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Benefit Cost Scenarios of Potential Oral Rabies Vaccination for Skunks in California

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ABSTRACT: Scenario-based analyses were computed for benefits and costs linked with hypothetical oral rabies vaccination (ORV) campaigns to contain or eliminate skunk-variant rabies in skunks (*Mephitis mephitis*) in California, USA. Scenario 1 assumed baiting eight zones (43,388 km^2 total) that comprised 73% of known skunk rabies locations in the state. Scenario 2 also assumed baiting these eight zones, but further assumed that added benefits would result from preventing the spread of skunk-variant rabies into Los Angeles County, USA. Scenarios assumed a fixed bait cost ($1.24 each) but varied campaigns (one, two and three annual ORV applications), densities of baits (37.5/km^2, 75/km^2 and 150/km^2), levels of prevention (50%, 75%, and 100%), and contingency expenditures if rabies recurred (20%, 40%, and 60% of campaign costs). Prorating potential annual benefits during a 12-yr time horizon yielded benefit-cost ratios (BCRs) between 0.16 and 2.91 and between 0.34 and 6.35 for Scenarios 1 and 2, respectively. Economic issues relevant to potentially managing skunk-variant rabies with ORV are discussed.

Key words: Benefit-cost analysis, California, economics, oral vaccination, rabies, skunks.

Oral rabies vaccination (ORV) of wildlife was first used in the 1970s to manage red fox (*Vulpes vulpes*) rabies in Europe (Steck et al., 1982; Winkler and Bőgel, 1992). In ORV campaigns, bait-containing packets of specific vaccines are distributed onto the landscape at prescribed densities, which allows targeted animals to forage on the bait matrix and self-dose with the vaccine (Johnston and Tinline, 2002).

In 2003, the California Department of Health Services (CDHS) began to research the impacts of skunk (*Mephitis mephitis*) rabies and to assess the feasibility of using ORV to reduce these impacts (Sterner et al., in press). Although no rabies vaccine or bait for skunks is currently available, development and production may be imminent (Dietzschold et al., 2003; Rupprecht et al., 2006). Stripped skunks and bats (Chiroptera) are the main reservoirs of wildlife rabies in the state (Krebs et al., 2005).

We computed scenario-based, benefit-cost analyses to assess the hypothetical use of ORV technology to control skunk-variant rabies in California. Analyses sought to reduce the economic uncertainty associated with a future ORV program. These economic outcomes would be integrated with other information (e.g., budgetary constraints, sociopolitical concerns) to facilitate future decisions on ORV in skunks by natural resource managers, public health officials, and policy makers. All analyses incorporated historic case and empirical cost data.

Specific latitude-longitude locations were obtained for 1,785 of 2,032 (87.8%) rabid skunks submitted for rabies diagnostic tests in California between 1992 and 2003 inclusive (Sterner et al., 2008). Areas of dense skunk-rabies cases were identified using the Spatial Analyst Program of ArcView® 3.2 Geographic Information System (GIS) software (ESRI, Redlands, California, USA). Potential ORV bait zones were derived using a density algorithm, which spreads the point values over a raster surface (grid). Selected ORV zones had densities of between 0.030 and 0.245 skunk rabies cases/km^2. A 16-km-wide buffer was then imposed

