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# WILD CARNIVORES AS PLAGUE INDICATORS IN CALIFORNIA - A COOPERATIVE INTERAGENCY DISEASE SURVEILLANCE PROGRAM

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**ABSTRACT:** A cooperative interagency program of sampling and testing wild carnivores for plague antibody has been utilized as an important component of an integrated plague surveillance program in California since 1974. The carnivore serology program involves the California Department of Health Services, the U.S. Department of Agriculture, APHIS/Animal Damage Control, the U.S. Department of Health and Human Services, Centers for Disease Control, and various other cooperators. This paper summarizes the results of the testing of wild carnivores, opossums, and feral pigs over the past two decades from 49 of California's 58 counties, and discusses the importance of the program to the overall statewide plague surveillance and control effort. A total of 8,962 samples have yielded 1,076 plague positives from wild carnivores, opossums, and feral pigs in 32 California counties. The highest percent positives have been from pine martens, mountain lions, bobcats, and grey foxes. A propensity for certain rodent prey species may increase the chance of plague infection for individual carnivorous species. The methodology has proven cost effective, allowed for detection of plague over a broader scale and in regions with no previous disease history, and demonstrated persistence of disease in apparent geographical foci within the state. In addition, the sampling of carnivorous animals in winter/spring in specific endemic regions has proven useful as an early alert system for disease activity, preceeding summer plague epizootics among susceptible rodent populations, and when human plague cases associated with epizootics normally occur.

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## INTRODUCTION

The surveillance and control of plague has been a routine practice in California since the 1930s, following the earlier human epidemics and fatalities which occurred in San Francisco and Los Angeles in the early 1900s (Link 1953). Concerns with this important disease continue to be the potential pneumonic spread to humans triggered by an initial case of pneumonic plague and an ensuing epidemic, and the potential transfer of the disease from the sylvatic source to commensal rat populations with close human contact in heavily urbanized regions. Consequently, the surveillance and control of plague remains an important element in public health prevention in the state of California.

Thirty-two human cases and seven fatalities have occurred in California from 1962 to 1993. Six of the 32 cases (18%) developed secondary plague pneumonia, an increase in incidence rate over previous decades, as noted for all western states by Barnes (1982). Mortality among cases in California, as in other western states, has remained high despite the availability of specific antibiotic therapy.

A plague surveillance and suppression program under the coordination of the California Department of Health Services is a cooperative interagency program involving state, federal and local agencies in the prevention of human cases utilizing education, epidemiological and epizootiological investigation, direct surveillance of host and vector populations, serological sampling of wild carnivores and domestic pets, laboratory testing, vector suppression, and disease management. A cooperative wild carnivore serology program to detect plague antibody to *Yersinia pestis* using carnivores as sentinels of disease activity among rodent prey species has been an important component of the surveillance effort in California since 1974.

The objectives of the carnivore sera sampling and testing program have been to:

1. Compare the cost effectiveness of carnivore serology as a surveillance method to other surveillance methods.
2. Help define the extent of epizootic plague in investigations.
3. Detect disease in regions with little or no disease history.
4. Detect disease persistence within apparent geographical disease foci, and help delineate foci of infection.
5. Detect trends in the geographic scope and intensity of rodent plague.
6. Provide an early warning system of disease detection early in the year for endemic areas, prior to when human cases normally occur.

Smith, Nelson & Barnes (1984) reported on the use of the carnivore serology program in determining patterns of disease activity among rodent populations in California. This paper summarizes the results of the testing of wild carnivore sera from 49 of California's 58 counties, evaluates the program in meeting the above stated objectives, and discusses the importance of the program to the overall statewide plague surveillance and suppression effort in California.

## BACKGROUND

Carnivores obtain plague infection through ingestion of infected rodent or rabbit tissue, or by fleabite of infected rodent fleas. Most carnivores are resistant to the disease, show little clinical evidence, and produce rapid serologic response to infection, developing antibodies to *Y. pestis*, which may persist for several months. The occurrence of plague antibody titers in wild carnivores

offers indirect evidence of plague infections among wild rodents that comprise a major portion of such predator's diets.

