6
Richmond	26.3	0	0	43.5	46.5	0	178.5	31.7	54.1	212.2	62.5	0	87.7	0	30.3	49.1
Roanoke	0	0	0	44.4	73.2	0	35.7	0	0	0	0	0	31.3	0	41.7	19.9
Southside	0	62.5	0	105.3	218.8	484.8	270.8	183.3	185.2	222.2	243.9	184.8	291.7	285.7	232.6	220.6
Thomas Jefferson	132.1	92.1	149.3	137.3	183.9	191.9	169.5	207.2	250	230.3	150	85.5	142.9	222.2	177.1	177.6
Three Rivers	89.7	141.2	161.6	97.1	207.9	111.1	197.8	198.4	177.8	163.5	202	212.1	231.6	279.6	252.6	182.6
Virginia Beach	0	0	0	63.3	59.2	97.2	65.1	63	64.3	80.3	43.2	91.4	127.6	100	61.9	72
West Piedmont	0	0	0	118.6	68	110.4	67.6	137.3	125	83.3	48	90.2	89.1	162.5	120	93.8
Western Tidewater	0	0	262.3	252.9	155.8	75.5	163.9	102	169.5	107.7	129.9	26.7	63.5	232.6	87	127.2
Total	84.8	73.6	99.5	113.9	121.8	132.4	128	144.9	153.9	144.2	142.7	142.7	123.4	152.9	147.5	130.1

TABLE 5. Cumulative (1989-2003) rate of infection in submitted animals with a known or suspected exposure to humans, by species.

Species	**N**	**Rate**[a]
Bat	83	48.5
Cat	289	21.8
Dog	52	6.5
Fox	141	275.9
Raccoon	401	221.9
Skunk	104	462.2
Bovine	84	82.4
Equine	26	53.1
Other	45	9.0
Total	1225	38.3

[a] – Rate per 1000 of specified species submissions.

TABLE 6. Cumulative (1989-2003) rate of infection in submitted animals with a known or suspected exposure to domestic animals, by species.

Species	**N**	**Rate**[a]
Bat	75	63.3
Cat	66	57.2
Dog	22	34.9
Fox	301	263.6
Raccoon	3124	505.4
Skunk	1303	725.5
Bovine	7	225.8
Equine	6	150.0
Other	57	12.9
Total	4961	299.0

[a] – Rate per 1000 of specified species submissions.

TABLE 7. Cumulative (1989-2003) human exposures to rabid animals, by animal and health district.

Health District	Bat	Cat	Dog	Fox	Raccoon	Skunk	Bovine	Equine	Other	Total
Alexandria	4	1	1	0	1	0	0	0	0	7
Alleghany	1	3	1	4	5	1	1	0	3	35
Arlington	2	3	0	2	14	0	0	0	1	22
Central Shenandoah	8	37	6	16	25	31	27	14	6	170
Central Virginia	2	13	3	2	19	7	3	0	3	52
Chesapeake	0	3	0	5	3	0	0	0	0	11
Chesterfield	3	6	3	1	16	1	0	0	1	31
Crater	2	5	3	5	19	1	0	0	0	35
Cumberland Plateau	0	0	2	2	4	1	0	4	0	13
Danville	1	4	2	1	4	1	2	0	0	15
Eastern Shore	0	5	1	5	15	0	0	0	0	26
Fairfax	18	14	2	15	34	3	1	0	2	89
Hampton	0	0	0	0	2	0	0	0	0	2
Hanover	3	9	0	4	11	7	2	0	3	39
Henrico	3	6	0	0	2	0	1	0	0	12
Lenowisco	3	0	2	0	0	0	1	0	0	6
Lord Fairfax	6	16	3	11	31	7	8	2	2	86
Total	-	-	-	-	-	-	-	-	-	-

Health District	Bat	Cat	Dog	Fox	Raccoon	Skunk	Bovine	Equine	Other	Total
Loudoun	3	15	0	6	22	1	1	1	3	52
Mount Rogers	1	13	4	2	8	4	9	1	2	44
New River	3	9	1	2	6	2	7	0	3	33
Norfolk	0	1	0	1	1	0	0	0	0	3
Peninsula	0	6	1	5	10	0	0	0	2	24
Piedmont	1	4	1	3	22	7	2	1	2	43
Portsmouth	0	0	0	0	1	0	0	0	0	1
Prince William	7	8	2	4	5	1	1	0	3	35
Rappahannock	3	24	1	11	16	5	2	1	2	65
Rappahannock Rapidan	3	18	0	8	15	13	13	1	0	71
Richmond	0	0	0	0	3	0	0	0	0	3
Roanoke	0	2	0	0	1	0	0	0	1	4
Southside	0	9	2	6	2	1	0	1	0	21
Thomas Jefferson	2	10	3	5	22	7	3	0	3	55
Three Rivers	0	28	3	9	16	1	0	0	2	59
Virginia Beach	3	7	0	5	21	0	0	0	0	36
West Piedmont	1	3	4	2	16	1	1	0	0	28
Western Tidewater	0	6	1	1	3	0	0	0	1	12
Total	83	288	52	141	401	104	84	26	45	1224

TABLE 8. Annual totals for rabies virus variants detected by DCLS.

Virus Type	1996	1997	1998	1999	2000	2001	2002	2003	Total
Raccoon[a]	2	26	135	237	471	330	523	499	2407
Skunk	0	0	0	5	0	1	0	0	6
Bat	0	1	4	5	9	11	13	10	53
Unknown	0	1	7	10	6	4	8	5	41
Total	2	28	146	257	486	346	544	514	2507

[a] – Includes the raccoon B and new raccoon variants.

TABLE 9. Non-Raccoon A rabies virus variants by year and locality (excluding bat strains).

Virus Type	1999	2000	2001	2002	2003	Total
Raccoon B	Prince William (1[a])	Prince William (1)	-	Accomack (1) Clarke (1) Warren (1)	Clarke (1)	6
New Raccoon	Fredericksburg (1)	Fredericksburg (1)	-	-	-	2
Skunk	Bristol (1) Scott (4)	-	Scott (1)	-	-	6
Total	7	2	1	3	1	14

[a] – Number of cases given in parentheses.

FIGURE 1.

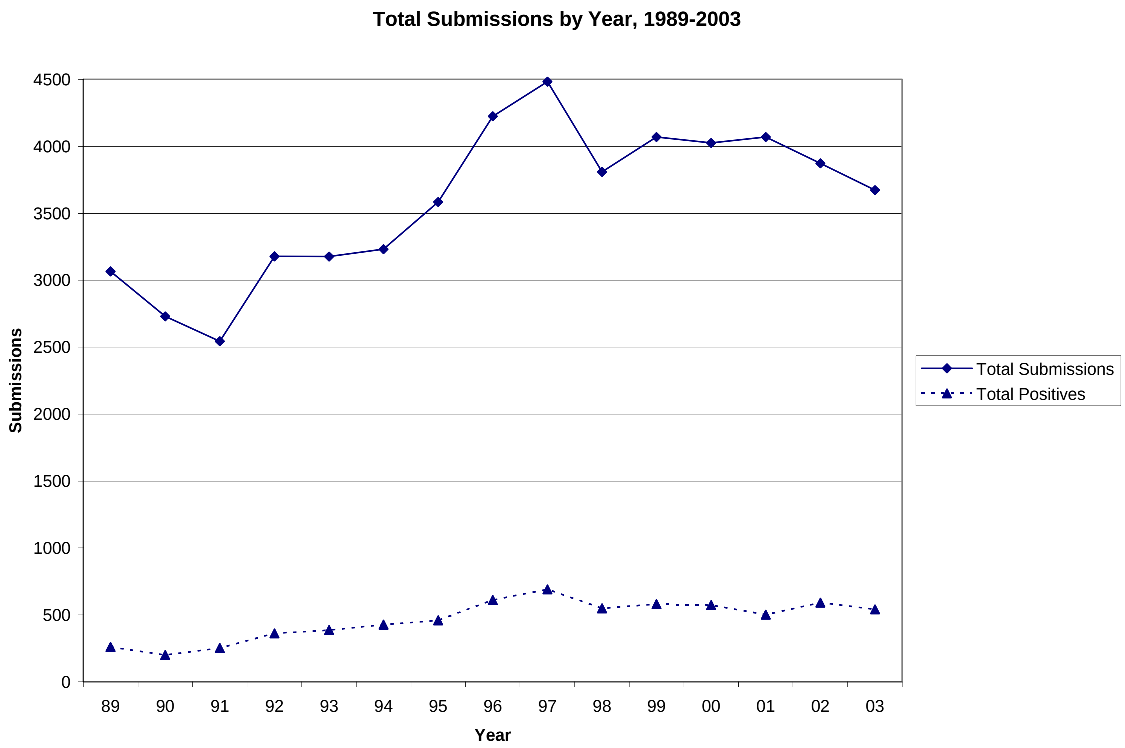


FIGURE 2.

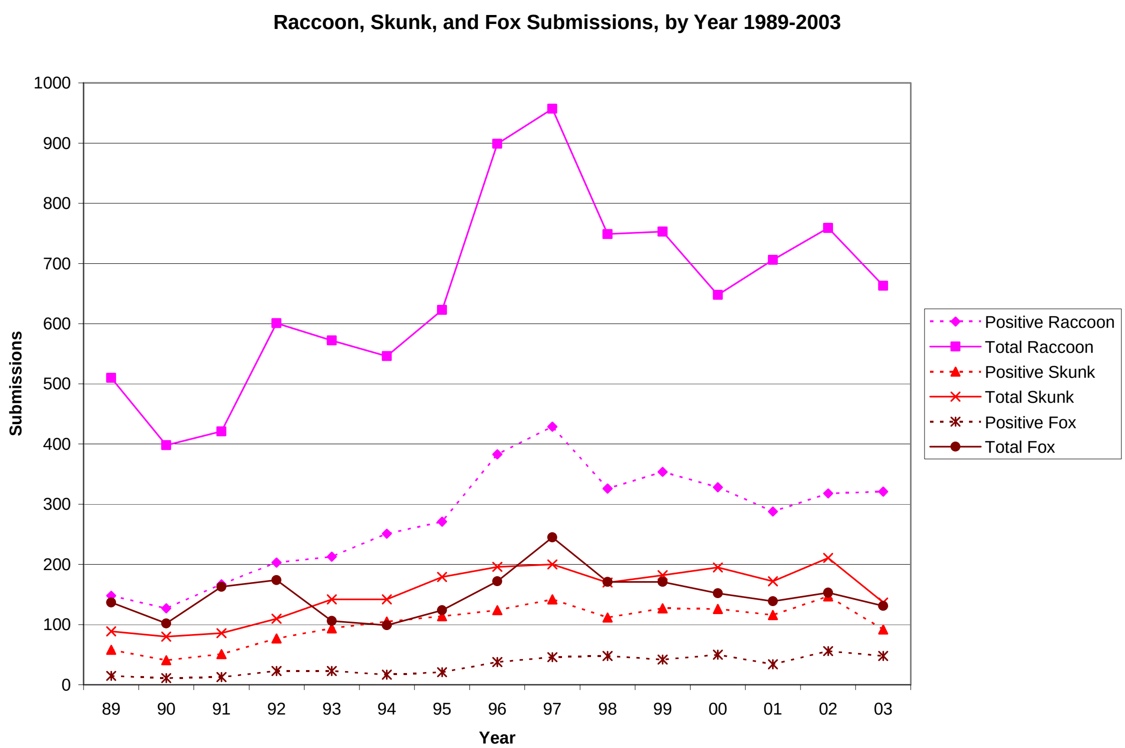


FIGURE 3.

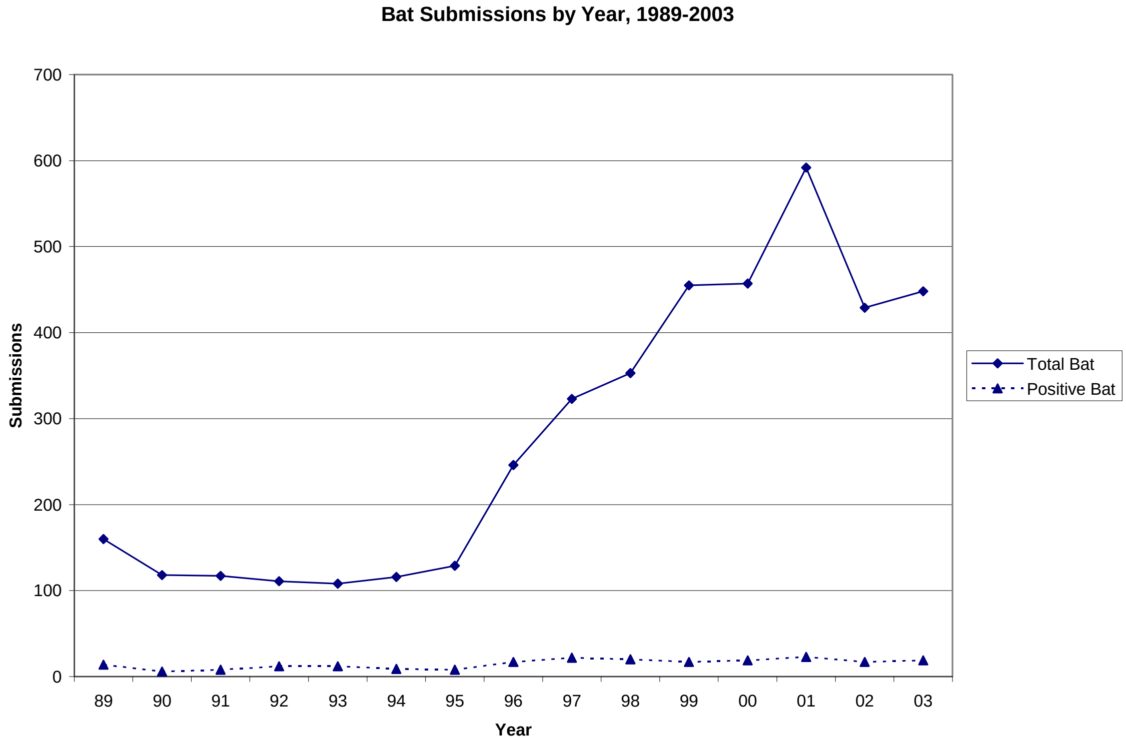


FIGURE 4.

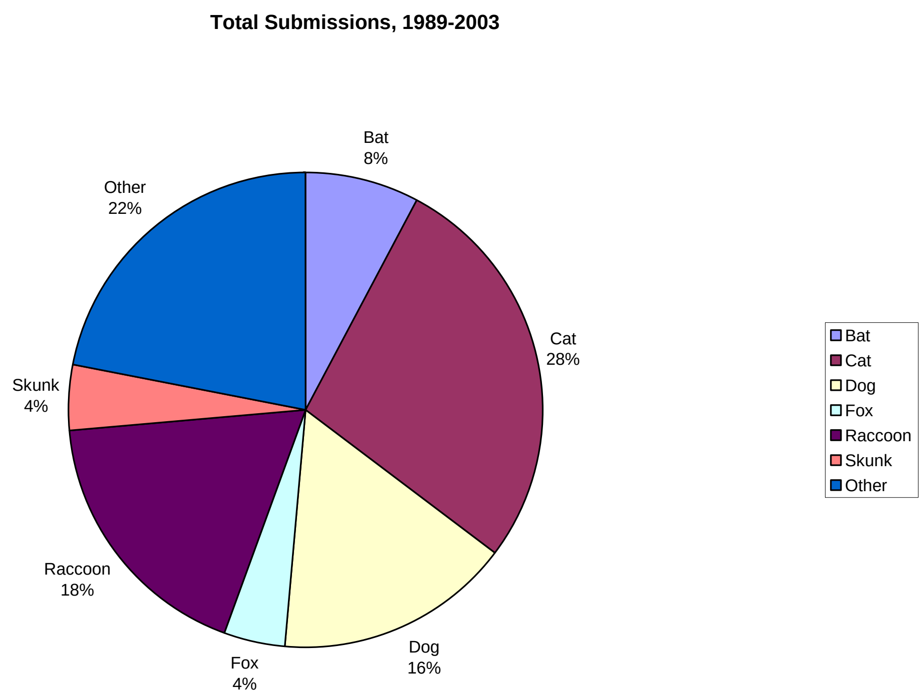


FIGURE 5.

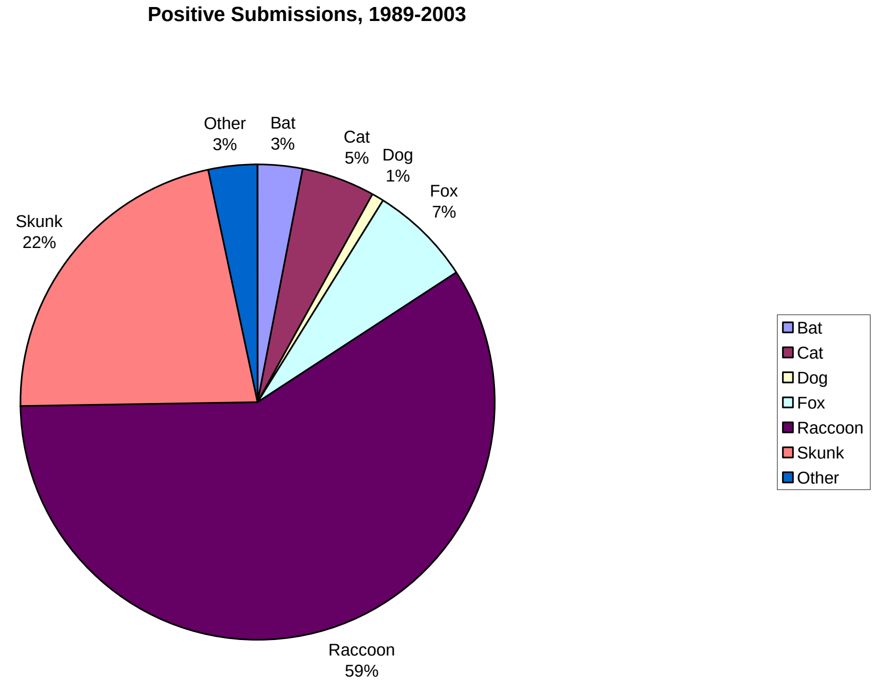


FIGURE 6a.

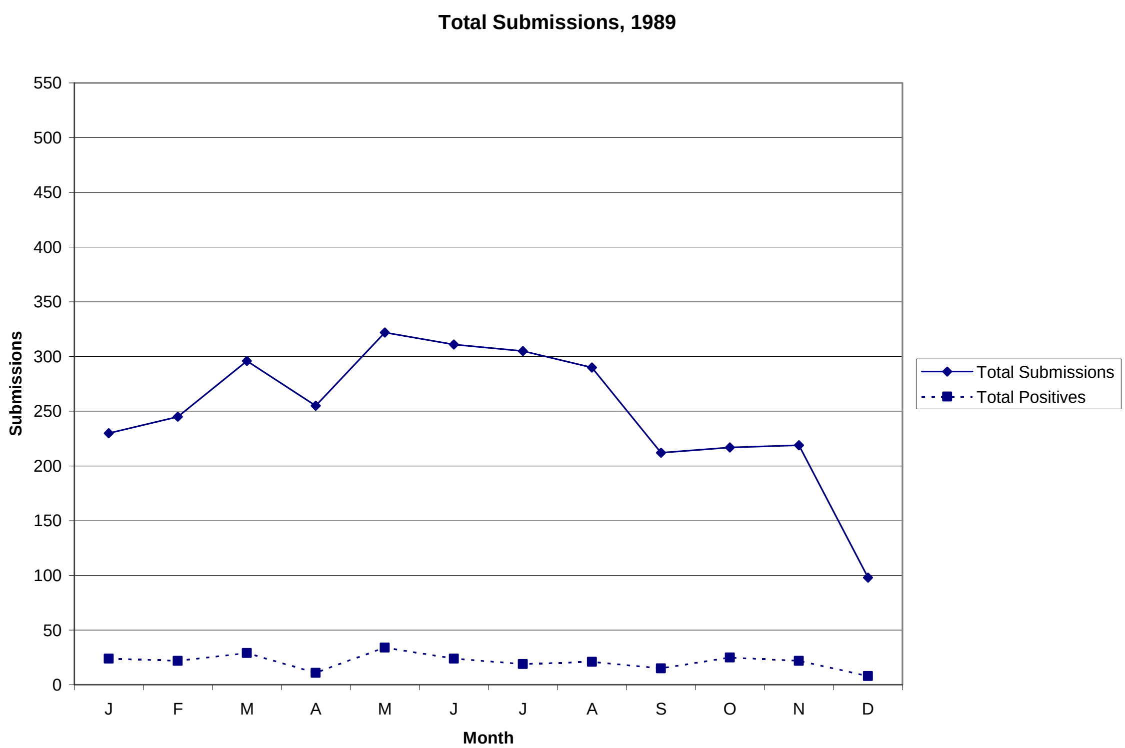


FIGURE 6b.

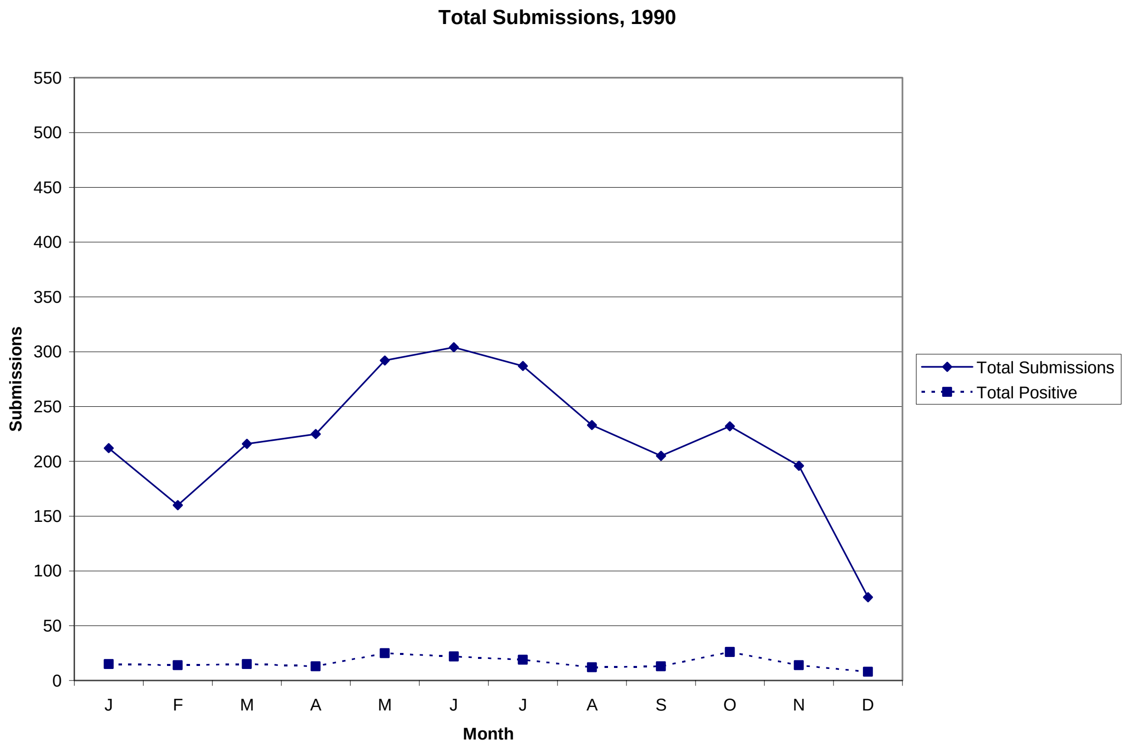


FIGURE 6c.

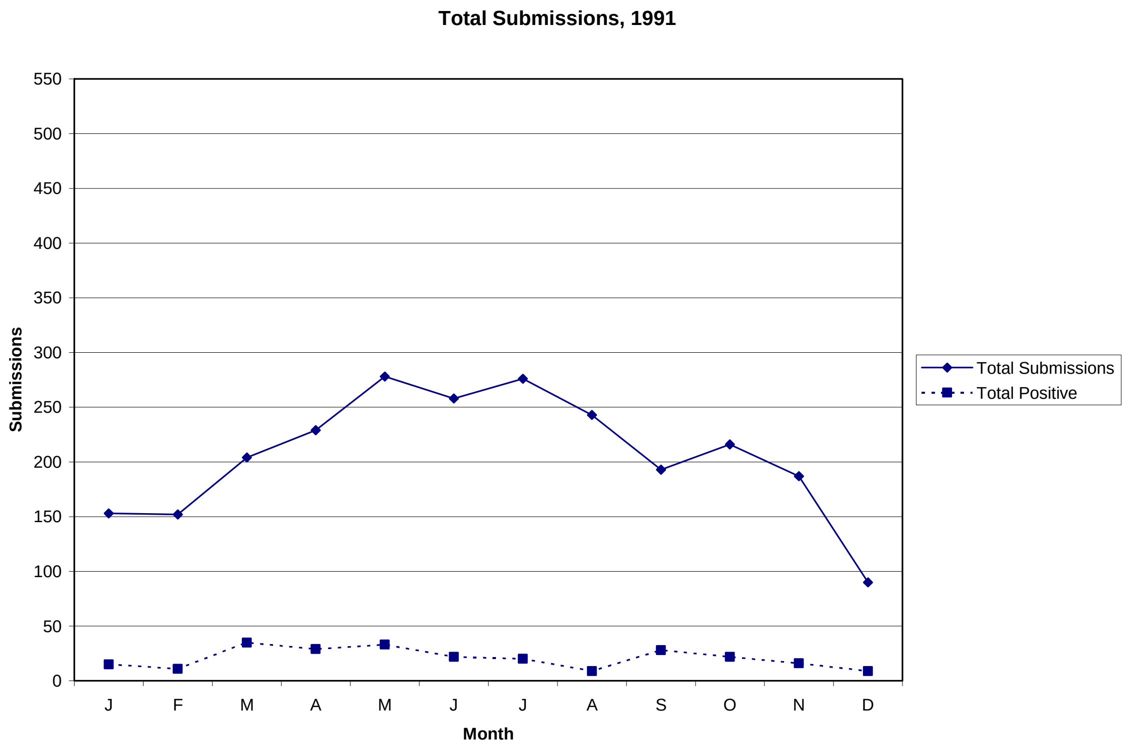


FIGURE 6d.

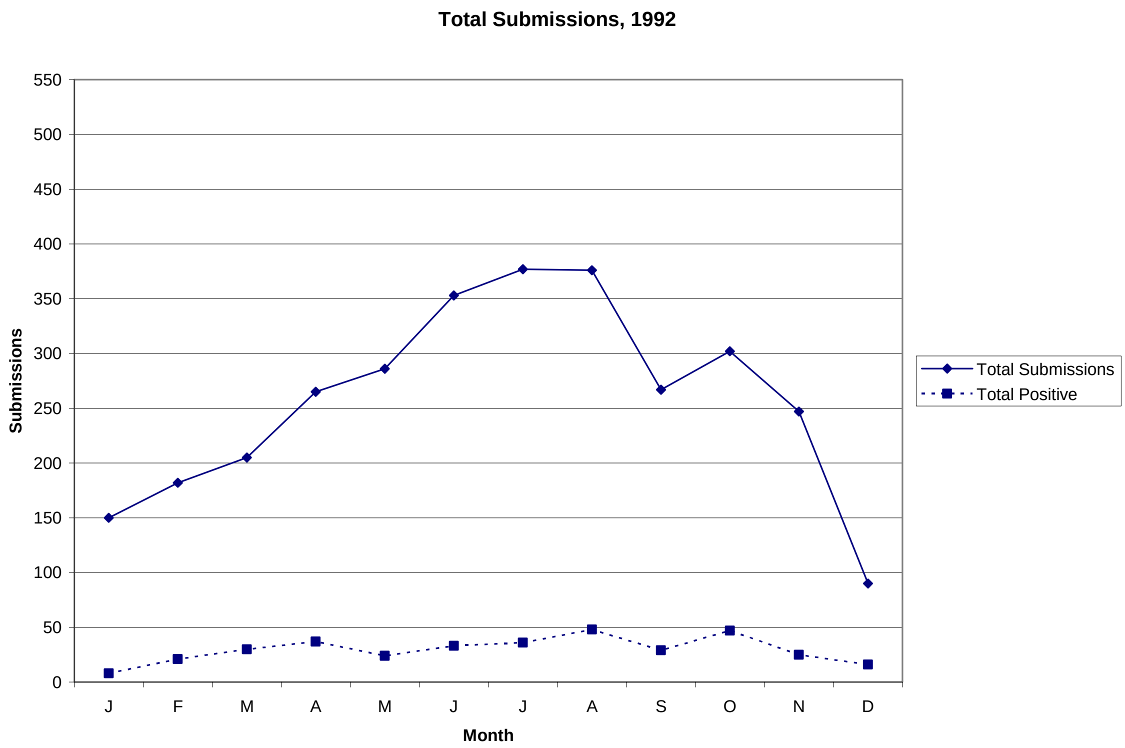


FIGURE 6e.

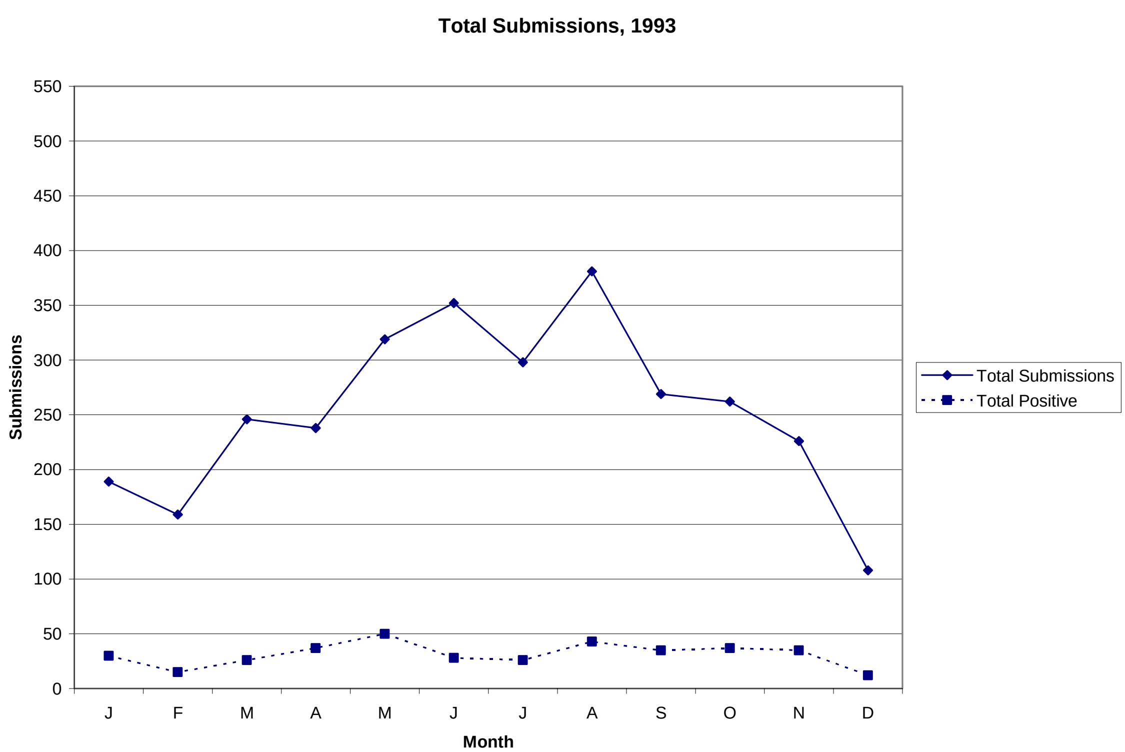


FIGURE 6f.

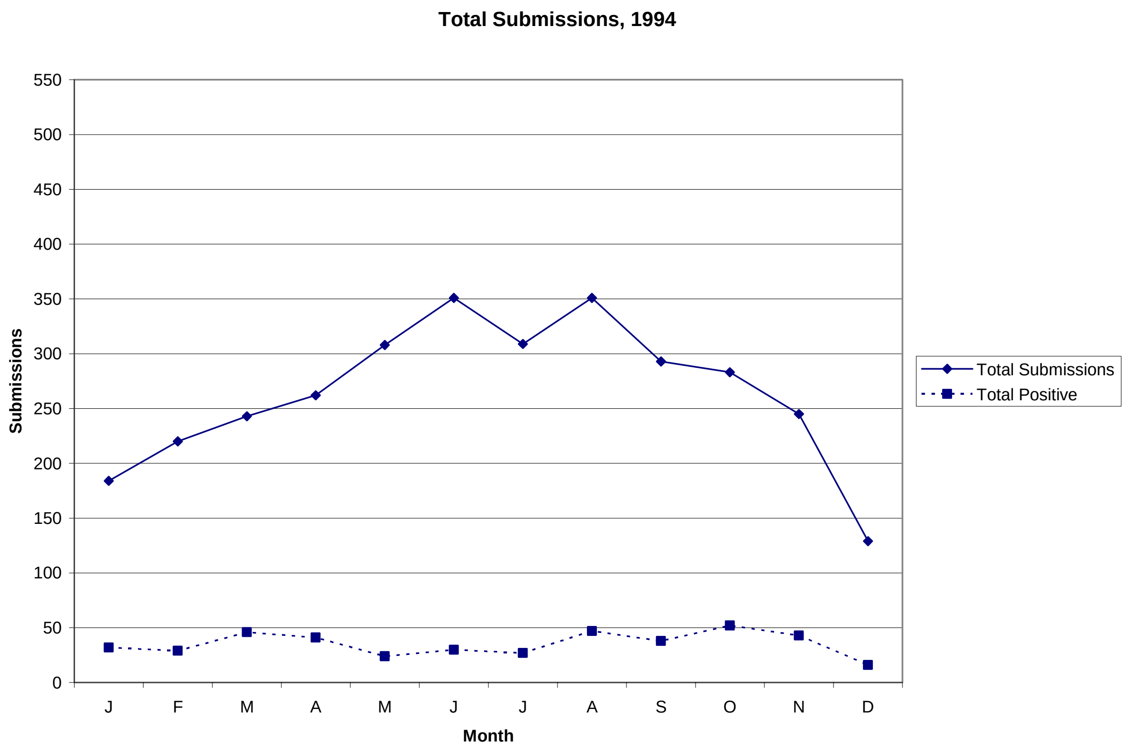


FIGURE 6g.

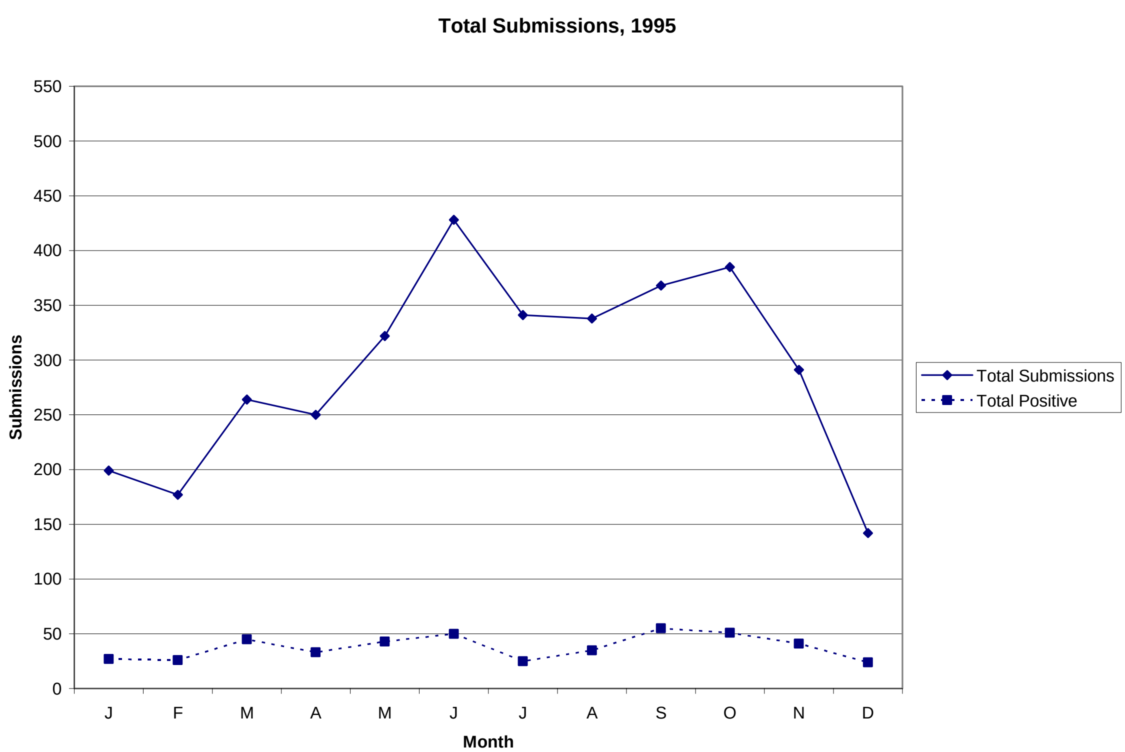


FIGURE 6h.