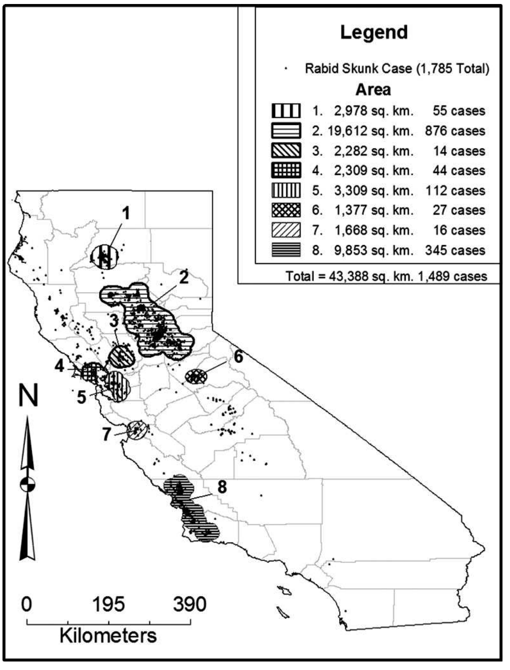

FIGURE 1. Map of California, USA, Geographic Information System (GIS)–located skunk-rabies cases from 1992 to 2003, showing eight, dense hot spots with 16-km buffers hypothesized as potential oral rabies vaccination (ORV) bait zones.

around identified clusters of cases (i.e., <0.030 cases/km^2 of skunk-rabies cases surrounding designated ORV zones and excluding over-water areas). Eight hot spots plus buffers, encompassing 43,388 km^2 and containing 1,489 of the rabid skunk locations (i.e., 73.3% of the known rabid-skunk locations), were delineated using this method (Fig. 1).

Two scenarios were devised to estimate potential ORV-induced benefits. Scenario 1 assumed baiting the eight hotspots plus buffers to directly control skunk-variant rabies (Fig. 1); benefits included savings accrued from projected reductions in human postexposure prophylaxis (PEP) treatments and skunk-rabies diagnostic tests (see Shwiff et al., 2007). Scenario 2 assumed baiting these same eight zones, recouping the Scenario 1 benefits, plus garnering added savings from the prevented spread of skunk rabies into densely populated Los Angeles County, USA. Los Angeles County, USA, was not within the hot-spot zones, but it was assumed in Scenario 2 that baiting prevented skunk rabies from spreading to this heavily populated area. To estimate the additional benefit of prevented spread, we derived a population-based rate of human exposure and skunk-diagnostic testing similar to those reported for Santa Barbara and San Luis Obispo counties, USA (Shwiff et al., 2007); then we extrapolated these potential empirical rates using the human population (United States Bureau of Census, 2000) in Los Angeles County, USA.

Benefit-cost methodology was used in the analyses (Meltzer, 1996; Zerbe and Dively, 1994). Benefit-cost ratios (BCRs) were calculated using the ratio of benefits and costs. The BCRs for skunk ORV were derived for Scenarios 1 and 2 through the monetary value of skunk specimen collections, tests, and human exposure costs saved during a future 12-yr time horizon by baiting in the current period. The BCR computational formula was

$$BCR = \frac{Benefits}{Costs} = (\$\ Value\ of\ skunk\ collection\ and\ test\ and\ human\ exposure\ costs\ saved \div \$\ Cost\ of\ ORV\ baiting) \quad (1)$$

A BCR of 1.0 indicated that the benefits and costs were equal—one unit of costs yielded one unit of benefits.

Five parameters determined ORV costs: 1) area of bait application (in square kilometers), 2) bait price (dollars/bait), 3) bait density (baits/square kilometer), 4) campaigns (n), and 5) mode of bait distribution (i.e., fixed-winged aircraft and ground baiting), with possible contingency costs included for rebaiting (percentage of original campaign costs). These assumptions were based upon the current program for ORV baiting of raccoons (*Procyon lotorin*) in the eastern United States. Computations were derived using the 43,388 km^2 comprising the eight ORV zones (Fig. 1), a price of \$1.24/bait (Slate et al. 2005), three bait densities (37.5, 75, and 150 baits/km^2), and three campaign frequencies (1, 2, or 3 campaigns annually). Empirical cost estimates for fixed-winged transects and ground-baiting, based upon topographic analysis, surveillance, project planning (including personnel costs), and ORV evaluation costs for the eight zones, were obtained using the Vaccine Application Control Center (National Rabies Management Program, 2005). This software contained calculations used to determine the cost of the ORV baiting of raccoons in the eastern United States. Contingency costs (i.e., to control unexpected recurrence of rabid skunks in the zones) were arbitrarily set at 20%, 40%, and 60% of original ORV campaign costs, with BCRs recalculated for both Scenarios 1 and 2 to reflect assumed 50% and 75% prevention of future human exposure and skunk diagnostic testing with the contingency spending.