Studies by Rust, Cavanaugh et al. (1971) and Rust, Miller et al. (1971) demonstrated that domestic dogs were somewhat resistant to plague infection and suggested the possibility that domestic dogs might serve as sentinels of plague activity where exposed to wild rodents and fleas in endemic areas. Archibald and Kunitz (1971) utilized this theory to elucidate plague activity on Indian Reservations in the southwestern United States. A summary of the serological surveillance of plague among domestic carnivores in California has been prepared by Chomel, et al. (in press).

Based on the concepts developed for dogs, Barnes (1974) conducted pilot field and laboratory studies using wild carnivores as plague serological sentinels in conjunction with the U.S. Department of Agriculture, APHIS, Animal Damage Control, and various state health departments. The concept of sample collection using a simple filter paper strip collection method, as described by Wolff and Hudson (1974), received enthusiastic acceptance among sample takers, and led the way for extensive widespread serosurveys. California was one of the first states to implement the program on a trial basis in cooperation with the Centers for Disease Control.

Marshall et al. (1972) demonstrated that swine showed similar appearance of high antibody titers to infection with *Y. pestis* as that seen among wild carnivores. The serological sampling of feral swine has been added to the current plague surveillance program for the past several years in California where feral swine occur, and can be sampled.

## METHODS

The wild carnivore serology component of the plague surveillance program in California is a cooperative interagency effort involving the California Department of Health Services, Vector-Borne Disease Section, the U.S. Department of Agriculture, APHIS, Animal Damage Control program, the U.S. Department of Defense, and the U.S. Department of Health and Human Services, Centers for Disease Control, Bacterial Zoonoses Branch, Ft. Collins, Colorado.

Blood samples are collected in the field by cooperators during studies or in the normal course of animal damage control operations on filter paper strips by dipping directly in the blood. Specimens are air-dried, placed in individual envelopes with collection data, and sent to the state program where they are collected, cataloged, and forwarded to the Centers for Disease Control for laboratory testing. In addition to Animal Damage Control personnel, samples are submitted by private fur trappers, wildlife researchers, county agriculture departments, local vector control districts, and by the Department of Defense from California military installations.

Specimens on filter paper sample strips are tested in the laboratory using the specific passive or indirect hemagglutination and inhibition tests as described by the World Health Organization Expert Committee on Plague (Chen and Meyer 1966). Testing results are reported as a dilution ratio of 1:4 to 1:16,384 with titers greater than

1:32 considered positive (Wolff & Hudson 1974). Testing results are provided from the Centers for Disease Control to the state program which tabulates results and in turn disseminates information through quarterly and annual plague reports to the various cooperators.

Samples from California include those of coyote, bobcat, badger, skunk, raccoon, grey fox, kit fox, island fox, black bear, mountain lion, pine marten (Carnivora), opossum (Marsupialia) and feral pig (Artiodactyla). Limited samples have been taken from fisher, mink, and weasel (Mustelidae).

## RESULTS

Wild carnivore, opossum and feral pig serum samples have been collected for plague testing in 49 of California's 58 counties, 1974 to 1993. Positives have been found in 32 of 49 counties sampled. California counties with positives, counties sampled with negative results, and counties with no sampling are shown in Figure 1 (map). Total numbers of samples taken annually since 1974, numbers and percent of positive samples, and the geometric mean titer of positive samples are shown in Table 1. A total of 8,962 samples from wild carnivores, opossum, and feral pigs have been tested for plague antibody from California counties, 1974 to 1993. One thousand and seventy-six positives have been recorded. Los Angeles County began a program of wild carnivore sampling for plague testing in 1986. Specimens from Los Angeles County in our totals reflect totals prior to 1986 only. Thomas and Hughes (1992) have reported the results of the Los Angeles County program.

Numbers tested by animal species, percentage of the species among the total sampled, and numbers and percent positive for each species are shown in Table 2. Coyotes represent 62% of the sample size reflecting the major objectives of the federal and state predator damage control programs that provide the majority of the samples. Percent positive antibody among coyotes is 9.7% overall. The highest percent positives among species most frequently sampled include bobcat (7% of sample, 22.6% positive), bear (9% of sample, 13% positive), feral pig (8% of sample, 18.5% positive), grey fox (4% of sample, 18.4% positive), and mountain lion (1.3% of sample, 21.6% positive). The highest percent positives have been in pine martens (34%); however, pine martens represent less than 0.5% of the sample size, and samples were limited to one wildlife research study (Zielinski, 1984).

