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Skunk Rabies in California (1992–2003)—Implications for Oral Rabies Vaccination

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ABSTRACT: Skunk-variant rabies is endemic in California (United States), and the development of oral vaccines and baits to vaccinate skunks is in progress. In 2003, the California Department of Public Health (CDPH) began to quantify the impacts of skunk-variant rabies and to assess the feasibility of using oral rabies vaccination (ORV) as a containment measure. The CDPH rabies case data for skunks were spatially depicted and analyzed using a geographic information system. Statewide, rabid skunks (1992–2003) primarily occurred in seven physiographic regions: Central Coast, North Coast, North Sierra, Sacramento Valley, San Francisco Bay and Delta, San Joaquin Valley, and South Sierra. Detailed analysis of rabid skunks in San Luis Obispo (SLO) and Santa Barbara (SB) counties showed that skunk rabies was endemic in the coastal plain of SLO County between 1992 and 2000, but only became epizootic in SB County during 2002. Despite the widespread distribution of striped skunks (*Mephitis mephitis*) throughout most of California, the skunk rabies variant has not been found in Los Angeles County since 1979. Results imply that future ORV campaigns for skunk-variant rabies in the Pacific Coastal Plain could deter spread from SLO into SB County, as well as deterring the reintroduction of skunk-variant rabies into southern California.

Key words: California, epizootic, GIS, oral vaccination, rabies, skunks, spatiotemporal pattern, strategy, wildlife.

Rabies is enzootic in California (United States), with about 70% of cases linked to terrestrial species that include striped skunks (*Mephitis mephitis*), spotted skunks (*Spilogale putorius*), and gray foxes (*Urocyon cinereoargenteus*); about 30% of cases involve bats (Chioptera) (Crawford-Miksza et al., 1999). The striped skunk accounts for the preponderance of terrestrial rabies cases and is distributed throughout all but the arid desert counties of southeastern California (Jameson and Peeters, 1988; Crawford-Miksza et al., 1999).

In 2003, the California Department of Public Health (CDPH) began to quantify the impacts of skunk-variant rabies and to assess the feasibility of using oral rabies vaccination (ORV) as a control measure. Although no vaccine for use in skunks is currently available, development is underway (Dietzschold et al., 2003; Rupprecht et al., 2006).

The use of ORV to control wildlife rabies began in Western Europe during the 1970s (Steck et al., 1982; Winkler and Bőgel, 1992). Specialized vaccine baits used to prevent rabies in red foxes (*Vulpes vulpes*) were distributed over wide areas—foxes foraged on the baits and self-dosed on ampoules–reservoirs containing the vaccines (Winkler and Bőgel, 1992). With the exception of Germany and several Eastern European countries, this approach was eventually successful in creating large areas free of fox rabies—Switzerland, France, Belgium, and Luxembourg claimed to be "rabies-free" by 2001 (Aubert, 1994; Stőhr and Meslin, 1996; Vos, 2003). While ORV technology has improved dramatically in the past decade (Johnston and Tinline, 2002; Rupprecht et al., 2006), much remains to be learned about the strategies and benefits of using ORV with wildlife, especially regarding skunks.

We used geographic information system (GIS) technology to map traditional areas of rabid skunks in California and to depict spatiotemporal occurrence of the disease within San Luis Obispo (SLO) and Santa Barbara (SB) Counties (California, USA).

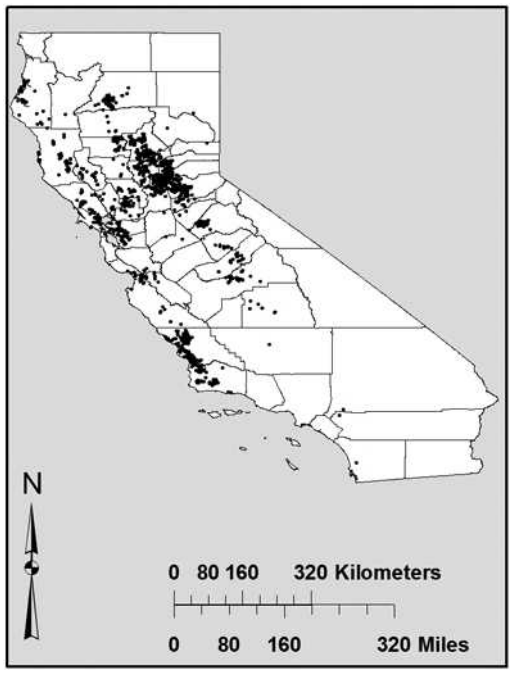

FIGURE 1. A GIS map of California showing 1,785 skunk rabies cases between 1992 and 2003. Note—The positive skunk cases shown for southern California represent "spillover" infections involving bat rabies, not skunk-variant rabies.