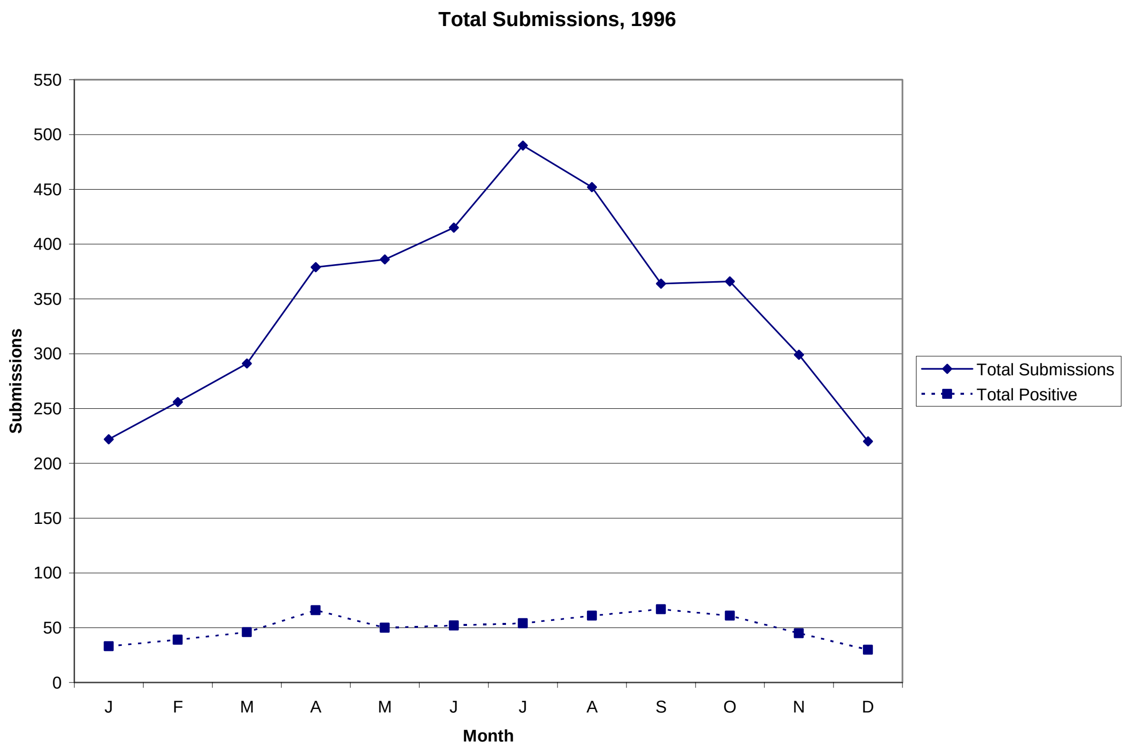


FIGURE 6i.

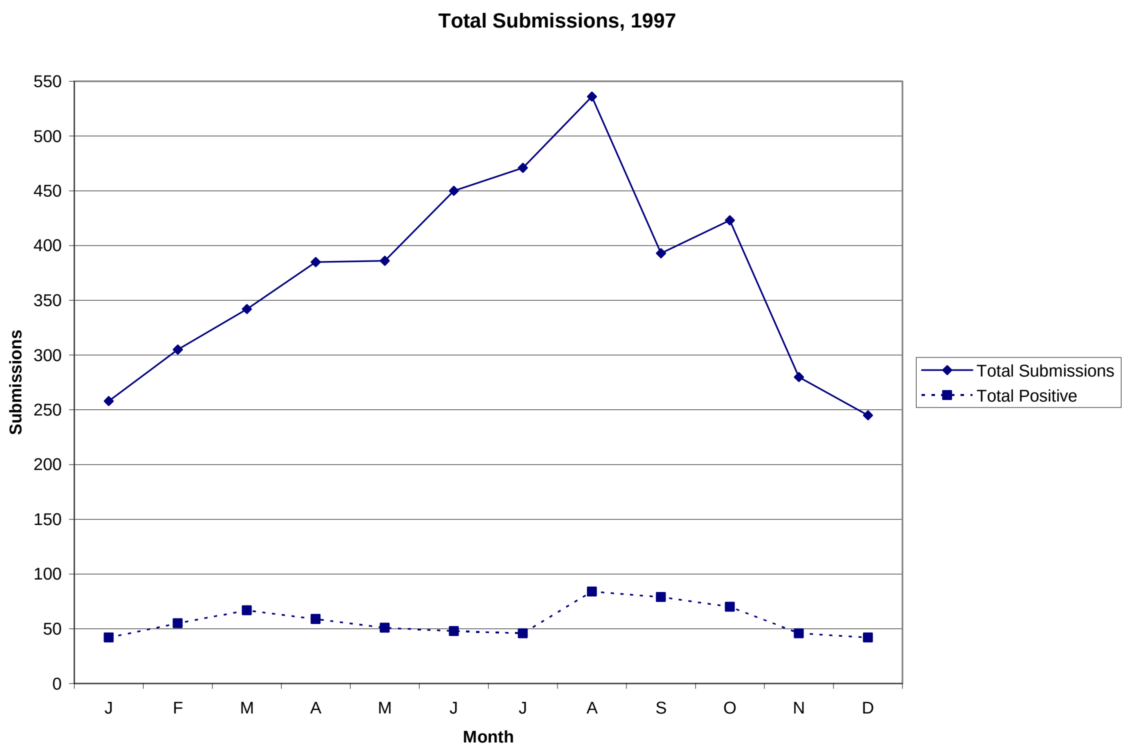


FIGURE 6j.

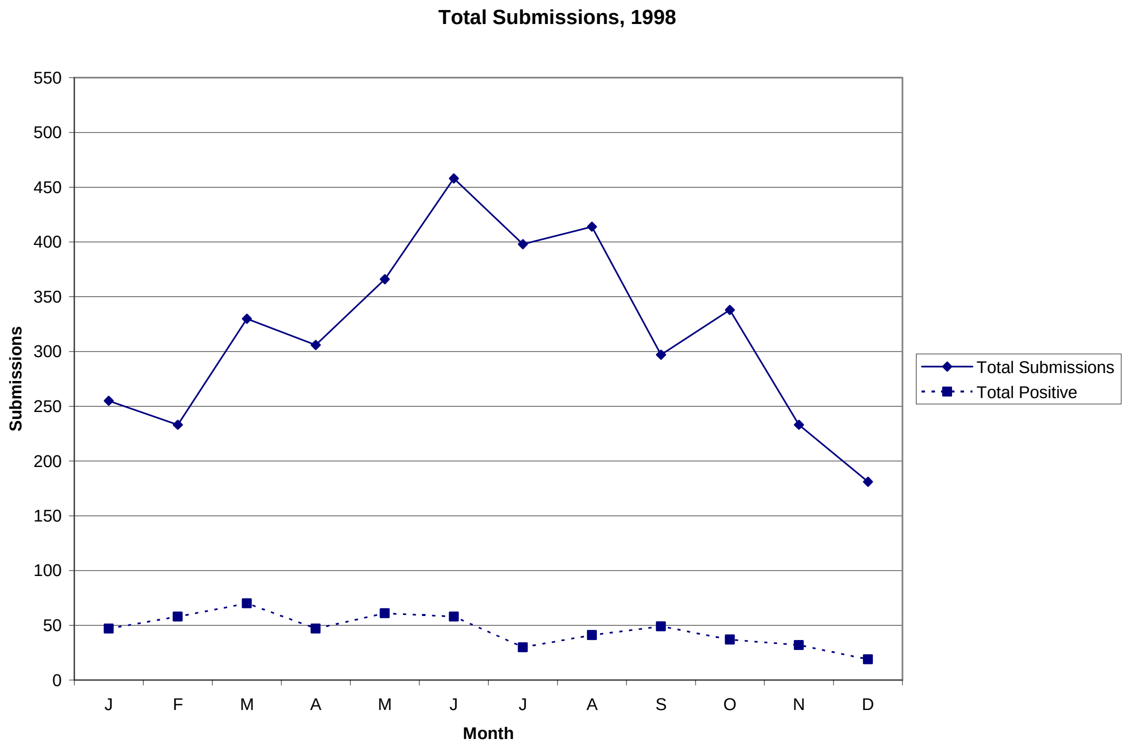


FIGURE 6k.

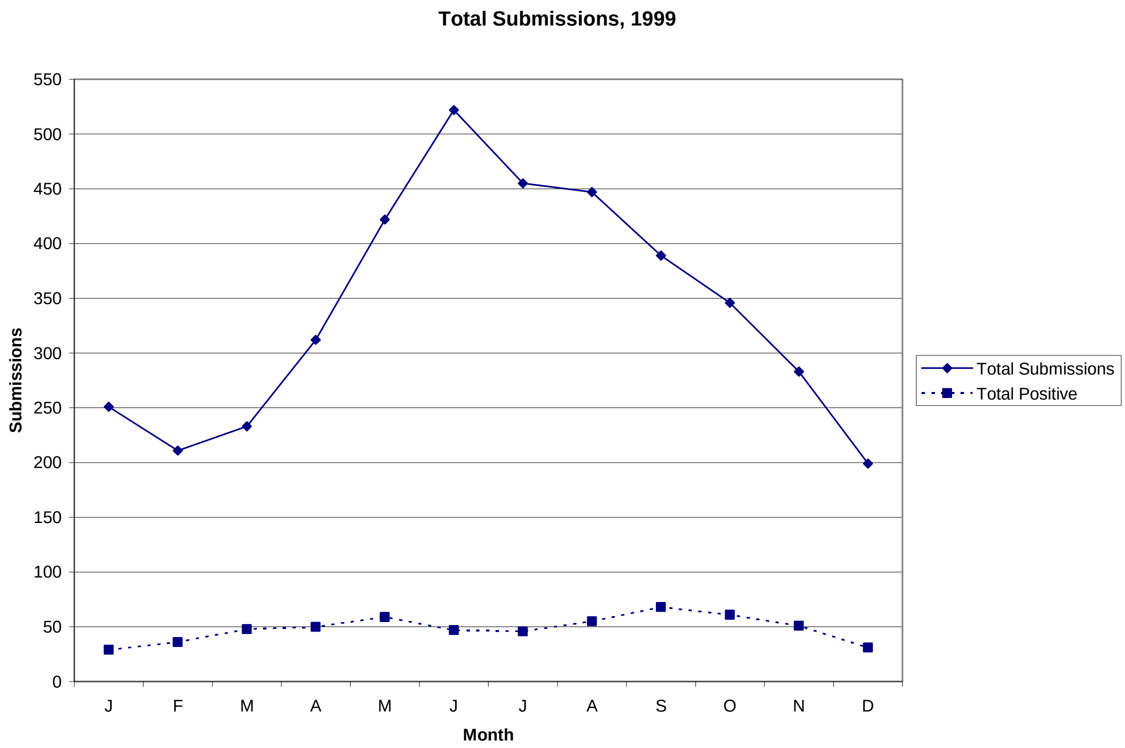


FIGURE 6l.

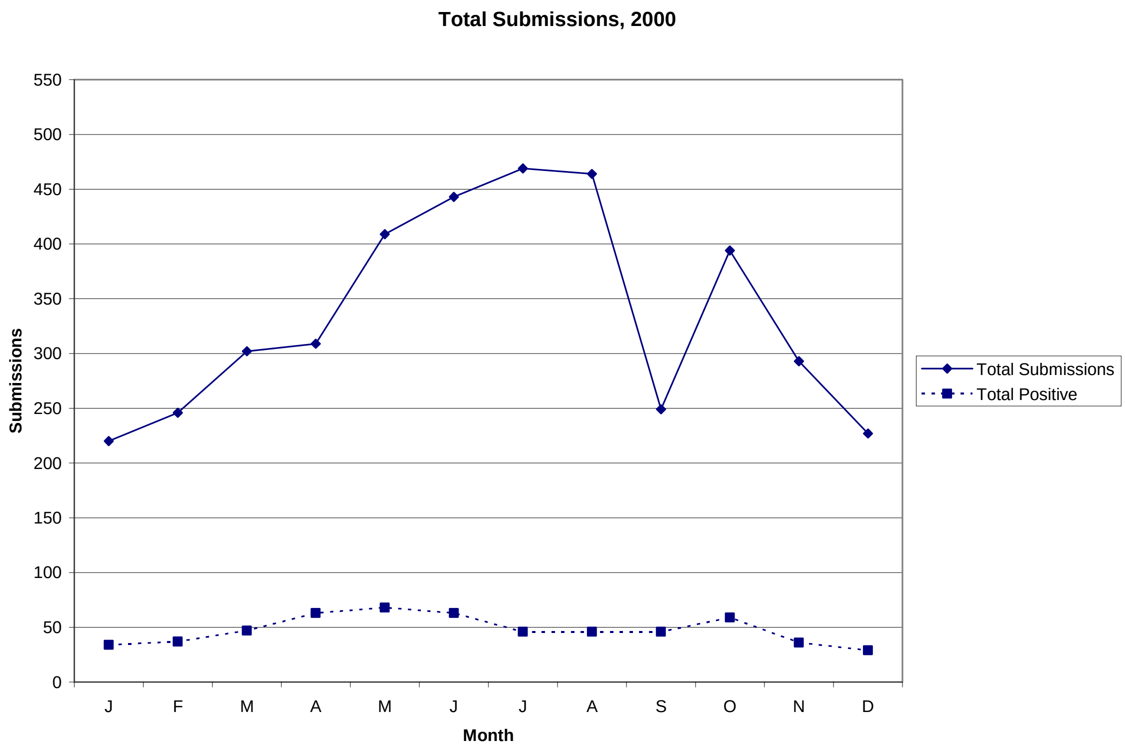


FIGURE 6m.

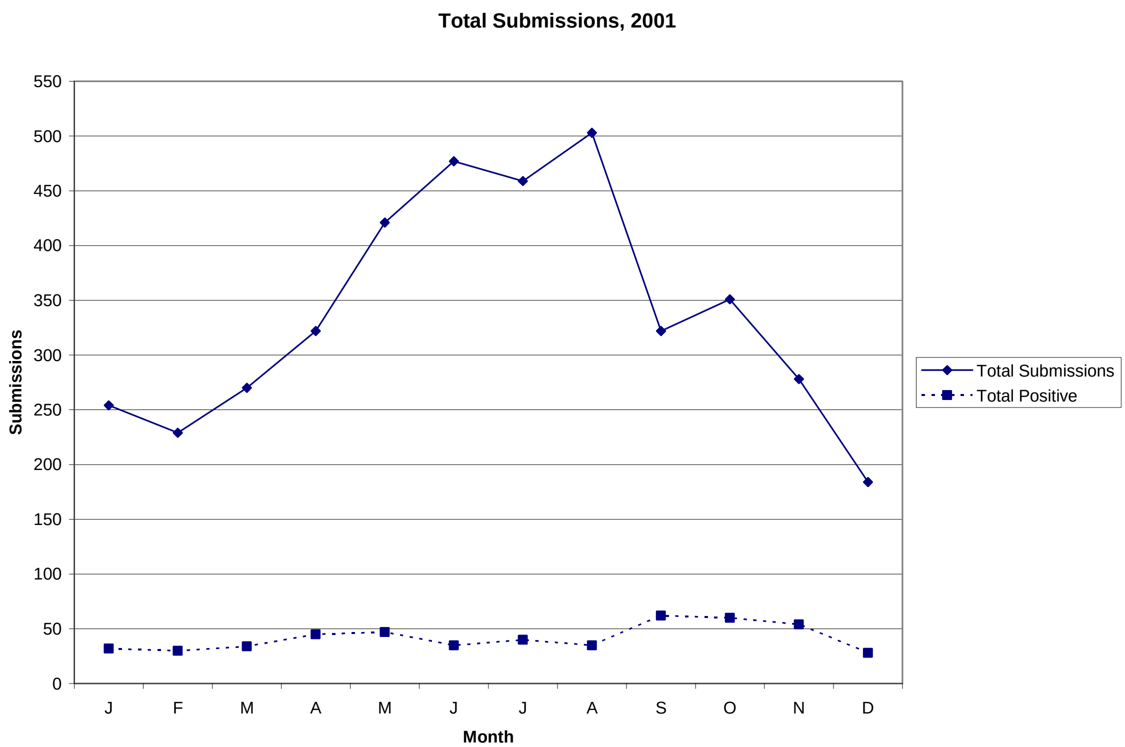


FIGURE 6n.

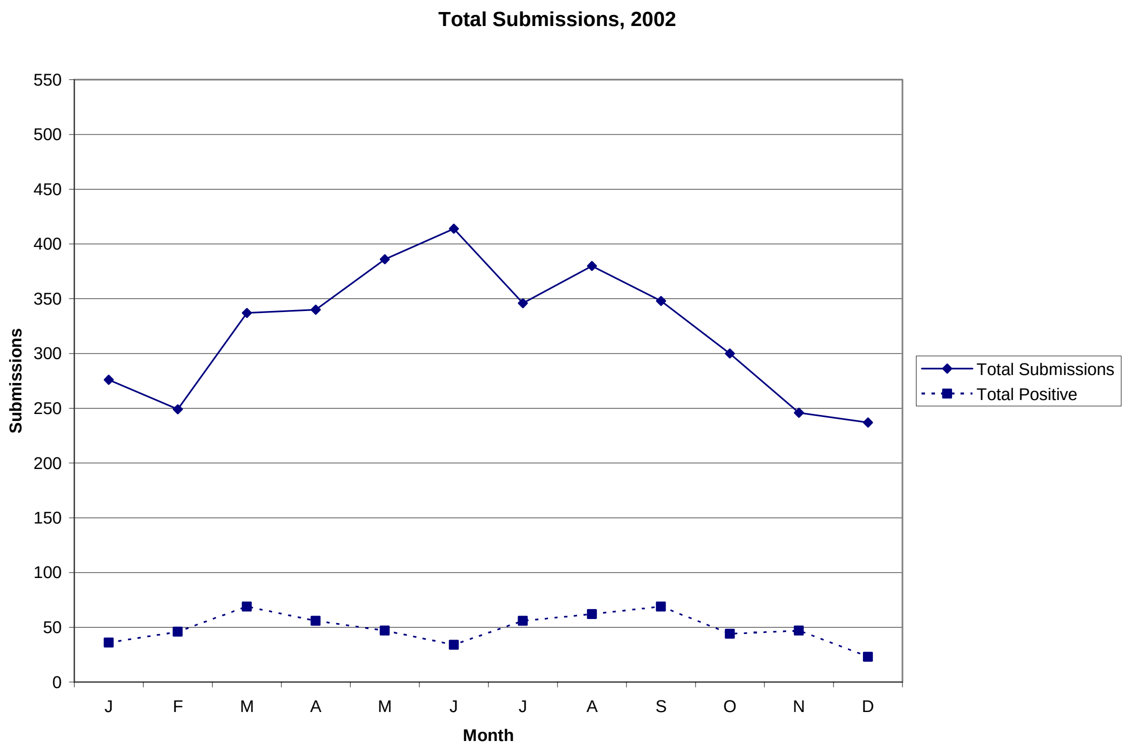


FIGURE 6o.

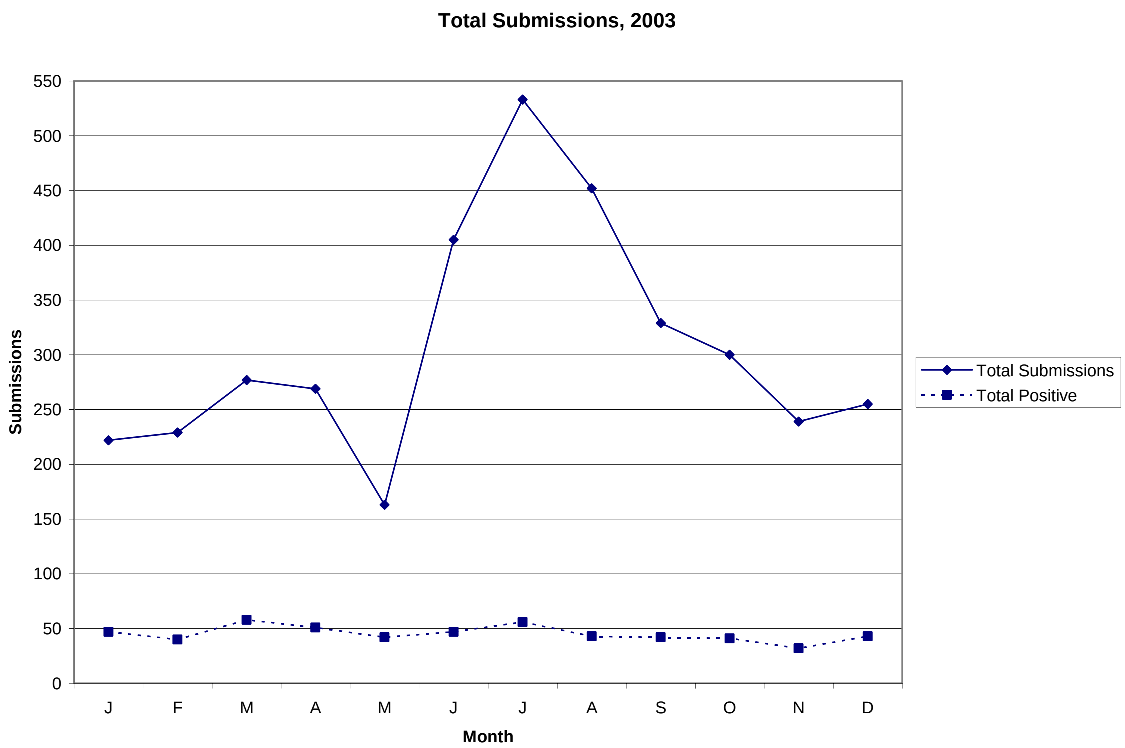


FIGURE 7a.

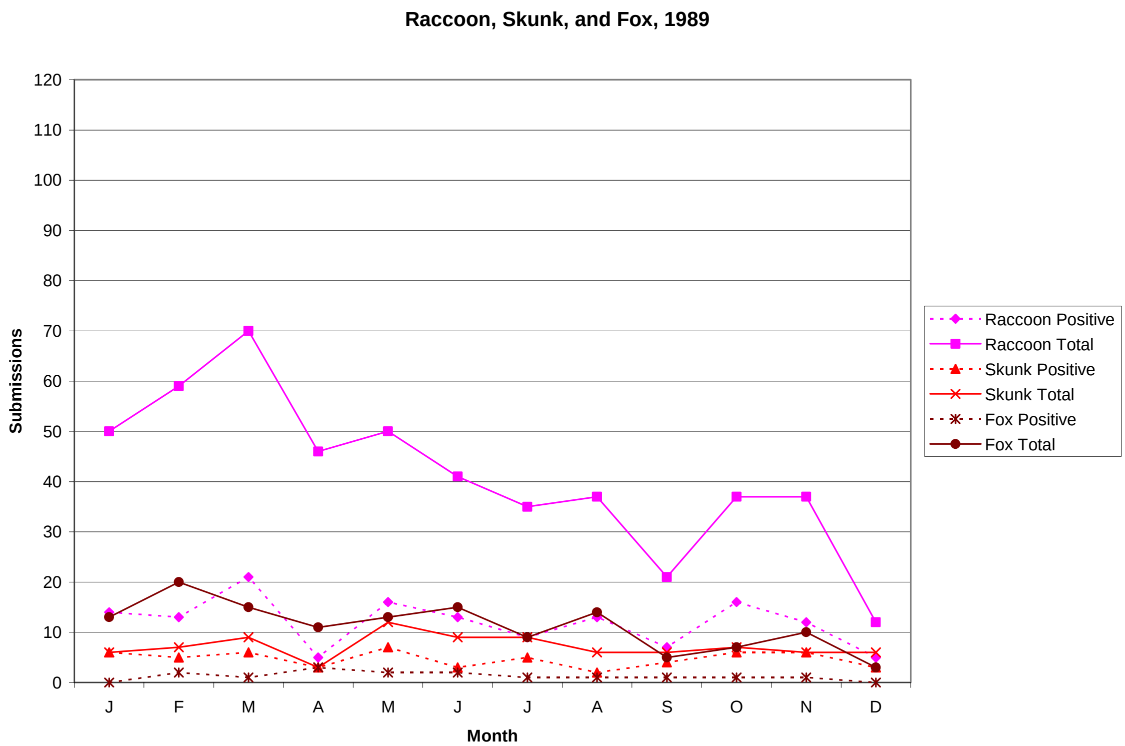


FIGURE 7b.

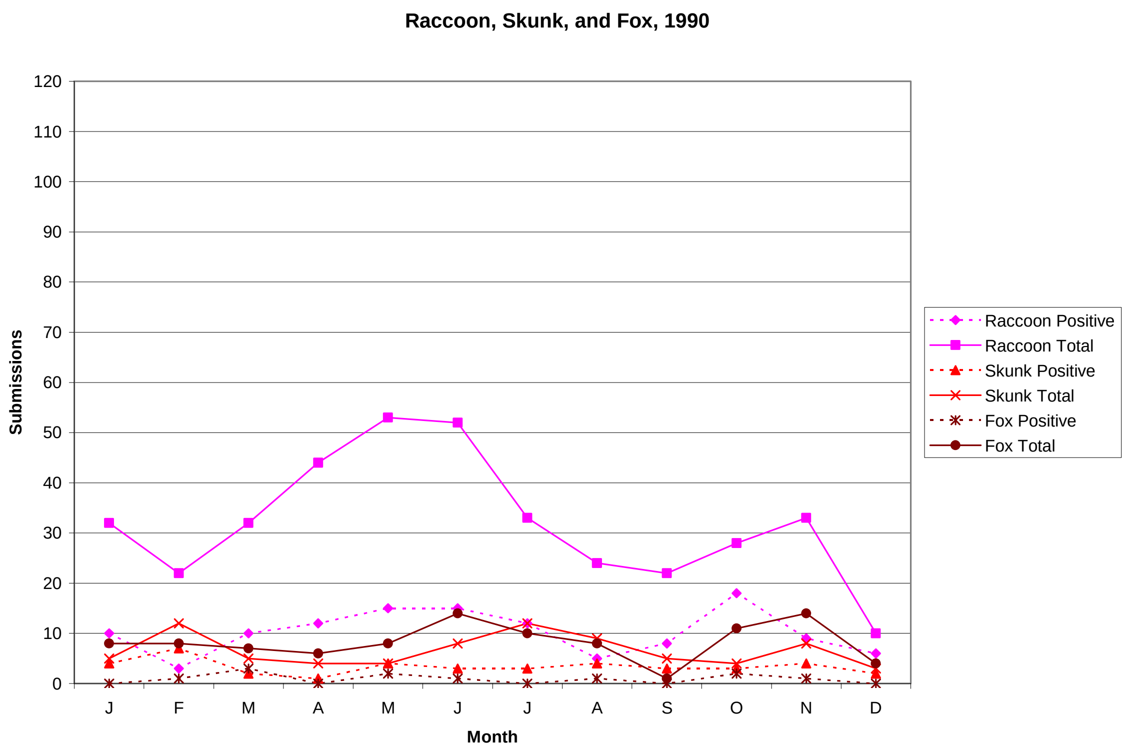


FIGURE 7c.

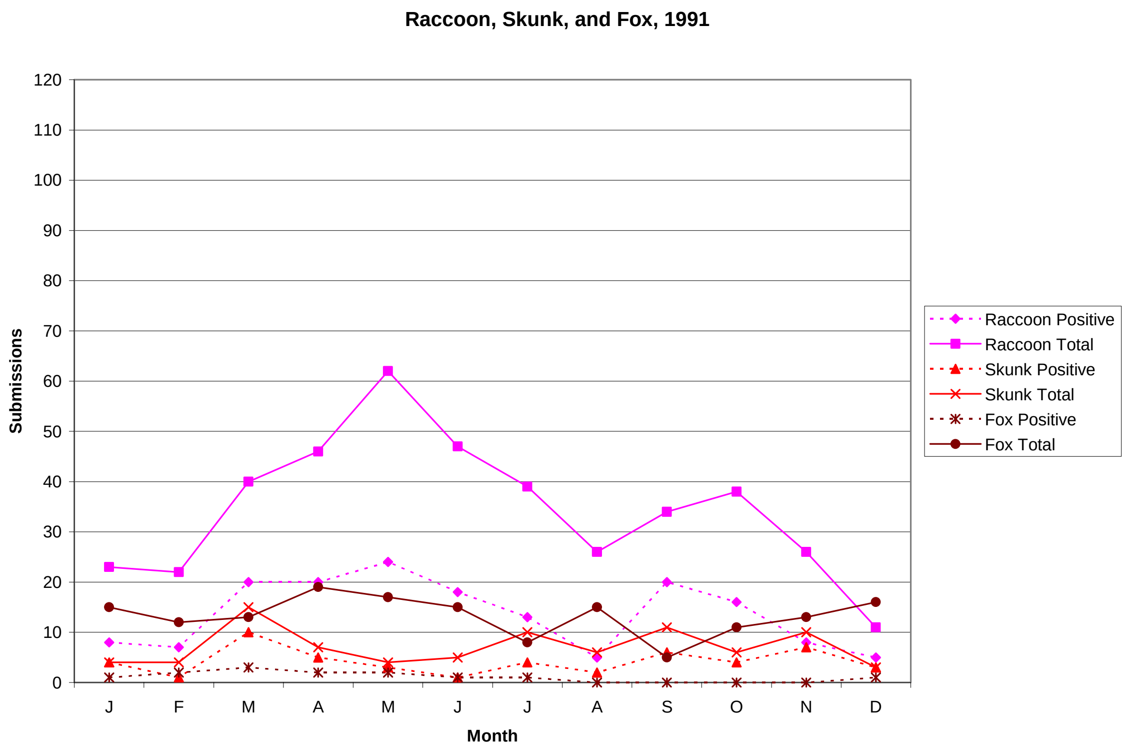


FIGURE 7d.

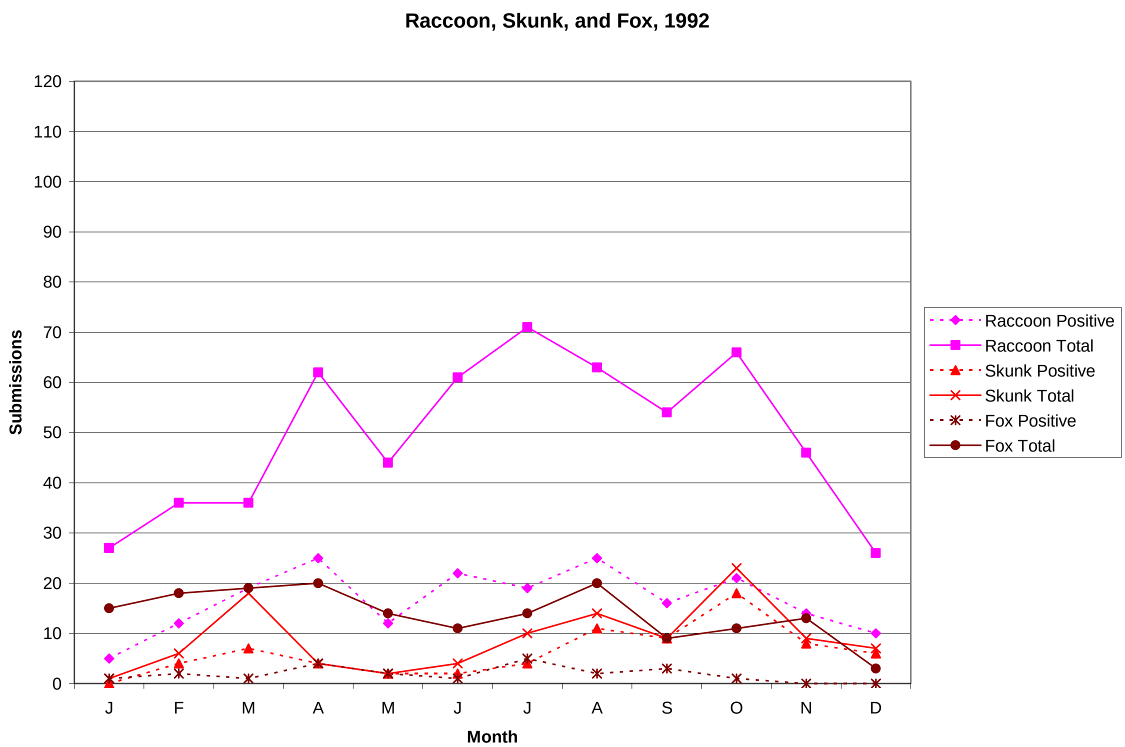


FIGURE 7e.

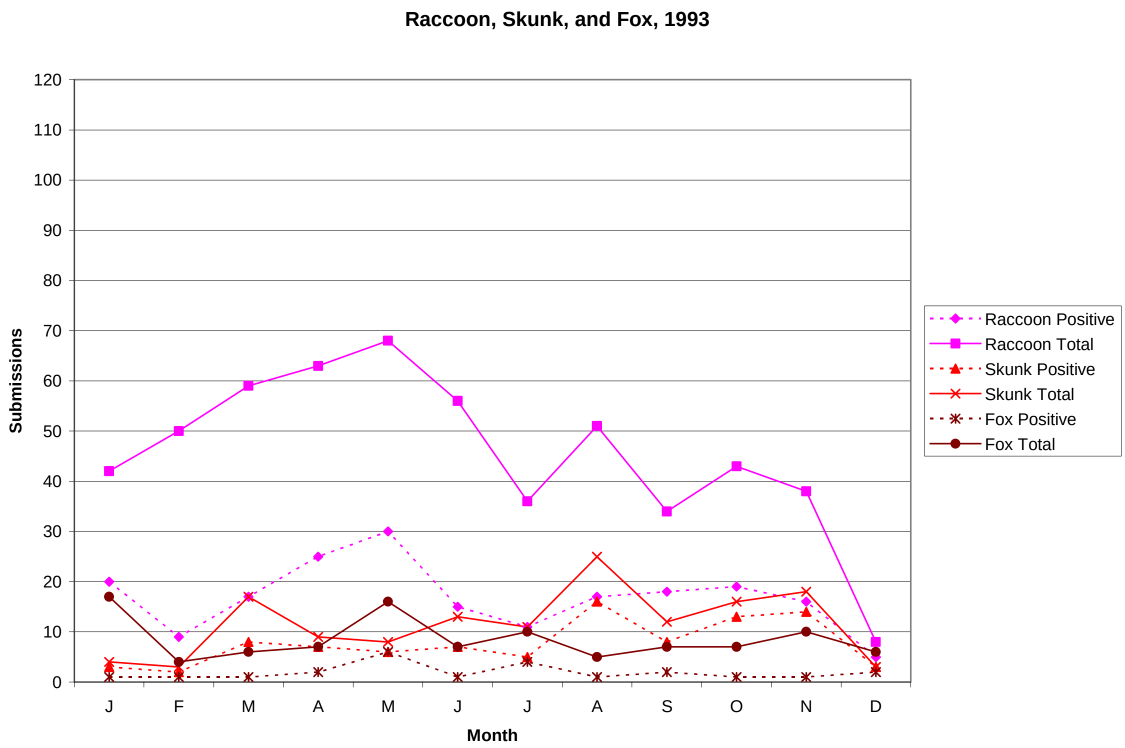


FIGURE 7f.

