THE CONTROL OF RACCOON RABIES IN ONTARIO CANADA: PROACTIVE AND REACTIVE TACTICS, 1994–2007

Authors: Rosatte, R. C., Donovan, D., Allan, M., Bruce, L., Buchanan, T., et al.

Source: Journal of Wildlife Diseases, 45(3) : 772-784

Published By: Wildlife Disease Association

URL: https://doi.org/10.7589/0090-3558-45.3.772

Journal of Wildlife Diseases, 45(3), 2009, pp. 772–784

THE CONTROL OF RACCOON RABIES IN ONTARIO CANADA: PROACTIVE AND REACTIVE TACTICS, 1994–2007

R. C. Rosatte,[1,3] D. Donovan,[1] M. Allan,[1] L. Bruce,[1] T. Buchanan,[1] K. Sobey,[1] B. Stevenson,[1] M. Gibson,[1] T. MacDonald,[1] M. Whalen,[1] J. C. Davies,[1] F. Muldoon,[2] and A. Wandeler[2]

[1] Ontario Ministry of Natural Resources, Wildlife Research and Development Section, Trent University, DNA Building, 2140 East Bank Dr., Peterborough, Ontario, K9J 7B8, Canada
[2] Canadian Food Inspection Agency, Ottawa Laboratory Fallowfield, PO Box 11300, Station H, Nepean, Ontario, K2H 8P9, Canada
[3] Corresponding author (email: rick.rosatte@ontario.ca)

ABSTRACT: Proactive and reactive tactics have been utilized in Ontario, Canada, to prevent raccoon rabies from becoming established. A total of 96,621 raccoons (*Procyon lotor*) and 7,967 striped skunks (*Mephitis mephitis*) were live captured using 1,221,044 trap nights, vaccinated against rabies by injection, and released, during proactive Trap-Vaccinate-Release (TVR) programs in southern Ontario during 1994–2007. During those years, on average, 43% to 83% of the raccoon populations were vaccinated against rabies. In addition, 20,129 raccoons and 2,735 skunks were vaccinated against rabies, and 8,311 raccoons and 1,449 skunks were euthanized, using 576,359 trap nights, during reactive Point Infection Control (PIC) operations in eastern Ontario during 1999–2005. A significant correlation was detected between trapping effort and the percentage of the raccoon population that was vaccinated. Between 1999 and 2007, 132 cases of raccoon variant rabies (130 raccoons, two striped skunks) were reported in eastern Ontario. The last case occurred on 23 September 2005 with Ontario being free of reported raccoon rabies to 10 November 2008, proving that TVR and PIC are effective tactics for the control of this disease.

Key words: *Mephitis mephitis*, *Procyon lotor*, rabies control, raccoon, striped skunk.

INTRODUCTION

Rabies in raccoons, which is endemic in eastern North America, is caused by an antigenically distinct rabies virus variant, which was named raccoon rabies virus variant (Winkler and Jenkins, 1991; Slate et al., 2005). The spread of the disease, which we hereafter call raccoon rabies, is well documented in the United States by Winkler et al. (1991). Prior to its arrival in Ontario, the Ontario Ministry of Natural Resources (OMNR) took proactive steps in an attempt to prevent the disease from becoming enzootic in the province. That included the formation of a raccoon rabies task force, as well as designing a contingency plan to respond to the disease if it was detected in Ontario (Rosatte et al., 1997). One proactive tactic that was implemented along the Niagara (in 1994) and St. Lawrence rivers (in 1995) was called Trap-Vaccinate-Release (TVR). The TVR strategy was designed to prevent the spread of raccoon rabies from neighboring New York State by immunizing raccoons (*Procyon lotor*) and striped skunks (*Mephitis mephitis*) via intramuscular injection (Rosatte et al., 1992, 1993, 2007d). When raccoon rabies was first reported in Ontario, Canada, during July 1999, OMNR responded by implementing reactive Point Infection Control programs (PIC) which included the euthanasia of raccoons and skunks, vaccination using TVR, and the aerial distribution of Vaccinia-Rabies Glycoprotein baits (V-RG; Wandeler and Salsberg, 1999; Rosatte et al., 2001). Combinations of proactive and reactive tactics have been in use in Ontario through 2008. To date (10 November 2008), a total of 132 cases (130 raccoons, two striped skunks) of raccoon rabies have been reported in the province (Rosatte et al., 2006, 2007b, c, d; Fig. 1). However, the last case of raccoon rabies was reported in Ontario on 23 September 2005. This paper details the design and delivery of proactive and reactive programs implemented by OMNR during 1994–2007 to contain and eliminate raccoon rabies in Ontario.

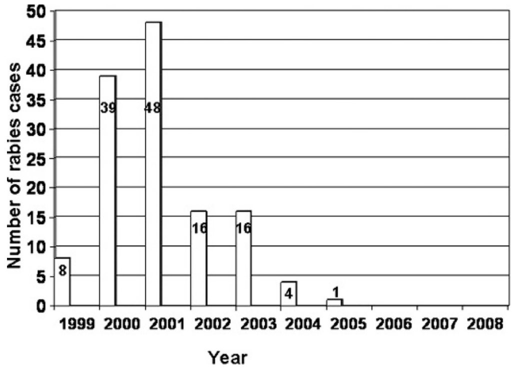

FIGURE 1. Number of raccoon rabies cases in Ontario, 1999–2008.

MATERIALS AND METHODS

TVR programs

Niagara TVR program, 1994–2007 (a proactive program): During 1994 to 2007, OMNR technicians placed live traps (Tomahawk #106, #108, Tomahawk Live-trap Co., Tomahawk, Wisconsin, USA), baited with sardines, in an approximate 600 to 700 km^2 area west of the Niagara River (43°03′N, 79°07′W; Table 1 and Fig. 2). Trapping generally occurred during late June to late October annually, except during 1994 when trapping commenced in early May. Seventy-five traps were placed in each of the trapping cells (rural cells were about 12 km^2 in size, and urban cells were about 3 km^2 each) during the initial trapping period (eight nights over a 2 wk period), during 1994–2005. All of the cells were retrapped for a minimum of four nights with 25 traps between 1–6 wk following the initial trapping period. This was done to collect data for calculation of population density estimates using mark-recapture data.

Trapping cells with low raccoon density (produced less than 15 raccoon captures during the previous year) were only trapped for four nights and retrapped for four nights. During 2006–07, and in some high density cells beginning in 2002, a total of 100 traps were placed in each trapping cell for 12 nights. This was done in an attempt to increase the percentage of the raccoon population that was captured and vaccinated. During some years, cells were retrapped until the percentage of raccoons vaccinated was >60%.

