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Source: Journal of Wildlife Diseases, 37(2) : 265-279

Published By: Wildlife Disease Association

URL: https://doi.org/10.7589/0090-3558-37.2.265

Journal of Wildlife Diseases, 37(2), 2001, pp. 265–279

EMERGENCY RESPONSE TO RACCOON RABIES INTRODUCTION INTO ONTARIO

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ABSTRACT: During 15 July to 4 October, 1999, rabies control programs were implemented with the objective being to contain the first three confirmed cases of raccoon rabies in Canada. The strategy, called point infection control (PIC) involved the use of three tactics: population reduction (PR), trap-vaccinate-release (TVR) and oral rabies vaccination with baits (ORV), to control the spread of raccoon rabies. A total of 1,202 raccoons (*Procyon lotor*) and 337 skunks (*Mephitis mephitis*) were captured and euthanized using 24,719 trap-nights in the three PR zones around the location of the three rabies cases, near Brockville, Ontario. That represented an 83% to 91% reduction in the raccoon populations in an approximate 225 km^2 area around the three rabies cases. Raccoon density in the PR zones declined from 5.1–7.1/km^2 to 0.6–1.1/km^2 following control. All tested specimens were negative for rabies by the fluorescent antibody test (FAT). In addition, 1,759 raccoons and 377 skunks were intramuscularly vaccinated against rabies and released using 27,956 trap-nights in an approximate 485 km^2 TVR zone implemented outside of the PR zones. A total of 856 cats from both PR and TVR areas were also captured, vaccinated and released. Cost for the three PIC operations was $363,000.00 Cdn or about $500.00 Cdn/$km^2$. To further contain the outbreak, about 81,300 baits containing Raboral® V-RG oral rabies vaccine were aerially distributed on 8 and 27 September 1999, to create an 8 to 15 km wide buffer zone (1,200 km^2 area) of vaccinated raccoons immediately beyond the PR and TVR zones. This was the first time that V-RG was used in Canada to orally vaccinate free ranging raccoons against rabies. Baiting costs were $241,000.00 Cdn or about $200.00 Cdn/$km^2$ including post baiting assessment costs. As of 31 August, 2000, thirty-five additional cases (38 in total) of raccoon rabies have occurred in the control and vaccination zones. This number is far below the level of rabies prevalence in USA jurisdictions where raccoon rabies was epizootic. In the future, PIC methodologies will continue to be used in Ontario to contain isolated cases of raccoon rabies.

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

INTRODUCTION

During the early 1990's, raccoons (*Procyon lotor*) found to be infected with a specific reported variant of rabies virus (referred to as raccoon rabies) were very close to the Ontario (Canada) border in the vicinity of Niagara Falls (New York, USA). As a result, staff from the Ontario Ministry of Natural Resources (OMNR) and its provincial and federal partners designed and implemented a contingency plan to prevent the disease from becoming enzootic in Ontario (Rosatte et al., 1997). Part of that proactive plan included creating buffer zones of vaccinated raccoons along the New York/Ontario International border using a method called trap-vaccinate-release (TVR) (Rosatte et al., 1992a; Rosatte et al., 1997). Despite those efforts, three cases of raccoon rabies in eastern Ontario (north of the vaccination zones) were confirmed by Canadian Food Inspection Agency (CFIA) staff during July–September 1999. These were the first confirmed cases of the raccoon variant of rabies in Canada (Wandeler and Salsberg, 1999).

The first case of raccoon rabies (14 July, 1999) occurred in a juvenile raccoon found dead in a dog kennel (with 3 dogs that were later euthanized) on a rural residential property (near Domville, Ontario) about 5 km NW of Prescott, Ontario (44°45′N, 75°35′W). OMNR, Rabies Re-