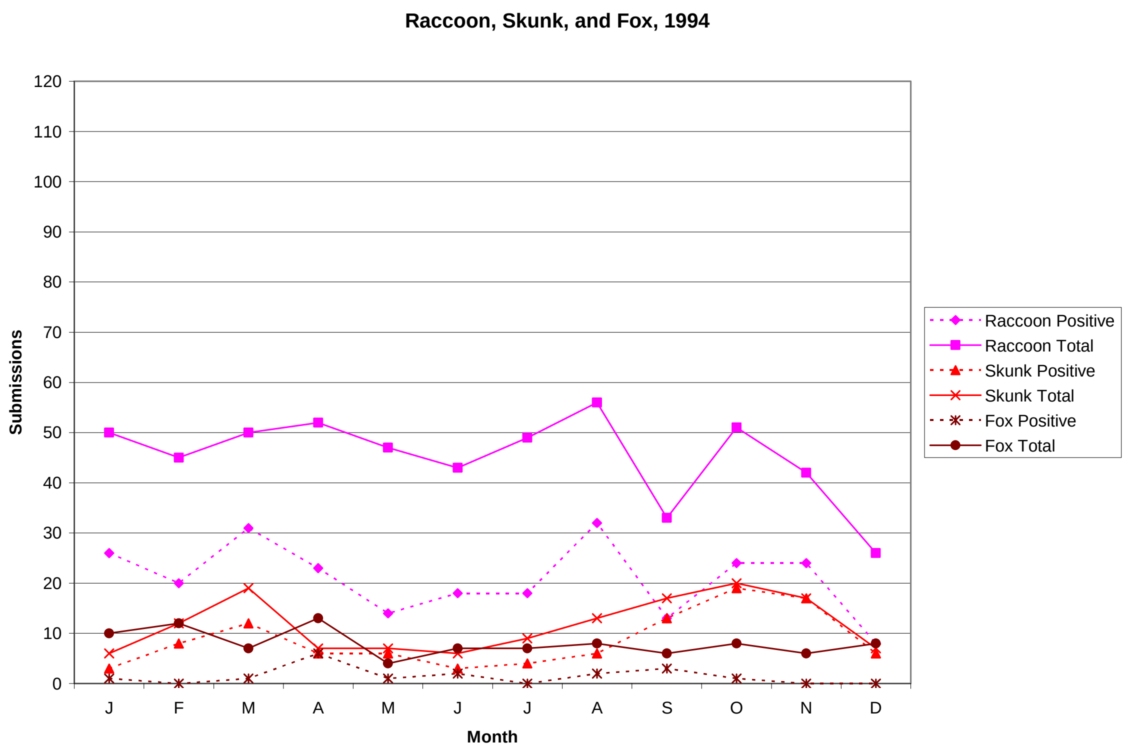


FIGURE 7g.

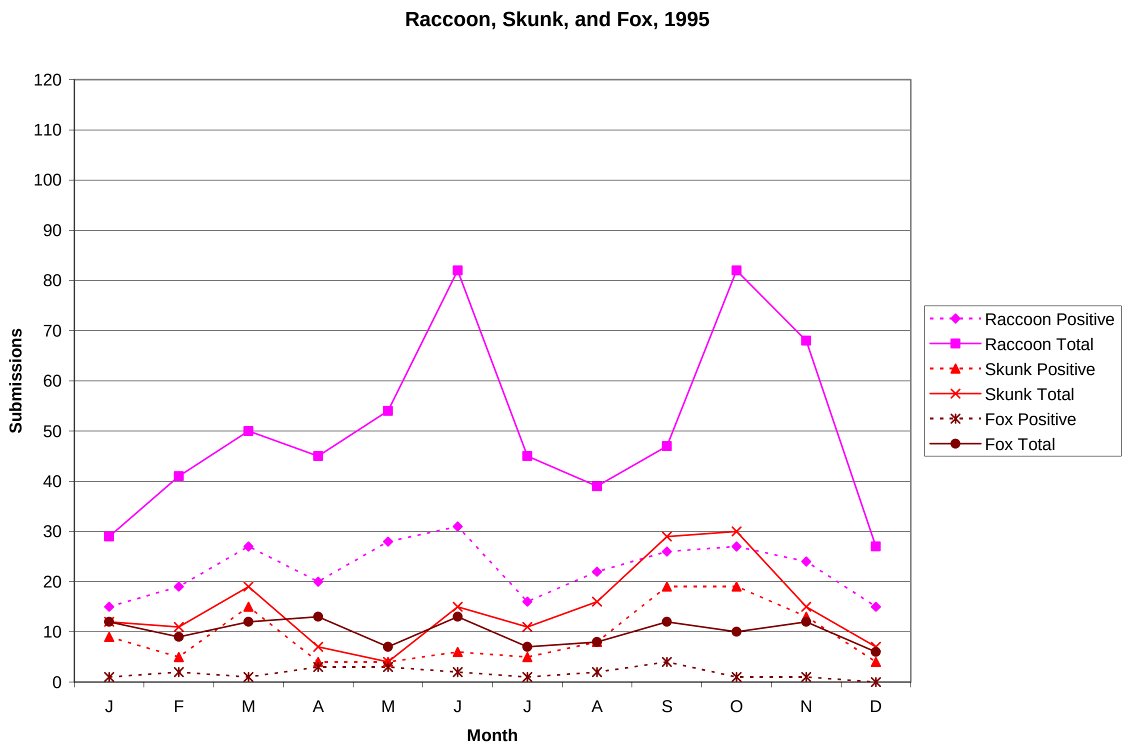


FIGURE 7h.

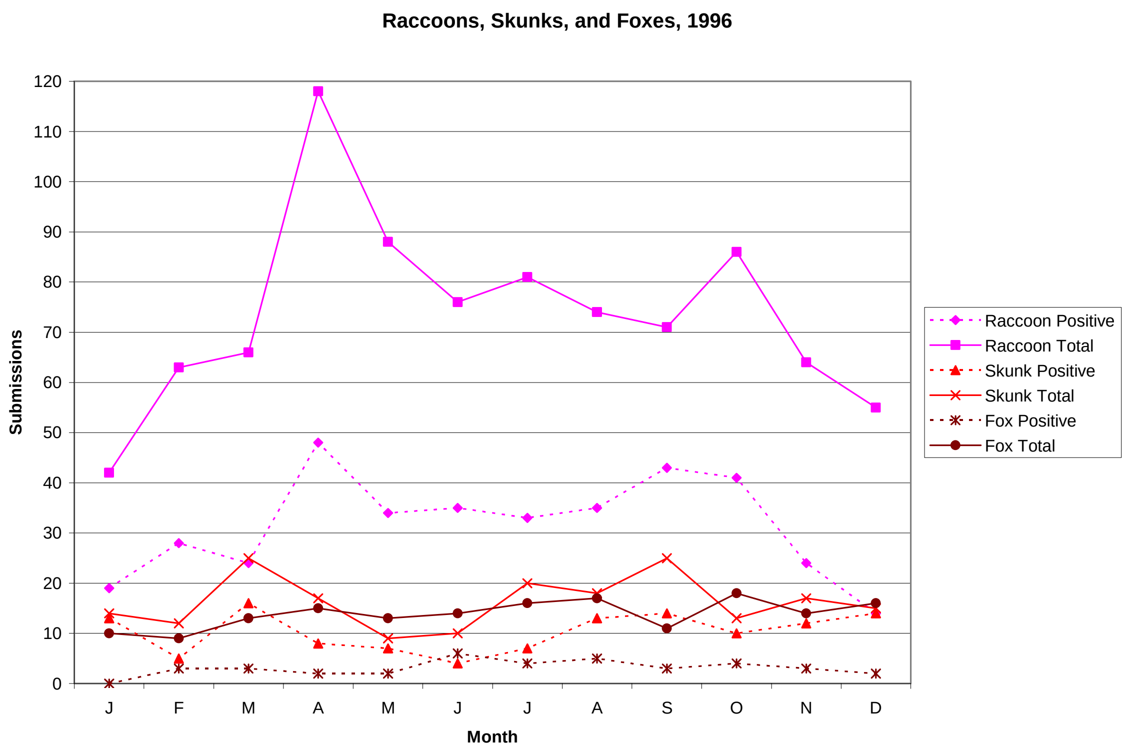


FIGURE 7i.

Raccoon, Skunk, and Fox, 1997

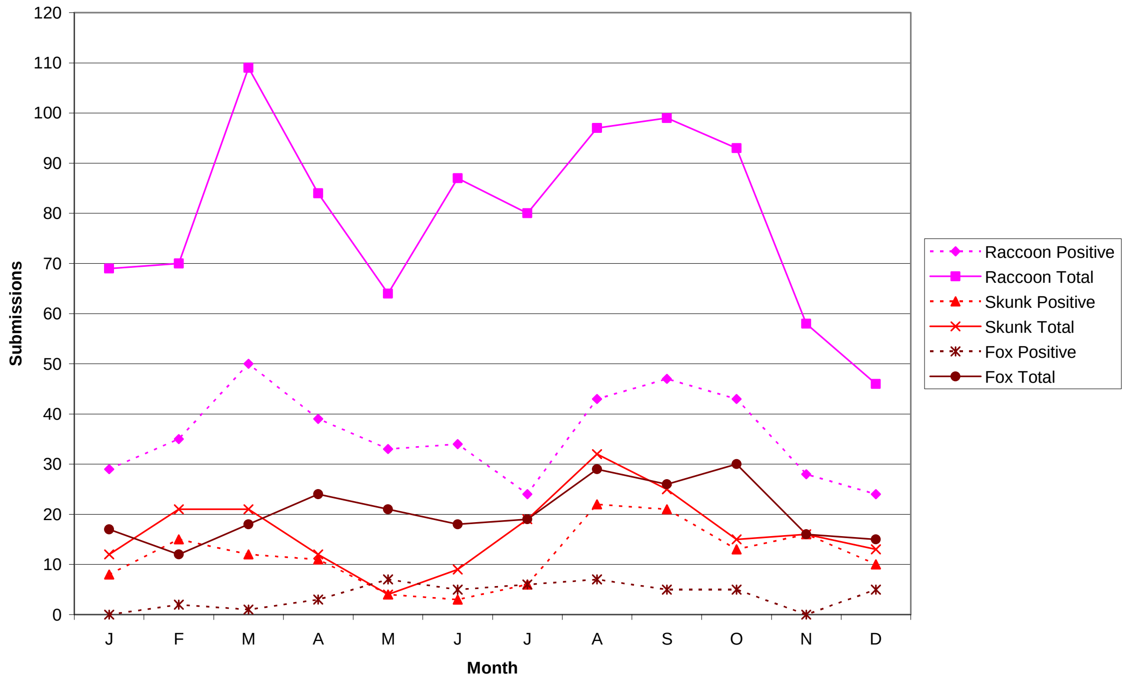


FIGURE 7j.

Raccoon, Skunk, and Fox, 1998

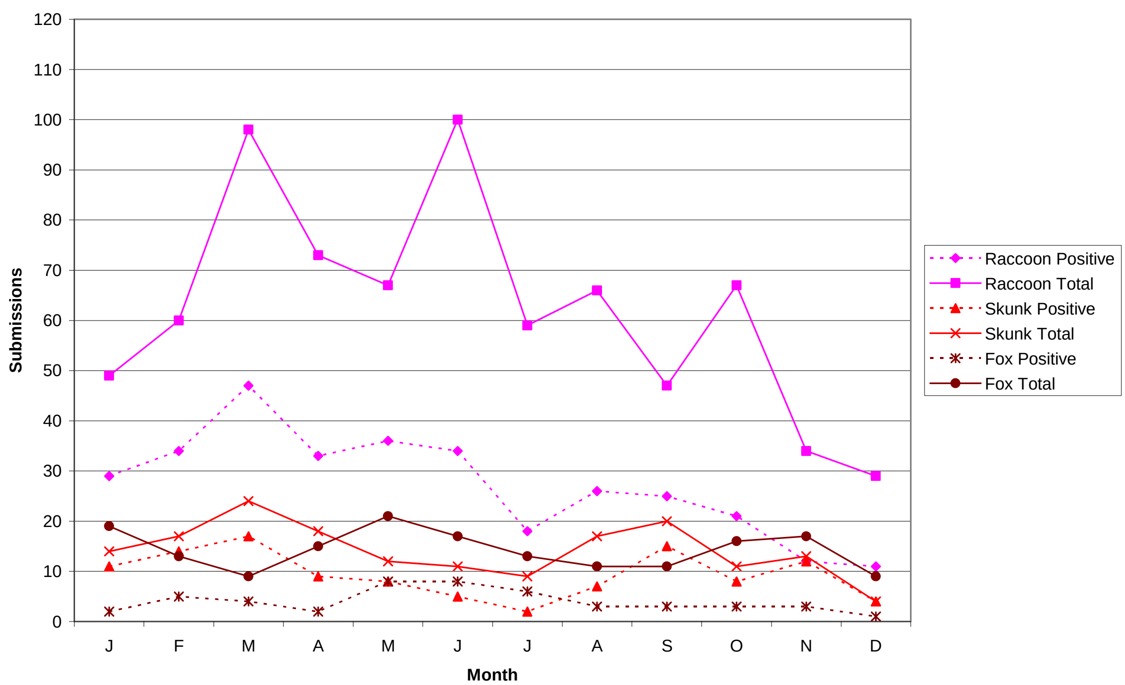


FIGURE 7k.

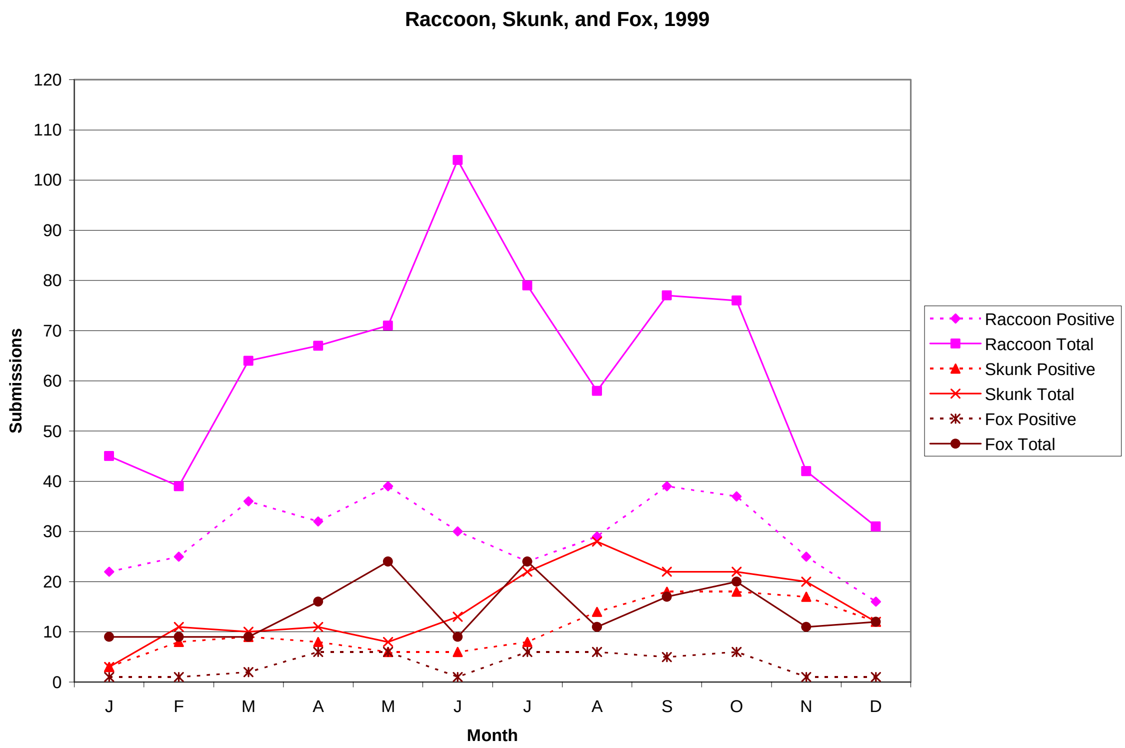


FIGURE 7l.

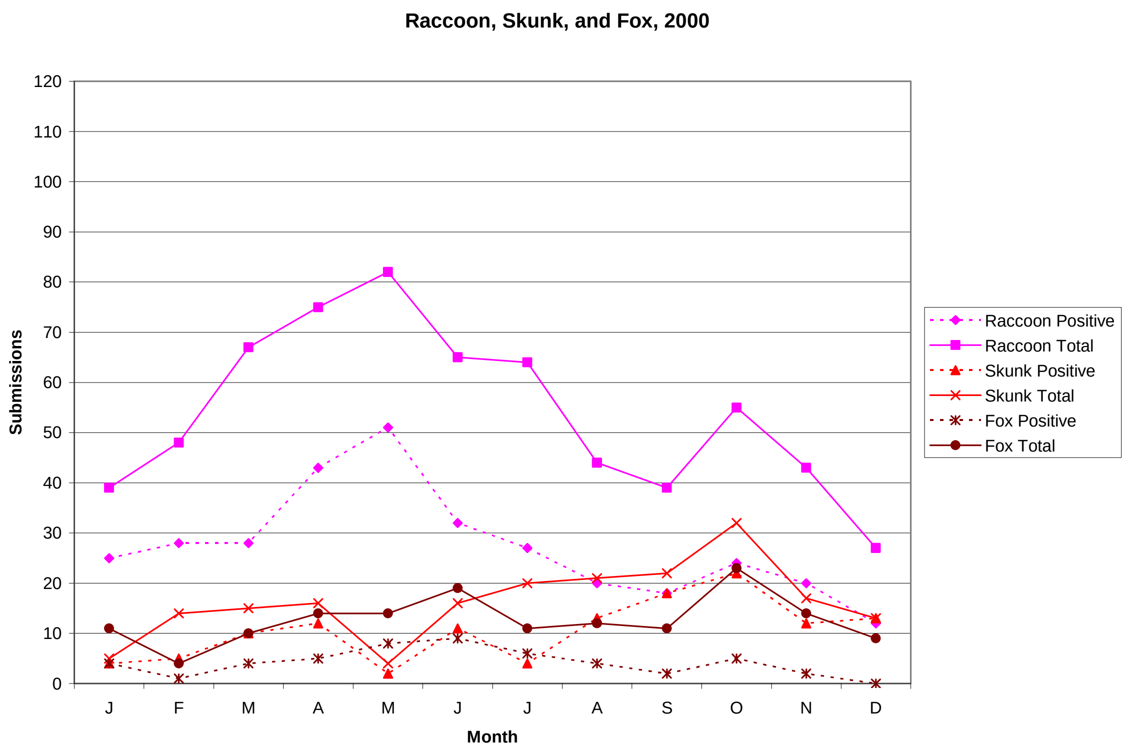


FIGURE 7m.

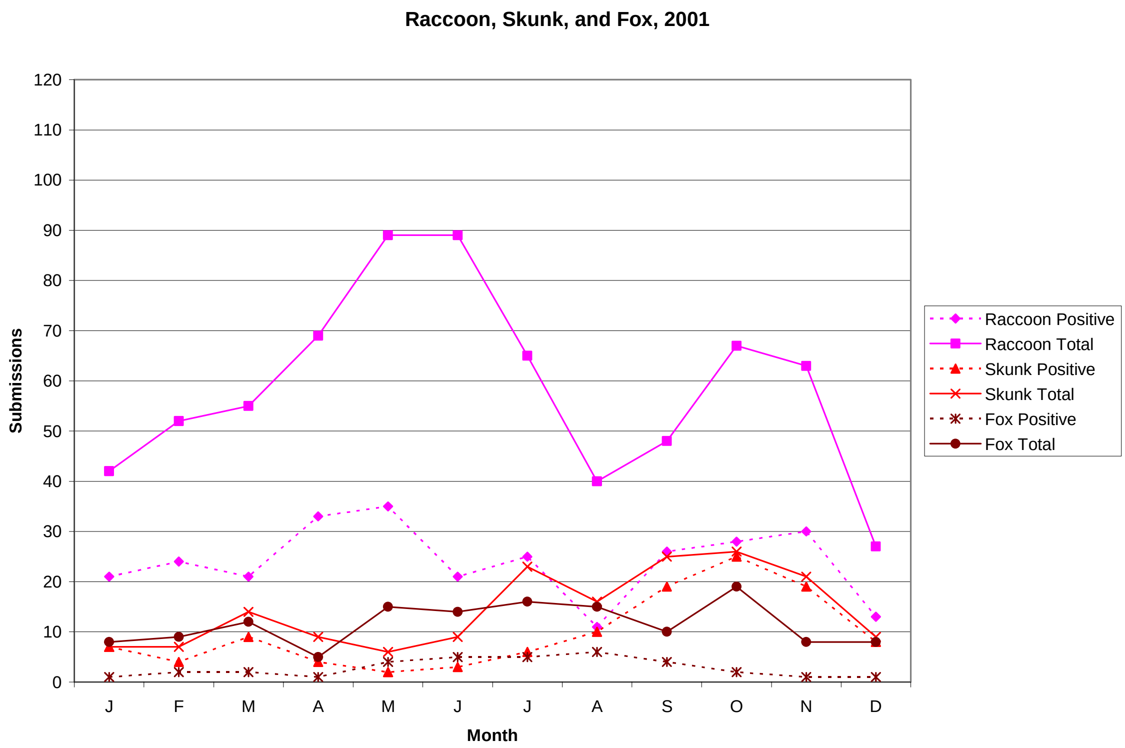


FIGURE 7n.

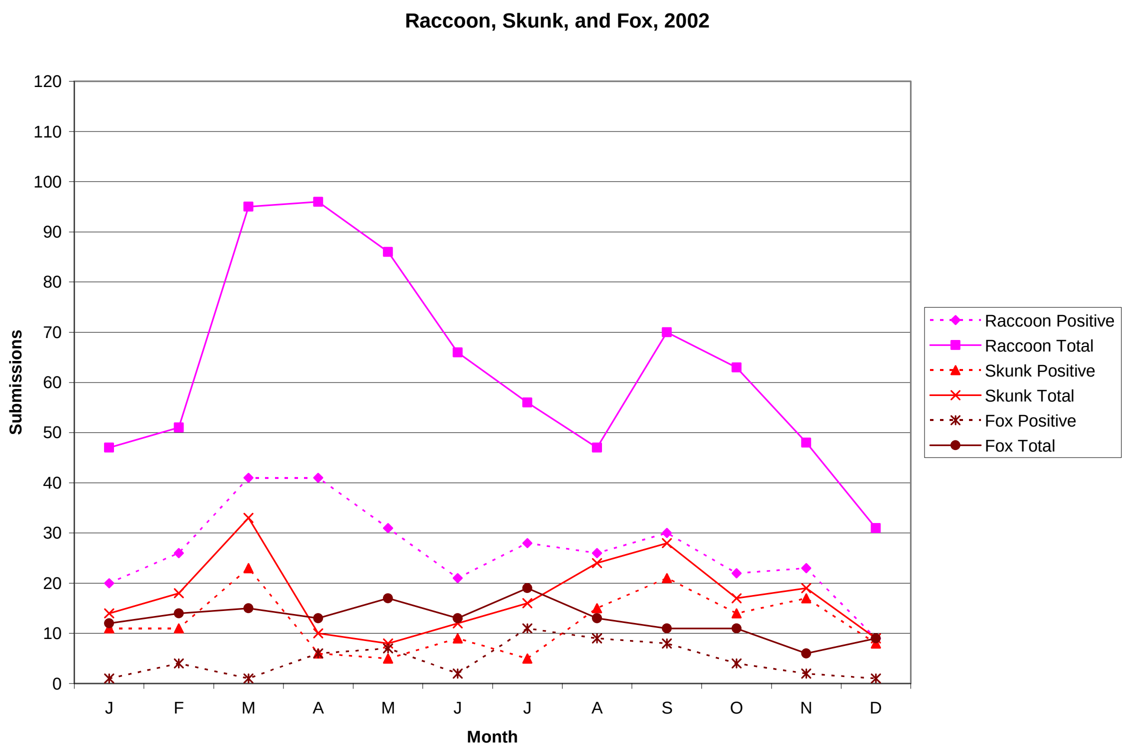


FIGURE 7o.

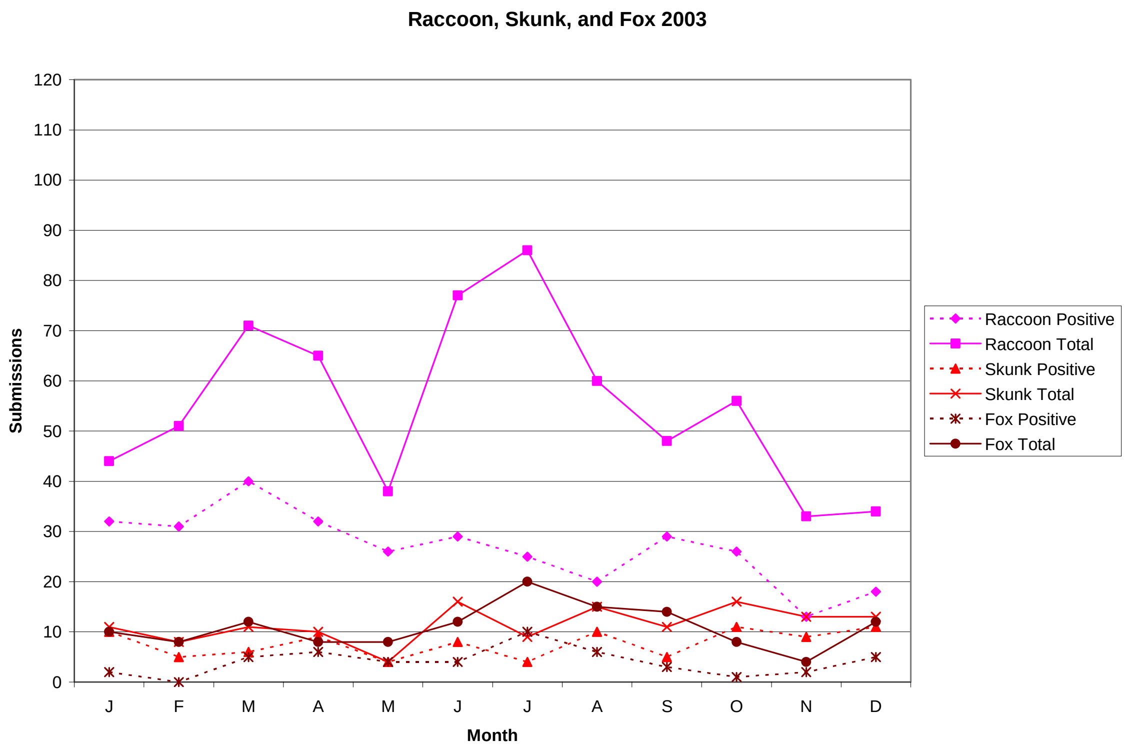


FIGURE 8a.

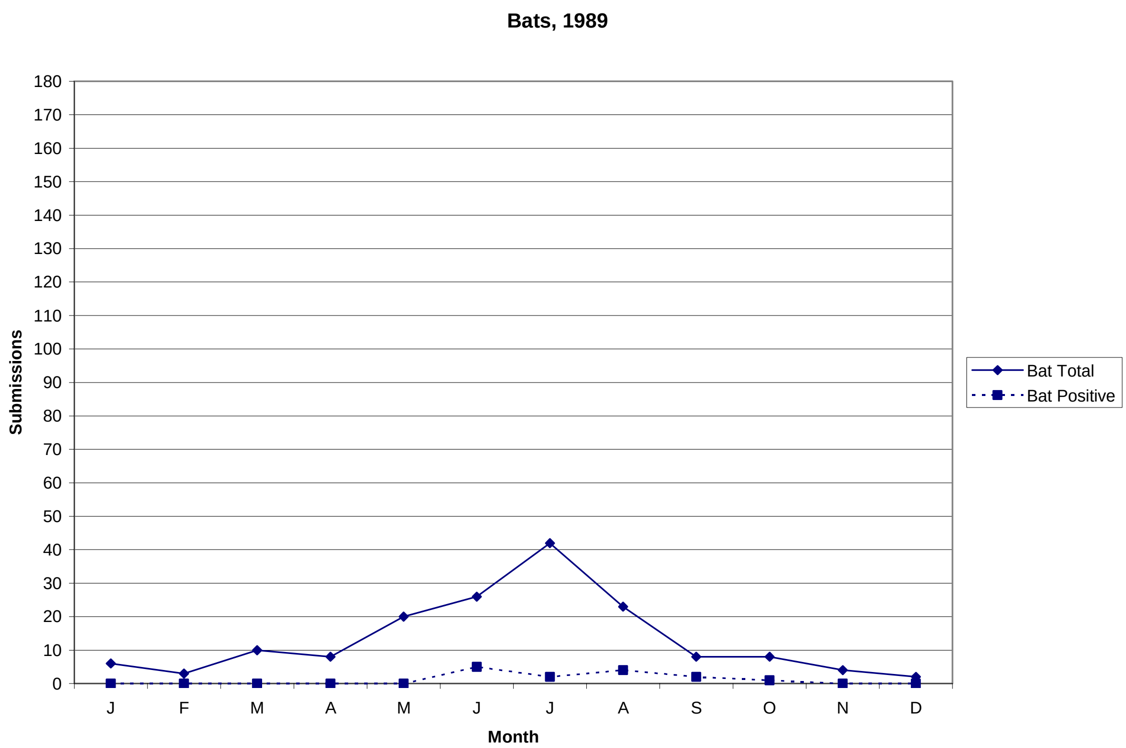


FIGURE 8b.

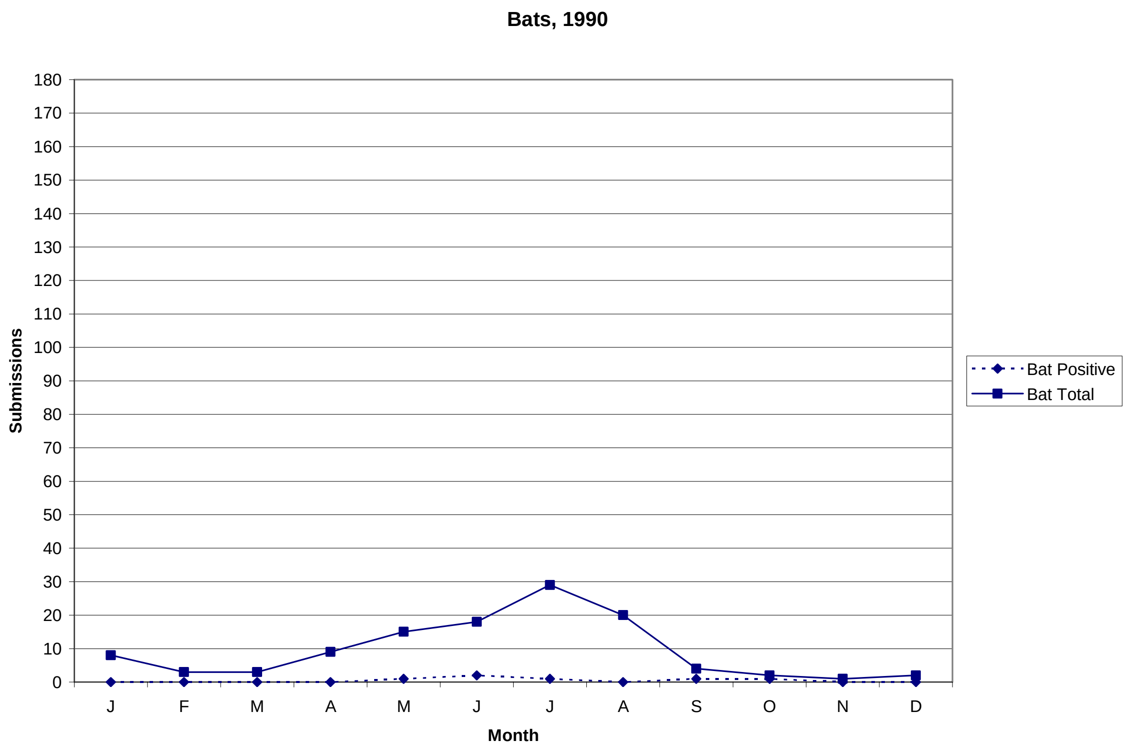


FIGURE 8c.

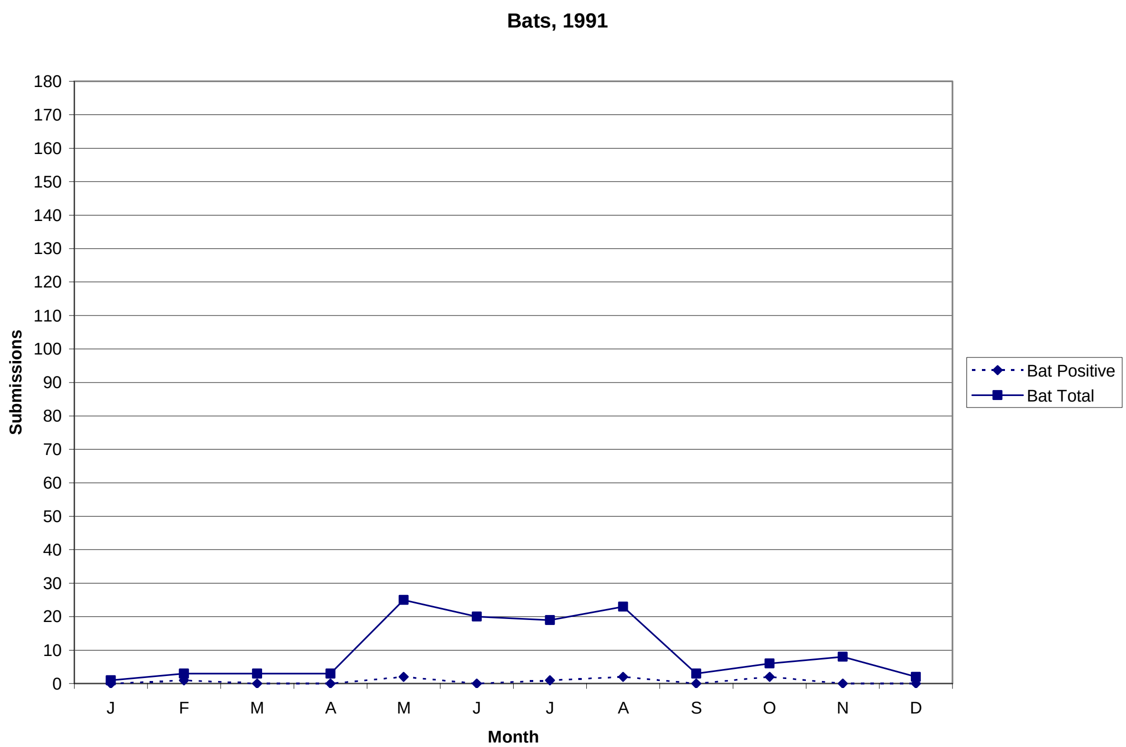


FIGURE 8d.