Captured raccoons, skunks, and red foxes (*Vulpes vulpes*) were ear-tagged for identification (numbered size 3 for raccoons and size 1 for skunks, National Band and Tag Co., Newport, Kentucky, USA), vaccinated against rabies with an intramuscular injection of inactivated rabies vaccine (Imrab® 3 - Merial Inc., Athens, Georgia, USA), and released at the point of capture.

St. Lawrence TVR program, 1995–2007 (proactive 1995–99; reactive 1999–2007): During 1995 to 2007, (except 2004–05 where PIC replaced

TABLE 1. Summary for the Niagara Trap-Vaccinate-Release (TVR) program, 1994–2007.[a]

Year	Area (km^2)	Trap nights (n)	Raccoon captures (T[D])[b]	Skunk captures (T[D])[b]	Raccoon population size mean (95% CL)	% Raccoons vaccinated against rabies mean (95% CL)
1994	680	45,941	6,154 (4,335)	201 (169)	6,738 (5,815–7,672)	64 (57–75)
1995	680	57,939	7,120 (4,355)	303 (227)	5,828 (5,620–6,057)	75 (72–78)
1996	700	51,728	6,043 (3,793)	110 (82)	5,205 (5,004–5,426)	73 (70–76)
1997	700	51,895	7,322 (4,617)	116 (90)	5,887 (5,561–6,139)	78 (75–83)
1998	700	48,823	7,045 (4,721)	222 (165)	6,145 (5,896–6,422)	77 (74–80)
1999	700	47,378	5,830 (4,154)	279 (209)	7,098 (6,661–7,615)	59 (55–62)
2000	700	49,361	6,587 (4,634)	260 (190)	8,270 (7,686–8,978)	56 (52–60)
2001	700	49,606	6,653 (4,553)	423 (338)	7,299 (6,947–7,700)	62 (59–66)
2002	700	47,533	7,914 (5,365)	383 (298)	9,002 (8,591–9,466)	60 (57–62)
2003	680	42,706	7,000 (5,014)	473 (379)	9,272 (8,788–9,829)	54 (51–57)
2004	640	49,810	7,611 (5,123)	644 (464)	8,223 (7,738–8,821)	62 (58–66)
2005	679	55,751	7,818 (5,278)	481 (389)	8,345 (7,998–8,731)	63 (61–66)
2006	577	71,840	7,300 (4,670)	515 (343)	7,035 (6,755–7,346)	66 (64–69)
2007	596	71,978	6,915 (4,166)	271 (189)	5,540 (5,337–5,764)	75 (72–78)
Total	na	742,289	97,312 (64,778)	4,681 (3,532)	na	na

[a] Trapping occurred from late June/early July to late October each year except during 1994 when trapping commenced during early May; na = not applicable.

[b] T=total animals captured including recaptures; D = different animals captured.

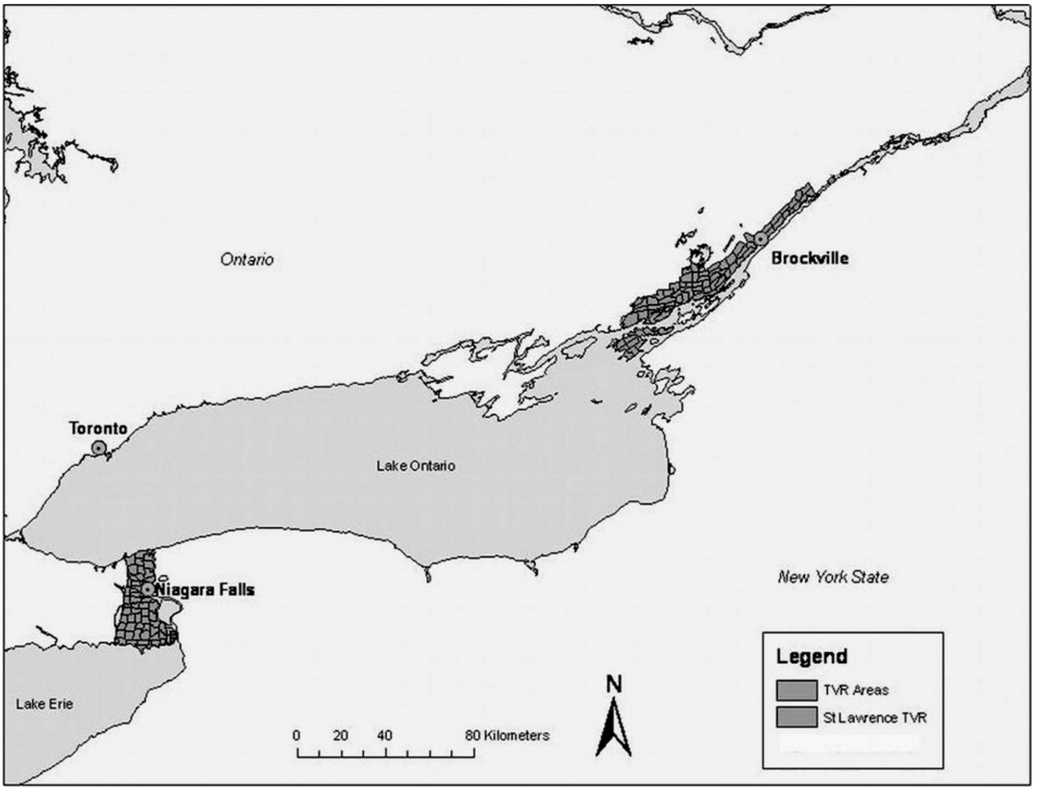

FIGURE 2. Location of the Niagara and St. Lawrence Trap-Vaccinate-Release (TVR) programs in Ontario during 1994 to 2007.

TVR) similar methodologies were employed along the St. Lawrence River (44°45′N, 75°50′W) as in Niagara to capture and immunize raccoons and skunks against rabies (Fig. 2). Trapping generally occurred during late June/early July to late October/early November, except during 2007 when trapping occurred in July/August. Trapping effort in 1995–96 included distributing 100 live traps for four consecutive nights during the first week, followed by 25 traps for four nights in the second week. During 1997–99, trapping effort consisted of placement of 75 live traps for eight nights over a 2-wk period in each cell followed by eight nights with 25 traps in a 2-wk period. Trapping effort was 100 live traps/cell for 12 nights over a 3-wk period (four nights/week) during 2000 to 2007.