Figure 2 compares the yearly prevalence of antibody titers to *Yersinia pestis* in wild felines (bobcat, mountain lion), and canids (coyote, foxes) in California since the inception of the sampling program. As a group the highest percentage of positives on a statewide basis continue to be from wild felines.

## DISCUSSION

Nelson (1980) discussed the ecology of plague among wild rodent species in California and the existence of the disease within known and suspected plague foci. Both reservoir and susceptible or recipient rodent species are necessary for a natural focus of infection to exist. The disease is cyclic, periodically spreading outward during epizootics among susceptible rodent species such as ground squirrels or chipmunks, then retreating once

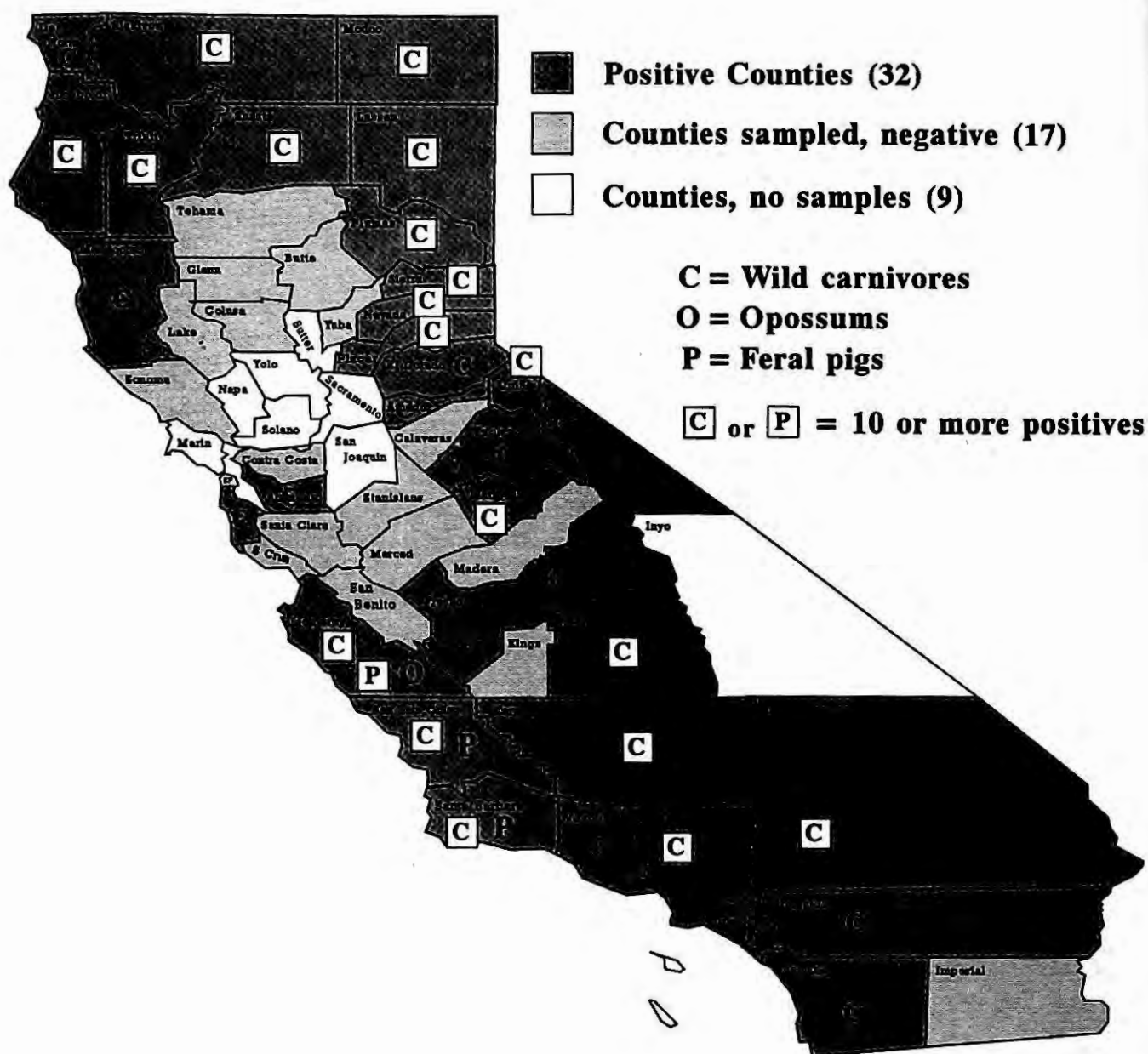


Figure 1. Geographical distribution of positive plague serology in wild carnivores, opossums, and feral pigs in Californian, 1974 to 1993.