Historic rabies case data allowed for the determination of potential benefits for Scenarios 1 and 2. Shwiff et al. (2007) reported a study of direct (e.g., PEP, patient copayment) and indirect (e.g., public health investigation, animal control activities, patient incidentals for travel, child care, alternative medicines) costs of human exposure and animal testing in Santa Barbara and San Luis Obispo counties, USA (1998 to 2002 data). Results showed that each human exposure had a mean cost of $3,688 (in 2004 US dollars). Shwiff et al. (2007) also reported a mean cost of $424 (in 2004 US dollars) for the collection, shipment, preparation, and rabies diagnostic testing of each animal specimen. An arbitrary 10-yr average of skunk examinations and tests between 1991 and 2000 for the state was 1,128, with 214 (19.0%) of these specimens positive for rabies, and of those 214, an average of 19 (8.9%) resulting in human PEP treatments (Sterner et al., 2008). We extrapolated from these data the human population-based projections of case loads

TABLE 1. Baiting costs for 8 oral rabies vaccination (ORV) zones (see Fig. 1).

Zone	Cost (US $)		
	Bait density (No./km^2)		
	37.5	75	150
1	158,582	268,040	490,015
2	1,041,670	1,777,444	3,269,561
3	125,222	211,425	386,241
4	96,977	160,790	290,201
5	194,915	310,859	544,283
6	72,143	124,712	231,320
7	89,671	152,225	279,081
8	481,488	826,470	1,526,076
Total	2,260,668	3,831,964	7,016,779

as benefits of ORV baiting to the areas described for Scenarios 1 and 2.

A single application of baits over the eight ORV zones was estimated to cost $2,260,668 (37.5 baits/km^2), $3,831,964 (75 baits/km^2), and $7,016,779 (150 baits/km^2) in 2004 US dollars, respectively (Table 1). For these three estimates, the cost of bait made up approximately 67%, 81%, and 89% of the total, respectively. As bait densities were doubled, total costs increased nonlinearly—fuel and flight time costs stayed constant, whereas bait costs doubled. Zone 2, centered on Butte and Sutter counties, USA, was the largest ORV zone (19,612 km^2) and contained 876 skunk rabies cases; this zone accounted for ≈50% of the total ORV expenses (Table 1). Zone 8, centered on Santa Barbara and San Luis Obispo counties, USA, was the second largest ORV zone (9,853 km^2), with 345 rabid skunks reported; this zone accounted for ≈20% of the total ORV costs.

Results showed that the potential, average, annual, eight-zone expense for scenario 1 was $548,344, with 50%, 75%, and 100% deterrence of cases expected to yield annual potential benefits of $274,172, $411,258, and $548,344, respectively (Table 2). These represented the maximum annual benefits that could be recouped from ORV. Human PEP treatments accounted for ≈13% ($70,072) of

TABLE 2. Annual potential benefits associated with Scenarios 1 and 2.

	Benefits (cost savings, $)		
Scenario/site	Testing	Human exposure	Total
Scenario 1	478,272	70,072	548,344
Scenario 2	1,011,240	188,088	1,199,328
Los Angeles County, USA, only	532,968	118,016	650,984

these benefits. Additionally, inclusion of projected human exposure and skunk diagnostic testing for Los Angeles County, USA, more than doubled potential rabies-incurred costs (Scenario 2 benefits).