PIC programs and establishment of high risk areas

PIC programs, 1999–2005 (reactive): A total of 17 PIC operations were completed in eastern Ontario (44°45′N, 75°50′W) during 1999–2003 (Figs. 3a–d). Generally, a PIC operation included live trapping a predetermined core area (normally a 5-km radius; see Rosatte et al., 2001) around the location of a raccoon or skunk diagnosed with raccoon rabies. Trapping cell size was variable but generally between 10 km^2 and 15 km^2 in size. Trapping effort in each trapping cell was variable depending on raccoon density, but generally each cell received between 800 and 1,400 trap nights of effort over 2 to 4 wk (usually 100 traps/cell/night). All captured raccoons and skunks were immobilized with ketamine hydrochloride and euthanized (except in the TVR portion of a PIC) with an intercardiac injection of T-61. This was done to remove animals that might have been incubating rabies or were clinically rabid because vaccination would not work on those animals. Brain samples were removed and submitted for rabies testing (using a fluorescent antibody test) (Webster and Casey, 1988) at the Canadian Food Inspection Agency, Ottawa Laboratory Fallowfield, in Nepean, Ontario. Raccoon density was estimated using a catch/unit effort model as noted in Krebs (1989). Normally, an estimate of the percentage of the raccoon population that was removed was calculated using the number of raccoons euthanized over time and the population estimate; however, often this was not possible because raccoon capture success did not consistently decline over time due to irregular weather, especially when trapping occurred during the late fall, winter, or early spring. A reduction of 80% to 90% of the raccoon population was targeted. If this was not achieved, additional trapping usually was done.

Raccoons and skunks captured in a 5-km radial area outside of the population reduction area were vaccinated by injection as in the TVR programs. If >60–65% of the raccoons were vaccinated, trapping generally was discontinued in that cell. However, in some cases, a population estimate was not possible due to insufficient captures in some trapping cells. The size and shape of the PIC area was based on the location and number of rabies cases; e.g., a single point source infection versus a cluster of cases—see Figures 3a–d.

Distribution of vaccinia-rabies glycoprotein (V-RG) baits (reactive): During 1999 to 2006, V-RG rabies vaccine baits were aerially- and hand-distributed outside of PIC and TVR areas in the St. Lawrence region to form a 50 km buffer around the location of raccoon rabies cases. Those methodologies are reported in Rosatte et al. (2008).

Establishment of a High Risk Zone in eastern Ontario (reactive): During 2000 to 2007, a High Risk Zone was established in eastern Ontario to assist with the prevention of the spread of rabies from the containment areas. The size of the zone included a 50 km perimeter around the location of a rabid raccoon. The relocation of raccoons, skunks, and foxes was prohibited in the High Risk Zone until 2007 to reduce the risk of spreading rabies to uninfected areas of Ontario.

Data analysis

During PIC and TVR programs, an estimate of the percentage of the raccoon population that was vaccinated in each trapping cell was calculated using a modified Petersen model and the number of raccoon captures (Krebs, 1989). An effort was also made to estimate the percentage of the raccoon population that was removed using the number of raccoons euthanized over time and a Leslie Regression model (Krebs, 1989). The relationship between trapping effort and the percentage of raccoon populations vaccinated was analyzed using least squares estimation in Statistica 6.0 (StatSoft, 1999). To check model assumptions, a normal probability plot of residuals was completed to test normality, and residuals were plotted against the explanatory variable. Model validity was assessed by computing F-statistics and calculating the coefficient of determination (r^2). Predicted and residual scores were also examined for outliers using case-wise plots of standard residuals. The simple regression model was extended to higher-order polynomial equations to examine the best fit (r^2) among variables while determining the most parsimonious model to describe the relationship among trap effort and percent vaccination of raccoon populations. Trap effort required to vaccinate a desired percentage of the raccoon population was determined by substituting this value (y) into the model equation and solving for the independent variable (x). The cost of TVR and PIC programs were calculated using the cost for staff salaries, accommodations, vehicles, equipment and supplies, and dividing that by the study area size.

RESULTS

Niagara TVR program, 1994–2007

A total of 64,778 individual raccoons (97,312 captures) and 3,532 skunks (4,681 captures) were captured, vaccinated, and released utilizing 742,289 trap nights in the Niagara TVR area during 1994–2007 (Table 1). An average of 54% to 78% of the raccoon population was vaccinated against rabies during those years (Table 1).

St. Lawrence TVR program, 1995–2007

A total of 31,844 different raccoons (49,941 captures) and 4,435 skunks were captured, vaccinated, and released, utilizing 478,755 trap nights in the St. Lawrence TVR area during 1995–2007 (Table 2). An average of 43% to 83% of the raccoon population was vaccinated against rabies during those years (Table 2).

PIC programs, 1999–2005

During 1999 to 2005, a total of 8,311 raccoons and 1,449 skunks were euthanized using 576,359 trap nights during 17 PIC operations in eastern Ontario in response to raccoon rabies cases (Table 3). In many of the PICs, raccoon captures did not consistently decline over time in many