Table 1. Wild carnivore, opossum, and feral pig sera tested annually for plague antibody in California, 1974 to 1993.

Year	No. Sampled	No. Positive	No. Negative	% Positive	GMT <sup>1</sup>
1974	112	9	103	8.0	1.14
1975	113	13	120	9.8	1.59
1976	251	29	222	11.5	1.64
1977	369	11	358	2.9	1.15
1978	354	55	299	15.5	2.54
1979	584	107	477	18.3	2.98
1980	593	62	531	10.4	1.79
1981	677	86	591	12.7	2.09
1982	450	43	407	9.3	1.64
1983	614	75	539	12.2	1.89
1984	827	150	677	18.1	2.41
1985	667	106	561	15.8	1.97
1986	655	62	593	9.4	1.52
1987	590	38	552	6.4	1.34
1988	481	17	464	3.5	1.18
1989	605	68	537	11.2	1.78
1990	463	96	367	20.7	2.60
1991	170	24	146	14.1	2.15
1992	163	14	149	8.5	1.45
1993	204	12	192	5.8	1.30

<sup>1</sup> GMT = Geometric Mean Titer; Negative results included.

Table 2. Species tested and results of wild carnivore serological sampling and testing program in California, 1974 to 1993.

Species	No. Sampled	% of Total	No. Positive	% Positive
Coyote	5535	61.7	539	9.7
Bobcat	617	6.8	140	22.6
Badger	184	2.0	20	10.8
Raccoon	197	2.1	22	11.1
Skunk	242	2.7	8	3.3
Grey Fox	358	3.9	66	18.4
Kit Fox	61	0.5	1	1.6
Island Fox	14	>0.5	0	0.0
Bear	801	8.9	105	13.1
Pine Marten	29	>0.5	10	34.4
Opossum	56	0.5	2	3.5
Mountain Lion	120	1.3	26	21.6
Weasel	4	>0.1	0	0.0
Mink	5	>0.1	0	0.0
Fisher	1	>0.1	0	0.0
Feral Pig	738	8.2	137	18.5