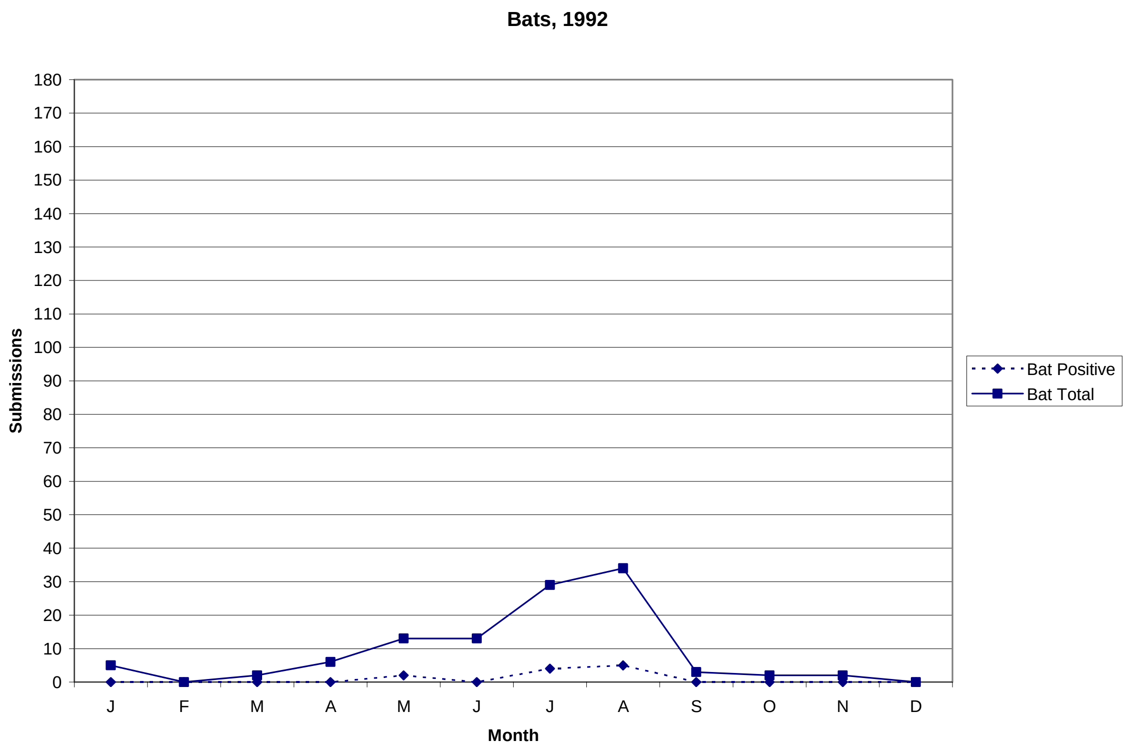


FIGURE 8e.

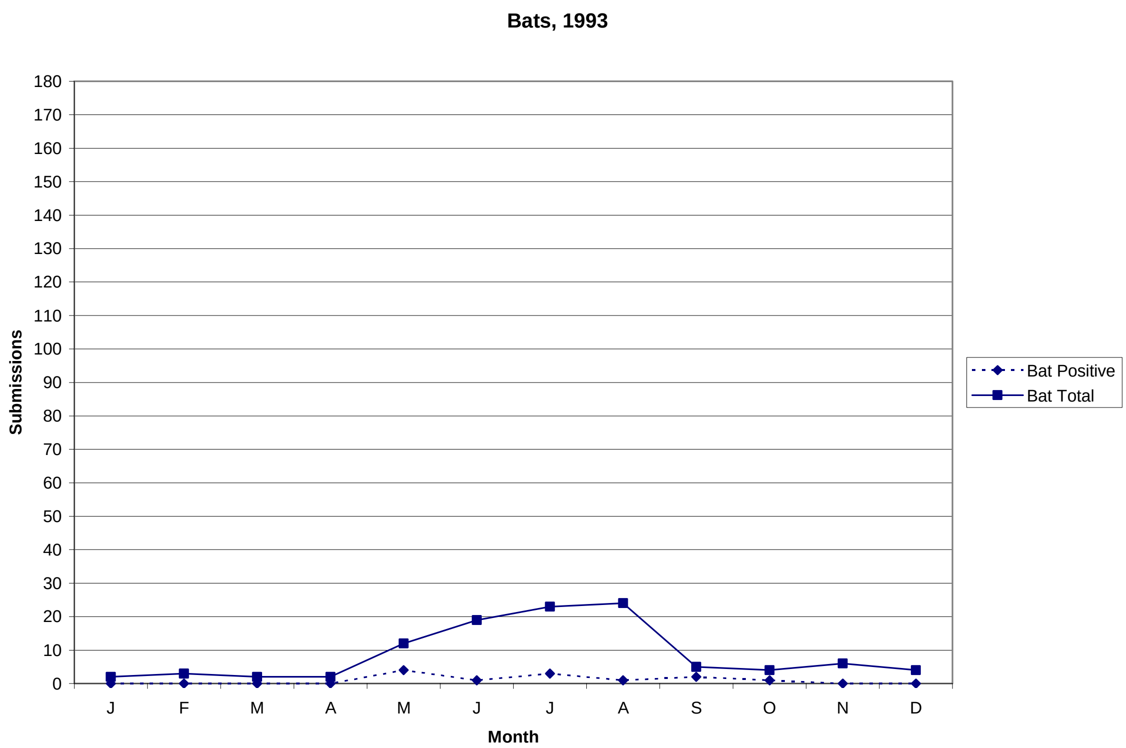


FIGURE 8f.

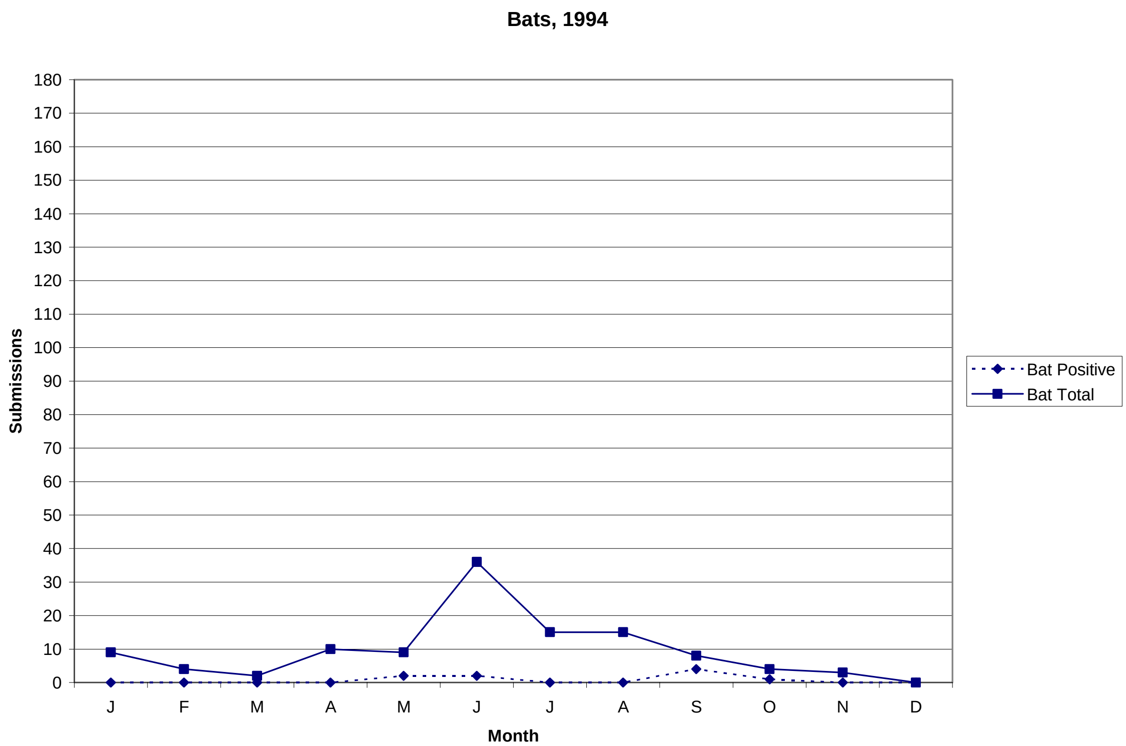


FIGURE 8g.

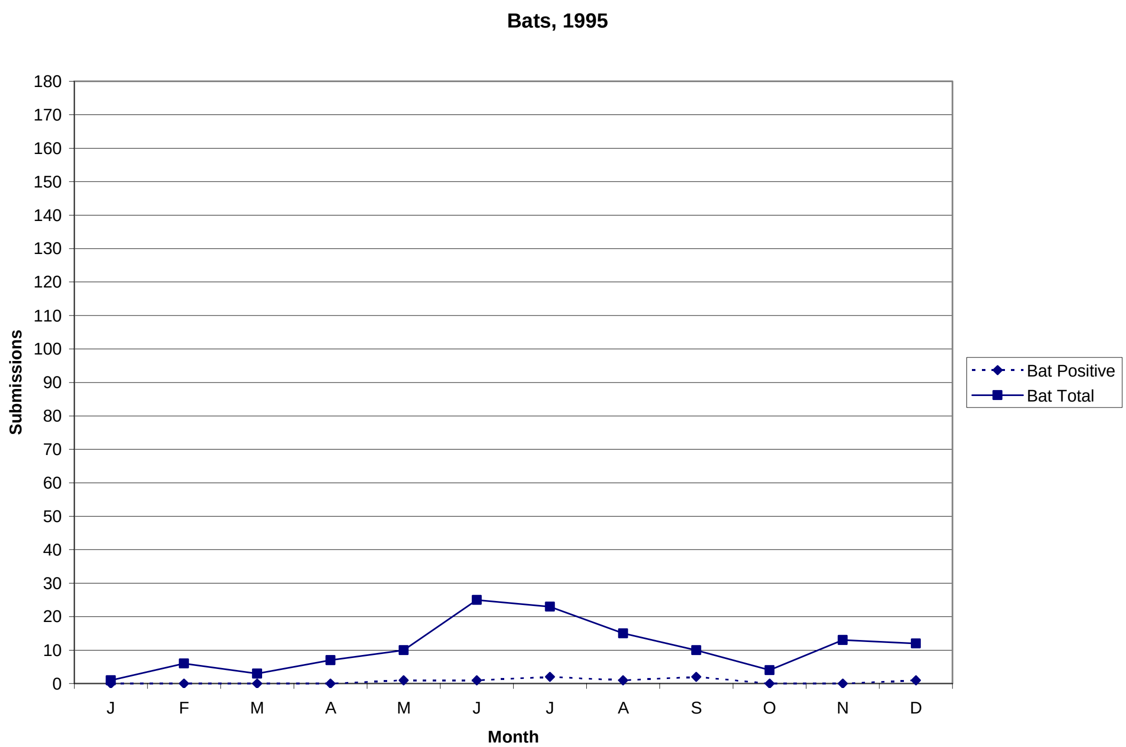


FIGURE 8h.

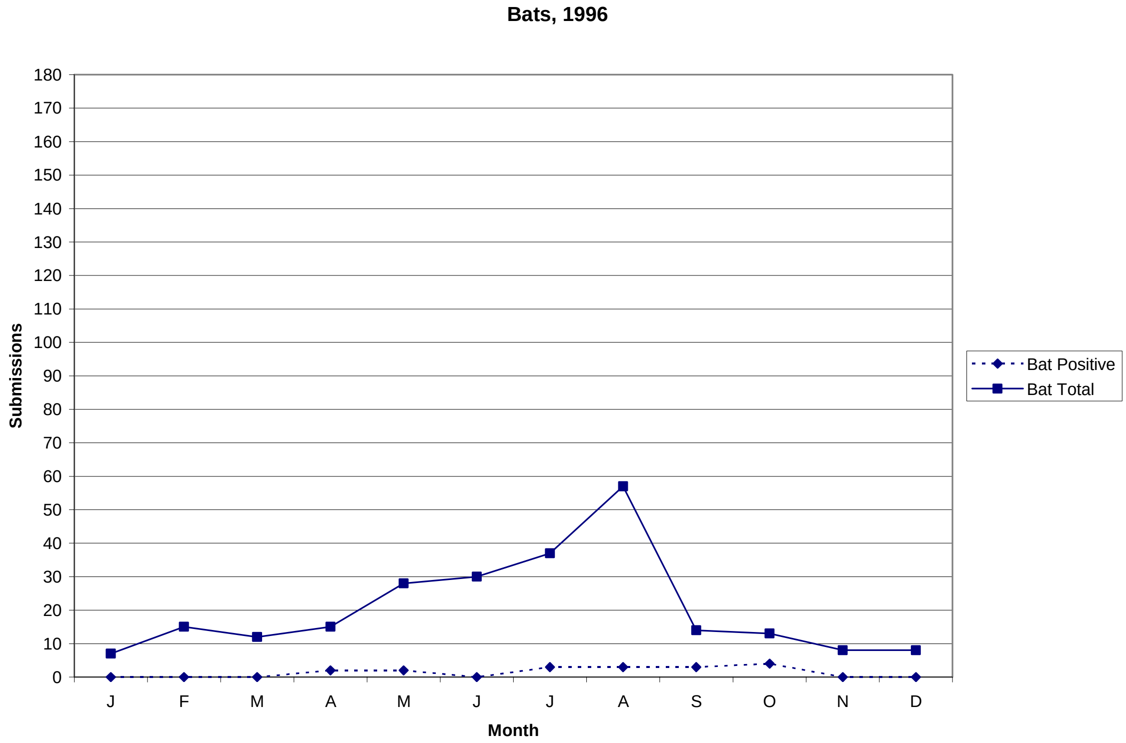


FIGURE 8i.

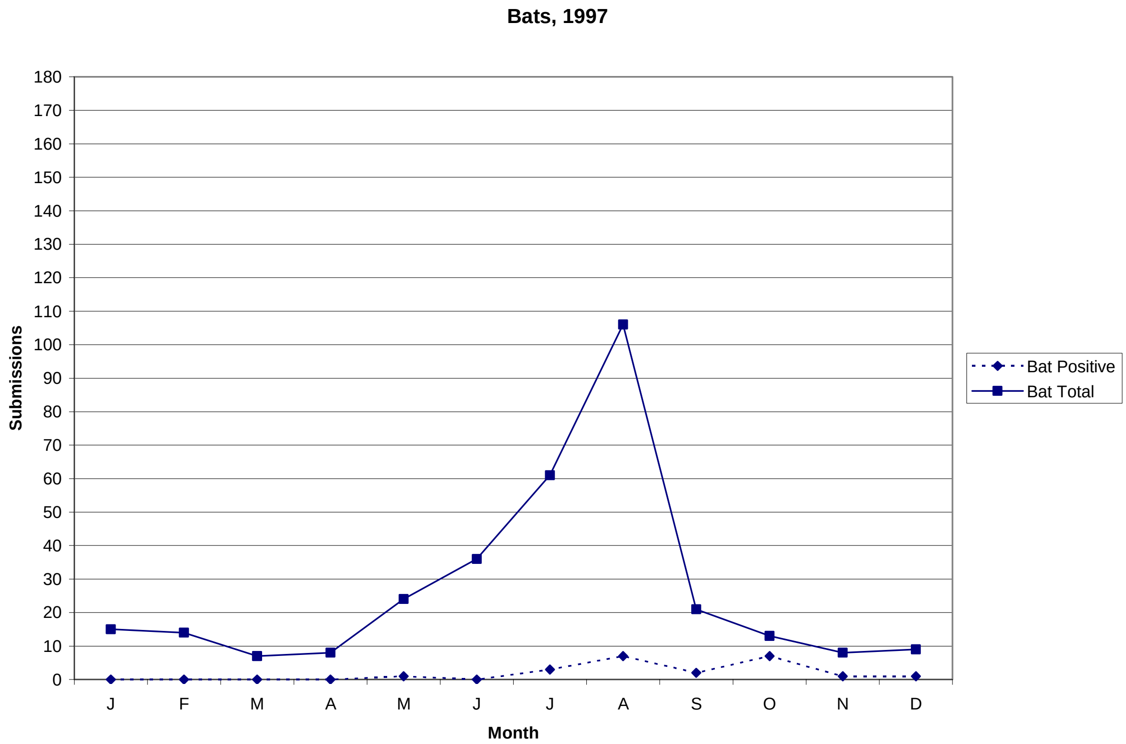


FIGURE 8j.

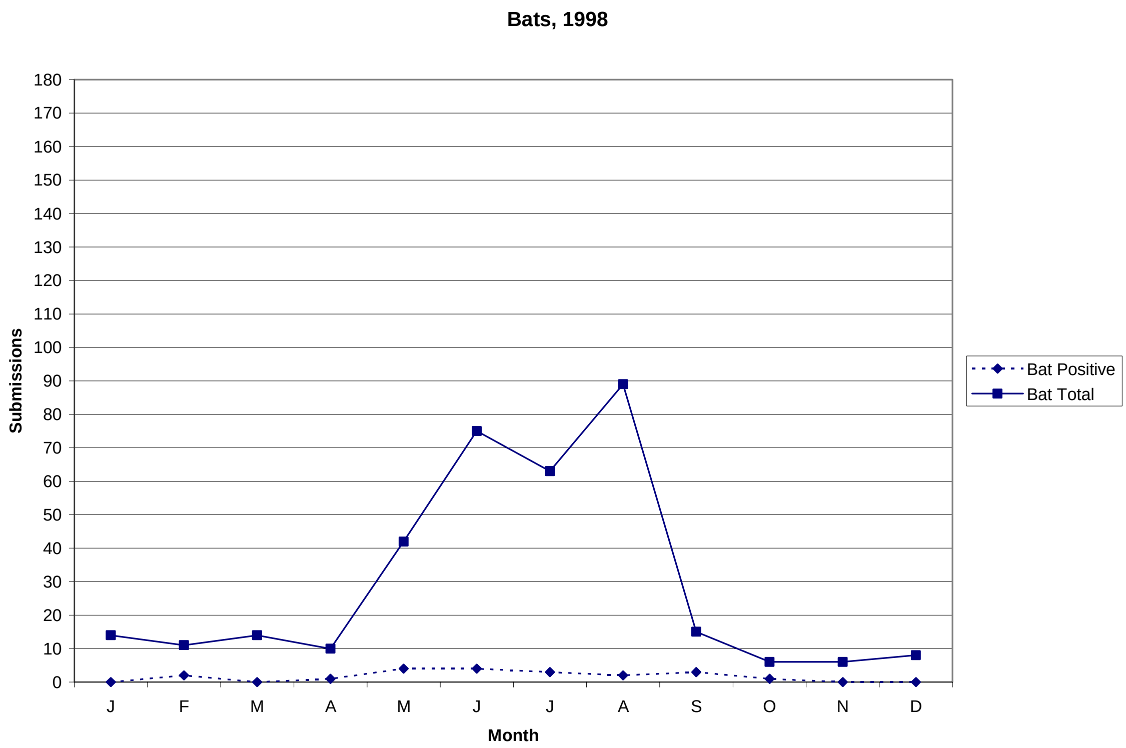


FIGURE 8k.

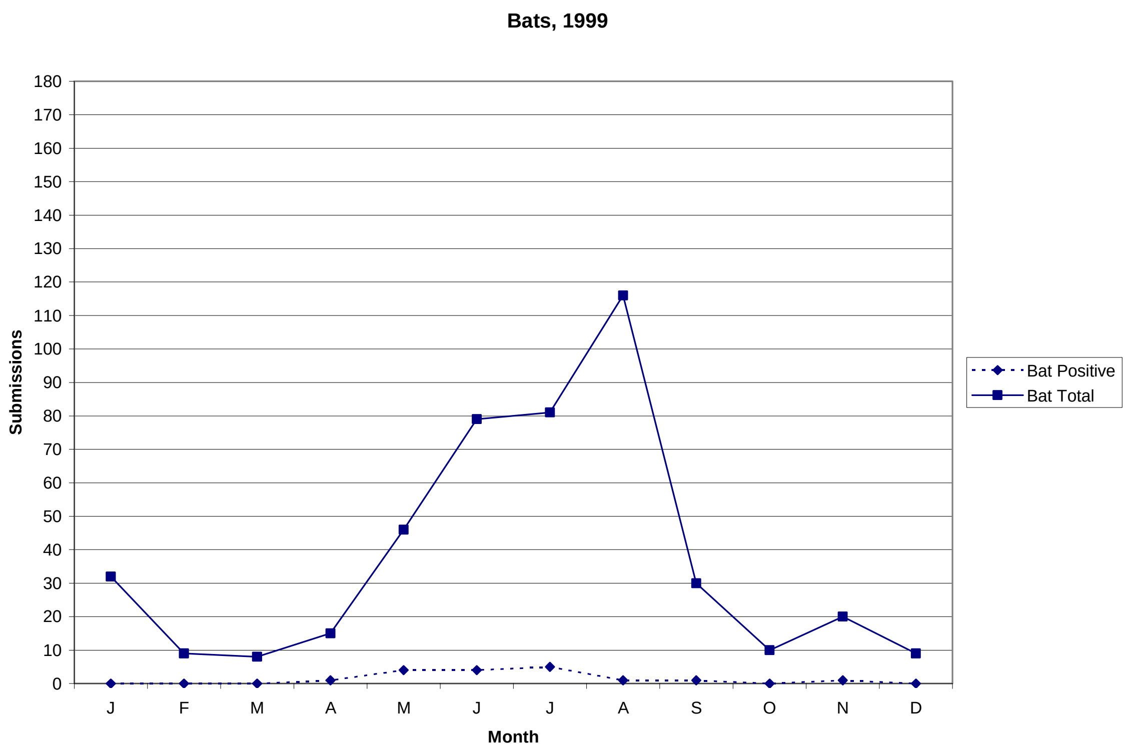


FIGURE 8l.

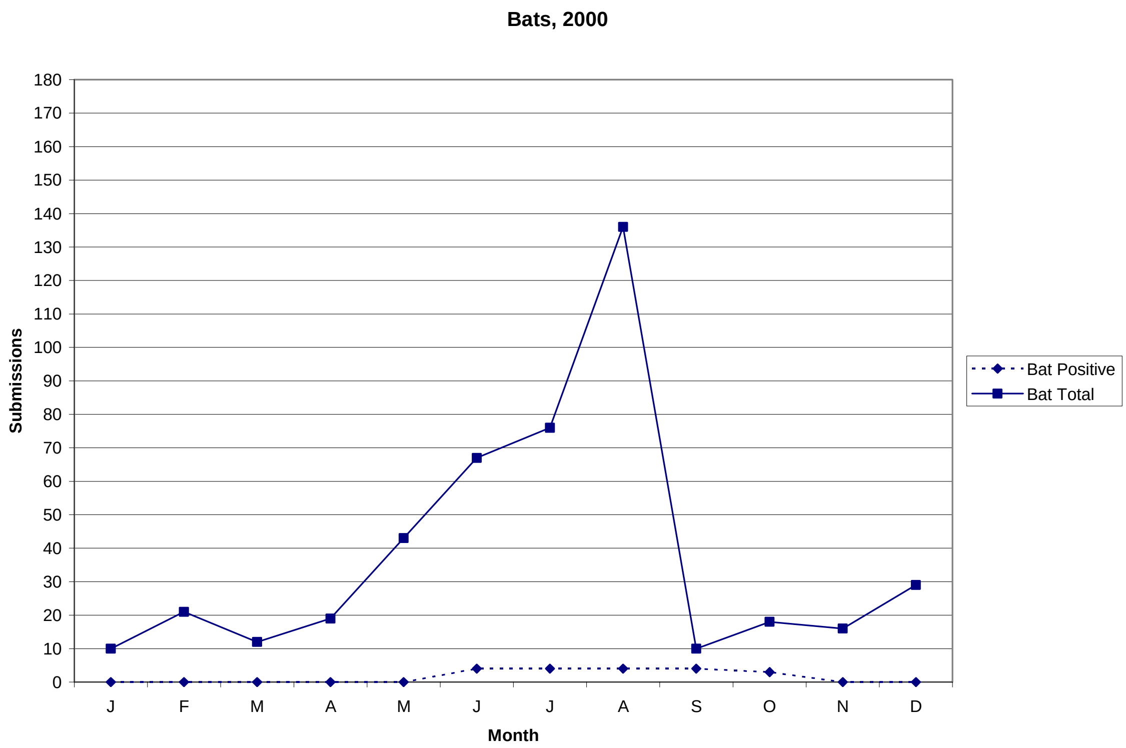


FIGURE 8m.

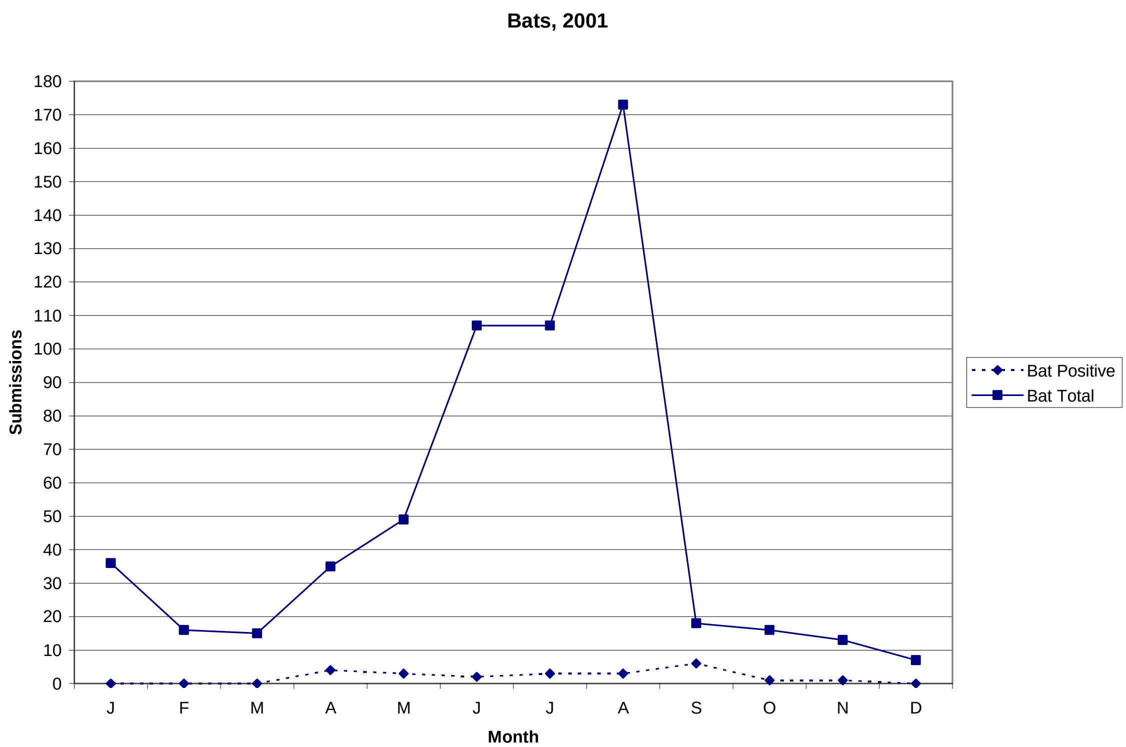


FIGURE 8n.

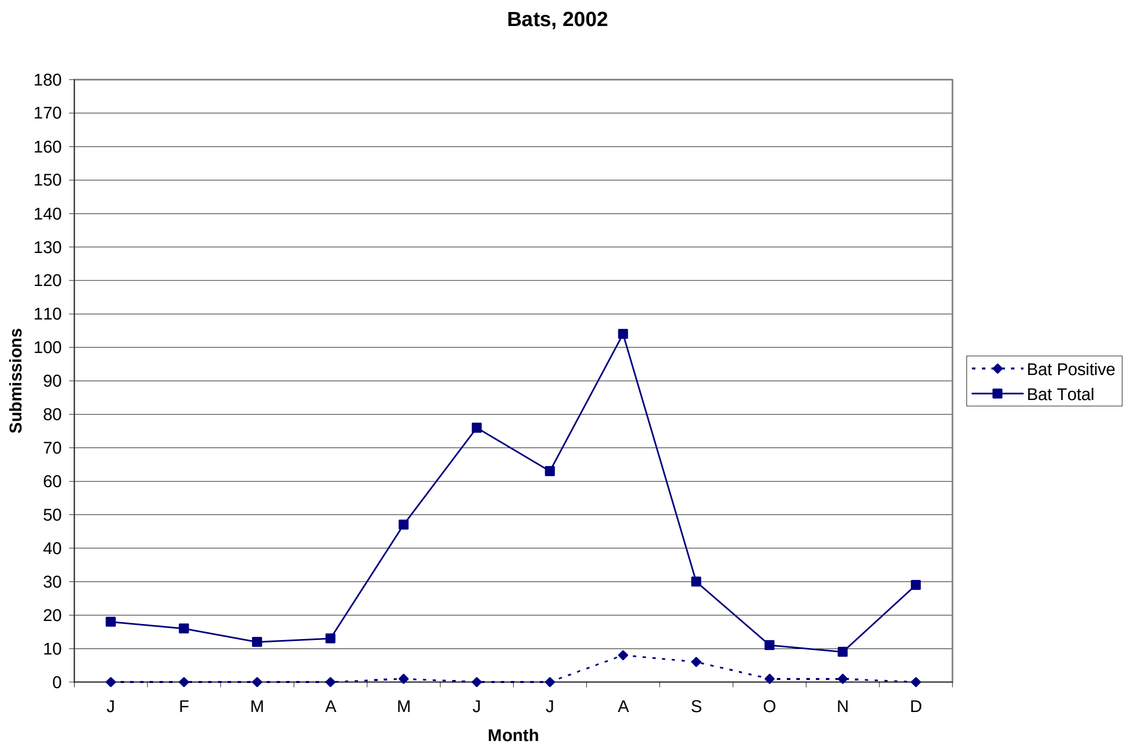


FIGURE 8o.

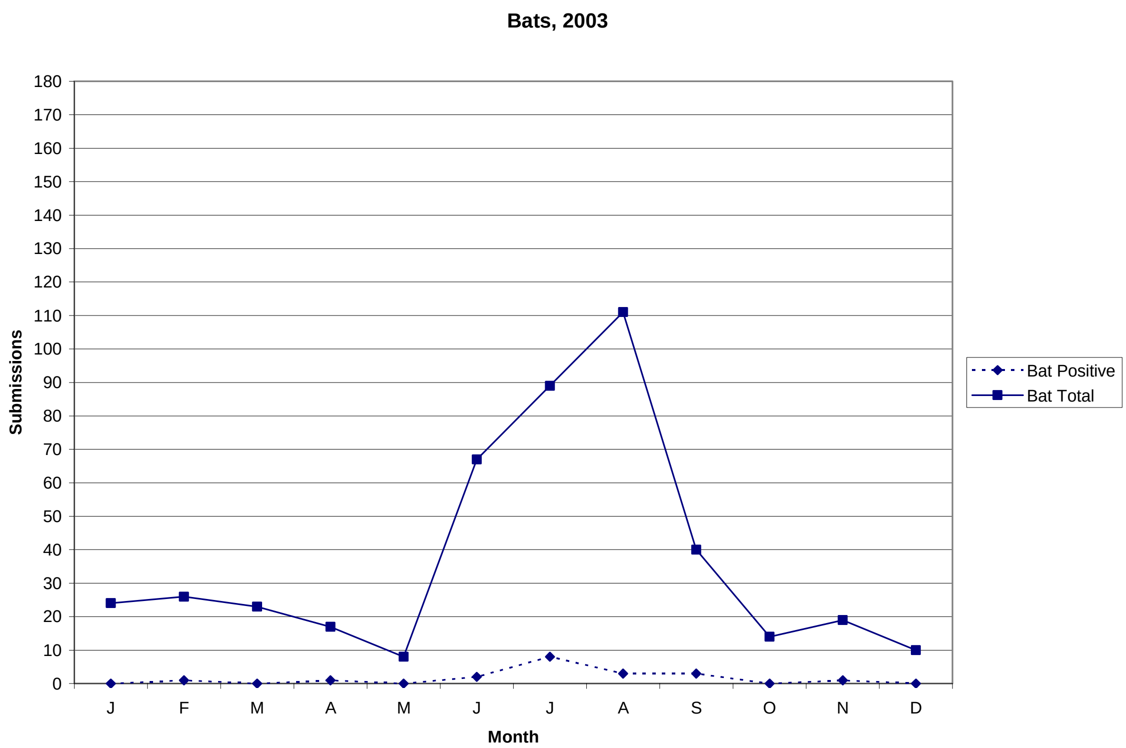


FIGURE 9a.

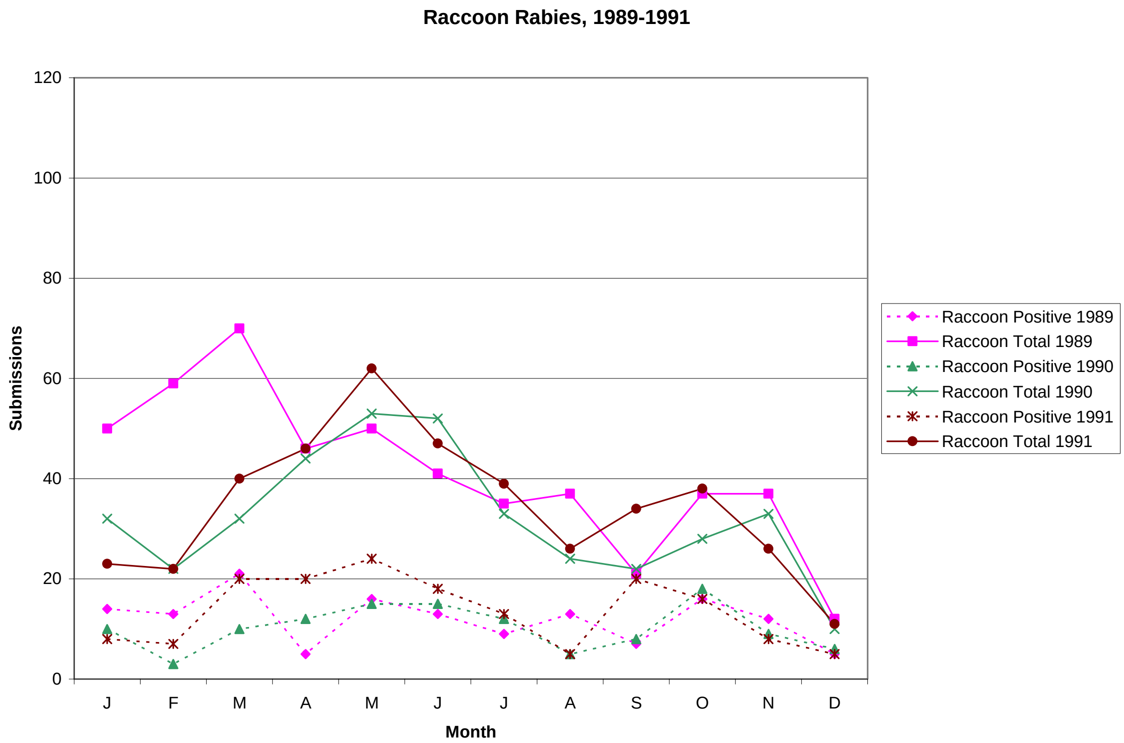


FIGURE 9b.