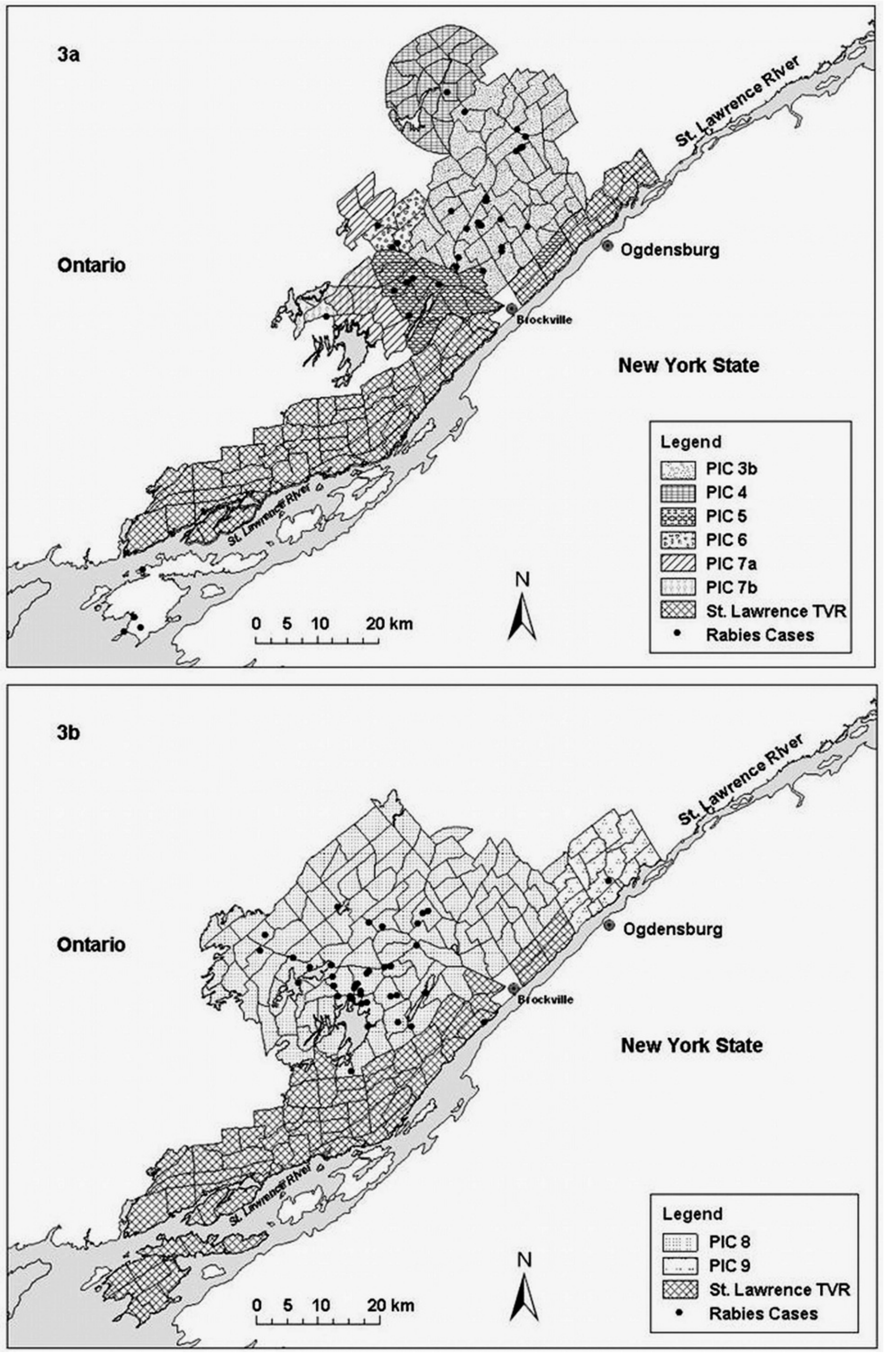

FIGURE 3. Location of the 17 Point Infection Control (PIC) Programs in Ontario during 1999–2003. Point Infection Controls 1, 2, 3a are depicted in Fig. 1 of Rosatte et al. (2001). a=2000 operations; b=2001 operations; c=2002 operations; d=2003 operations.

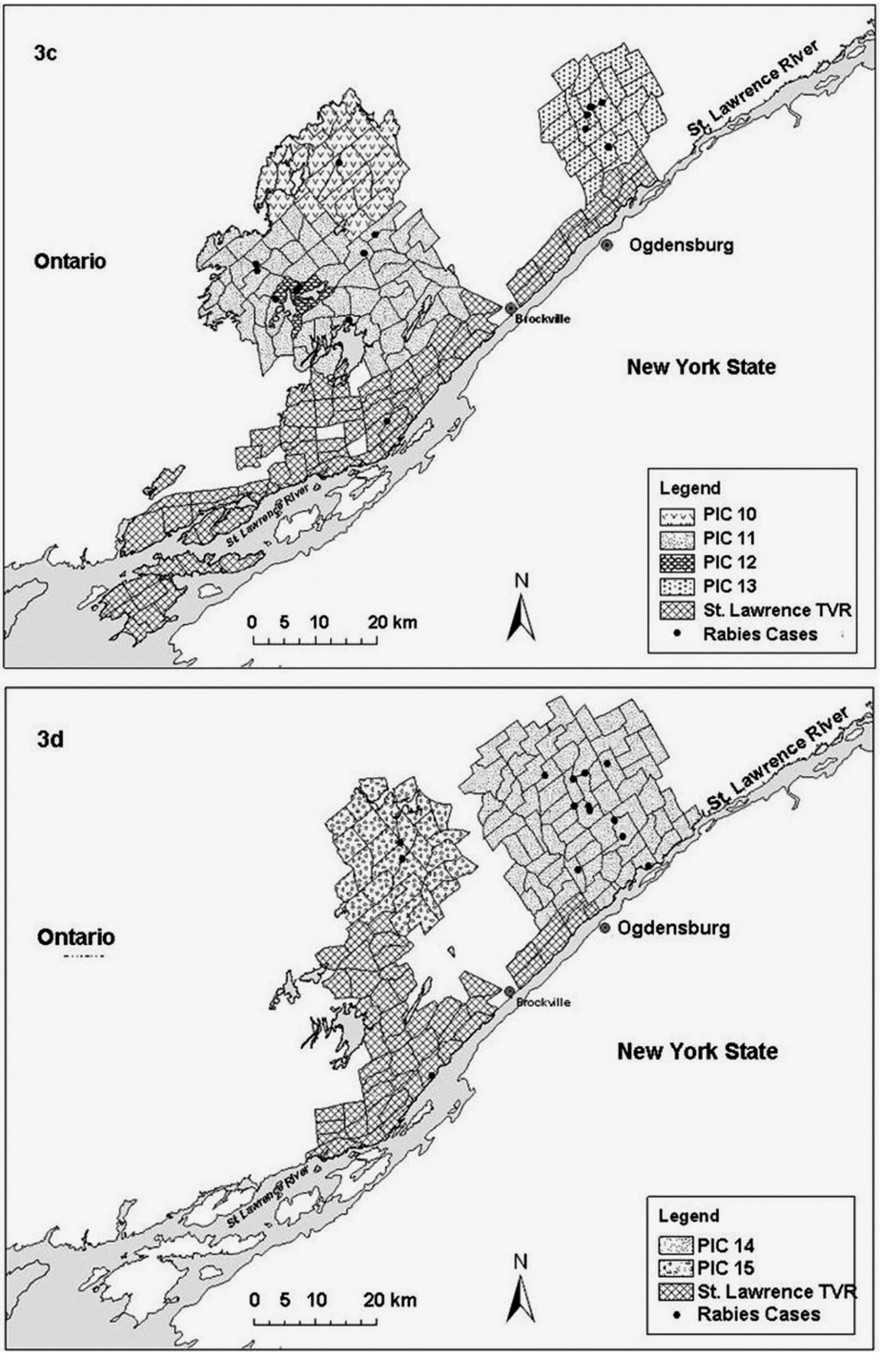

FIGURE 3. Continued.