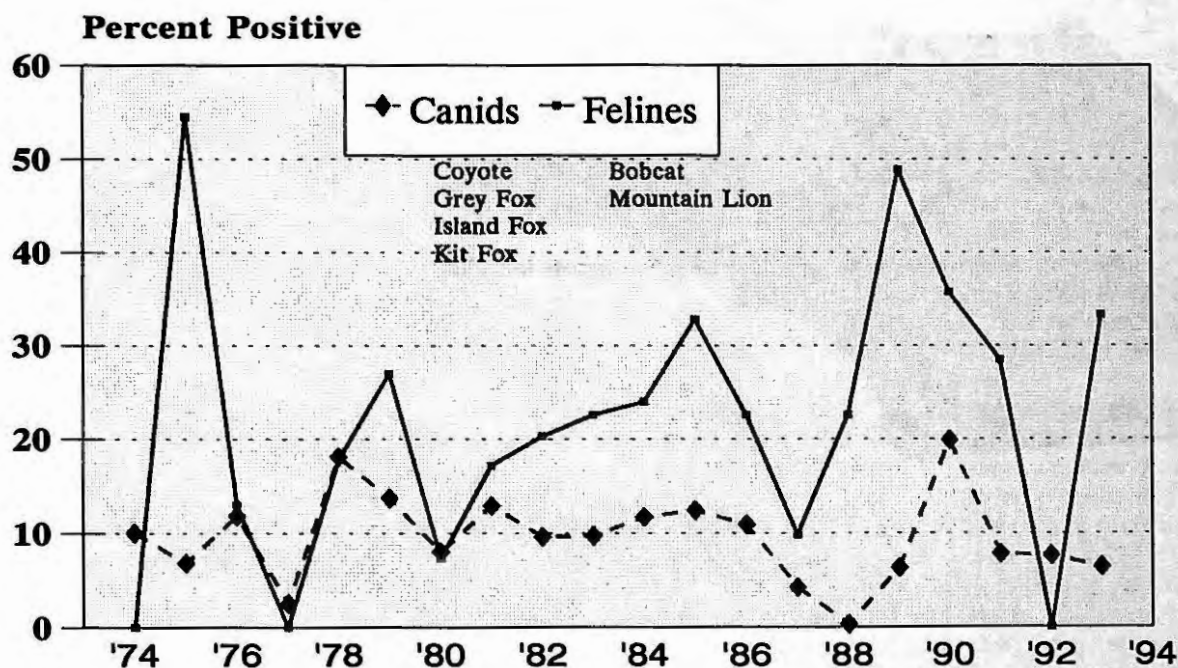


Figure 2. Yearly prevalence of plague antibody in wild canids and felines in California, 1974 to 1993.

again into a more quiescent form persisting among the smaller, more resistant reservoir species such as deer mice, meadow mice, or woodrats. Wild carnivores, opossum, and feral pigs obtain transient plague infection and resulting antibody from ingestion of a variety of rodent species. A propensity for a particular prey species may increase the chance of plague infection through ingestion within a given geographical focus.

#### Food Habits and Plague Infection

Chapman & Feldhamer (1982) reviewed food studies for wild mammals in their book "Wild Mammals of North America." Bobcats and grey foxes consume cottontail rabbits, woodrats, and occasionally ground squirrels, allowing for plague infection through consumption of both reservoir and susceptible rodent species in a plague focus. Foxes consume rabbits, ground squirrels, and meadow mice and consequently, like the bobcat, may be infected through consumption of both reservoir and susceptible rodent species. The preferred food of mountain lion are deer; however, where deer have been depleted lions may consume wild rodents. It is significant to note that where the majority of plague positive mountain lions have occurred in central and southern California, deer populations have indeed been depleted. Feral pigs are opportunistic feeders, and they are known to take carrion. Feral pigs are apparently infected through ingestion of both plague reservoir and susceptible rodent species. Pine martens and badgers are primary consumers of wild rodents. Pine martens feed on microtines, but also on chipmunks and small ground squirrels in boreal forest habitat. Since they are feeding on both reservoir and susceptible rodent species, the chance of plague infection for pine martens in a plague focus would be relatively high. Badgers feed more exclusively on ground squirrels, which are susceptible rodent species. Messick et al. (1983) felt that badgers could be used as sentinels for plague epizootic activity among ground squirrel populations in plague endemic areas in Idaho. The lower percentage of positive plague antibody among badgers in California may be reflective of their feeding on ground squirrels. Positive badgers may indicate active squirrel epizootics, and negative results may indicate inter-epizootic periods. Coyotes, skunks, raccoons, opossums, and bears show somewhat lower infection rates than the above animals, as shown in Table 2. Their more omnivorous feeding habits may account for the lower levels of plague antibody, since rodent prey make up only a percentage of their diets.

#### Meeting Program Objectives

The collaborative interagency program of sampling and testing wild carnivores for plague has proven to be a cost-effective method of disease surveillance in California. Smith, Nelson & Barnes (1984) and Nelson, Madon, & Tilzer (1986) have reported on the effectiveness of the program in helping to define the extent of plague epizootics over a broad scale during disease investigations in California. This methodology continues to be a cost effective tool for disease determination during investigations in California, utilizing both domestic and wild carnivore serology.

Plague was detected for the first time in the coastal mountains and inter-mountain valleys of northwestern California utilizing wild carnivore serology. Clover et al. (1989) used the serological testing of black bears and wild rodents closely associated with bear dens, to describe the existence of an enzootic plague focus in a temperate rain forest habitat of the northwestern California coast, north of Eureka. Sero-testing of wild carnivores has since demonstrated the occurrence of plague in the valleys of Mendocino County, south of Eureka (Table 3). The sampling and testing of wild carnivores for plague antibody has allowed for a rediscovery of plague activity in several regions of California with historical evidence of epizootics, but little recent disease history. Consistent wild carnivore sampling in many of these locations has demonstrated disease persistence within rodent prey populations, and aided in circumscribing apparent geographical disease foci within the state.