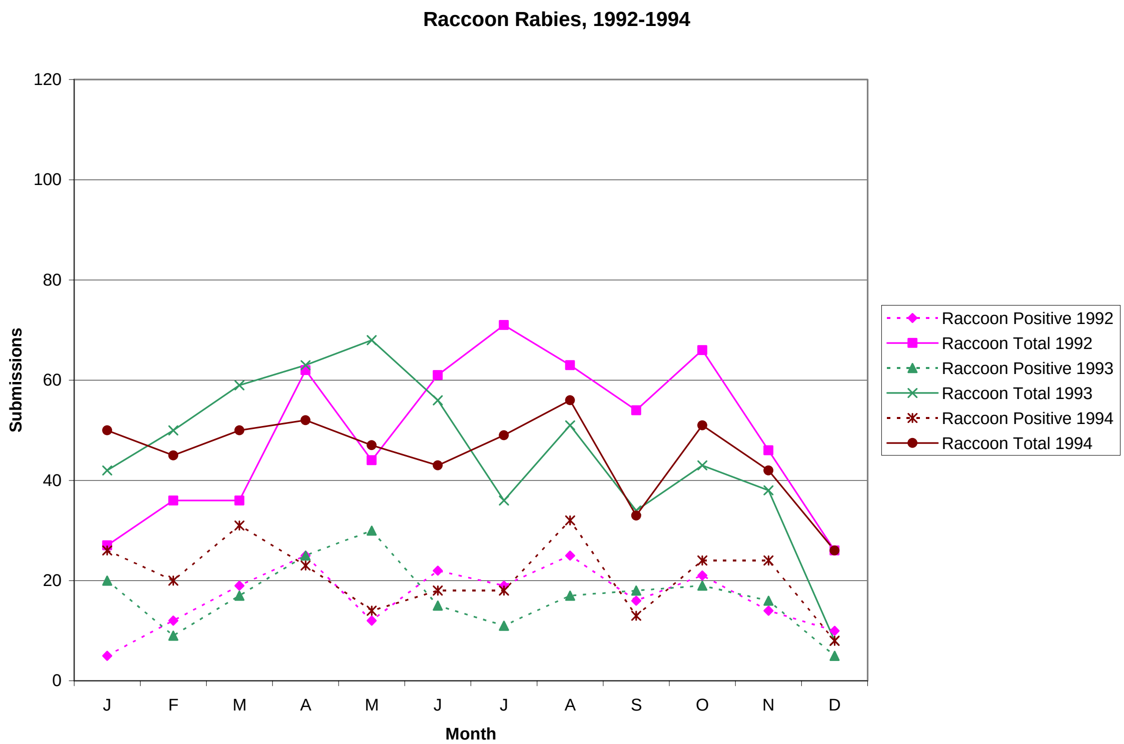


FIGURE 9c.

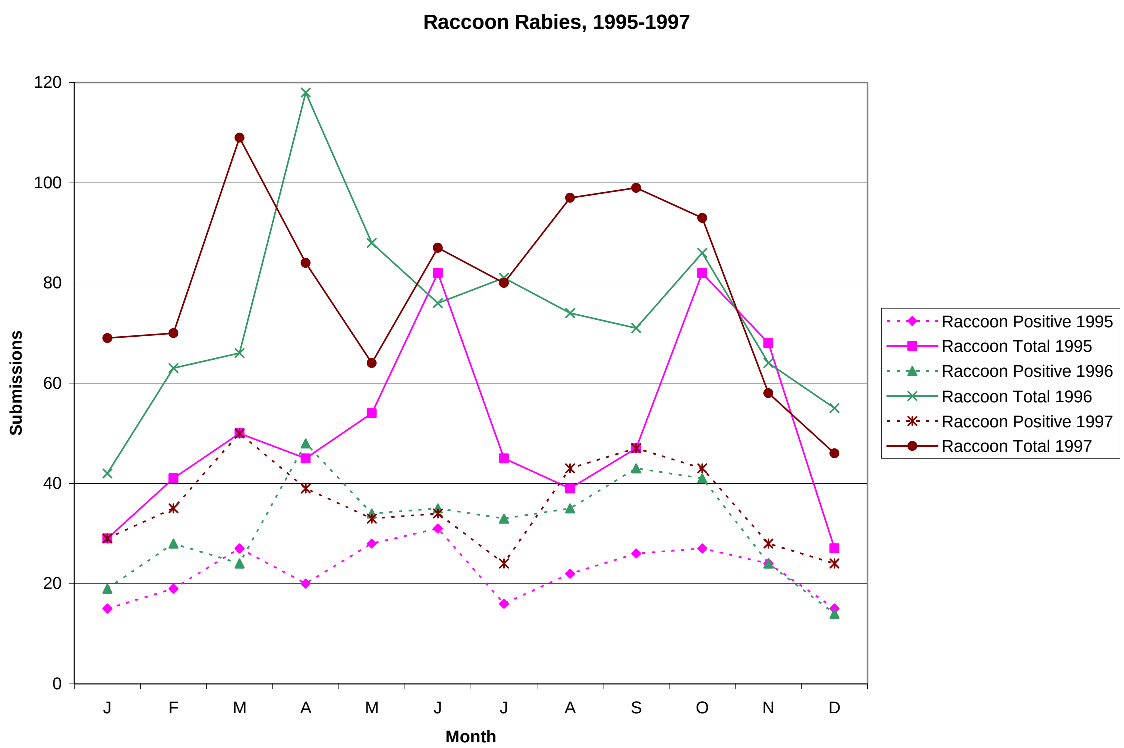


FIGURE 9d.

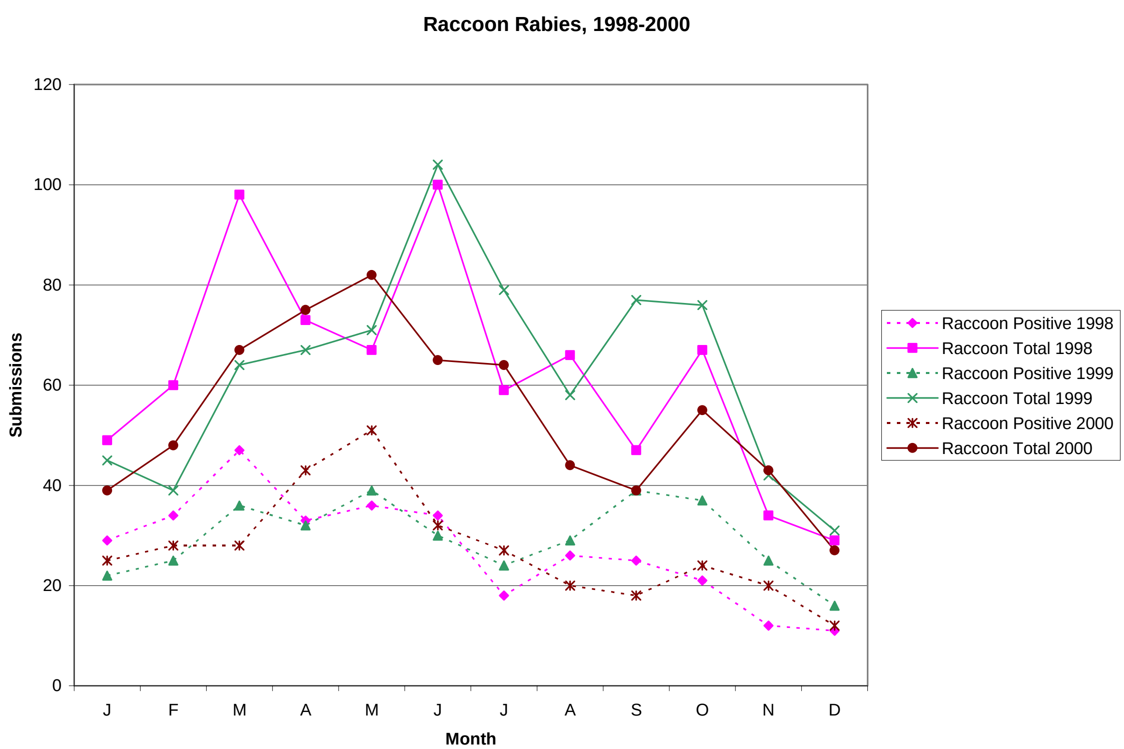


FIGURE 9e.

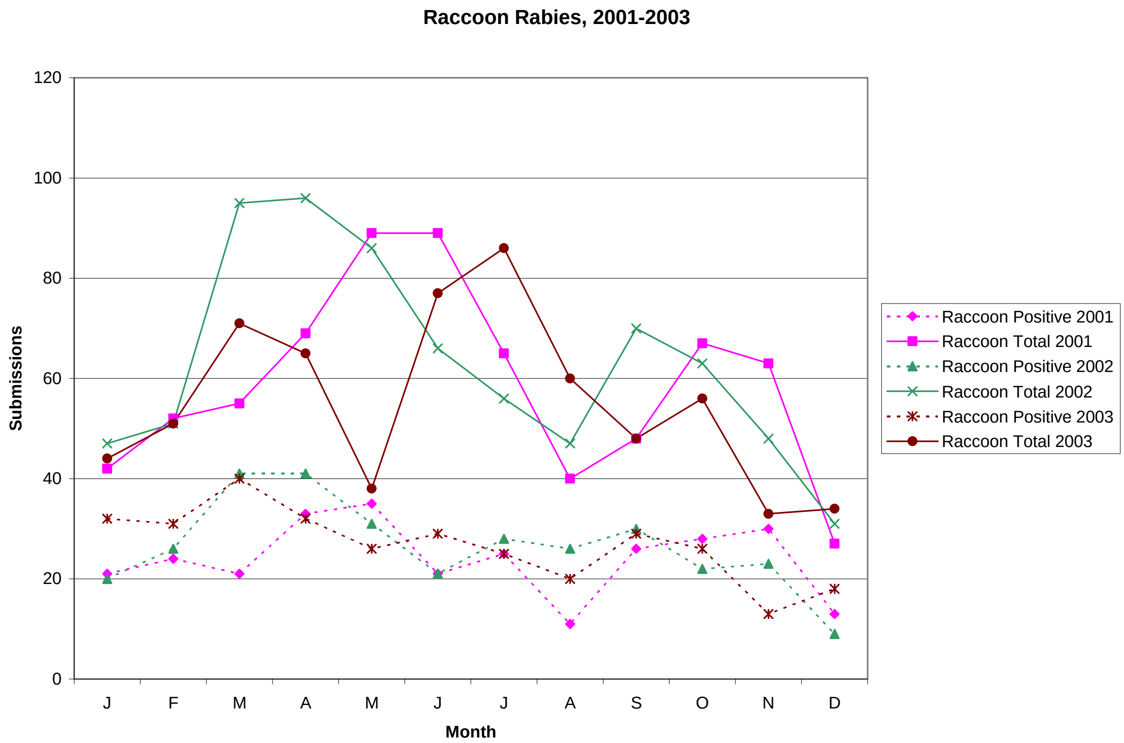


FIGURE 10a.

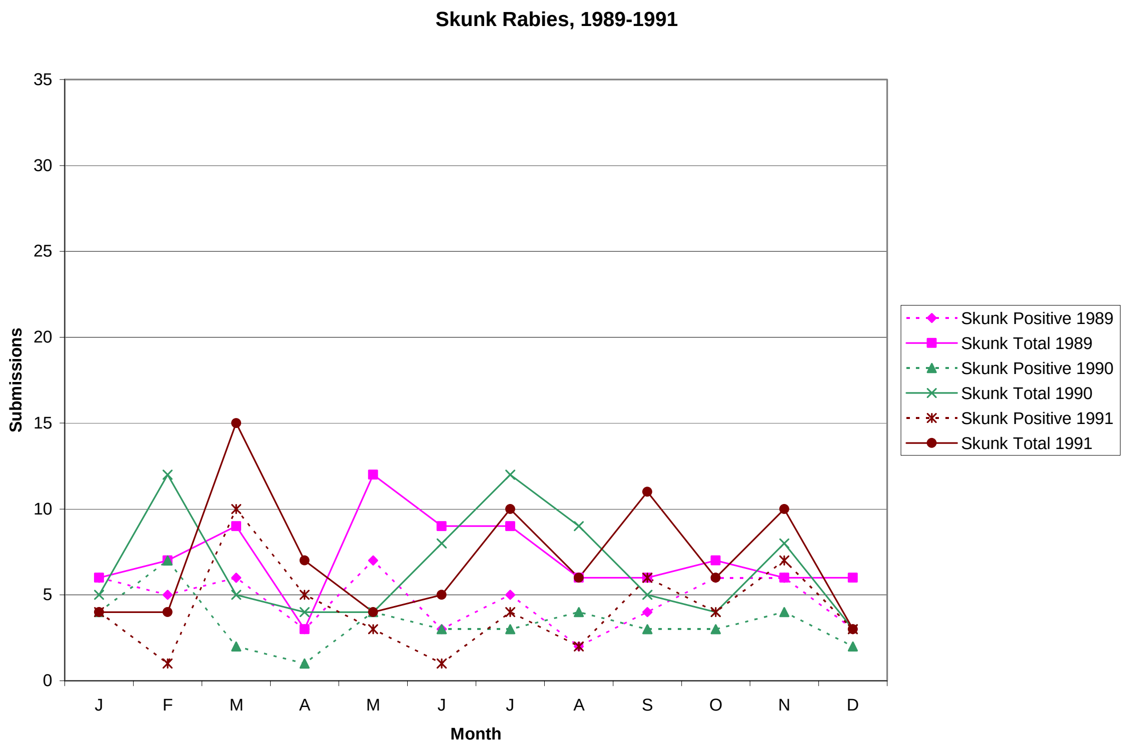


FIGURE 10b.

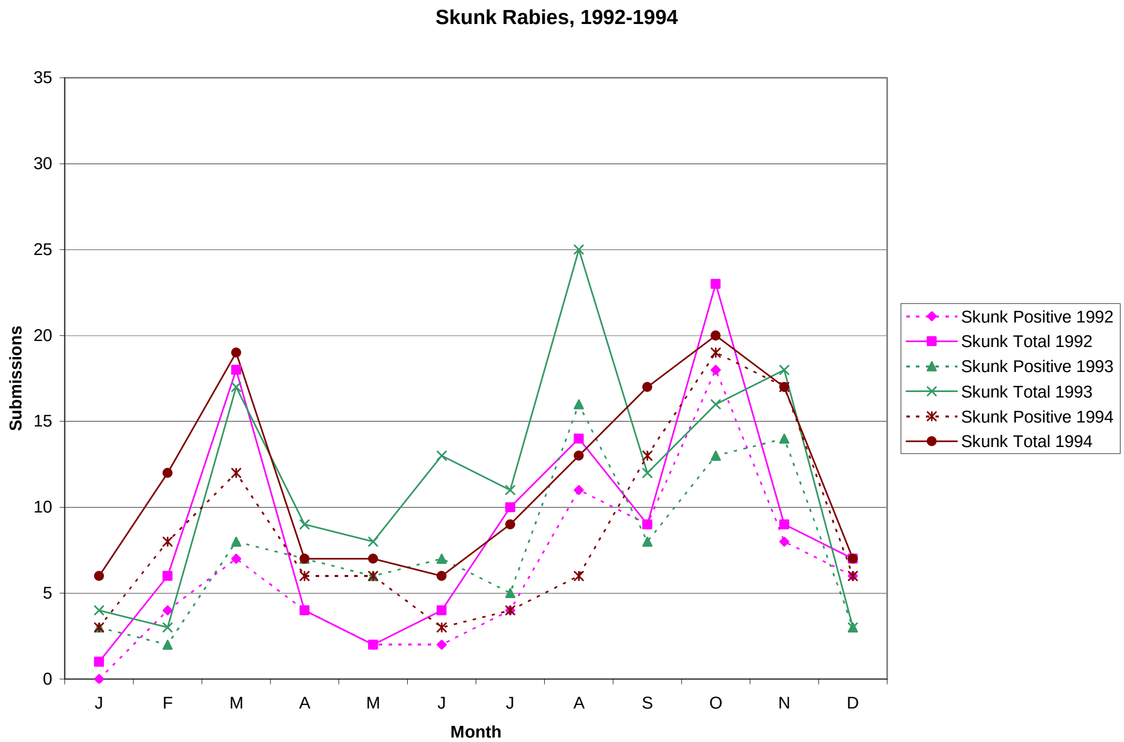


FIGURE 10c.

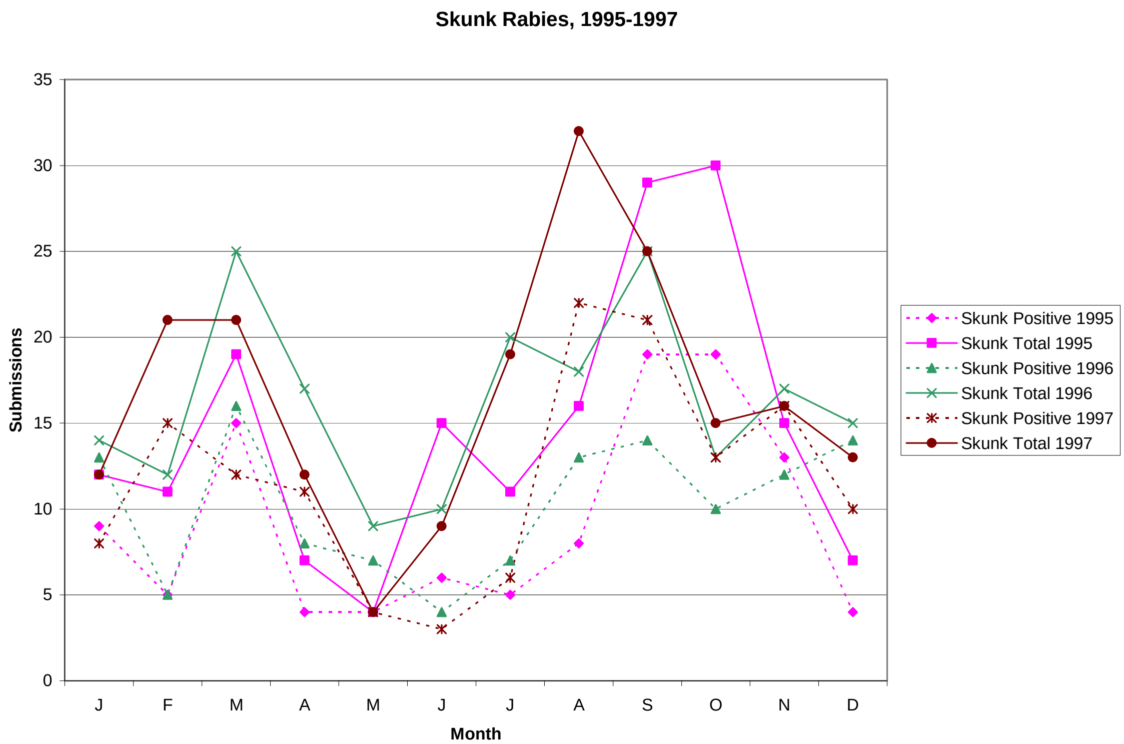


FIGURE 10d.

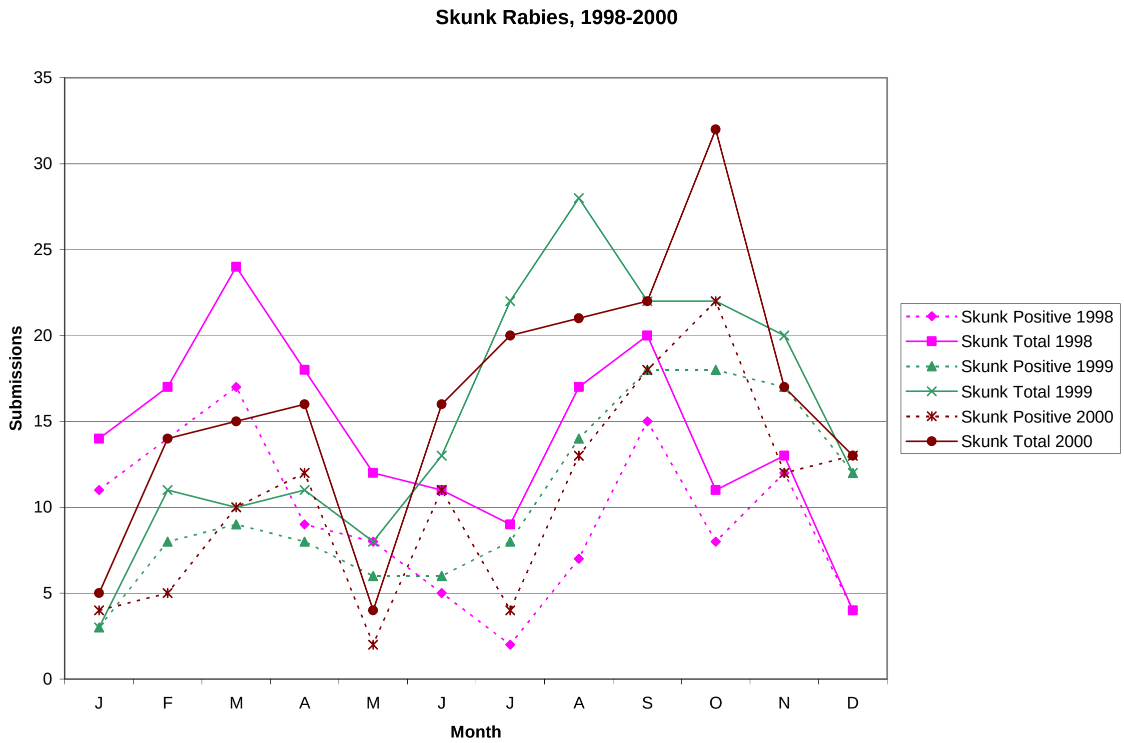


FIGURE 10e.

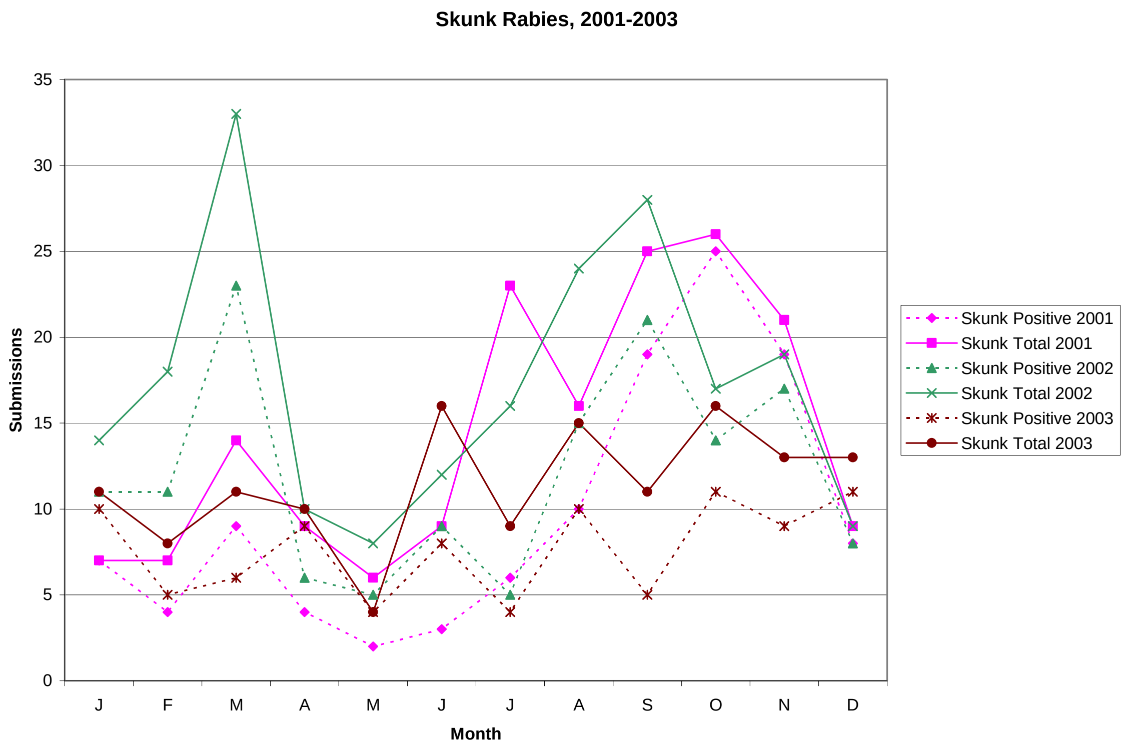


FIGURE 11a.

Rabies Cases Associated with Human Exposure(s), 1989-1991

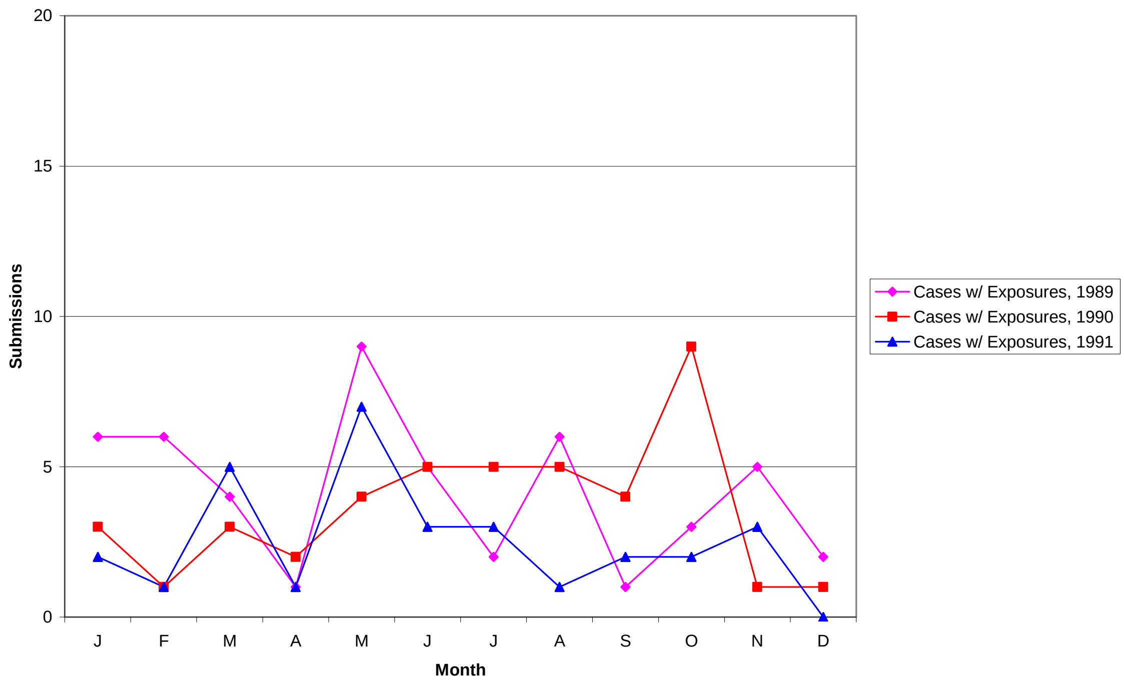


FIGURE 11b.

Rabies Cases Associated with Human Exposure(s), 1992-1994

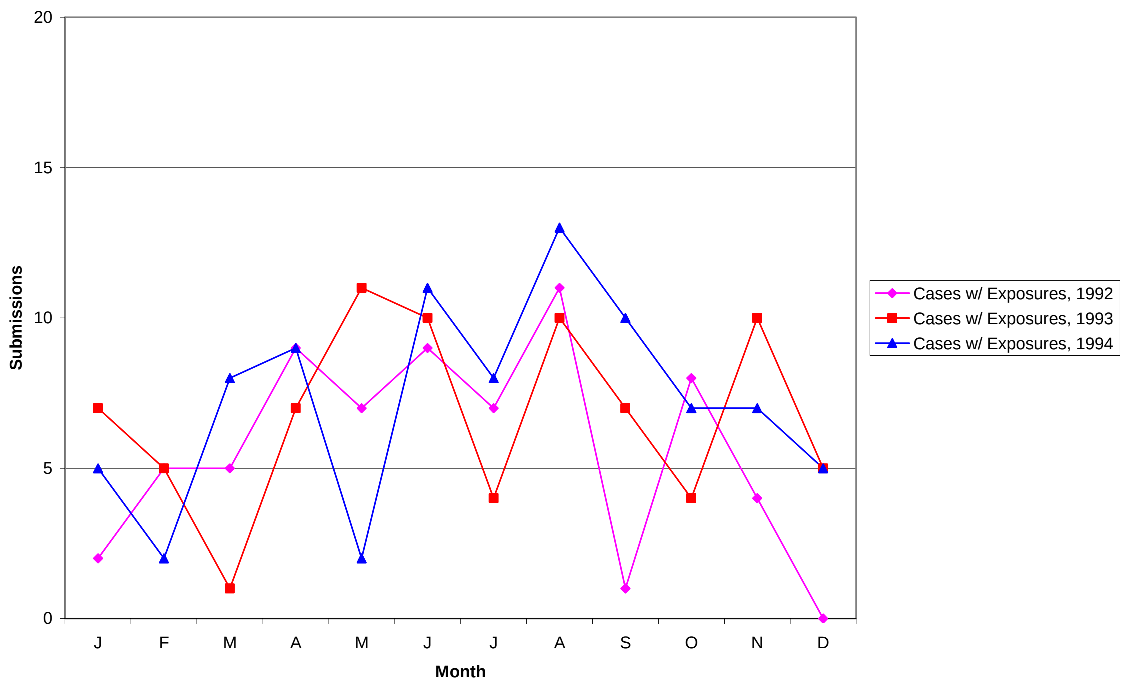


FIGURE 11c.

Rabies Cases Associated with Human Exposure(s), 1995-1997

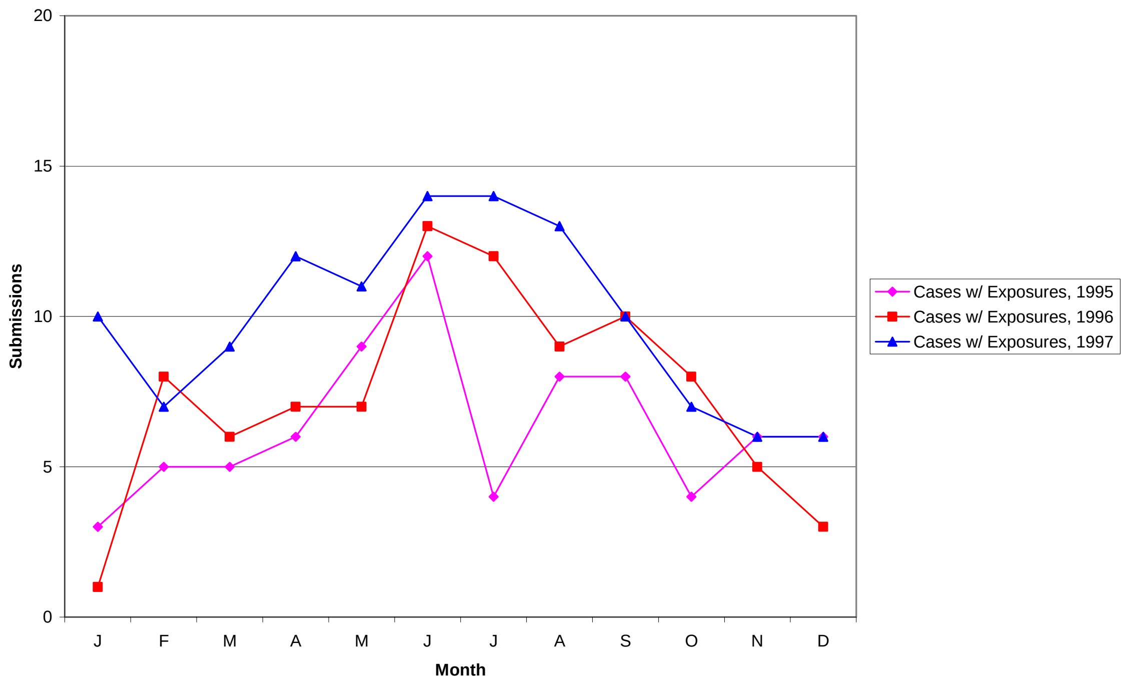


FIGURE 11d.

Rabies Cases Associated with Human Exposure(s), 1998-2000

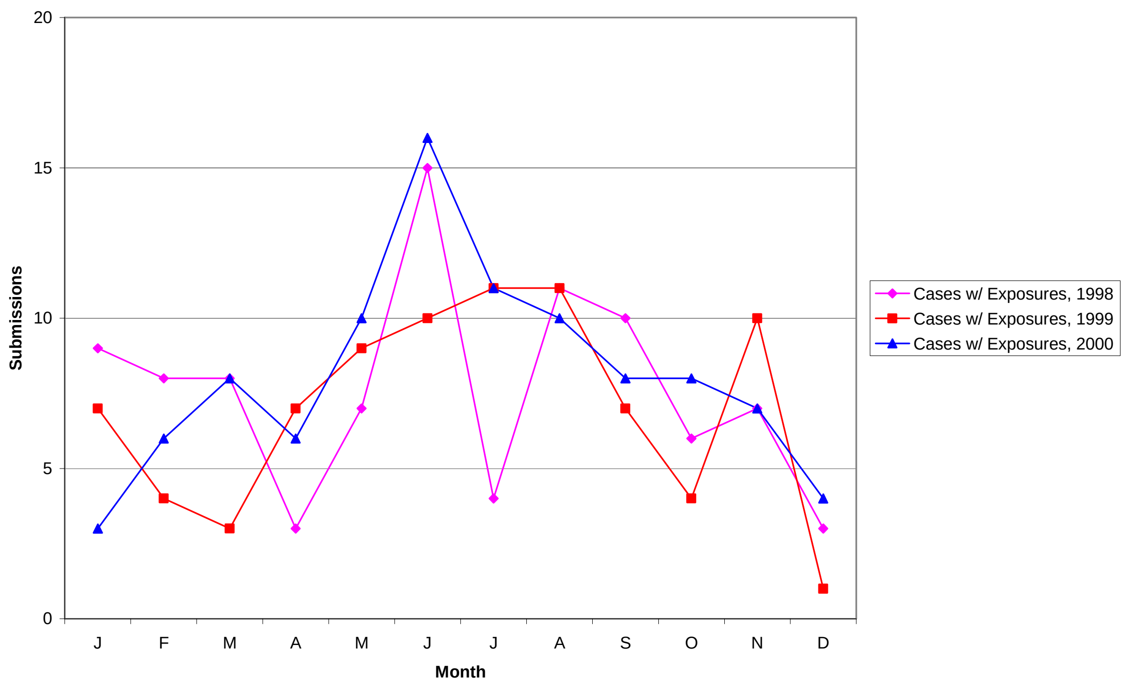


FIGURE 11e.

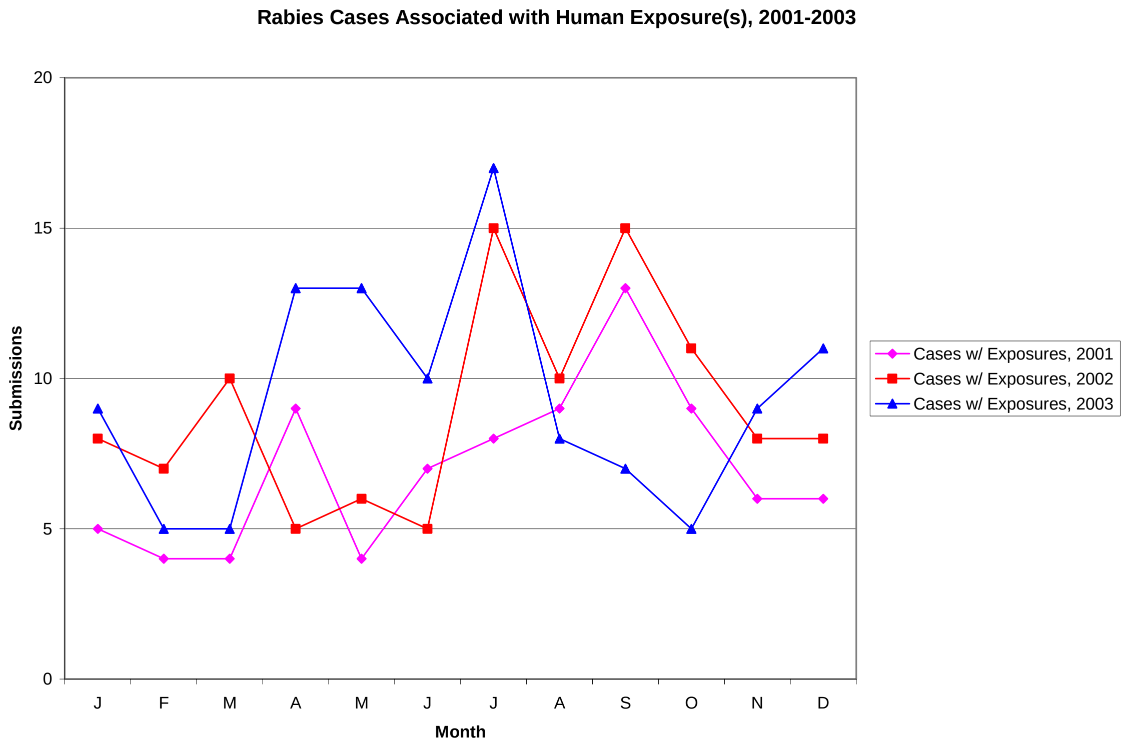


FIGURE 12a.