search Unit staff immediately implemented a point infection control (PIC) program to contain the case. Before that operation was complete, the second case was confirmed by the CFIA on 26 July, 1999. The animal in question was an adult female raccoon that had attacked a dog on a rural residential property about 15 km north of Brockville near the village of Jellyby, Ontario (44°45′N, 75°50′W) (15 km west of the location of the first case) (Fig. 1). The OMNR subsequently moved another team of trappers into the zone on 27 July, 1999, to implement a second PIC program. On 17 September, 1999, the third case of raccoon rabies (an adult female raccoon) was confirmed in Ontario. This case was located 15 km north of the first case. This animal had been wandering aimlessly in a small residential community in rural eastern Ontario and was euthanized by a resident (5 km southwest of the village of Oxford Station at 44°55′N, 75°35′W) (Fig. 1). OMNR staff implemented another PIC operation on 20 September 1999. As a precautionary measure about 81,300 rabies vaccine baits [Raboral® Vaccinia-Rabies Glycoprotein (V-RG)]; Merial, (Athens, Georgia, USA) were aerially dropped (on 8 and 27 September, 1999) outside of the TVR zones to further augment the control of the three cases of raccoon rabies.

Since the PIC operations were completed, 35 additional cases of raccoon rabies have been confirmed in Ontario (to 31 August, 2000). Twenty-nine of those were within the PIC zones and 6 occurred on Wolfe Island, where a TVR program had been implemented during July 1999 (Fig. 1). This paper reports on the actions taken in response to the first cases of raccoon rabies in Canada.

METHODS

General

Upon receiving notification that Ontario had its first case of raccoon rabies, the "Point Infection Control Strategy" document (Rosatte, 1999) was reviewed by OMNR Rabies Research Unit staff and appropriate agencies/staff were notified to assist with the implementation of the plan. Within 24 hr of notification of the first case, OMNR Rabies Research Unit staff had moved a team of 15 trappers and eight support staff into the area to initiate a PIC Program. PIC involves the use of population reduction (PR), TVR and oral rabies vaccination (ORV) methodologies. Using PR, raccoons and skunks (*Mephitis mephitis*) are live-trapped and euthanized by injection while TVR includes live-trapping raccoons and skunks, vaccinating against rabies by injection and releasing the animal at the point of capture. ORV involves the distribution of baits containing liquid rabies vaccine. Raccoons are vaccinated when they orally contact liquid rabies vaccine while chewing the vaccine bait. Trapping effort in both PR and TVR areas was designed to be very intense so that the majority of raccoons and skunks would be removed from the PR area and the majority of raccoons and skunks in the TVR areas would be vaccinated against rabies.

Trapping commenced on Thursday, 15 July 1999. The target zone for the PIC operation included a 300 km^2 area defined by a 10 km radial area around the location of the first rabies case (Fig. 1). The area was divided into 30 trapping cells or pre-defined areas to be trapped. The PIC plan included live-trapping and euthanizing all raccoons and skunks captured within a 5 km radius of the case location (Fig. 1). This was called the PR zone. That zone was about 75 km^2 in area and was divided into eight trapping cells each one being about 10 km^2 in area. Trappers gained verbal permission directly from landowners before setting traps on private property. Each of eight trappers assigned to those cells set about 100 livetraps (#106, #108 Tomahawk, Tomahawk Live-Trap Co., Tomahawk, Wisconsin, USA) for 7 consecutive nights in each trapping cell. Sardines were used as bait. All captured raccoons and skunks from the PR zone were brought to a field lab located in a vacant OMNR building north of the control zone at Limerick Forest. Raccoons and skunks were immobilized with an intramuscular (IM) injection of 1–2 ml (100 mg/ml) of ketamine hydrochloride (Ketaset-Rogar/STB Inc., London, Ontario, Canada). About 10 cc of blood was collected from all raccoons and skunks via cardiac puncture using 10 ml Vacutainer serum separation tubes and 22 gauge needles (Becton Dickinson, Oakville, Ontario, Canada). Blood was centrifuged, sera collected and stored in 2 ml provials (Sarstedt Inc., St. Leonard, Quebec, Canada), frozen (−21 C) and later transported to CFIA (Nepean, Ontario) for detection of rabies neutralizing antibody using an ELISA test. All rac-