Table 3 demonstrates the occurrence of plague as shown by the sampling and testing of wild carnivores, opossums, and feral pigs in a variety of geographical habitats within California. These include the Modoc Plateau in northeastern California, where plague was rediscovered through wild carnivore sampling after a long apparent absence of epizootic plague since the 1940s; Yosemite National Park, where a cooperative sampling of black bears with the U.S. National Park Service has shown persistence of disease in a subalpine habitat of the Sierra Nevada Mountains, foothill oak woodland and yellow pine forest of the Tehachapi and Piute Mountains, and the coastal interior of Mendocino County in northwestern California and coastal interior of Monterey County in central California. In Monterey County, in an oak woodland/chaparral habitat, the sampling of feral pigs by the U.S. Army has proven to be an effective sentinel of plague activity, supplementing the sampling of wild carnivores.

#### Early Warning Detection

Evidence from several locations in California suggested that if consistent wild carnivore sampling for plague antibody could be carried out in winter/spring in a known area of endemic plague, positive winter/spring results could provide an early warning of disease activity in a given location prior to when epizootics or human cases normally occur in summer. The early warning could be used for predictive value and an alert response provided to lessen the potential of a human case in summer months in the same environment. Smith, Nelson & Barnes (1984) reported that winter positive evidence among wild carnivores did precede a summer plague epizootic in ground squirrels at Lava Beds National Monument, California in 1977. Serological sampling for plague antibody from coyote, bobcat, and grey fox in winter months in the Carson River drainage near Markleeville in eastern California has shown a high percentage of positives each year for a 13 year period as shown in Table 4. This represents the highest percent positives among wild carnivores for all regions sampled in California over the past two decades. The area is a transitional zone at the eastern fringe of the Sierra Nevada mountains and the western extent of the Great Basin desert habitat which extends further to the east. There is

Table 3. Prevalence of plague antibodies in wild carnivores, opossums, and feral pigs from geographically distinct habitats in California, 1980 to 1993.

Region/Habitat	No. Sampled	No. Positive	% Positive
Modoc Plateau (Juniper/sagebrush)	342	54	15.7
Tehachapi/Piute Mtns. (Oak woodland/grassland)	529	79	14.9
Monterey Coast (Oak woodland/chaparral)	1585*	244	15.3
Yosemite/High Sierra (Subalpine forest)	352**	20	5.6
Mendocino Valleys (Oak woodland/grassland)	294	21	7.1

\* = 38% of samples are from feral pigs

\*\* = All samples from black bears

Table 4. Prevalence of plague antibodies among wild carnivores in the Carson River drainage near Markleeville, California, 1980 to 1993.

Year	No. Sampled	No. Positive	% Positive
1980	25	7	28.0
1981	21	18	85.7
1982	18	16	88.8
1983	31	16	51.6
1984	34	17	50.0
1985	60	35	58.3
1986	41	16	39.0
1987	4	1	25.0
1988	None	-	-
1989	21	17	80.9
1990	10	10	High 100.0
1991	18	2	Low 11.0
1992	8	3	37.5
1993	None	-	-

ample evidence of a continuing persistence of plague among rodent prey populations in this region as demonstrated by wild carnivore serological sampling. The high percent positives among wild carnivores in the winter of 1990 (10/10 or 100%) did precede epizootic plague among ground squirrels and chipmunks in the same river drainage later that same summer, and serve as an early warning of disease activity in the river drainage.

In summary, the wild carnivore serology component has been an important element in the overall plague

surveillance program as coordinated by the Department of Health Services for the State of California. The methodology has proven to be cost effective, and the originally intended objectives of the program have been achieved. Plague has been detected over a broader scale through the sampling and testing of wild carnivore sera, new regions of disease activity have been described, and the program has been extremely valuable in determining the persistence of disease in apparent geographical foci of infection within the state. Lastly, consistent winter/spring

sampling of wild carnivores in specific locations may allow for an early warning predictive system of disease activity in certain plague endemic regions. An early disease alert can lead to increased response awareness by health authorities and prove valuable in the prevention of human cases of this important vector-borne disease.

#### ACKNOWLEDGMENTS

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