The CDPH records of rabid skunk specimens for the 12-yr period of 1992 to 2003 comprised the data set. A total of 2,032 rabies-positive skunks were reported statewide for the period, with a mean (SD) of 169 (76) cases annually. Latitude–longitude locations (some derived using residential addresses and zip codes) were obtained for 1,785 (88%) of the positive cases. ArcGIS® 9.1 software (ESRI, Redlands, California, USA) was used to map the locations (Fig. 1).

Rabid skunks were concentrated in the coastal plains, valleys, and uplands that comprise seven main physiographic regions of the State: Central Coast, North Coast, North Sierra, Sacramento Valley, San Francisco Bay and Delta, and South Sierra (see Welsh, 1994). Locations of rabid skunks formed along three bands that crossed these physiographic regions: 1) the western foothills of the Sierra Nevada Mountains, which included the eastern San Joaquin Valley northward into most of the Sacramento Valley and the Stanislaus, El Dorado, and Plumas National Forests (Fresno, Madera, Mariposa, Tuolumne, Calaveras, Amador, Sacramento, El Dorado, Placer, Tulare, Yuba, Butte, and Shasta Counties); 2) the eastern San Francisco Bay area and northwestward into the North Coast, which included Mendocino and Trinity National Forests (Contra Costa, Solano, Marin, Sonoma, Mendocino, and Humboldt Counties); and 3) the south Central Coast abutting the western slopes of the Sierra Madre and San Rafael Mountains in SLO and SB Counties.

The two most concentrated areas of rabid skunks were in the Sacramento Valley and Central Coast regions (Fig. 1). Almost all of the rabid skunks occurred in the middle two thirds of the State; the southern one fourth of the State and the extreme northern tier of counties were essentially void of skunk-variant rabies (except for a few spillover infections in Riverside, San Bernardino, and San Diego Counties). In fact, the last known case of skunk variant rabies in the Los Angeles Basin (Orange and Los Angeles counties) occurred in 1979, and intense brush fires at that time were implicated in the eradication of the disease from the Basin (Los Angeles County Department of Health Services, 2004).

We also examined the number of rabid skunks found in SLO and SB Counties (the south Central Coast). Between 1992 and 2003, 749 and 348 skunk specimens from SLO and SB Counties, respectively, were submitted to the state public health laboratory for rabies diagnostic tests. A total of 280 SLO County specimens and 88 SB County specimens tested positive for rabies. Annual mean (SD) rabid skunks were 23.3 (21.2) and 7.3 (9.3) for SLO and SB Counties, respectively, but variances were sizable.

There was a "crossover" pattern for the two counties in the annual number of skunk rabies cases that occurred from 2000 to 2002 (Fig. 2). San Luis Obispo

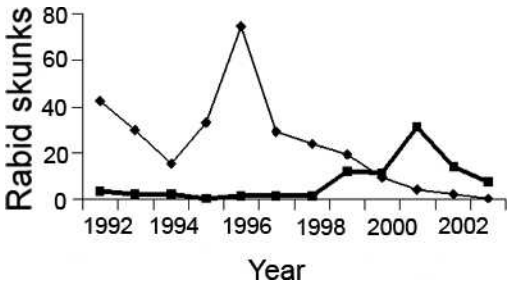

FIGURE 2. Graph of annual numbers of rabid skunk cases for SLO (diamonds/fine line) and SB (squares/heavy line) Counties between 1992 and 2003.

County reported ≥15 rabid skunks/year between 1992 and 1999, but reported ≤9 cases annually for the remainder of the study period. Santa Barbara County had ≤3 rabid skunks/year between 1992 and 1998, but reported ≥8 cases annually between 1999 and 2003. A peak of 75 cases occurred in SLO County during 1996, while a peak of 32 cases occurred in SB County 5 years later (2001). This abrupt temporal shift (1998–2003) in skunk rabies cases confirmed that an epizootic likely emerged in SLO County and spread southward to SB County.