For Scenario 1, BCRs for all combinations of campaign, bait density, and skunk rabies prevention variables ranged between 0.16 and 2.91 (Table 3). No combinations of the bait density and skunk rabies prevention variables involving three campaigns yielded BCRs≥1.0 (Table 3). Seven conditions emerged as economically efficient (BCRs≥1.0) for one to two baitings. Computed BCRs decreased as bait densities and campaigns increased, but BCRs were greater as the assumed prevention of future skunk cases improved from 50% to 75% to 100%. As expected, inclusion of contingency baiting costs degraded BCRs in Scenario 1 (Table 4). Only six combinations of the ORV variables with contingency costs yielded BCRs≥1.0, and all of these occurred for one ORV campaign at 37.5 baits/km^2 or 75 baits/km^2.

For Scenario 2, results yielded greater potential benefits and economic efficiency. All combinations of the 37.5 baits/km^2, one to three campaigns, and 50% to 100% prevention of future human exposure and skunk diagnostic testing yielded BCRs≥1.0 (Table 3). Efficiency was also achieved at the 75 baits/km^2 for one to two campaigns, assuming 100% prevention of skunk rabies, as well as for one to two campaigns at 75% prevention, and one campaign at 50% prevention. The estimated annual potential benefit was $1,199,328 (Table 2). These benefits were attributed to $548,344 from the eight zones in Scenario 1 and the additional $650,984 from the projected savings that an ORV program would afford in prevented human exposure and skunk diagnostic testing to Los Angeles County, USA. That is, we projected that Los Angeles County, USA, would expend $532,968 (1,257×

TABLE 3. Benefit-cost ratios (BCRs) of rabies campaigns for Scenarios 1 and 2 at different prevention rates, bate densities, and numbers of batings.[a,b]

	Prevention rate (%)								
	100			75			50		
	Bait density (No./km^2)								
No. Baitings	37.5	75	150	37.5	75	150	37.5	75	150
Scenario 1									
1	2.91*	1.72*	0.94	2.18*	1.29*	0.70	1.46*	0.86	0.47
2	1.46*	0.86	0.47	1.09*	0.64	0.35	0.73	0.43	0.23
3	0.97	0.57	0.31	0.73	0.43	0.23	0.49	0.29	0.16
Scenario 2									
1	6.35*	3.75*	2.05*	4.76*	2.81*	1.54*	3.18*	1.87*	1.02*
2	3.18*	1.87*	1.02*	2.38*	1.41*	0.77	1.59*	0.94	0.51
3	2.12*	1.25*	0.68	1.59*	0.94	0.51	1.06*	0.62	0.34

[a] The economically efficient BCRs are marked with an asterisk (*).

[b] Scenarios assumed a fixed bait cost ($1.24 each) but varied campaigns (one, two and three annual ORV applications), densities of baits (37.5/km^2, 75/km^2, and 150/km^2), levels of prevention (50%, 75%, and 100%), and contingency expenditures if rabies recurred (20%, 40%, and 60% of campaign costs).

TABLE 4. Benefit-cost ratios (BCRs) of rabies campaigns for Scenarios 1 and 2 with contingency expenditures for rabies recurrence at different prevention rates, bate densities, and numbers of batings.[a]

	Scenario 1							Scenario 2					
	Prevent 75%			Prevent 50%				Prevent 75%			Prevent 50%		
No. baitings and contingency rate (%)	Bait density (No./km^2)						No. baitings and contingency rate (%)	Bait density (No./km^2)					
	37.5	75	150	37.5	75	150		37.5	75	150	37.5	75	150
1 Baiting							1 Baiting						
20	1.82	1.07	0.59	1.21	0.72	0.39	20	3.97	2.34	1.28	2.65	1.56	0.85
40	1.56	0.92	0.50	1.04	0.61	0.33	40	3.40	2.01	1.10	2.27	1.34	0.73
60	1.36	0.80	0.44	0.91	0.54	0.29	60	2.98	1.76	0.96	1.99	1.17	0.64
2 Baitings							2 Baitings						
20	0.91	0.54	0.29	0.61	0.36	0.20	20	1.99	1.17	0.64	1.32	0.78	0.43
40	0.78	0.46	0.25	0.52	0.31	0.17	40	1.70	1.00	0.55	1.13	0.67	0.37
60	0.68	0.40	0.22	0.45	0.27	0.15	60	1.49	0.88	0.48	0.99	0.59	0.32
3 Baitings							3 Baitings						
20	0.61	0.36	0.20	0.40	0.24	0.13	20	1.32	0.78	0.43	0.88	0.52	0.28
40	0.52	0.31	0.17	0.35	0.20	0.11	40	1.13	0.67	0.37	0.76	0.45	0.24
60	0.45	0.27	0.15	0.30	0.18	0.10	60	0.99	0.59	0.32	0.66	0.39	0.21