TABLE 2. Statistics for the St. Lawrence Trap-Vaccinate-Release (TVR) program, 1995–2007.[a]

Year	Area (km^2)	Trap nights	Raccoon captures (T[D])[b]	Skunk captures (T[D])[b]	Raccoon population size mean (95% CL)	% vaccinated against rabies mean (95% CL)
1995	470	28,909	2,109 (1,490)	478 (367)	2,235 (2,056–2,459)	67 (61–73)
1996	801	25,175	1,971 (1,614)	270 (223)	3,791 (3,357–4,399)	43 (37–48)
1997	720	40,870	4,215 (2,896)	555 (388)	4,575 (4,322–4,867)	63 (59–67)
1998	720	40,620	3,391 (2,495)	664 (487)	3,868 (3,591–4,209)	65 (59–70)
1999	650	36,297	3,082 (2,311)	655 (484)	4,415 (3,971–5,008)	52 (46–58)
2000	764	71,576	7,863 (4,853)	1,152 (588)	6,495 (6,272–6,737)	75 (72–77)
2001	892	72,699	7,144 (4,368)	1,396 (768)	6,067 (5,847–6,309)	72 (69–75)
2002	690[c]	70,080	8,971 (5,275)	916 (468)	5,693 (5,525–5,874)	79 (77–82)
2003	595	48,629	5,410 (3,217)	451 (260)	4,282 (4,117–4,464)	75 (72–78)
2006	416	30,700	4,254 (2,466)	671 (336)	3,065 (2,978–3,160)	81 (78–83)
2007	125	13,200	1,531 (858)	133 (66)	1,041 (975–1,120)	83 (77–88)
Total	na	478,755	49,941 (31,843)	7,341 (4,435)	na	na

[a] Trapping occurred from late June/early July to late October each year; TVR did not occur during 2004 or 2005—Point Infection Control programs replaced TVR programs during those years; na = not applicable.

[b] T = total animals captured including recaptures; D = different animals captured.

[c] During 2002, only 690 km^2 of the 864 km^2 area was trapped sufficiently due to initiation of Point Infection Control Programs.

TABLE 3. Raccoons and skunks euthanized or vaccinated against rabies during Point Infection Control (PIC) operations in eastern Ontario during 1999–2005 (Wolfe Island not included).[a]

PIC no.	Date	Area (km^2)	Trap nights (n)	Raccoon euthanized (n)	% rabid % (n)	Raccoons vaccinated (n)	Skunks euthanized (n)[a]	Skunks vaccinated (n)
1	July 1999	300	24,973[b]	487[b]	0	767[b]	93[b]	199[b]
2	July/August 1999	300	18,946[b]	385[b]	0	785[b]	116[b]	107[b]
3a	September/October 1999	135	8,756[b]	330[b]	1 (1)[c]	207[b]	128[b]	71[b]
3b	April/August 2000	275	32,209	977	0.7 (7)	212	228	24
4	May/June 2000	225	17,159	143	0	382	43	70
5	June/July 2000	196	12,943	951	0	2	161	0
6	August/October 2000	56	5,426	609	0.2 (1)	12	109	0
7a	October/November 2000	245	2,498	282	0	0	39	0
7b	December 2000	78	938	23	0	0	2	0
8	January/August 2001	1,424	116,282	2,463	0.2 (5)	4,339	250	478
9	June/July 2001	182	20,653	80	0	656	7	143
10	April 2002	346	30,727	176	0	961	34	116
11	May/August 2002	782	74,901	0	0	3,470	0	362
12	September 2002	33	1,270	74	0	35	4	1
13	October 2002	312	25,226	394	1.5 (6)	755	85	178
14	April/July 2003	861	82,506	762	0	1,884	119	290
15	June/September 2003	395	33,715	0	0	1,297	0	253
16	August/October 2004	362	31,115	98	1.0 (1)	1,938	9	195
17[d]	September 2005	416	36,116	77	0	2,427	22	248
Total	1999–2005	na	576,359	8,311	0.26 (21)	20,129	1,449	2,735

[a] None of the euthanized skunks reported in this table tested positive for rabies; na = not applicable.

[b] Data published in Rosatte et al., 2001 but is reported here to show total animals euthanized.

[c] 118 were tested for rabies; one was positive.

[d] PIC 17 was done in place of the 2005 St Lawrence TVR program.

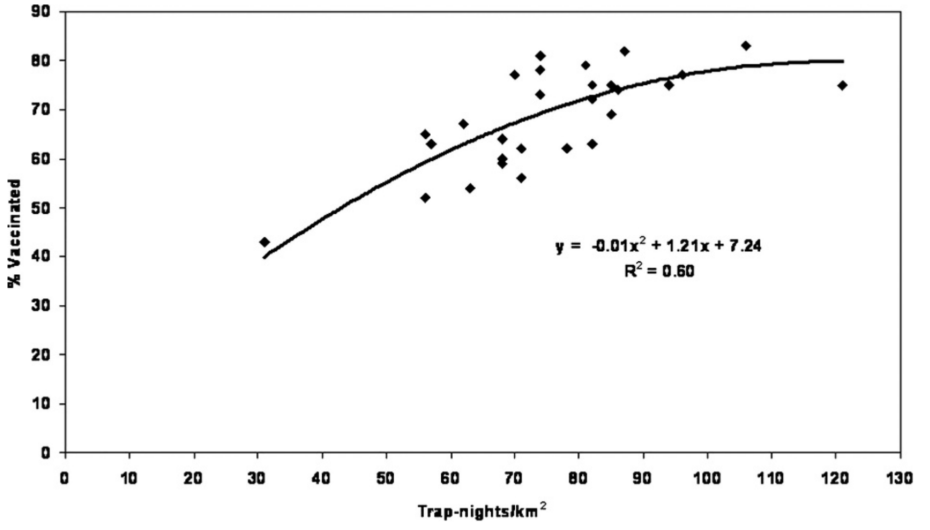

FIGURE 4. Second-order polynomial relationship between trapping effort and the percentage of the raccoon populations vaccinated between 1994–2007 during trap-vaccinate-release (TVR) programs in Niagara and the St. Lawrence regions and Point Infection Control (PIC) operations in eastern Ontario.

cells, making it impossible to estimate the percentage of the population that was euthanized. However, during some operations (e.g., PIC 10), >90% of the raccoon population was removed from the population reduction area. Less than 1% (0.26) of the raccoons and no skunks in the samples were diagnosed as rabid. In addition, 20,129 raccoons and 2,735 skunks were vaccinated against rabies and released in the PIC areas (Table 3). During operations where sufficient data were available to estimate raccoon density, the percentage of the population that was vaccinated in the TVR portions of the PICs 14, 15, 16, and 17 averaged 77%, 69%, 74%, and 82%, respectively.