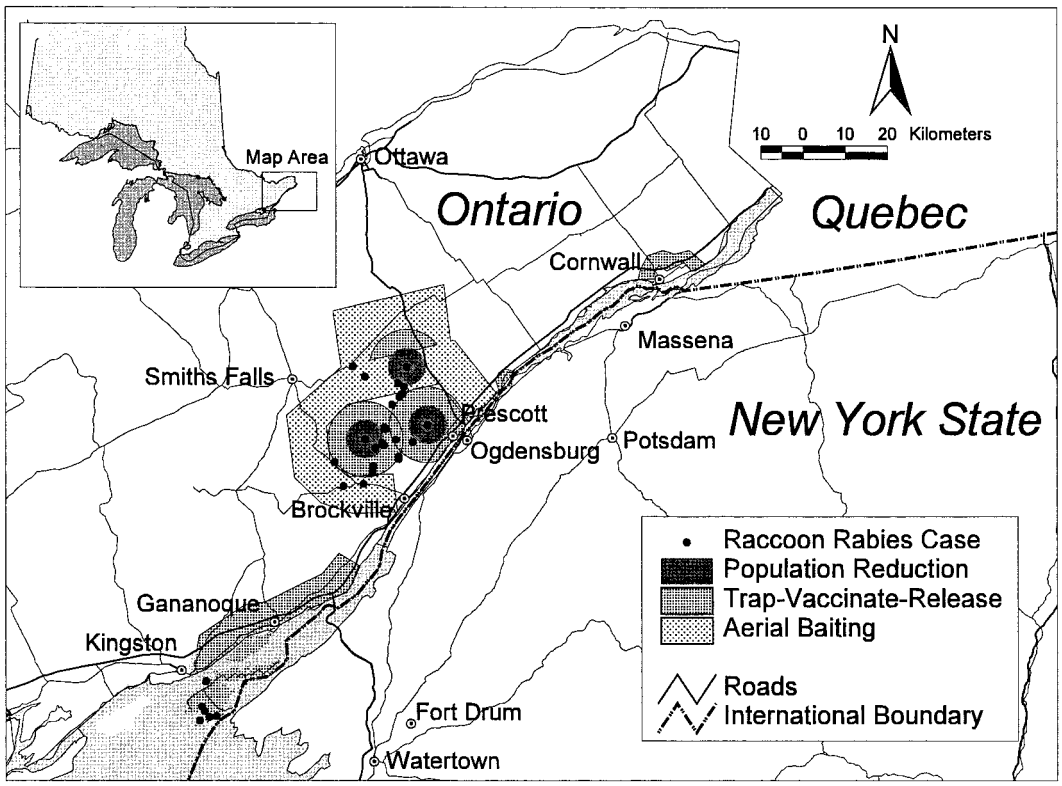

FIGURE 1. Location of the 38 cases of raccoon rabies including the population reduction (PR), trap-vaccinate-release (TVR) and aerial baiting zones in Ontario, Canada, 14 July 1999 to 31 August 2000. Raboral® Vaccina-Rabies Glycoprotein (V-RG) baits were used in the aerial baiting zones.

coons and skunks were then euthanized with an intracardiac injection of 1–2 ml of T-61 euthanasia solution (Hoechst Canada, Inc., Regina, Saskatchewan, Canada) following anesthesia. Brain samples were collected (via syringe) from all euthanized raccoons and skunks, frozen and transported to CFIA diagnostic laboratory in Nepean, where they were examined using a fluorescent antibody test (FAT) as described by Webster and Casey (1988). Carcasses were transported and incinerated at the Agricultural College (Kemptville, Ontario).

While the PR program was being implemented, a TVR program was initiated at the same time, in the area immediately adjacent to the PR zone (Fig. 1). All raccoons and skunks captured 5–10 km (225 km^2—22 trapping cells) from the case location were vaccinated with Imrab® 3 inactivated rabies vaccine (Merial Inc.) via IM injection, fitted with ear tags (numbered size 1 and 2) (National Band and Tag Co., Newport, Kentucky, USA) for identification and released at the point of capture. Seven trappers were assigned to those cells and utilized the same trapping effort (i.e., 100 traps/trapper/night) as during the PR operation. During the next 7 nights the 15 trappers from both PR and TVR zones trapped the remaining cells in the TVR area.