[a] Scenarios assumed a fixed bait cost ($1.24 each) but varied campaigns (one, two and three annual ORV applications), densities of baits (37.5/km^2, 75/km^2, and 150/km^2), levels of prevention (50%, 75%, and 100%), and contingency expenditures if rabies recurred (20%, 40%, and 60% of campaign costs).

$424) and $118,016 (32×$3,688) for annual skunk diagnostic and PEP costs, respectively, by extrapolating historic incident frequencies (Shwiff et al., 2007). Inclusion of these potential benefits afforded more options for economic efficiency with Scenario 2 (Table 3). Furthermore, in contrast to Scenario 1, a total of 23 combinations of the ORV variables for Scenario 2 with contingency costs yielded BCRs≥1.0, with most of these contingency situations (n=14; 61%) involving one campaign (Table 4).

Results imply that the economic feasibility of an ORV program to control skunk-variant rabies in California, USA, will be likely for short-duration control efforts (i.e., less than three annual ORV campaigns will be efficient) involving low-bait densities (i.e., 37.5 baits/km^2 or 75 baits/km^2), low contingency costs (i.e., 20% or 40% of original costs), and prolonged (i.e., 12 yr) suppression. To date, published studies have shown that rabies ORV programs are usually lengthy. Reported programs in Canada and the United States have generally exceeded 7 yr (e.g., MacInnes et al., 2001; Sidwa et al., 2005; Slate et al., 2005). These studies have also described prolonged, postprogram, enhanced surveillance (i.e., increased public health monitoring, rabies analyses of road-killed target animals, and rabies analyses of trapped samplings of target animals) and establishment of maintenance ORV zones to prevent potential reinfection of resident animals from original foci or adjacent untreated areas (MacInnes et al., 2001; Sidwa et al., 2005; Slate et al., 2005).

For the raccoon, coyote (*Canis latrans*), and gray fox (*Urocyon cinereoargenteus*) ORV efforts in the United States, baits and bait applications have proved to be relatively expensive (Sidwa et al., 2005; Slate et al., 2005). These baits were produced at a cost of about $1.00 to $1.27 (in 2005 US dollars, depending on bait type) for federal use (Slate et al., 2005). Baiting densities differ greatly between red and gray fox and coyote (≈20–25/km^2) and raccoon (≈65–75/km^2) programs (Fearneyhough, et al., 1998; MacInnes et al., 2001; Sidwa et al., 2005; Slate et al., 2005). Although it is estimated by the authors that effective bait densities for skunks will be low, the density will require field testing and validation.

Inclusion of unexpected contingency costs in economic assessments of ORV related to incomplete elimination or control of rabies is prudent. Russell et al. (2005) described a 2004 breach of the Ohio-Pennsylvania, USA, ORV barrier for raccoon-variant rabies that led to costly trap-vaccinate-release, added ORV, and tests of more than 300 raccoon specimens to secure the former interstate barrier. Granted, the size of the area that would need to be rebaited is subject to speculation (Russell et al., 2005), but even low contingency costs (20% of campaign costs) would compromise the use of ORV in some of our scenarios.

In conclusion, our analyses have limited a wide array of options that could be used to evaluate future skunk-variant ORV campaigns in California, USA. Whether a county, group of counties, or a statewide program would be undertaken is unknown. Nevertheless, our analyses provide information that can be used to reduce the uncertainties of initiating such campaigns.

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