Relationship between trapping effort and the percentage of the population vaccinated

A total of 1,797,403 trap nights were utilized to capture raccoons and skunks during TVR and PIC operations in Ontario between 1994 and 2007 (Tables 1–3). Trapping effort varied between 31 and 125 trap nights/km^2 within the study areas. The mean trapping effort in all programs was 78.0 (18.9 SD) trap nights/km^2 and the mean percent vaccinated for raccoon populations was 68.8 (10.08 SD). The relationship between trap effort and percent vaccination of raccoon populations was found to be significant ($F_{1,27}$=29.33, P=0.00001) although only moderately described by a first-order (linear) model (R^2=0.52). Fitting a second-order polynomial equation to the data improved our model of effort and raccoon population vaccination (R^2=0.60) and indicated an asymptote in percent vaccinated was reached at approximately 80% over the range of effort expended (Fig. 4). Using this model, it was revealed that to achieve a target vaccination rate of 60% or 70%, would require a trap effort (±95% CL) of 66 (60–72) or 78 (73–82) trap nights/km^2, respectively.

Distribution of vaccinia-rabies glycoprotein (V-RG) baits

During 1999 to 2006, V-RG rabies vaccine baits were aerially distributed in eastern Ontario to assist with the control of raccoon rabies. The results of that program are reported in Rosatte et al. (2008).

Cost of rabies control tactics

The cost of each program (whether TVR or PIC) was variable, depending on the amount of trapping effort and the size of the treated area. During 1994–2003, TVR program costs varied between \$200–\$300/km^2 Cdn. However, as trapping effort was increased to maximize the percentage of the populations vaccinated, and vehicle and gas prices increased dramatically, the costs for TVR programs escalated from about \$350.00/km^2 in 2004 to \$625.00/km^2 in 2007. The cost of PIC programs during 1999–2005 was about \$300.00 to \$500.00/km^2. To put the costs into perspective, as noted in Tables 1, 2, 3, the size of the TVR treatment areas was $<$900 km^2 and the size of PIC areas was $<$1,500 km^2.

DISCUSSION

The most feasible tactic for immunizing terrestrial wildlife rabies vectors over large geographic areas is through the aerial distribution of oral rabies vaccine baits (ORV; Kappus et al., 1970; Bachmann et al., 1990; MacInnes et al., 2001; Rosatte et al., 2007d). However, because an effective oral rabies vaccination system had yet to be developed for striped skunks and raccoons when raccoon rabies entered Ontario, OMNR staff had to rely on labor intensive tactics such as population reduction and TVR to control the disease in those species (Rosatte et al., 2001). That is, at that time, we had more confidence in vaccination by injection and removal of vectors from the population than we did with oral vaccination of raccoons and skunks. However, the use of population reduction for the control of raccoon rabies might be viewed as controversial because animals are euthanized, and in our case, a low percentage of those were actually rabid (Kappus et al., 1970; Debbie, 1991; Winkler and Jenkins, 1991; Rosatte et al., 2007d). It needs to be emphasized that animals incubating rabies normally are not detected using routine rabies diagnostic techniques. Furthermore, vaccination does not work on raccoons or skunks that are incubating or clinical for rabies (Rosatte et al., 2007a). Taking into consideration that raccoon mortality due to rabies can approach 60% to 80% (Clavette, 1996), and there is an estimated 1 million raccoons in Ontario (Rosatte, 2000), euthanizing a few thousand animals will save many times more raccoons from death due to rabies. There are significant public health benefits from controlling rabies. In fact, in Ontario, human postexposure treatments declined by 50% from $>$2,000/yr during the 1980s to about 1,000/yr by the late 1990s following the implementation of wildlife rabies control programs for foxes (Nunan et al., 2002).

The proactive Niagara and St. Lawrence TVR programs played major roles in slowing the progression of raccoon rabies into Ontario (the barrier effect of the Niagara and St. Lawrence Rivers to raccoon movement cannot be discounted in slowing disease movement). No cases of raccoon rabies have been reported in the Niagara Falls, Ontario area, despite the disease having been enzootic in neighbouring Niagara County, New York, for more than a decade (New York State Department of Health, 1990–2006). In addition, raccoon rabies was not reported in eastern Ontario (outside of the St. Lawrence TVR zone) until 1999 (Wandeler and Salsberg, 1999). Therefore, a proactive approach with effective raccoon rabies control tactics is recommended to jurisdictions that are being challenged with a rabies front, because the resultant cost and public health benefits are significant if the disease is prevented from becoming enzootic.

The percentage of a raccoon population that is immunized against rabies is critical for the prevention of a rabies outbreak. During 2001 to 2003, a single case of raccoon rabies was reported in the St. Lawrence TVR area (i.e., the vaccinated area) during each of those 3 yr. The percentage of the raccoon population vaccinated averaged 72%, 79%, and 75%, during those years, respectively. Trap effort was about 82 trap nights/km^2. No additional cases were reported in the TVR area during those years, so it is believed that a level of 72% to 79% vaccination was sufficient to prevent outbreaks from occurring following the initial cases. However, during PIC operations in response to the second case of raccoon rabies in eastern Ontario, only 55% of the raccoons were vaccinated during the TVR portion of the PIC operation in 1999 (Rosatte et al., 2001). Fifteen additional rabies cases were reported in that area during 2000, suggesting the 55% vaccination rate was not sufficient to contain the outbreak (Rosatte et al., 2001). In addition, only 39% of the raccoons on Wolfe Island, Ontario, were vaccinated against rabies during TVR operations in 1999 (Rosatte et al., 2007b). Six cases of raccoon rabies occurred there during December 1999 and January 2000 (Rosatte et al., 2007b). Again, the low vaccination rate was not sufficient to prevent an outbreak of rabies. In summary, a vaccination level of <56% might not be sufficient to control raccoon rabies, whereas a level >71% should be sufficient to control the disease; we are uncertain about the efficacy of vaccination levels in raccoons between 56% and 71%, with respect to containing or eliminating an outbreak of raccoon rabies. Ideally, rabies vaccination programs should have a goal of vaccinating >71% of the raccoon population.