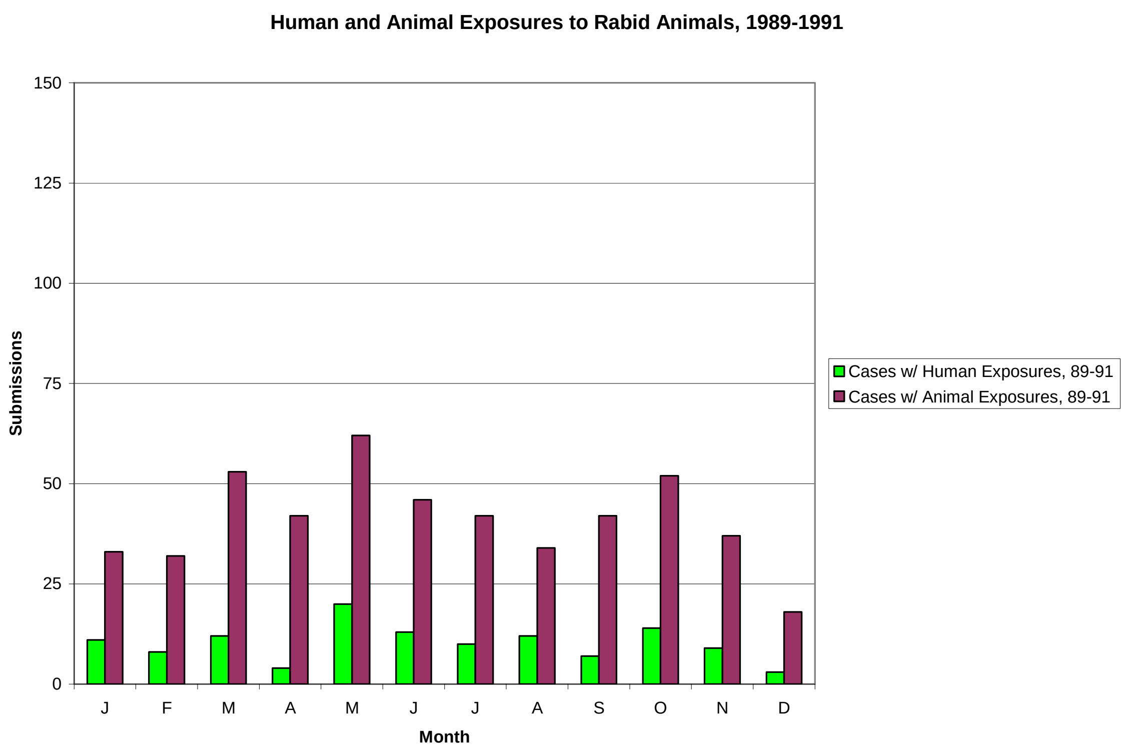


FIGURE 12b.

Human and Animal Exposures to Rabid Animals, 1992-1994

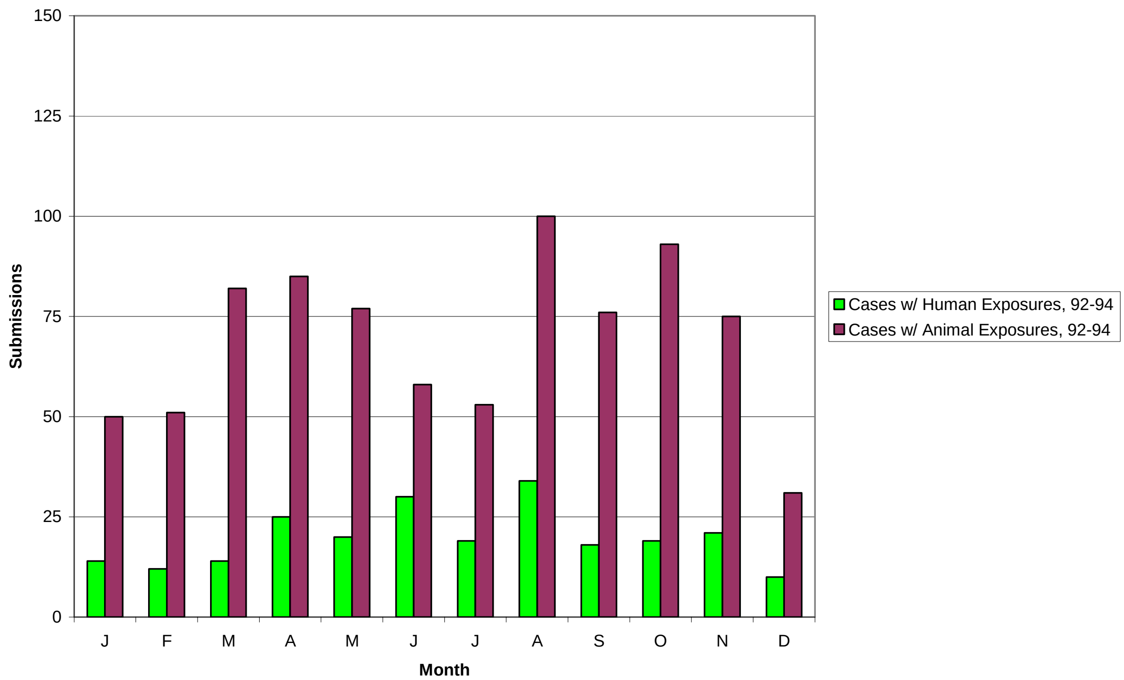


FIGURE 12c.

Human and Animal Exposures to Rabid Animals, 1995-1997

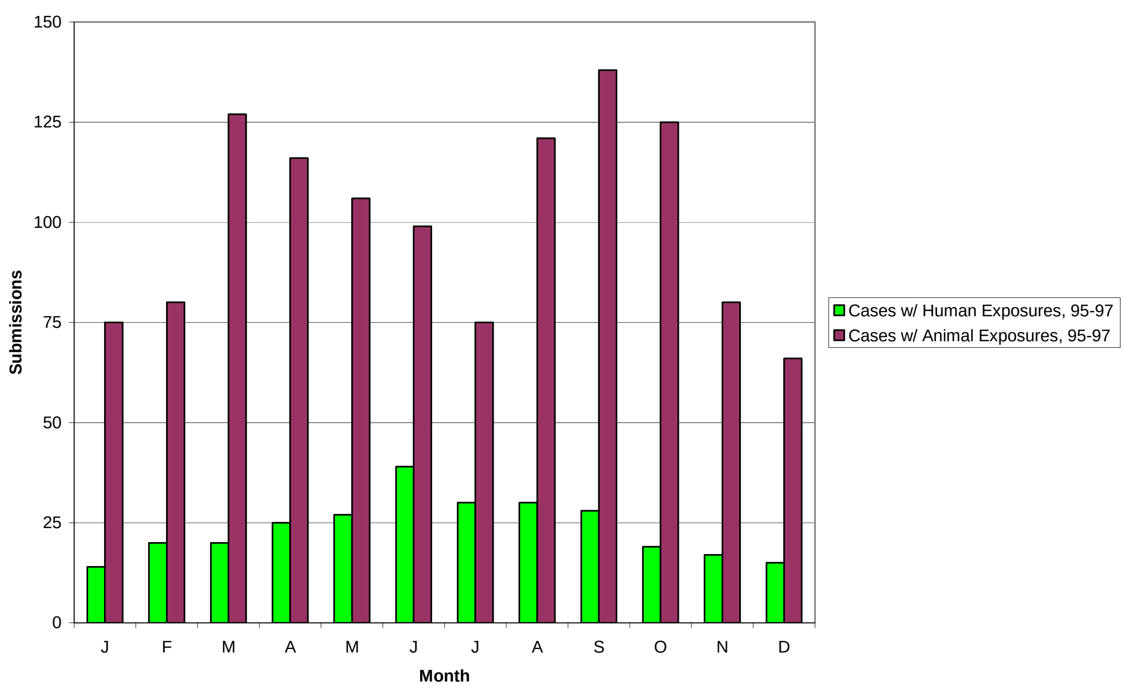


FIGURE 12d.

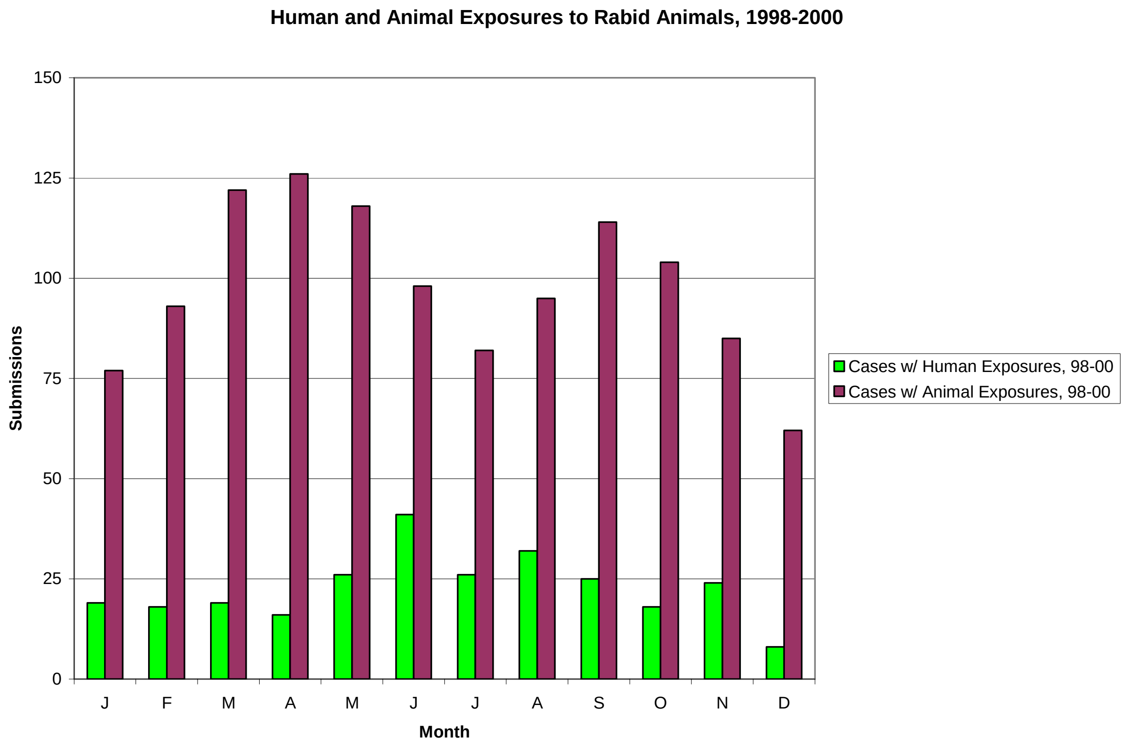


FIGURE 12e.

FIGURE 13.

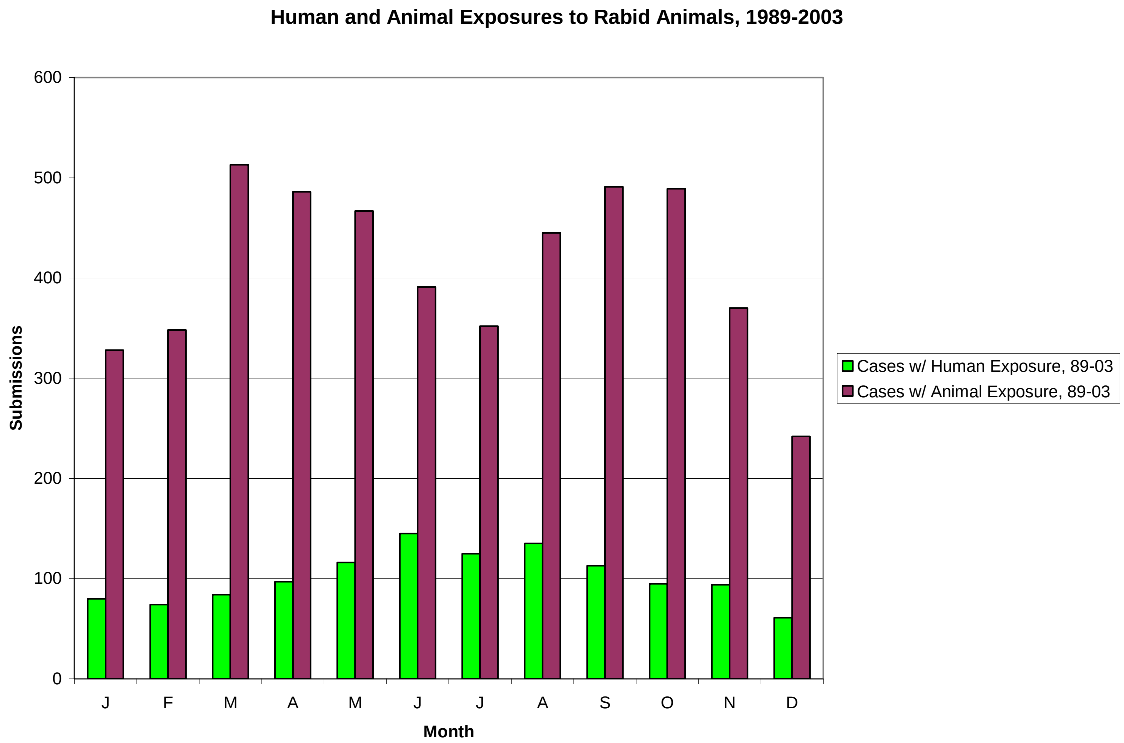
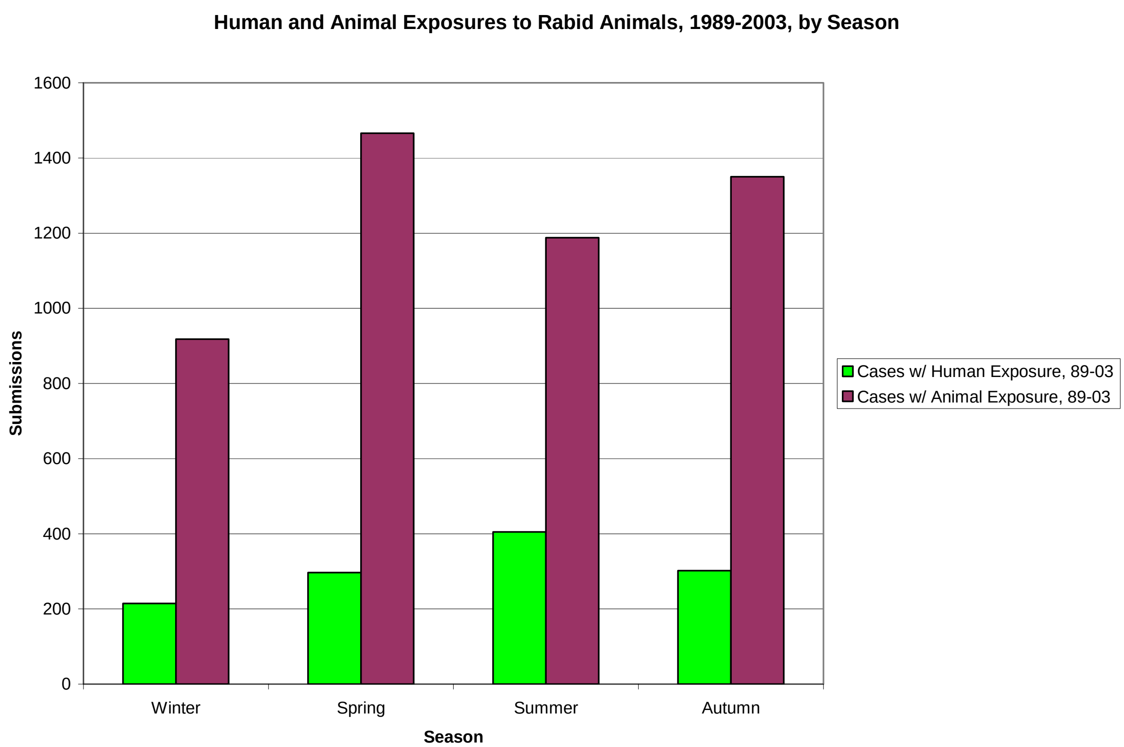
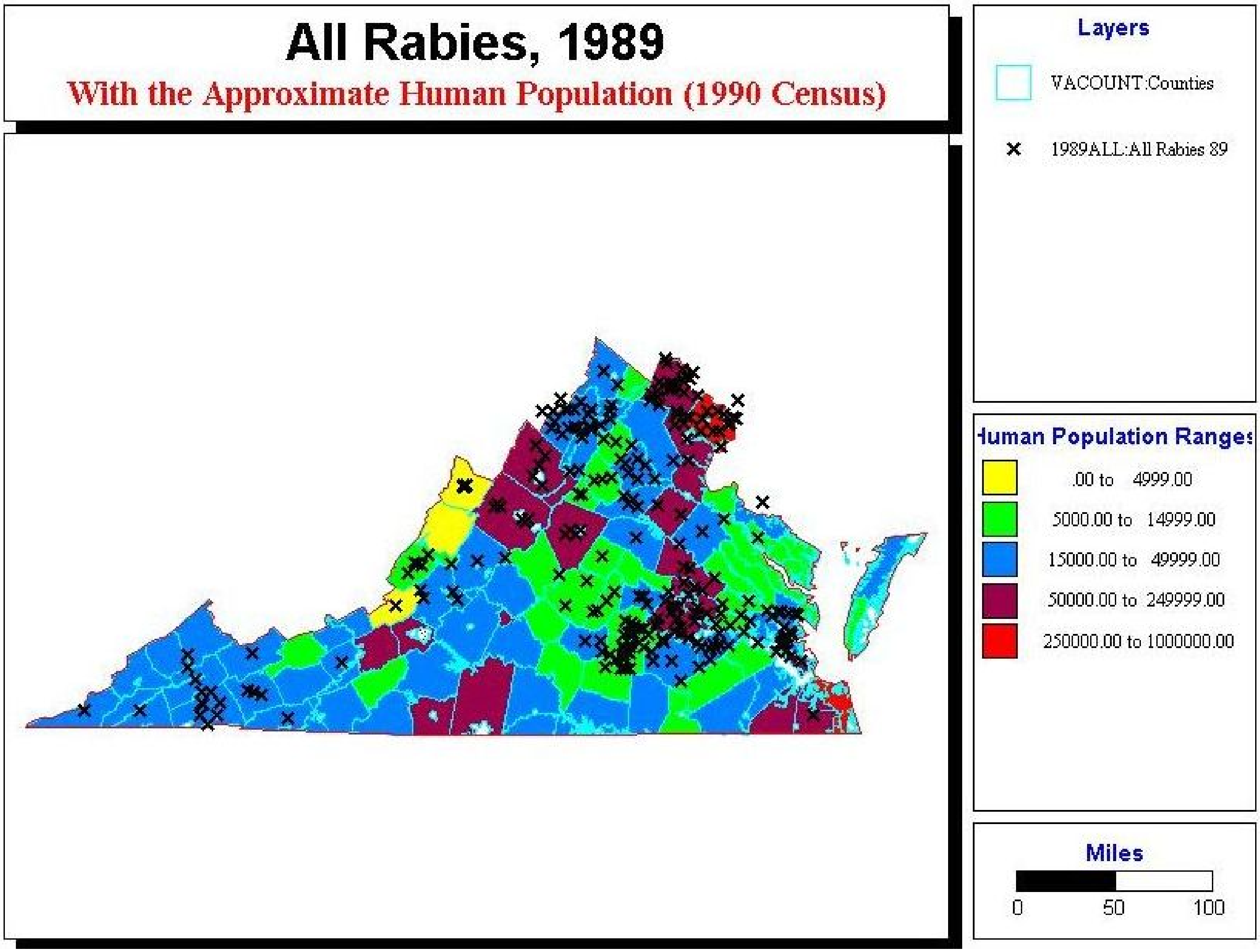


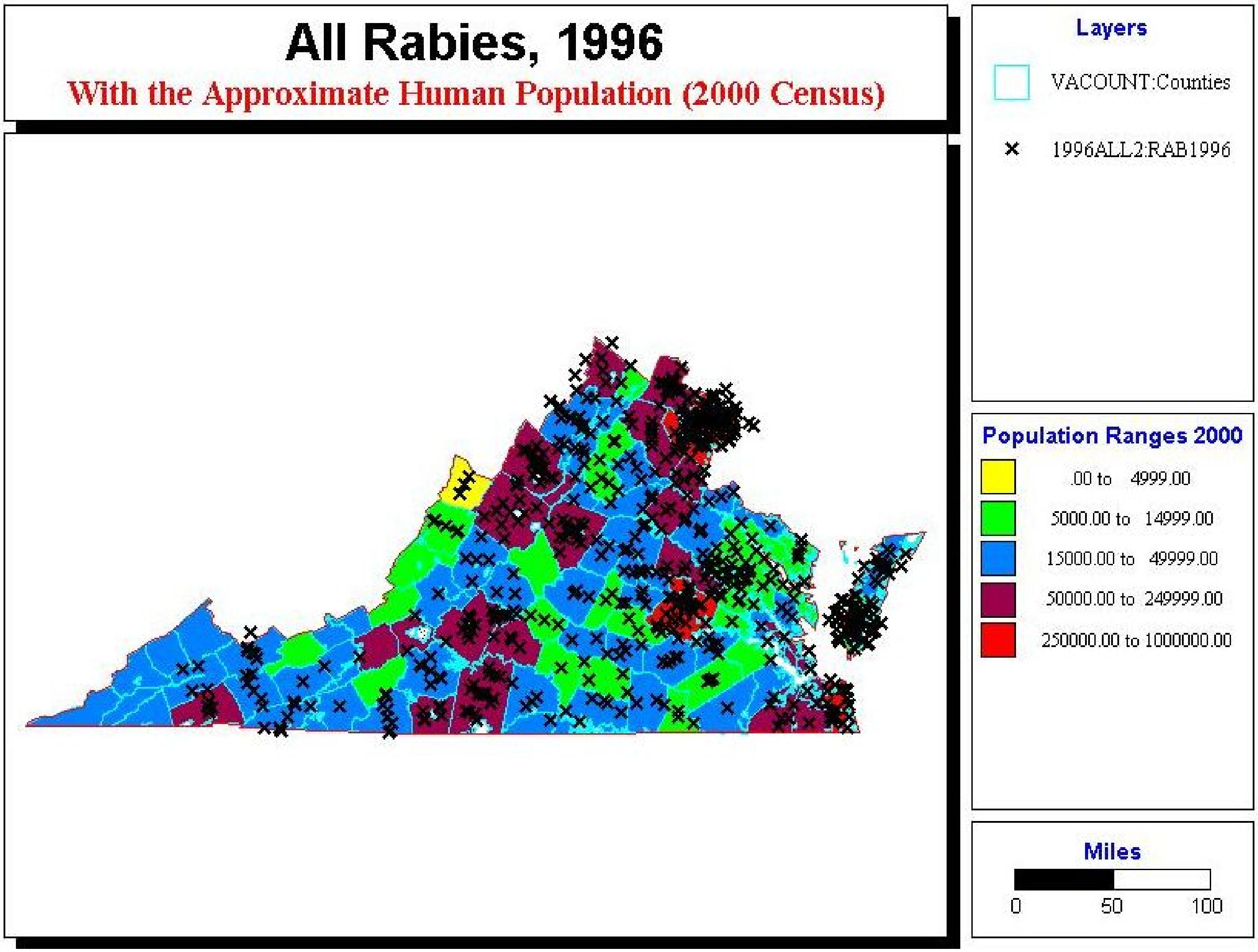
FIGURE 14.



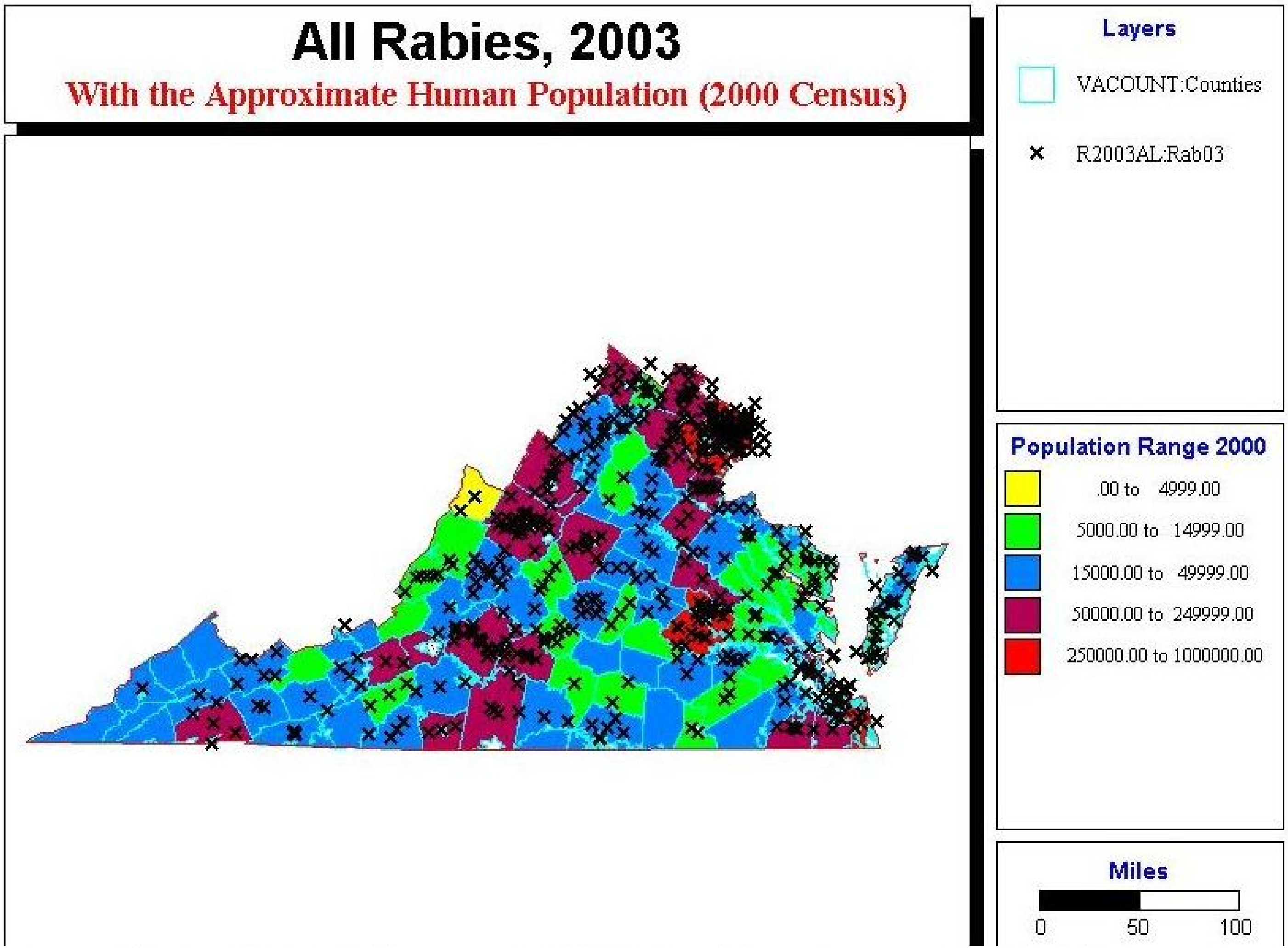
MAP 1.


All Rabies, 1989
With the Approximate Human Population (1990 Census)
Layers
VACOUNT:Counties
1989ALL:All Rabies 89
uman Population Range
.00 to 4999.00
5000.00 to 14999.00
15000.00 to 49999.00
50000.00 to 249999.00
250000.00 to 1000000.00
Miles
0
50
100

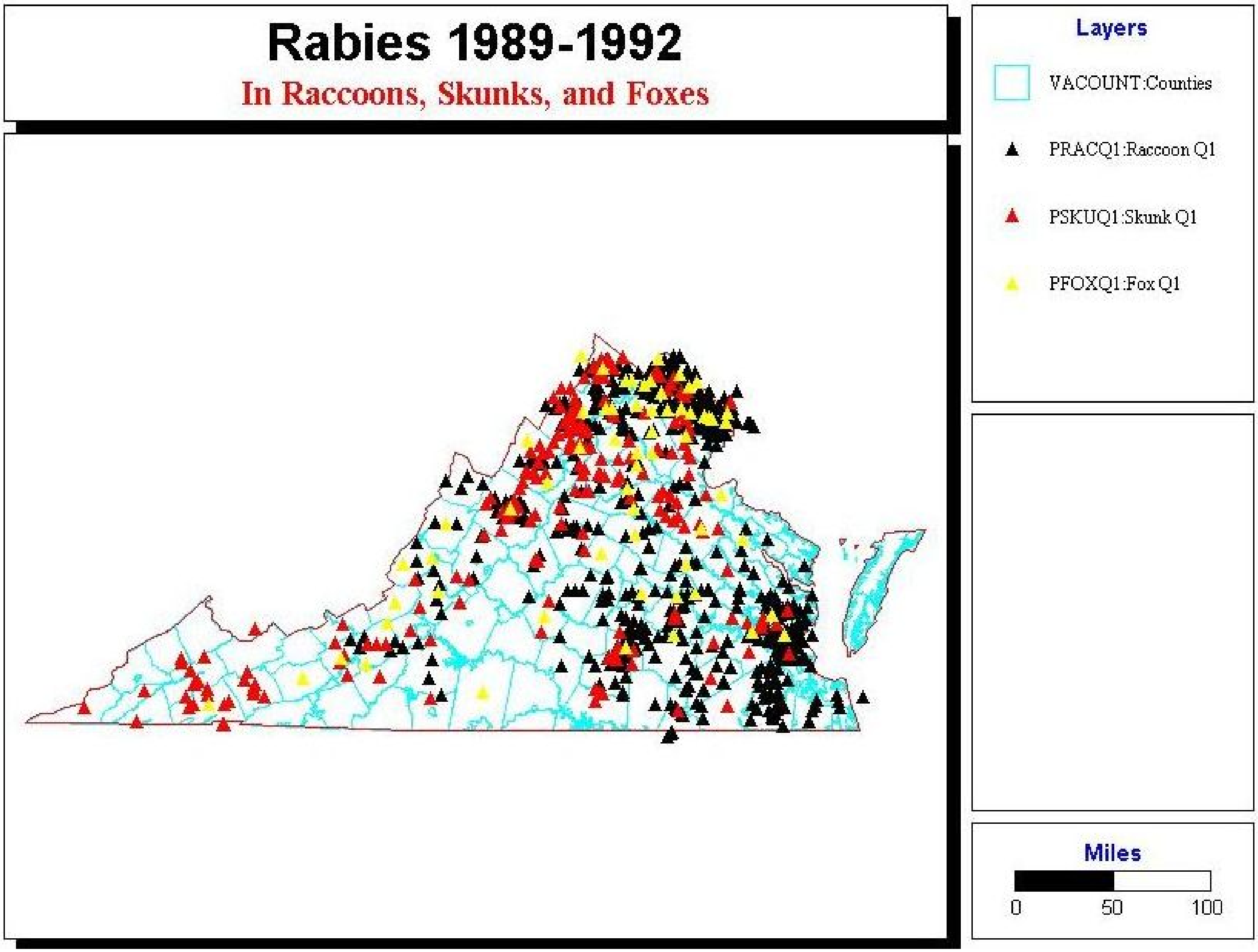
MAP 2.


All Rabies, 1996
With the Approximate Human Population (2000 Census)
Layers
VACOUNT:Counties
1996ALL2:RAB1996
Population Ranges 2000
.00 to 4999.00
5000.00 to 14999.00
15000.00 to 49999.00
50000.00 to 249999.00
250000.00 to 1000000.00
Miles
0
50
100

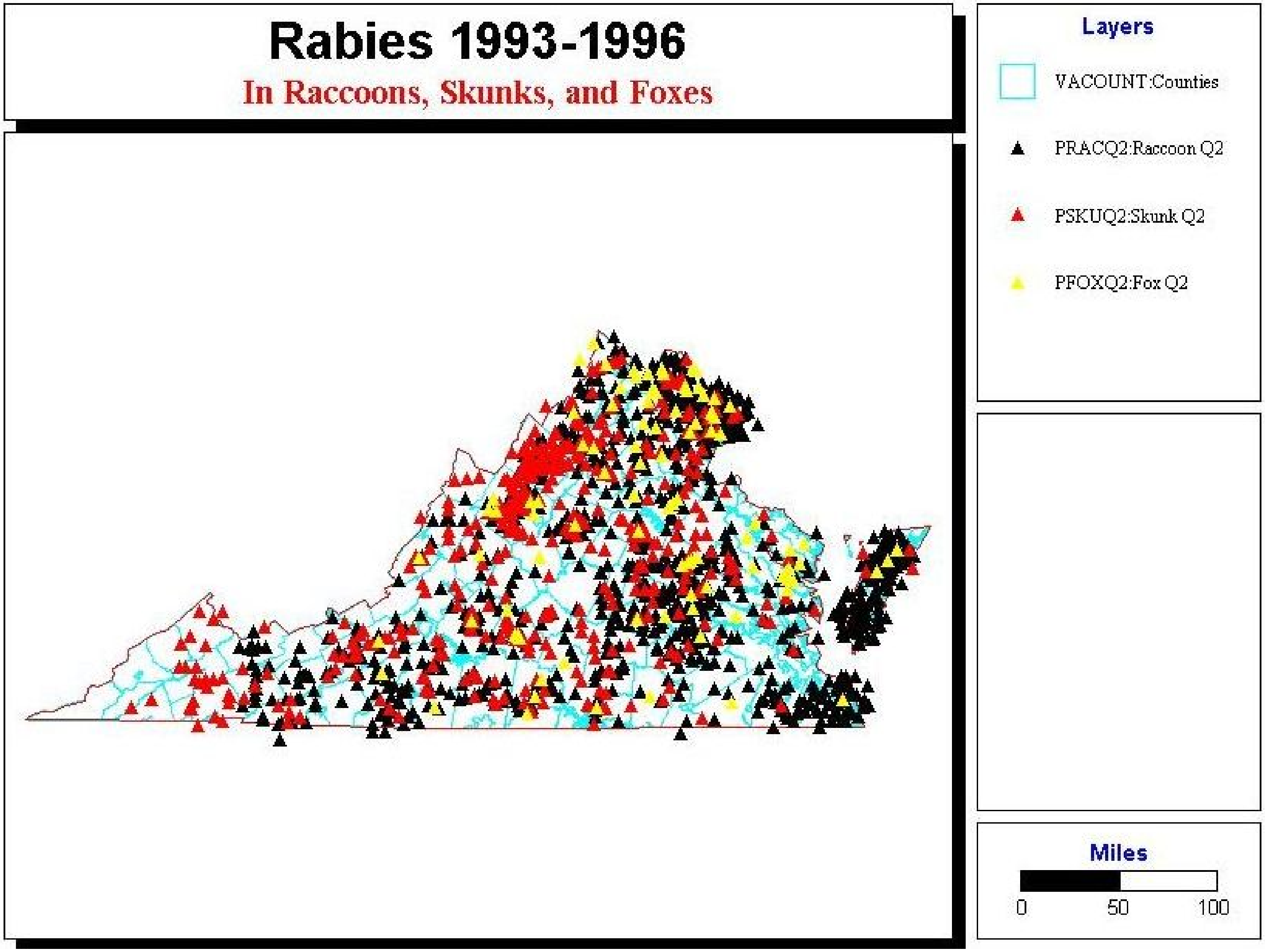
MAP 3.