Latitude–longitude locations were obtained for 363 (99%) of the 368 rabid skunks reported (1992–2003) in the two counties. Four sets of annual cases (1992–1994, 1995–1997, 1998–2000 and 2001–2003) were plotted onto county physiographic maps; annual rabid skunk locations were then plotted as successive sequences of symbols (Fig. 3a–d). The following spatiotemporal patterns were observed: 1) a dense occurrence of rabid skunks in SLO County between 1992 and 1997 (Fig. 3a,b); 2) increased cases of rabid skunks in SB County, especially during 1999 (Fig. 3c); and 3) the "crossover" of rabid skunk cases to SB County (i.e., relative lack of rabid skunks in SLO County) during 2001–2003 (Fig. 3d). Additionally, these maps showed that: 1) most rabid skunks occurred in lowland areas of the counties (a possible surveillance bias); 2) only one rabid skunk case occurred east of the Sierra Madre and San Rafael Mountains (Fig. 3c); and 3) 248 (67% of 368 total) cases were clustered in SLO County from 1992 to 1998, while 75 (20% of 368 total) cases were in SB County from 1999 to 2003 (Fig. 3a–d). The current physiographic descriptions add detail to prior published maps which cited only three foci of skunk-variant rabies—the Central Valley, the western slope of the Sierra Nevada, and the Central and North Coast Ranges (see Crawford-Miksza et al., 1999). In contrast, our maps revealed that skunk rabies was probably concentrated in the Central Pacific Coastal Plain, not in the adjacent mountain ranges (Fig. 3a–d).

Determination of the "spread rate" or "leading edge" of a possible skunk rabies epizootic from SLO to SB County proved difficult. At least one rabid skunk occurred in SB County in each year except 1995. Maximum linear distance from northwest SLO County to southeast SB County is ~130 km. By 1999 (the first year of outbreak in SB County), several rabid skunks were already reported ~30–40 km south in SB County (Fig. 3a–c).

A check of CDPH data between 1983 and 1991 (no latitude–longitude data available) revealed that SLO invariably had higher numbers of rabid skunks (≥12 cases) than did SB County (≤9), except for a 3-yr spike during 1985 to 1987 when there were 11, 40, and 17 cases, respectively. The abrupt shift in case loads from SLO to SB County between 2000 and 2002 (Figs. 2, 3a,b) implies that ORV campaigns along the SLO–SB county line, or throughout the coastal plain of SB County, could deter spread of the disease into SB County and, ultimately perhaps, prevent reintroduction of skunk-variant rabies into Ventura County.

Six parameters determine the costs of ORV bait distributions: 1) area of bait application (km^2); 2) bait price ($/bait); 3) bait density (baits/km^2); 4) bait application frequency (n); 5) mode of bait distribution (fixed-winged aircraft and ground baiting);