The intensity of trapping effort during TVR and PIC programs is very important with respect to controlling rabies. If trapping effort is low, a sufficient percentage of the target population will not be immunized to accommodate the elimination of the disease. We demonstrated that a trapping effort of about 80 trap nights/km^2 is sufficient to capture and vaccinate about 70% or more of the raccoon population. This assumes that raccoon density on average is about 5–10/km^2. Greater densities might require greater trapping effort, in some situations as high as 125 trap nights/km^2. Other factors that can affect capture success include trapper experience, weather patterns, habitat, and type of bait. Given these factors that can affect capture success, it is imperative that estimates regarding the percentage of the population that was vaccinated are calculated as the program is in progress. If estimates are low (e.g., <60% vaccinated) then additional trapping will be required. Again, experimentation will be needed, because intense epizootics might require that a greater percentage of the population be vaccinated to eliminate the disease, compared to the situation in Ontario where raccoon rabies prevalence was very low (<1%) during 1999–2005.

The size of the PIC or TVR area is important with respect to containing and eliminating rabies. The size of these zones was determined using raccoon ecologic data (rabid and nonrabid) and the fact that the majority of their movements are usually less than 5 km annually (Rosatte 2000; Rosatte et al., 1997, 2005, 2006, 2007b, c). Generally, in Ontario, a 10-km radial control zone (population reduction and TVR) around rabies case locations was sufficient to contain the disease to the area. In addition, V-RG baits were placed outside of those zones (as a proactive measure should raccoon rabies cases appear outside of the PIC zones) so that the total area of protection was defined by a 50 km radial area around cases. That strategy should be sufficient to prevent the spread of raccoon rabies, assuming raccoon density and movements as well as the intensity of the outbreak are similar to that found in Ontario during the years of control.

Any attempts to control or eliminate raccoon rabies will have to occur over several years, depending on the intensity and extent of the epizootic/enzootic. Areas need to be treated annually because raccoon population turnover is very rapid (Rosatte et al., 2007b, c) with the majority of the population being susceptible to rabies infection 1 yr posttreatment because they are unvaccinated juveniles. Control initiatives should continue in an area until there has been an absence of rabies cases for at least 2 yr and the area can be deemed as "free from rabies" (Office of International Epizootics, 2005). Intensive surveillance should continue in the absence of control so that tactics can be redeployed quickly should a case(s) of rabies be detected in the control zone.

The implementation of a High Risk Zone in eastern Ontario to limit the spread of rabies was crucial to the success of the program. The key to this tactic, from a rabies prevention point of view, was that it was illegal to move or relocate rabies vector species (raccoons, striped skunks, red foxes) within the zone. Historically in Ontario, rehabilitated and/or nuisance wildlife such as raccoons, have been relocated substantial distances from their point of origin (Rosatte, 2000). If those animals were incubating rabies at the time of relocation, significant spread of the disease could occur. The High Risk Zone limited this practice in eastern Ontario until 2007, when the zone was discontinued due to a lack of any new rabies cases for 2 yr. Legislation to limit human-assisted movement of rabies vector species is recommended in any area where the disease has a potential to become established (Rosatte et al., 2007d).

Raccoon rabies-associated costs in North America are estimated at several hundred million dollars annually (Rupprecht et al., 1995; Recuenco et al., 2007). In Ontario, if raccoon rabies became enzootic, annual costs would average \$8–\$12 million Cdn (Rosatte et al., 2001). Thus the decision to eliminate the disease from an area is financially prudent. In Ontario, the cost for TVR and PIC operations to control rabies ranged between \$250.00 and \$625.00/km^2 Cdn. Those costs seem high compared to the cost of oral rabies vaccination with baits (which in Ontario average about \$200.00/km^2; Rosatte et al., 2001). However, it must be remembered that TVR and population reduction areas are small (<2,000 km^2) in comparison to areas that are treated with baits aerially. For example, during 2003 an approximate 180,000 km^2 area of the eastern US was treated with baits to control raccoon rabies (Slate et al., 2005). Thus the costs on a unit basis (/km^2) really are not comparable due to the difference in the size of treatment areas among the different tactics. The annual savings to Ontario during 2007 alone due to elimination of raccoon rabies was estimated at \$6–\$10 million Cdn.

A multifaceted approach, which included PIC, TVR, ORV with baits, and establishment of a High Risk Zone were proven to be effective tactics to eliminate raccoon rabies from Ontario. In addition to these tactics, OMNR is currently field testing a human adenovirus-rabies recombinant vaccine (ONRAB®) in baits, which shows great promise to effectively orally immunize raccoons, skunks, and foxes against rabies. The last case of raccoon rabies in Ontario was reported in September, 2005. However, Ontario will have to remain vigilant because raccoon rabies is presently (2008) at the Ontario border in Jefferson, Niagara, and Erie counties, New York. In addition, a major epizootic of raccoon rabies in Quebec is about 100 km from the Ontario border and is spreading in a westerly direction. Most importantly, because raccoon rabies has been controlled in Ontario, the challenge will be to maintain OMNR staff with rabies control expertise who can respond if the disease is detected once again in this Province.

ACKNOWLEDGMENTS

The OMNR rabies control program was supported by the Rabies Advisory Committee, J. Broadfoot, chairman. Special thanks to the countless dedicated staff of the OMNR Rabies Unit who were involved with the PIC, TVR, and aerial baiting programs, especially P. Bachmann, K. Bennett, A. Silver, M. Purvis, L. Brown, S. Taylor, V. von Zuben, H.

Simpson, D. Grieve, D. Antonio, L. Howes, R. Warren, and B. Watts. A. McAllister dealt with communication issues as well as the High Risk Zone. We would also like to acknowledge with appreciation the staff of the rabies diagnostic laboratory of CFIA in Ottawa. Also acknowledged are the OMNR Air Services staff, especially N. Ayers, who were involved with the aerial bait distribution program.

LITERATURE CITED

Bachmann, P., R. Bramwell, S. Fraser, D. Gilmore, D. Johnston, K. Lawson, C. Macinnes, F. Matejka, H. Miles, M. Pedde, and D. Voigt. 1990. Wild carnivore acceptance of baits for delivery of liquid rabies vaccine. Journal of Wildlife Diseases 26: 486–501.

Clavette, M. 1996. Status of raccoon rabies in Connecticut. Connecticut Wildlife 16: 12.