All Rabies, 2003
With the Approximate Human Population (2000 Census)
Layers
VACOUNT:Counties
R2003AL:Rab03
Population Range 2000
.00 to 4999.00
5000.00 to 14999.00
15000.00 to 49999.00
50000.00 to 249999.00
250000.00 to 1000000.00
Miles
0
50
100

MAP 4a.

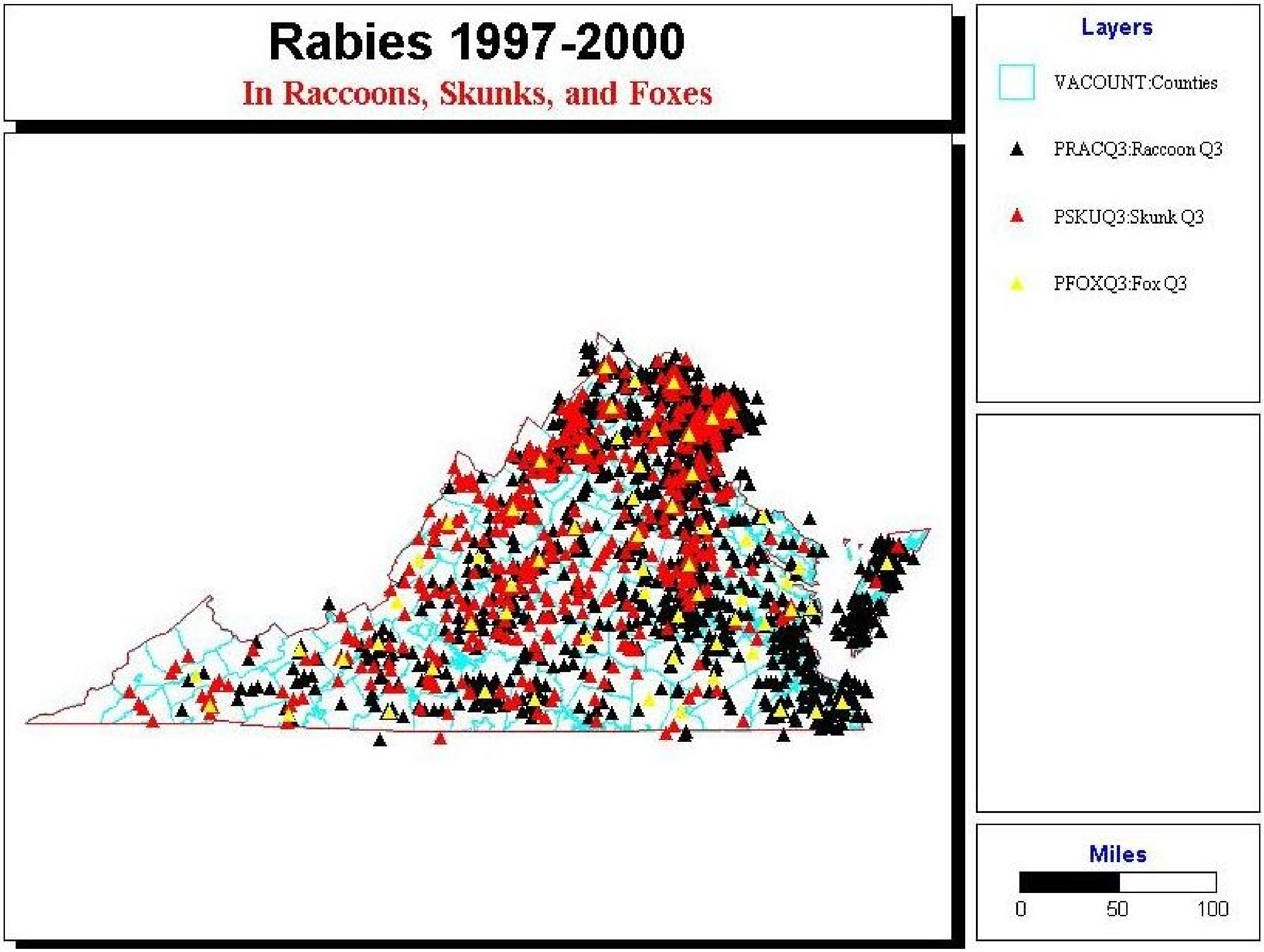

Rabies 1989-1992
In Raccoons, Skunks, and Foxes
Layers
VACOUNT:Counties
PRACQ1:Raccoon Q1
PSKUQ1:Skunk Q1
PFOXQ1:Fox Q1
Miles
0
50
100

MAP 4b.



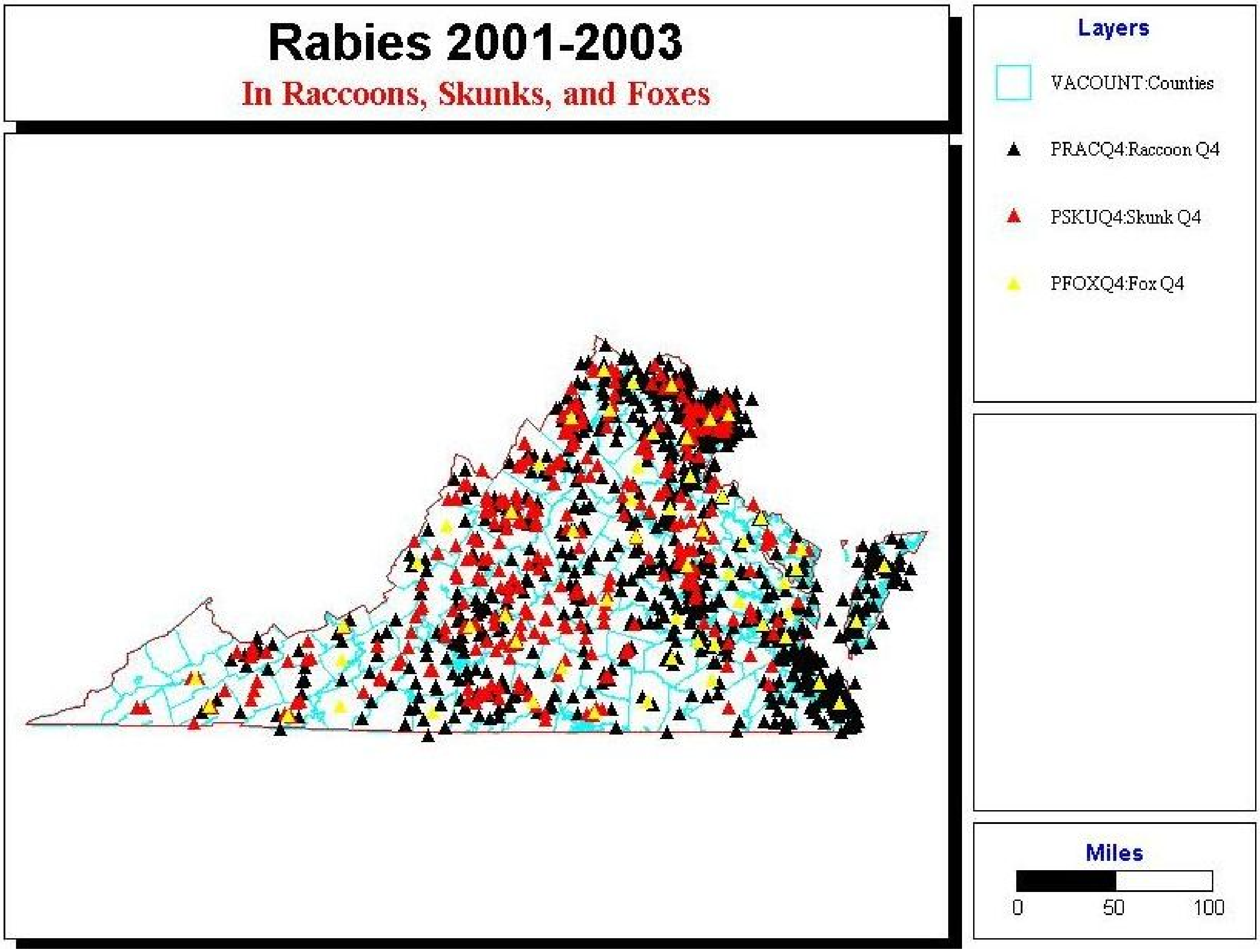
Rabies 1993-1996
In Raccoons, Skunks, and Foxes
Layers
VACOUNT:Counties
PRACQ2:Raccoon Q2
PSKUQ2:Skunk Q2
PFOXQ2:Fox Q2
Miles
0
50
100

MAP 4c.

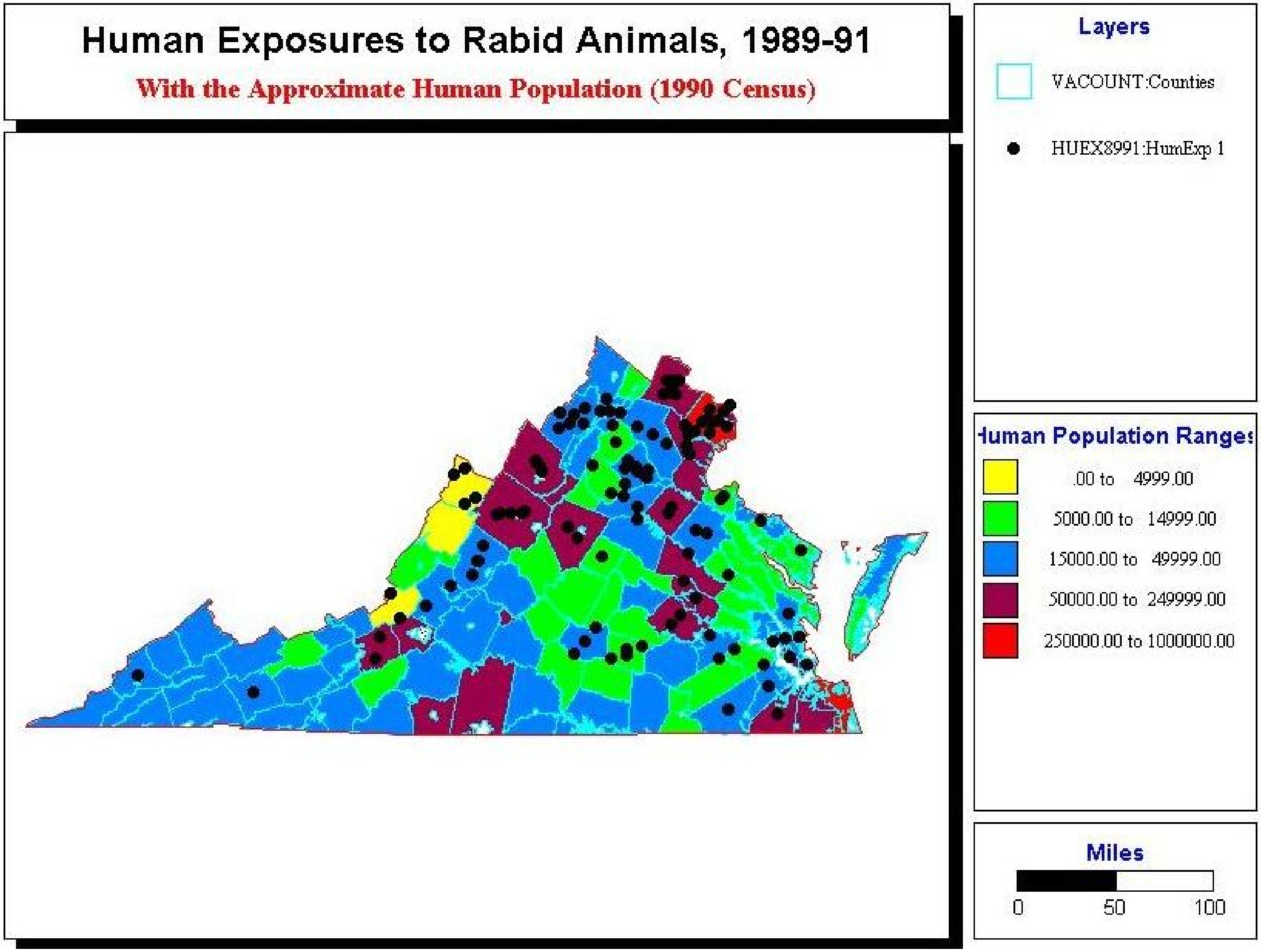


Rabies 1997-2000
In Raccoons, Skunks, and Foxes
Layers
VACOUNT:Counties
PRACQ3:Raccoon Q3
PSKUQ3:Skunk Q3
PFOXQ3:Fox Q3
Miles
0
50
100

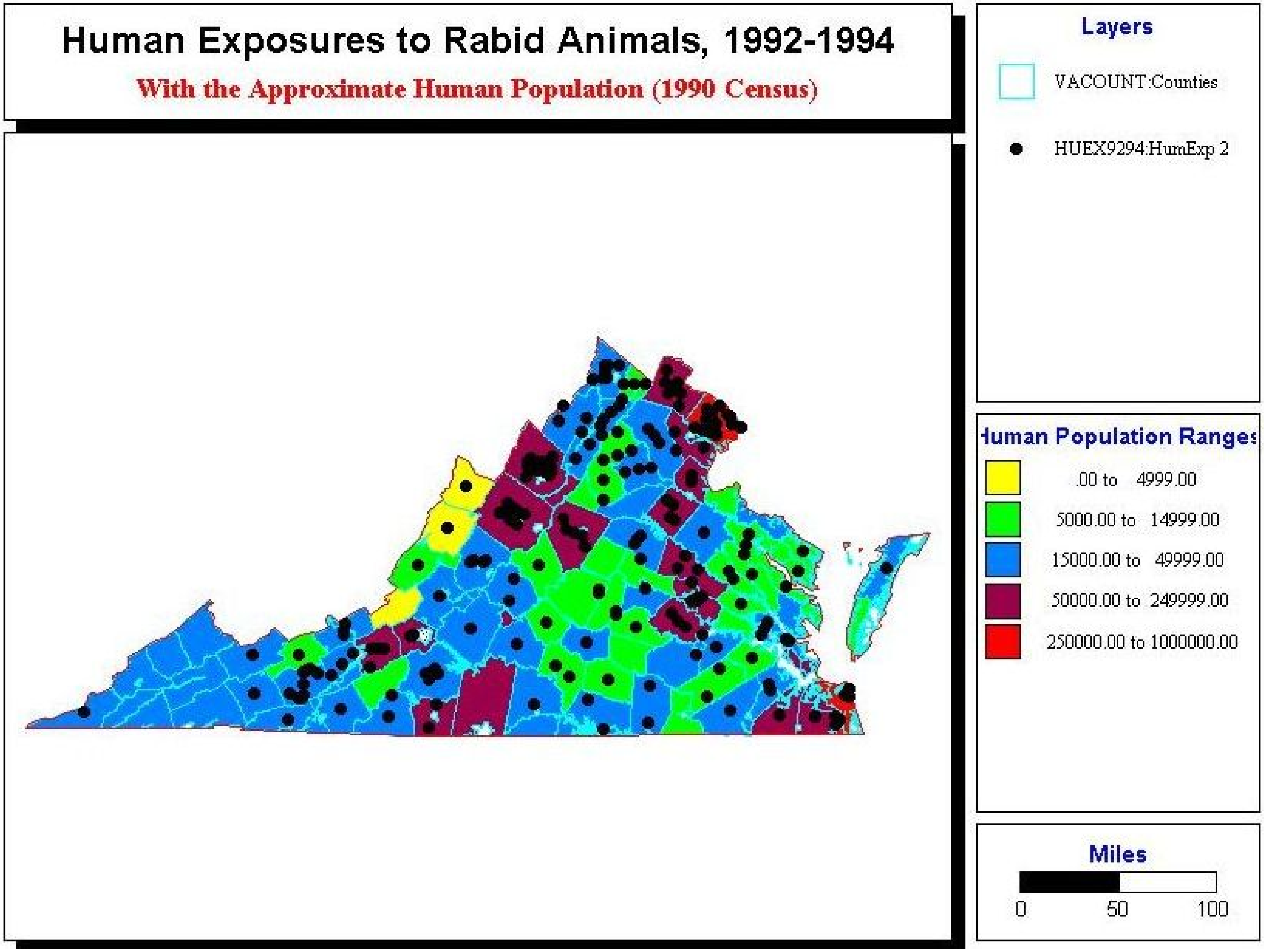
MAP 4d.


Rabies 2001-2003
In Raccoons, Skunks, and Foxes
Layers
VACOUNT:Counties
PRACQ4:Raccoon Q4
PSKUQ4:Skunk Q4
PFOXQ4:Fox Q4
Miles
0
50
100

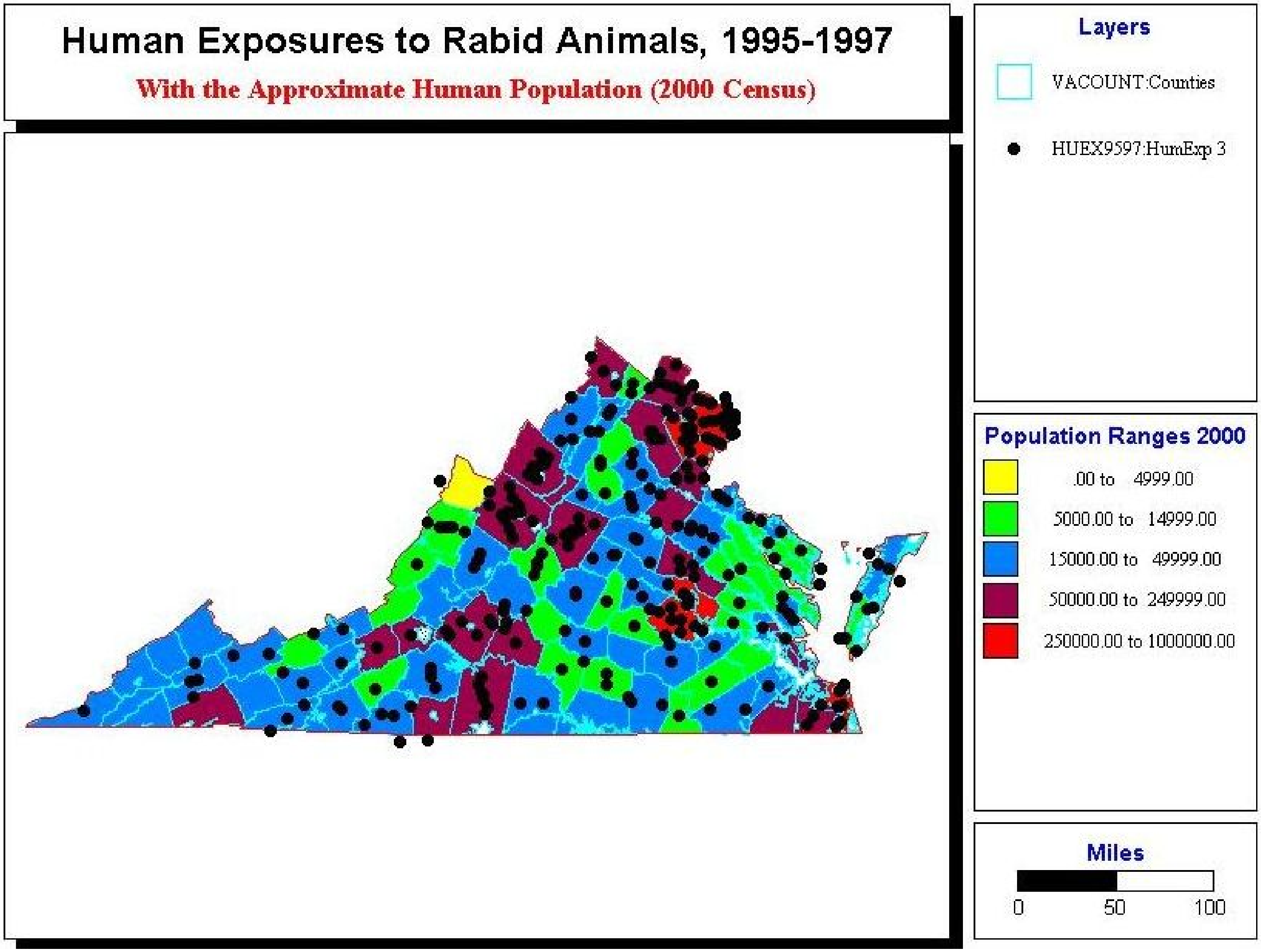
MAP 5a.


Human Exposures to Rabid Animals, 1989-91
With the Approximate Human Population (1990 Census)
Layers
VACOUNT:Counties
HUEX8991:HumExp 1
uman Population Range
.00 to 4999.00
5000.00 to 14999.00
15000.00 to 49999.00
50000.00 to 249999.00
250000.00 to 1000000.00
Miles
0
50
100

MAP 5b.

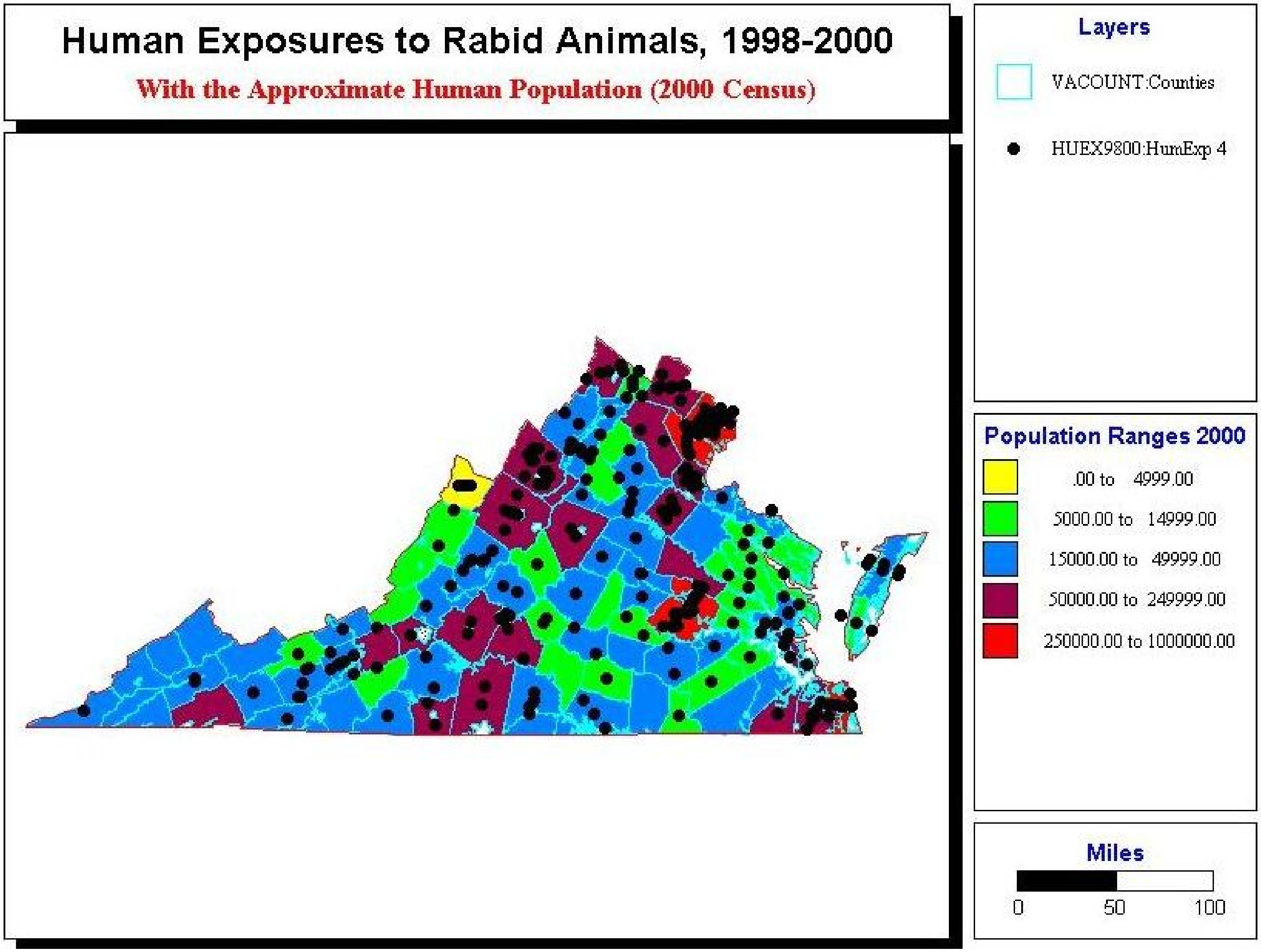

Human Exposures to Rabid Animals, 1992-1994
With the Approximate Human Population (1990 Census)
Layers
VACOUNT:Counties
HUEX9294:HumExp 2
Human Population Ranges
.00 to 4999.00
5000.00 to 14999.00
15000.00 to 49999.00
50000.00 to 249999.00
250000.00 to 1000000.00
Miles
0
50
100

MAP 5c.



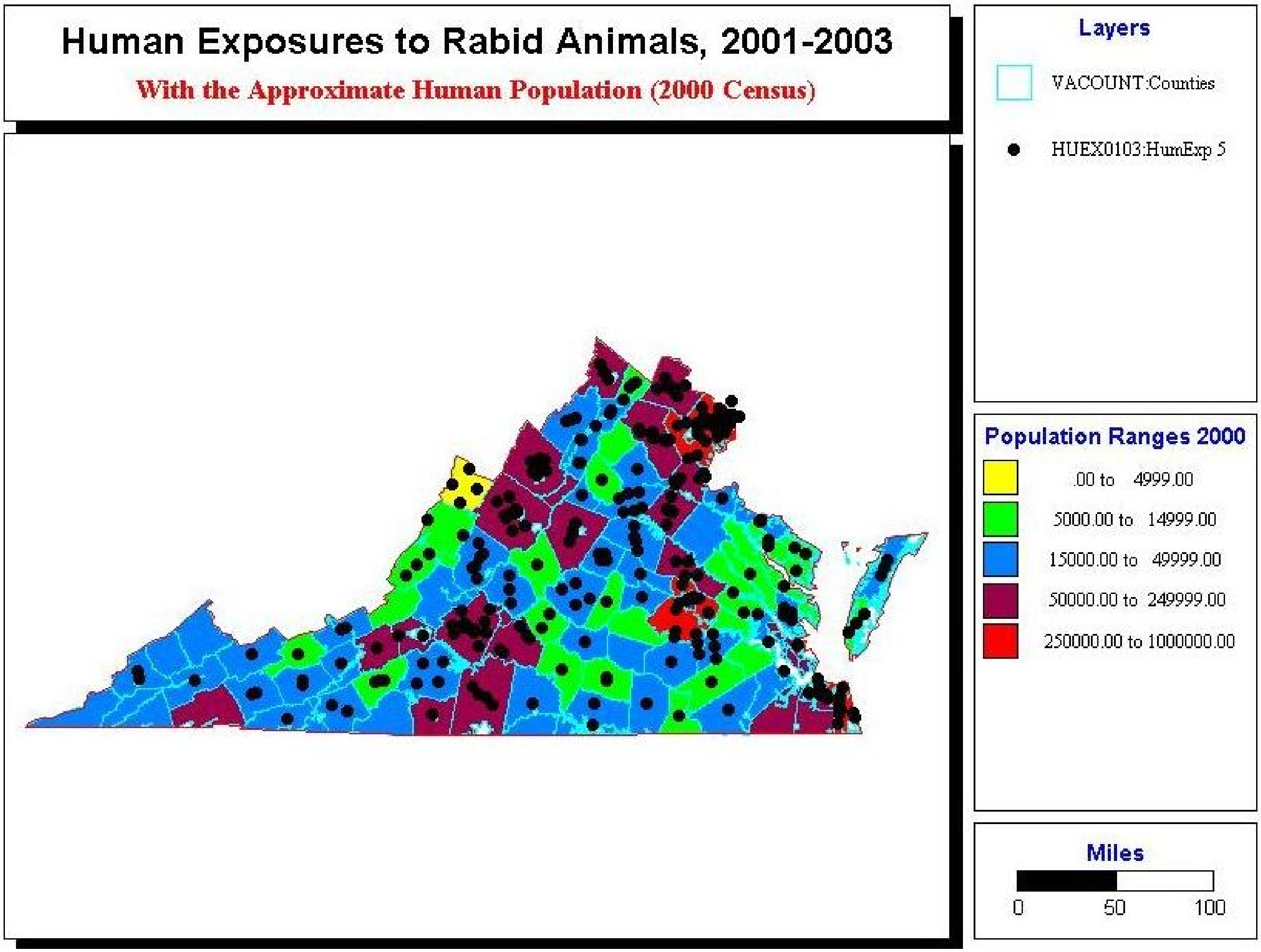
Human Exposures to Rabid Animals, 1995-1997
With the Approximate Human Population (2000 Census)
Layers
VACOUNT:Counties
HUEX9597:HumExp 3
Population Ranges 2000
.00 to 4999.00
5000.00 to 14999.00
15000.00 to 49999.00
50000.00 to 249999.00
250000.00 to 1000000.00
Miles
0
50
100

MAP 5d.



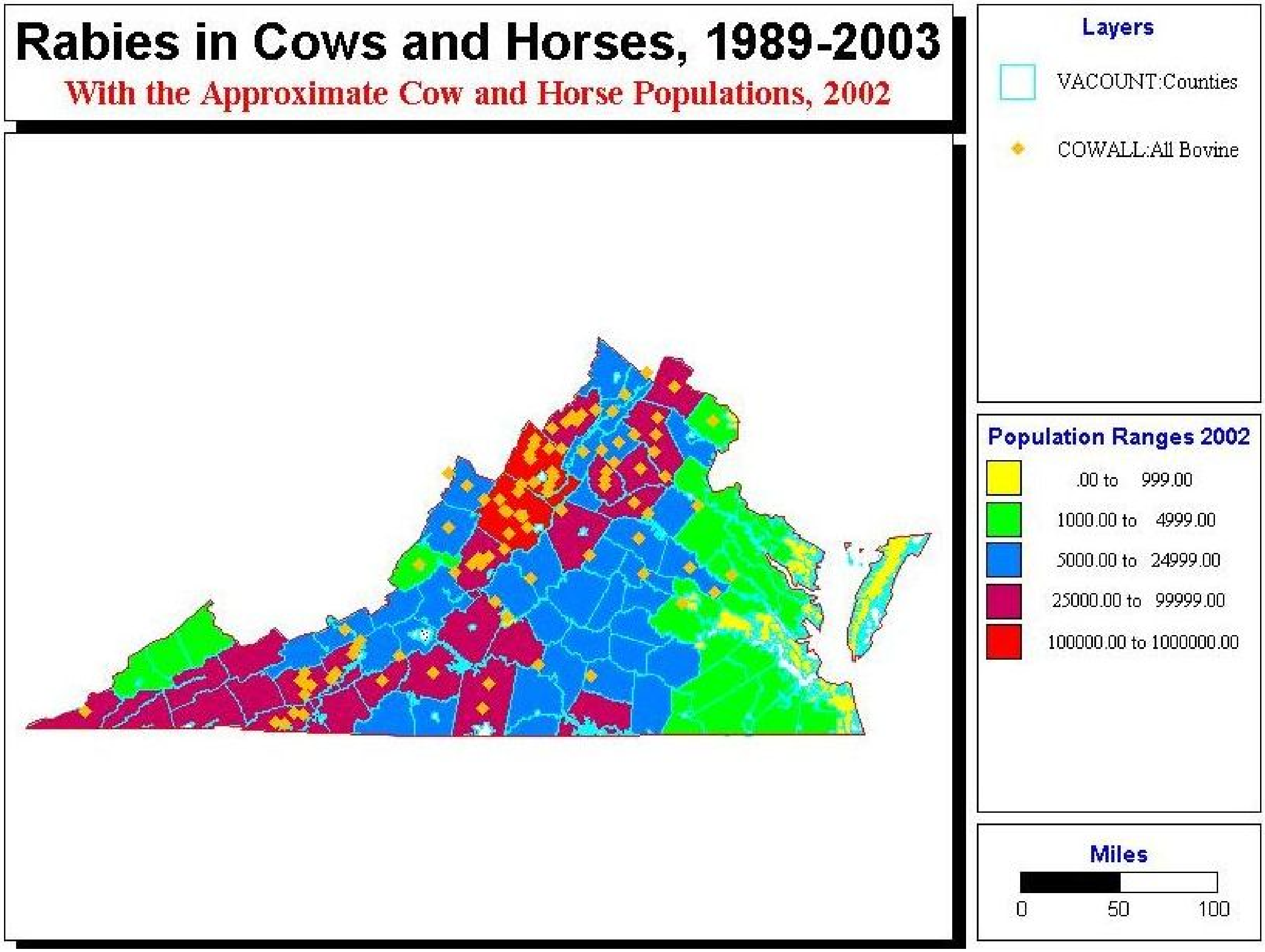
Human Exposures to Rabid Animals, 1998-2000
With the Approximate Human Population (2000 Census)
Layers
VACOUNT:Counties
HUEX9800:HumExp 4
Population Ranges 2000
.00 to 4999.00
5000.00 to 14999.00
15000.00 to 49999.00
50000.00 to 249999.00
250000.00 to 1000000.00
Miles
0
50
100

MAP 5e.



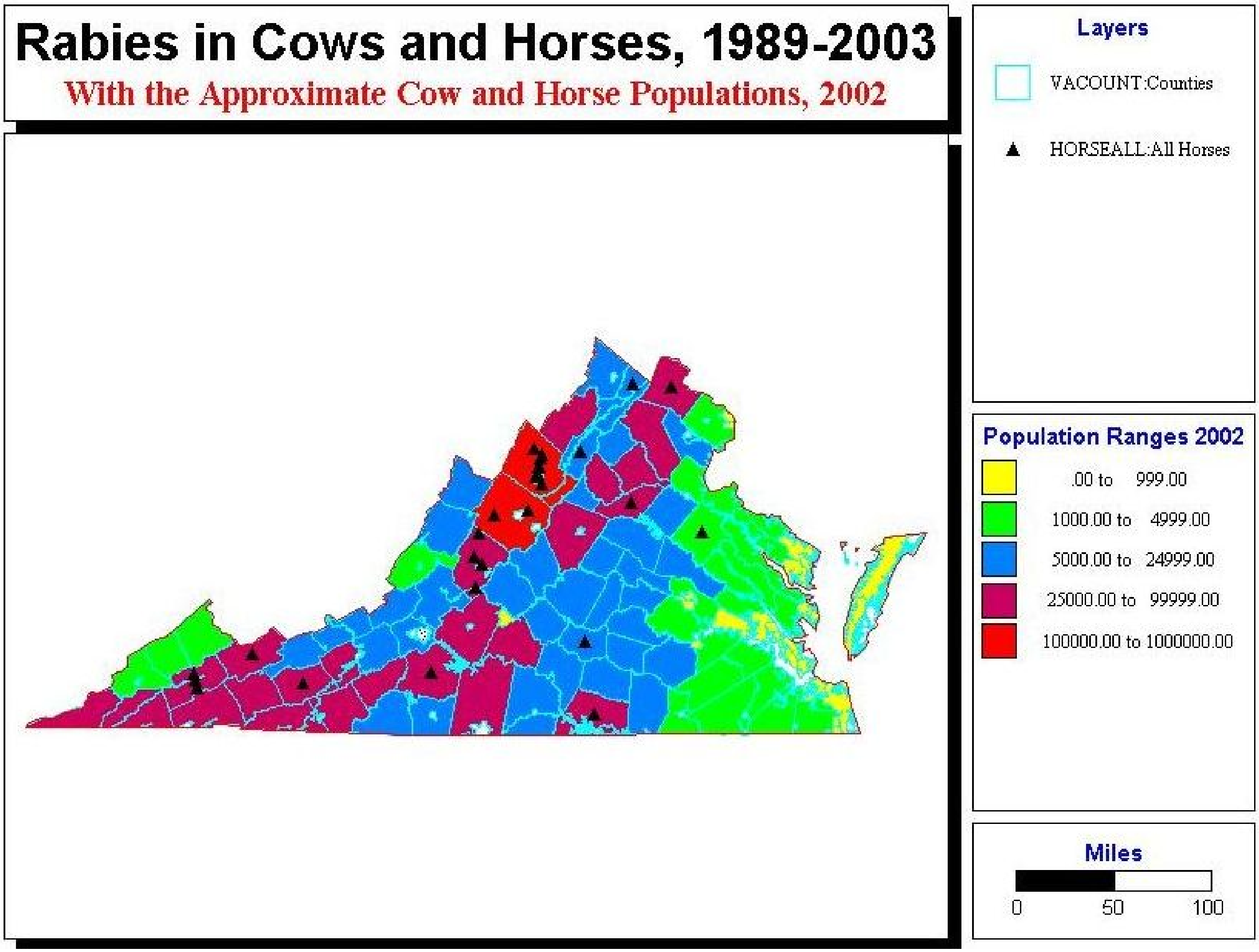
Human Exposures to Rabid Animals, 2001-2003
With the Approximate Human Population (2000 Census)
Layers
VACOUNT:Counties
HUEX0103:HumExp 5
Population Ranges 2000
.00 to 4999.00
5000.00 to 14999.00
15000.00 to 49999.00
50000.00 to 249999.00
250000.00 to 1000000.00
Miles
0
50
100

MAP 6a.