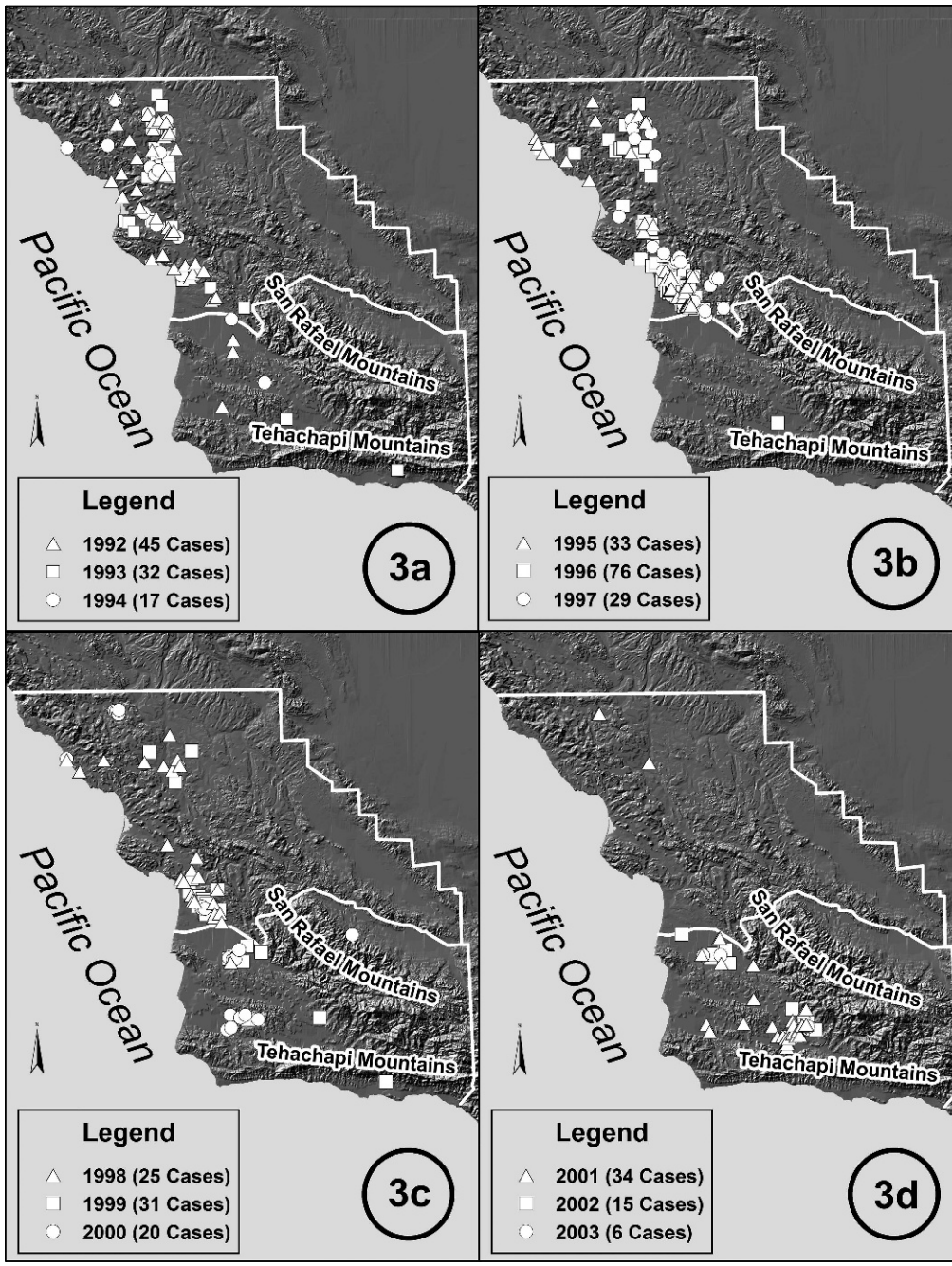

FIGURE 3a–d. Physiographic map of SLO (north) and SB Counties showing locations of 363 (i.e., 99% of 368 positive specimens) GIS-located skunk rabies cases between 1992 and 2003.

and 6) vaccination effectiveness, which determines the baiting frequency (Sterner et al., 2003; Sterner and Smith, 2006). Currently, bait costs range between $1.00 and $1.27/bait (Sterner and Smith, 2006). Empirical cost estimates for fixed-winged transects and ground-baiting, based upon topographic analysis (rural and urban), surveillance, project planning, and evaluation costs, can be determined using

United States Department of Agriculture, Wildlife Services software (specialized software that determines flight transects, ground baiting routes, etc.). This software uses GPS information and other topographic or urban data to guide flight drops or ground placements of ORV baits. The software includes costs for aircraft and automobile fuel, turning distances of aircraft to align baiting transects, personnel, etc. into comprehensive costs entailed in ORV bait applications (Johnston and Tinline, 2002; Slate et al., 2005).

Recently, the total mean direct and indirect costs associated with a suspected human rabies exposure for SLO and SB Counties was estimated at $3,688 (as of 2004), with indirect costs (e.g., public health, animal control, animal tests, nonmedical expenses for patients) alone accounting for roughly one-third of this amount (Shwiff et al., 2007). Indirect, nonpatient costs (animal control and public health) per suspected rabid animal equaled $424 (as of 2004; Shwiff et al., 2007). Between 1998 and 2002, 134 suspected human rabies exposures were reported for these counties (Shwiff et al., 2007). A total of 458 suspected rabid animal tests were performed during this period, with the majority involving skunks (CDPH data, unpubl.). The total rabies-related (mostly skunk-variant) cost for just this 5-yr period (1998–2002) exceeded $600,000 (as of 2004). Whether or not an ORV containment program in the two counties, or the involvement of the southern counties of the State, would prove economically efficient will require more detailed analysis (Kemere et al., 2002; Messonnier and Meltzer, 2003; Shwiff et al., unpubl.). Still, the current rabies-related costs make the future use of ORV in this situation worthy of in-depth study, particularly if a 5–10-yr time horizon for cost recovery is assumed.

In conclusion, our results suggest that future ORV campaigns to contain skunk-variant rabies in parts of California are feasible—based on our current understanding of the spatiotemporal dynamics of skunk rabies within the State. SLO and SB Counties should provide an initial area for studies of ORV efficacy. Ultimate use and effectiveness will depend on other factors, including an effective licensed oral vaccine; early detection and enhanced surveillance in all areas (i.e., including those surrounding current rabies distribution patterns); timely and well-coordinated ORV campaigns that achieve sufficient vaccination rates to contain and eliminate the particular variant of the rabies virus present in specific regions; and more in-depth economic analyses.

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