Debbie, J. 1991. Rabies control in terrestrial wildlife by population reduction. *In* The natural history of rabies. 2nd Edition, G. Baer (ed.). CRC Press, Boca Raton, Florida, pp. 477–484.

Kappus, K., W. Bigler, R. McLean, and H. Trevino. 1970. The raccoon an emerging rabies host. Journal of Wildlife Diseases 6: 507–509.

Krebs, C. J. 1989. Ecological methodology. Harper and Rowe, New York, New York, 654 pp.

MacInnes, C. D., S. Smith, R. Tinline, N. Ayers, P. Bachmann, D. Ball, L. Calder, S. Crosgery, C. Fielding, P. Hauschildt, J. Honig, D. Johnston, K. Lawson, C. Nunan, M. Pedde, B. Pond, R. Stewart, and D. Voigt. 2001. Elimination of rabies from red foxes in eastern Ontario. Journal of Wildlife Diseases 7: 119–132.

New York State Department of Health. 1990–2006. Annual rabies summaries. Wadsworth Centre Rabies Laboratory, Albany, New York, 17 pp.

Nunan, C., R. Tinline, J. Honig, D. Ball, P. Hauschildt, and C. Leber. 2002. Post-exposure treatment and animal rabies, Ontario 1958–2000. Emerging Infectious Diseases 8: 214–217.

Office of International Epizootics. 2005. Terrestrial Code, 14 Edition. Rabies, chapter 2.2.5, article 2.2.5.2, World Organization for Animal Health, Paris, France, pp. 102–104.

Recuenco, S., B. Cherry, and M. Eidson. 2007. Potential cost savings with terrestrial rabies control. Biomedcentral (BMC) Public Health 7: 47–56.

Rosatte, R. C. 2000. Management of raccoons (*Procyon lotor*) in Ontario, Canada: Do human intervention and disease have significant impact on raccoon populations? Mammalia 64: 369–390.

———, M. Power, C. Macinnes, and J. Campbell. 1992. Trap-vaccinate-release and oral vaccination for rabies control in urban skunks, raccoons and foxes. Journal of Wildlife Diseases 28: 562–571.

———, C. Macinnes, M. Power, D. Johnston, P. Bachmann, C. Nunan, C. Wannop, M. Pedde, and L. Calder. 1993. Tactics for the control of wildlife rabies in Ontario Canada. Reviews of the Science and Technical Office of International Epizootics 12: 95–98.

———, R. C. Macinnes, R. Williams, and O. Williams. 1997. A proactive prevention strategy for raccoon rabies in Ontario, Canada. Wildlife Society Bulletin 25: 110–116.

———, D. Donovan, M. Allan, L. Howes, A. Silver, K. Bennett, C. Macinnes, C. Davies, A. Wandeler, and B. Radford. 2001. Emergency response to raccoon rabies introduction into Ontario. Journal of Wildlife Diseases 37: 265–279.

———, M. Allan, R. Warren, P. Neave, T. Babin, L. Buchanan, D. Donovan, K. Sobey, C. Davies, F. Muldoon, and A. Wandeler. 2005. Movements of two rabid raccoons, *Procyon lotor*, in eastern Ontario. Canadian Field-Naturalist 119: 453–454.

———, K. Sobey, D. Donovan, L. Bruce, M. Allan, A. Silver, K. Bennett, M. Gibson, H. Simpson, C. Davies, A. Wandeler, and F. Muldoon. 2006. Behaviour, movements, and demographics of rabid raccoons in Ontario, Canada: Management implications. Journal of Wildlife Diseases 42: 589–605.

———, D. Donovan, M. Allan, ———, T. Buchanan, K. Sobey, C. Davies, A. Wandeler, and F. Muldoon. 2007a. Rabies in vaccinated raccoons from Ontario, Canada. Journal of Wildlife Diseases 43: 300–301.

———, E. Macdonald, K. Sobey, D. Donovan, L. Bruce, M. Allan, A. Silver, K. Bennett, L. Brown, K. Macdonald, M. Gibson, T. Buchanan., B. Stevenson, C. Davies, A. Wandeler, and F. Muldoon. 2007b. The elimination of raccoon rabies from Wolfe Island, Ontario: Animal density and movements. Journal of Wildlife Diseases 43: 242–250.

———, K. Sobey, D. Donovan, M. Allan, ———, T. Buchanan, and C. Davies. 2007c. Raccoon density and movements after population reduction to control rabies. Journal of Wildlife Management 71: 2373–2378.

———, R. Tinline, and D. Johnston. 2007d. Rabies control in wild carnivores. *In* Rabies, 2nd Edition, A. Jackson and W. Wunner (eds.). Academic Press, San Diego, California, pp. 595–634.

———, M. Allan, P. Bachmann, K. Sobey, D. Donovan, J. C. Davies, A. Silver, K. Bennett, L. Brown, B. Stevenson, T. Buchanan, L. Bruce, A. Wandeler, C. Fehlner-Gardiner, A. Beresford, A. Beath, M. Escobar, J. Maki, and C. Schumacher. 2008. Prevalence of tetracycline and rabies virus antibody in raccoons, skunks, and foxes following aerial distribution of V-RG baits to control raccoon rabies in Ontario, Canada. Journal of Wildlife Diseases 44: 946–964.

Rupprecht, C., J. Smith, M. Fekadu, and J. Childs. 1995. The ascension of wildlife rabies: A cause for public health concern or intervention. Emerging Infectious Diseases 1: 107–114.

Slate, D., C. Rupprecht, J. Rooney, D. Donovan, D. Lein, and R. Chipman. 2005. Status of oral rabies vaccination in wild carnivores in the United States. Virus Research 111: 68–76.

StatSoft, Inc. 1999. Statistics for Windows. StatSoft, Tulsa, Oklahoma, http://www.statsoft.com. Accessed December 2007.

Wandeler, A., and E. Salsberg. 1999. Raccoon rabies in eastern Ontario. Canadian Veterinary Journal 40: 731.

Webster, W. A., and G. A. Casey. 1988. Diagnosis of rabies infection. *In* Rabies, J. B. Campbell and K. M. Charlton (eds.). Kluwer Academic Publishers, Boston, Massachusetts, pp. 201–222.

Winkler, W. G., and S. R. Jenkins. 1991. Raccoon rabies. *In* The natural history of rabies. 2nd Edition, G. M. Baer (ed.). CRC Press, Boca Raton, Florida, pp. 325–340.

Received for publication 2 December 2008.