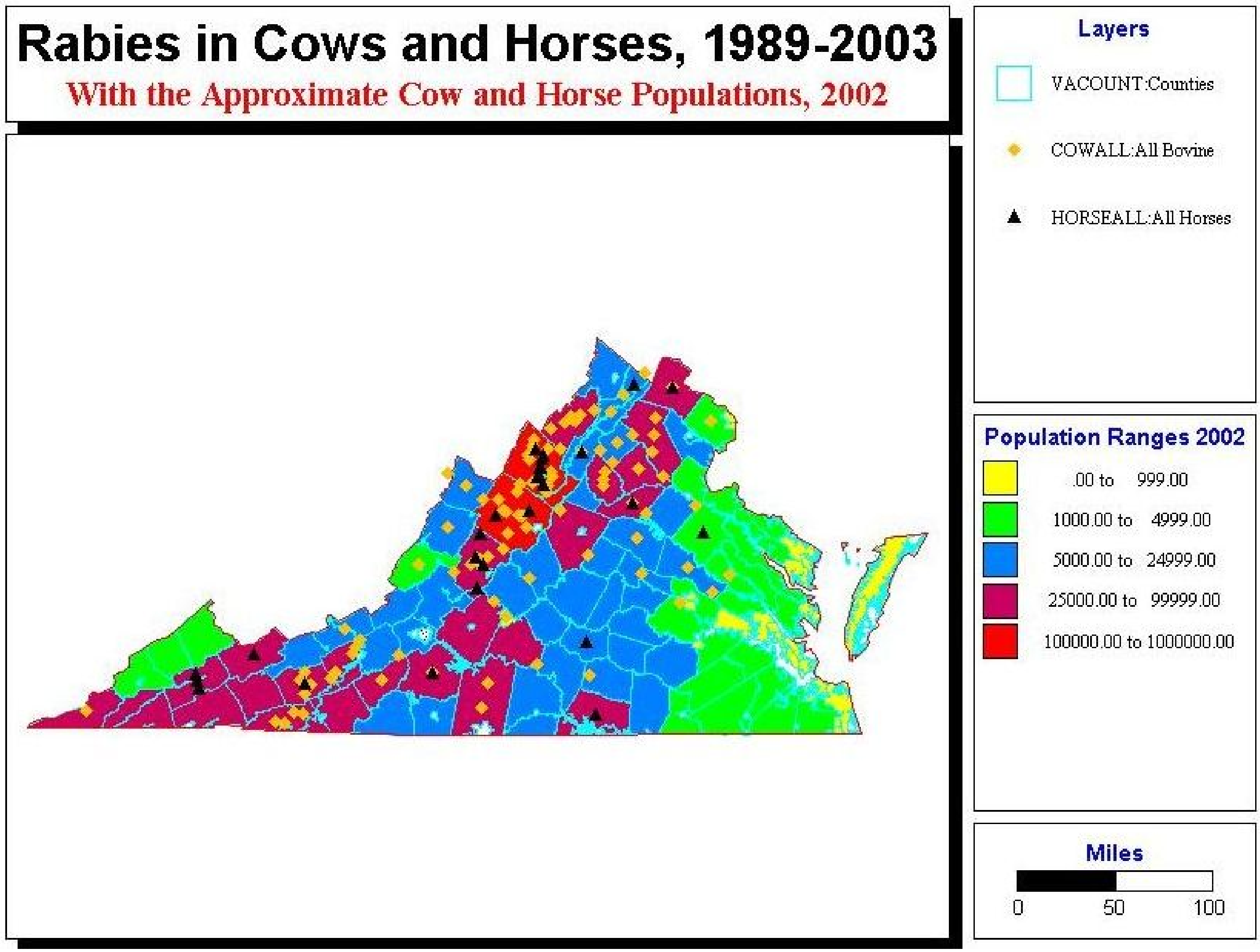


Rabies in Cows and Horses, 1989-2003
With the Approximate Cow and Horse Populations, 2002
Layers
VACOUNT:Counties
COWALL:All Bovine
Population Ranges 2002
.00 to 999.00
1000.00 to 4999.00
5000.00 to 24999.00
25000.00 to 99999.00
100000.00 to 1000000.00
Miles
0
50
100

MAP 6b.

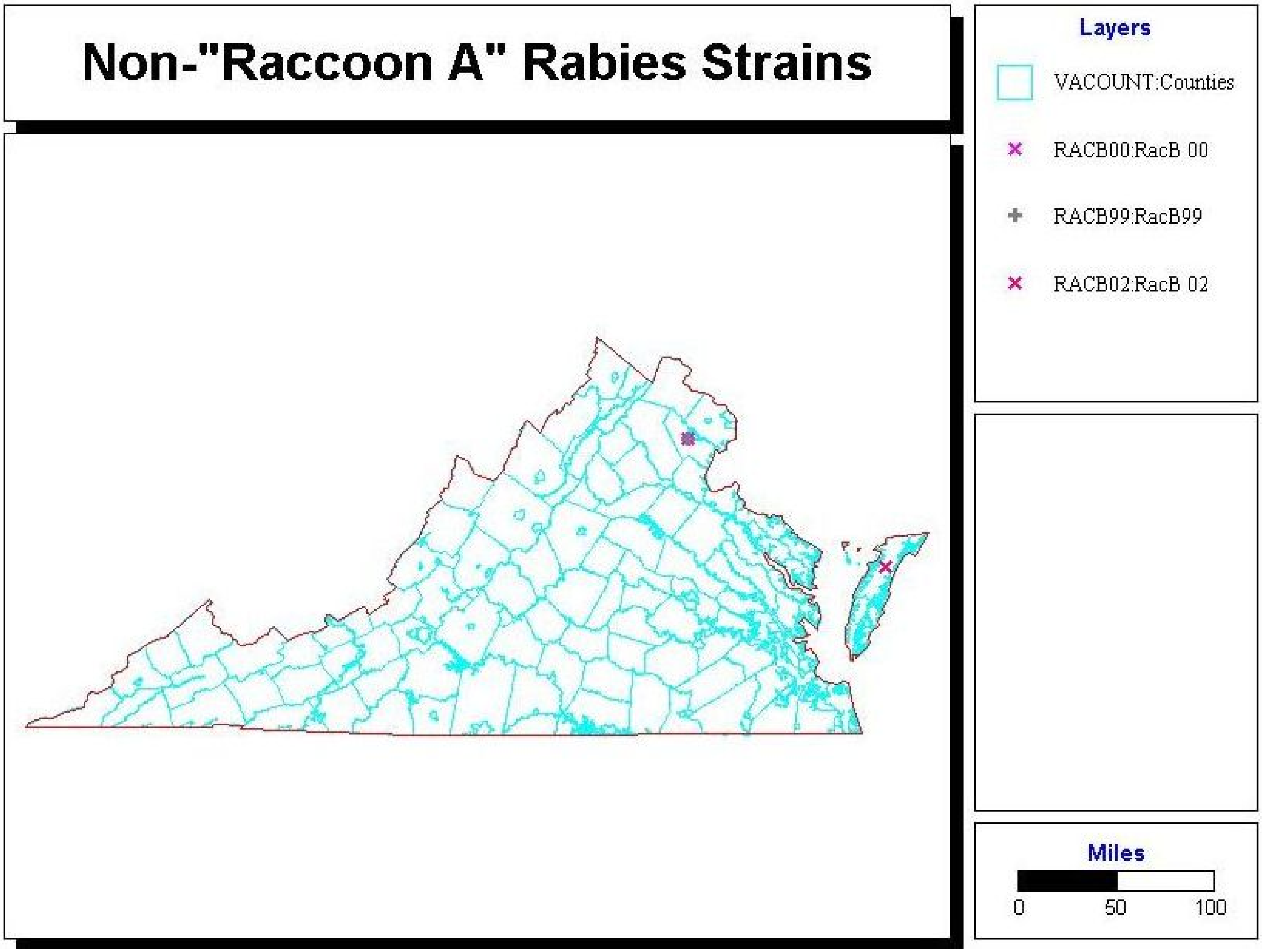

Rabies in Cows and Horses, 1989-2003
With the Approximate Cow and Horse Populations, 2002
Layers
VACOUNT:Counties
HORSEALL:All Horses
Population Ranges 2002
.00 to 999.00
1000.00 to 4999.00
5000.00 to 24999.00
25000.00 to 99999.00
100000.00 to 1000000.00
Miles
0
50
100

MAP 6c.

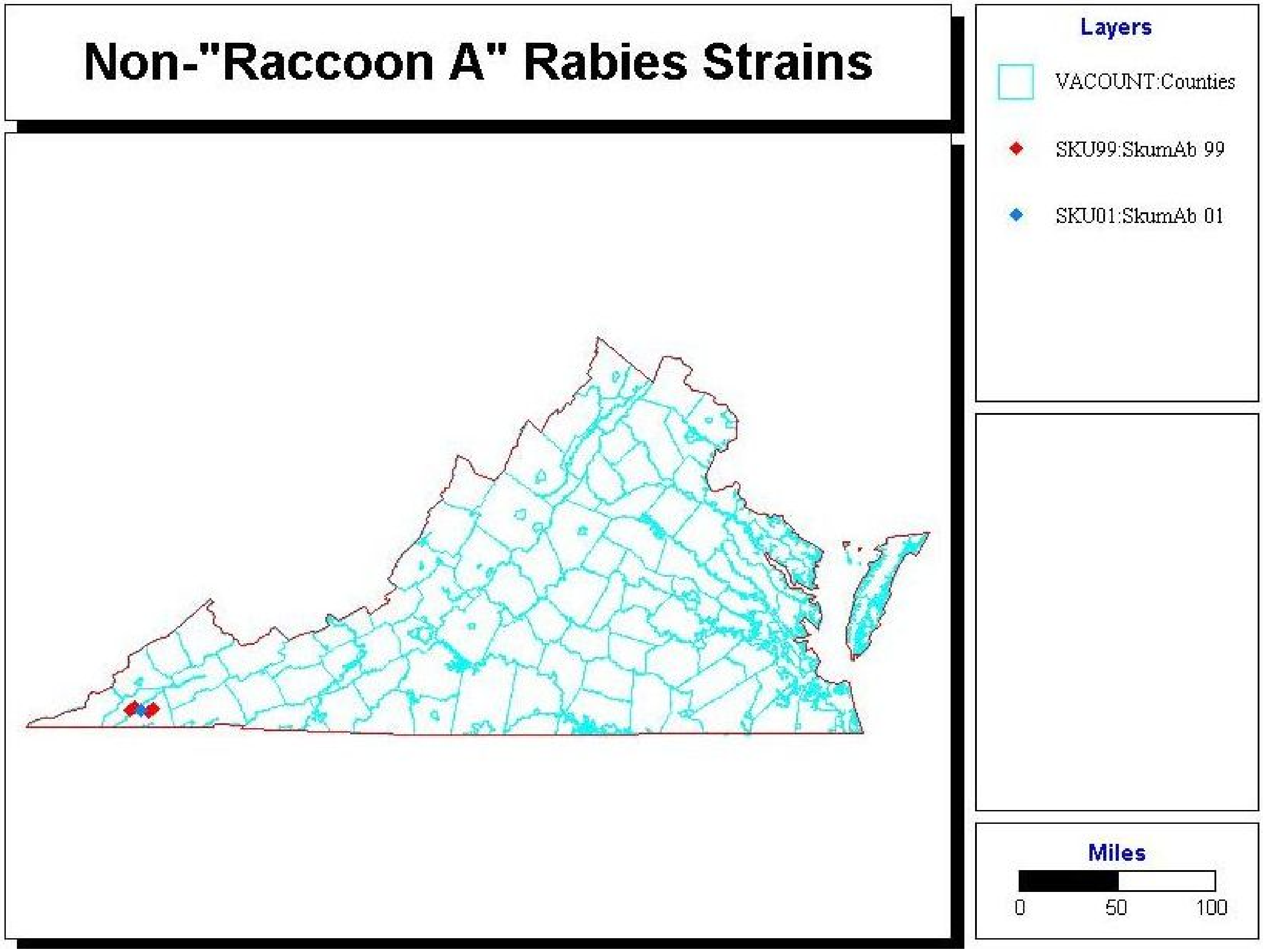


Rabies in Cows and Horses, 1989-2003
With the Approximate Cow and Horse Populations, 2002
Layers
VACOUNT:Counties
COWALL:All Bovine
HORSEALL:All Horses
Population Ranges 2002
.00 to 999.00
1000.00 to 4999.00
5000.00 to 24999.00
25000.00 to 99999.00
100000.00 to 1000000.00
Miles
0
50
100

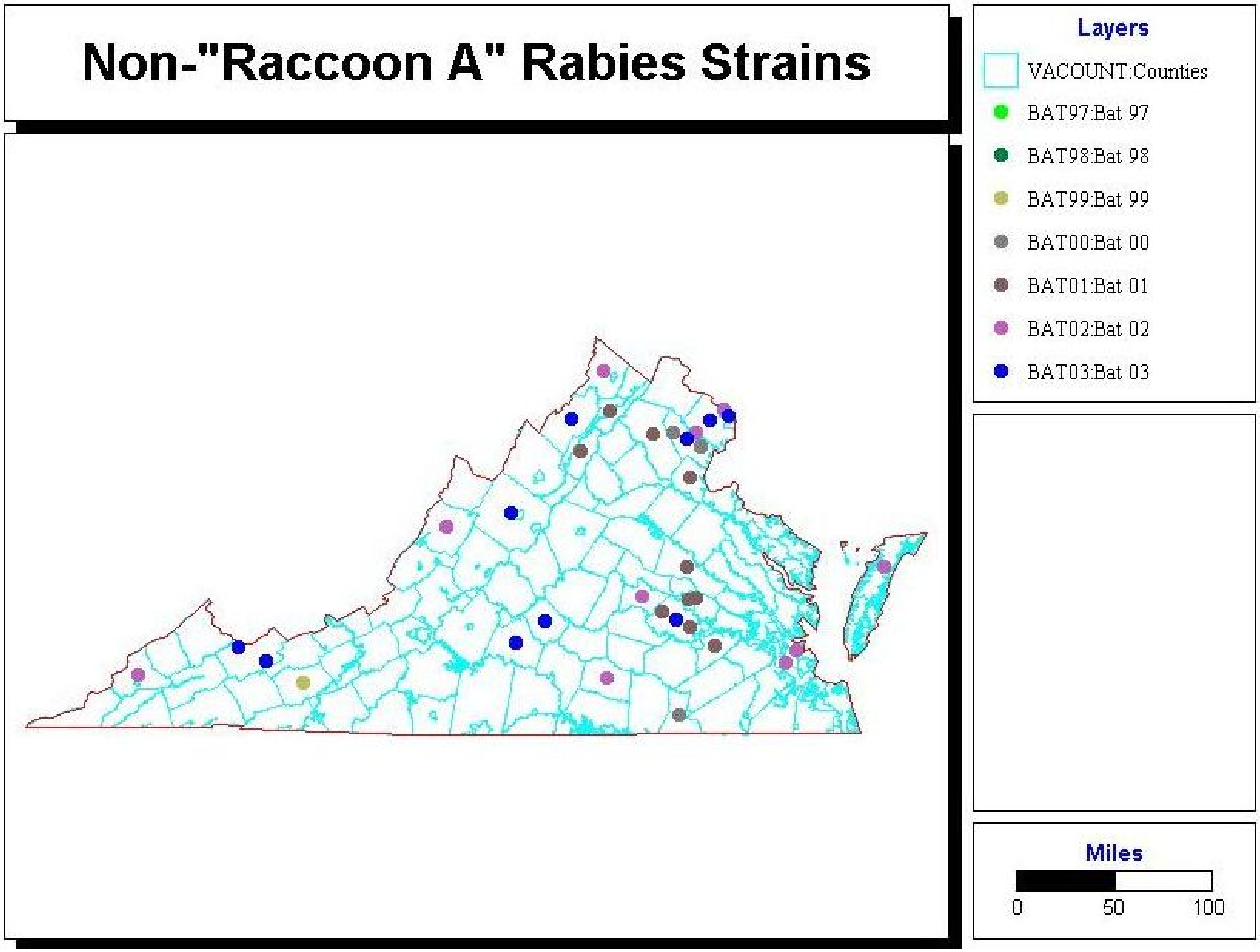
MAP 7a.


Non-"Raccoon A" Rabies Strains
Layers
VACOUNT:Counties
RACB00:RacB 00
RACB99:RacB99
RACB02:RacB 02
Miles
0
50
100

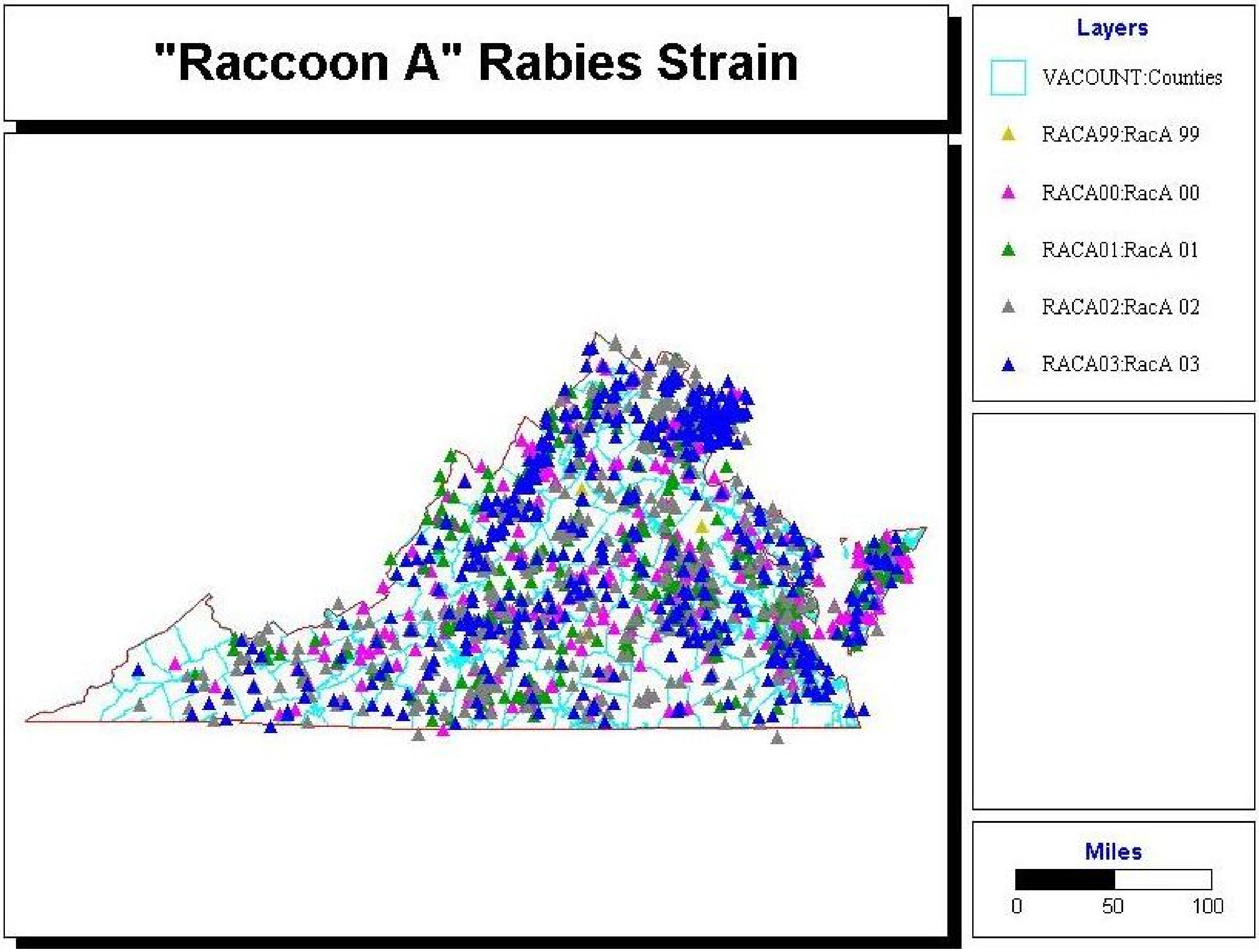
MAP 7b.


Non-"Raccoon A" Rabies Strains
Layers
VACOUNT:Counties
SKU99:SkumAb 99
SKU01:SkumAb 01
Miles
0
50
100

MAP 7c.


Non-"Raccoon A" Rabies Strains
Layers
VACOUNT:Counties
BAT97:Bat 97
BAT98:Bat 98
BAT99:Bat 99
BAT00:Bat 00
BAT01:Bat 01
BAT02:Bat 02
BAT03:Bat 03
Miles
0
50
100

MAP 7d.


"Raccoon A" Rabies Strain
Layers
VACOUNT:Counties
RACA99:RacA 99
RACA00:RacA 00
RACA01:RacA 01
RACA02:RacA 02
RACA03:RacA 03
Miles
0
50
100

Appendix

Example SPSS Syntax: 1989.

```
TITLE "RABIES DATA 1989".
SET BLANKS=SYSMIS /undefined=nowarn.

GET DATA /TYPE=XLS
   /FILE='C:\Documents and Settings\Andy\My Documents\MPH project\VDH rabies data
files\1989 mod1.xls'
   /SHEET=name 'RABIES89'
   /CELLRANGE=full
   /READNAMES=on.

RECODE
 HUMANEXPOS  ('N'='0')  ('Y'='1')  ('U'='9')
 /PET ('PET'='1') ('WILD'='0') ('STRAY'='2')  .
EXECUTE .

RECODE
  CTYCODE
  (1=006)  (3=028)  (4=015)  (5=003)  (7=022)  (6=030)  (8=013)  (9=034)  (10=032)  (11=022)
(12=039)  (13=026)  (14=020)
  (15=035)  (16=036)  (17=018)  (18=001)  (19=012)  (20=021)  (21=035)  (22=018)  (26=012)
(23=019)  (24=001)  (25=034)
  (100=029)  (101=005)  (102=012)  (103=025)  (104=013)  (105=013)  (106=007)  (107=001)
(108=001)  (109=013)  (110=018)
  (111=012)  (112=027)  (113=014)  (114=025)  (115=013)  (116=003)  (117=018)  (118=023)
(119=025)  (120=021)  (121=002)
  (122=012)  (123=004)  (124=025)  (125=014)  (126=022)  (127=033)  (128=009)  (129=004)
(130=019)  (131=005)  (132=016)
  (133=002)  (134=019)  (135=033)  (136=023)  (137=018)  (138=005)  (139=022)  (140=027)
(141=023)  (142=024)  (143=016)
  (144=001)  (145=035)  (146=034)  (147=003)  (148=033)  (149=033)  (150=033)  (151=017)
(152=010)  (153=005)  (154=025)
  (155=004)  (156=033)  (157=027)  (158=033)  (159=019)  (160=005)  (161=023)  (162=029)
(163=033)  (164=025)  (165=004)
  (166=002)  (167=016)  (168=015)  (169=021)  (170=025)  (171=022)  (172=011)  (173=019)
(174=004)  (175=033)  (176=012)
  (177=001)  (178=001)  (179=014)  (180=017)  (181=002)  (182=018)  (183=035)  (184=003)
(185=003)  (186=022)  (187=022)
  (188=014)  (189=002)  (190=018)  (191=033)  (192=017)  (193=018)  (194=034)  INTO
LOCALHDIST .
VARIABLE LABELS LOCALHDIST 'Local Health District'.
EXECUTE .

VARIABLE LABELS
 NewNumb 'New Number'
 /LABNUMBER 'Lab/VDH Number'
 /WEEKNUMBER 'CDC Week'
 /SPECNAME 'Species Name'
 /BREED 'Breed (Bat)'
 /SPECCODE 'Species Code'
 /OTHER 'Other Species'
 /PET 'Pet Status'
 /CTYNAME 'City Name'
```

/CTYCODE 'City Code'
/DATECOLECT 'Date Collected'
/DateCode 'Month Collected'
/HUMANEXPOS 'Human Exposure'
/NUMBEREXP 'Number Exposed'
/VACCINATIO 'Vaccination'
/BITEOTHER 'Bite, Other'
/SPECIESBIT 'Species Bitten'
/FRA 'FRA Test Result'
/LOCALHDIST 'Local Health District'.

VALUE LABELS
speccode 1 'bat' 2 'bovine' 3 'cat' 4 'chipmunk' 5 'deer' 6 'dog' 7 'equine' 8 'ferret' 9 'gray fox' 10 'red fox' 11 'fox' 12 'gerbil' 13 'goat' 14 'groundhog' 15 'guinea pig' 16 'hamster' 17 'mole' 18 'muskrat' 19 'opossum' 20 'pig' 21 'rabbit' 22 'raccoon' 23 'mouse' 24 'sheep' 25 'shrew' 26 'skunk' 27 'squirrel' 28 'vole' 29 'weasel' 30 'other' 31 'beaver' 32 'bear' 33 'bobcat' 34 'rat' 35 'wolf hybrid' 36 'otter' 37 'sugar glider' 38 'mink' 39 'lamb' 40 'llama' 41 'coyote' 42 'nutria' 43 'kangaroo' 44 'donkey' 45 'lynx' 46 'wolf' 47 'hedgehog' 48 'monkey (all spp.)' 49 'prairie dog' 50 'antelope' 51 'mule' 52 'buffalo' 53 'chinchilla' 54 'alpaca' 55 'woodchuck' 99 'unknown'
/pet 0 'Wild' 1 'Pet' 2 'Stray'
/ctycode 1 'Alexandria' 3 'Chesapeake' 4 'Danville' 5 'Fredericksburg' 6 'Hampton' 7 'Hopewell' 8 'Lynchburg' 9 'Newport News' 10 'Norfolk' 11 'Petersburg' 12 'Portsmouth' 13 'Richmond City' 14 'Roanoke City' 15 'Suffolk' 16 'Virginia Beach' 17 'Bristol' 18 'Buena Vista' 19 'Clifton Forge' 20 'Colonial Heights' 21 'Franklin City' 22 'Galax' 23 'Radford' 24 'Waynesboro' 25 'Williamsburg' 26 'Salem' 100 'Accomack' 101 'Albemarle' 102 'Alleghany' 103 'Amelia' 104 'Amherst' 105 'Appomattox' 106 'Arlington' 107 'Augusta' 108 'Bath' 109 'Bedford' 110 'Bland' 111 'Botetourt' 112 'Brunswick' 113 'Buchanan' 114 'Buckingham' 115 'Campbell' 116 'Caroline' 117 'Carroll' 118 'Charles City' 119 'Charlotte' 120 'Chesterfield' 121 'Clarke' 122 'Craig' 123 'Culpeper' 124 'Cumberland' 125 'Dickenson' 126 'Dinwiddie' 127 'Essex' 128 'Fairfax' 129 'Fauquier' 130 'Floyd' 131 'Fluvanna' 132 'Franklin' 133 'Frederick' 134 'Giles' 135 'Gloucester' 136 'Goochland' 137 'Grayson' 138 'Greene' 139 'Greensville' 140 'Halifax' 141 'Hanover' 142 'Henrico' 143 'Henry' 144 'Highland' 145 'Isle of Wight' 146 'James City' 147 'King George' 148 'King and Queen' 149 'King William' 150 'Lancaster' 151 'Lee' 152 'Loudoun' 153 'Louisa' 154 'Lunenberg' 155 'Madison' 156 'Mathews' 157 'Mecklenburg' 158 'Middlesex' 159 'Montgomery' 160 'Nelson' 161 'New Kent' 162 'Northampton' 163 'Northumberland' 164 'Nottoway' 0 'No Submitter' 165 'Orange' 166 'Page' 167 'Patrick' 168 'Pittsylvania' 169 'Powhatan' 170 'Prince Edward' 171 'Prince George' 172 'Prince William' 173 'Pulaski' 174 'Rappahannock' 175 'Richmond' 176 'Roanoke' 177 'Rockbridge' 178 'Rockingham' 179 'Russell' 180 'Scott' 181 'Shenandoah' 182 'Smyth' 183 'Southampton' 184 'Spotsylvania' 185 'Stafford' 186 'Surrey' 187 'Sussex' 188 'Tazewell' 189 'Warren' 190 'Washington' 191 'Westmoreland' 192 'Wise' 193 'Wythe' 194 'York'
/datecode 0 'Unknown/Invalid' 1'January' 2 'February' 3 'March' 4 'April' 5 'May' 6 'June' 7 'July' 8 'August' 9 'September' 10 'October' 11 'November' 12 'December'
/numberexp 0 '0' 1 '1' 2 '2' 3 '3' 4 '4' 5 '5' 6 '6' 7 '7' 8 '8' 9 '9' 10 '10' 11 '11' 12 '12' 13 '13' 14 '14' 15 '15' 16 '16' 17 '17' 18 '18' 19 '19' 20 '20' 99 'Unknown'
/humanexpos 0 'No' 1 'Yes' 9 'Unknown'
/vaccinatio 0 'No' 1 'Yes' 2 'Not Applicable' 9 'Unknown'
/biteother 0 'No' 1 'Yes' 9 'Unknown'
/fra 0 'Neg' 1 'Pos' 2 'NegBut' 3 'Non' 4 'Un' 9 'Missing'
/localhdist 0 'No Submitter' 001 'Central Shenandoah' 002 'Lord Fairfax' 003 'Rappahannock' 004 'Rappahannock Rapidan' 005 'Thomas Jefferson' 006 'Alexandria' 007 'Arlington' 009 'Fairfax' 010 'Loudoun' 011 'Prince William' 012 'Alleghany' 013 'Central Virginia' 014 'Cumberland Plateau' 015 'Danville' 016 'West Piedmont' 017 'Lenowisco' 018 'Mount Rogers' 019 'New River' 020 'Roanoke' 021 'Chesterfield' 022 'Crater' 023 'Hanover' 024 'Henrico' 025 'Piedmont' 026 'Richmond' 027 'Southside' 028 'Chesapeake' 029 'Eastern Shore' 030 'Hampton' 032 'Norfolk' 033 'Three Rivers' 034 'Peninsula' 035 'Western Tidewater' 036 'Virginia Beach' 039 'Portsmouth'
.

```
RECODE
  DateCode
  (0=0)  (1=1)  (2=1)  (3=2)  (4=2)  (5=2)  (6=3)  (7=3)  (8=3)  (9=4)  (10=4)  (11=4)  (12=1)  INTO
SeaCode .
VARIABLE LABELS SeaCode 'Season'.
EXECUTE .

VALUE LABELS
 SeaCode 0 'Unknown/Invalid' 1 'Winter' 2 'Spring' 3 'Summer' 4 'Fall'.
EXECUTE.

CROSSTABS
 /TABLES=speccode pet ctycode numberexp humanexpos vaccinatio biteother BY FRA
 /TABLES=pet ctycode numberexp humanexpos vaccinatio biteother BY speccode
 /TABLES=ctycode numberexp humanexpos vaccinatio biteother BY pet
 /TABLES=numberexp humanexpos vaccinatio biteother BY ctycode
 /TABLES=humanexpos vaccinatio biteother BY numberexp
 /TABLES=vaccinatio biteother BY humanexpos
 /TABLES=biteother BY vaccinatio
 /FORMAT= AVALUE TABLES
 /STATISTIC= RISK
 /CELLS= COUNT ROW COLUMN
 /COUNT ROUND CELL.

CROSSTABS
 /TABLES=speccode BY FRA
 /FORMAT= AVALUE TABLES
 /STATISTIC= RISK
 /CELLS= COUNT ROW COLUMN
 /COUNT ROUND CELL.

FREQUENCIES
 VARIABLES=localhdist
 /ORDER ANALYSIS.

CROSSTABS
 /TABLES=speccode BY fra
 /FORMAT= AVALUE TABLES
 /STATISTIC= RISK
 /CELLS= COUNT ROW COLUMN
 /COUNT ROUND CELL.

*Recode for mapmaking.
RECODE
 fra (1=1)(0=0)(2=0)into fra1.
EXECUTE.

*Crosstab for mapmaking.
CROSSTABS
 /TABLES=ctycode BY FRA
 /FORMAT= AVALUE TABLES
 /STATISTIC= RISK
 /CELLS= COUNT
 /COUNT ROUND CELL.
```

```
*Recode foxes for tables.
RECODE
  SPECCODE  (9=11)  (10=11)  (11=11)  .
EXECUTE .

*Recode all for tables.
RECODE
  SPECCODE  (9=11)  (10=11)  (11=11)  (3=3) (4 thru 5=99)  (8=99)  (12 thru 18=99)  (20 thru
21=99) (23 thru 25=99)  (27 thru Highest=99)  .
EXECUTE .

CROSSTABS
 /TABLES=localhdist BY FRA
 /FORMAT= AVALUE TABLES
 /STATISTIC= RISK
 /CELLS= COUNT ROW
 /COUNT ROUND CELL.

CROSSTABS
 /TABLES=humanexpos BY speccode BY FRA
 /FORMAT= AVALUE TABLES
 /STATISTIC= RISK
 /CELLS= COUNT ROW
 /COUNT ROUND CELL.

CROSSTABS
 /TABLES=speccode BY FRA By humanexpos
 /FORMAT= AVALUE TABLES
 /STATISTIC= RISK
 /CELLS= COUNT ROW
 /COUNT ROUND CELL.

CROSSTABS
 /TABLES=datecode BY FRA
 /FORMAT= AVALUE TABLES
 /STATISTIC= RISK
 /CELLS= COUNT
 /COUNT ROUND CELL.

CROSSTABS
 /TABLES=datecode BY FRA BY speccode
 /FORMAT= AVALUE TABLES
 /STATISTIC= RISK
 /CELLS= COUNT
 /COUNT ROUND CELL.

CROSSTABS
 /TABLES=datecode BY FRA By biteother
 /FORMAT= AVALUE TABLES
 /STATISTIC= RISK
 /CELLS= COUNT
 /COUNT ROUND CELL.
```