All cats trapped within both PR and TVR zones were vaccinated (Imrab 3) and released. Trappers who were designated as inspectors during the operation, were approved by CFIA to vaccinate cats pursuant to section 48 of the Health of Animals Act.

After the OMNR trappers completed trapping the PR zone (after the initial 7 nights of trapping) 12 trappers from the Ontario Fur Managers Federation were hired to trap raccoons and skunks within the PR zone for an additional 7 nights to capture and euthanize any raccoons or skunks that the OMNR team missed. All animals were processed as described above.

During the second PIC operation, all raccoons and skunks captured within 5 km of the case location were euthanized. In addition, all raccoons and skunks captured between 5 and 10 km from the case location were vaccinated (Imrab 3) and released. The second PIC zone

(Fig. 1) was divided into 22 trapping cells (7 in the PR zone and 15 in the TVR area). There were fewer trapping cells in the second PIC zone (compared to the first zone) as part of the 10 km radial area was trapped during the first PIC operation. Trapping cells in the second zone were also slightly larger than those in the first zone because of the orientation of roads. Eleven trappers were used for the PR and TVR operations over 14 nights. Six trappers were used to re-trap the PR zone for an additional 7 nights.

Since the third case of raccoon rabies (Fig. 1) occurred within the area that received Raboral® V-RG baits on September 8/99, a full PR program but only a partial TVR program was implemented (i.e., TVR was not implemented in the portion of the 10 km radial zone around the case location that received ORV baits). A full PR program was warranted as sufficient time had not passed to allow raccoons to develop full immunity following contact with vaccine in the baits (Hanlon et al., 1998). The third PIC zone was divided into 12 trapping cells (7 for the PR zone and 5 for the TVR area). As with the first two operations, all raccoons and skunks within a 5 km radius of the location of the third case of raccoon rabies were euthanized following capture. For the PR operation (75 km^2 area), 7 trappers were utilized over a 7 night period. The area was then re-trapped for 7 nights with 7 different trappers. The 60 km^2 TVR area was trapped for 7 nights using 5 trappers. All raccoons, skunks and cats were vaccinated in the TVR area as during the first two PIC operations. Cats also were vaccinated and released in the PR zone.

As 11 cases of raccoon rabies occurred during December 1999 and January 2000 within areas where either a PR or TVR program had been completed during 1999, additional full PIC operations were not initiated in response to the additional cases. However, a public awareness campaign was increased through door-to-door notification of residents in the vicinity of the 11 cases. Surveillance was also increased through requesting residents to report any abnormal acting raccoons, and two Ontario Fur Manager Federation trappers were hired to trap and euthanize raccoons in the immediate vicinity around the 11 case locations during January 2000.

Mean raccoon population density and standard error (SE) estimates were calculated by input of capture/recapture data from the TVR programs into a software version of the modified Petersen model as used in Krebs (1989). A catch/unit effort removal model (Leslie plot with linear regression) was used to estimate mean raccoon density and SE with data from the PR programs (Krebs, 1989). Percent vaccinated estimates were determined by dividing the number of different raccoons vaccinated in a given area by the estimated raccoon population size and multiplying that by 100. Percent removal estimates were calculated by dividing the number of raccoons euthanized by the estimated population size and multiplying that by 100.

The habitat where the PIC programs were implemented, centered in the villages of Jellyby, Domville, and Oxford Station, Ontario, was a combination of agricultural pastureland/cropland, blocks of deciduous and coniferous forest, interspersed with wetland areas. Human population density was very low as the majority of the area was farmland and forest with a few small villages.

V-RG Baiting

During August 1999 a formal application was forwarded to the CFIA, Veterinary Biologics and Biotechnology Section (Nepean, Ontario) to approve use of Raboral® V-RG (Merial Inc.) oral rabies vaccine in baits in Ontario to assist with the control of raccoon rabies. Approval was granted by the CFIA in early September 1999. This was the first time that Raboral® V-RG had been approved for field use in Canada. On 8 September, 1999, about 50,000 baits containing Raboral® V-RG were distributed aerially (using 2 OMNR de Havilland Twin Otter aircraft) in an 8 to 10 km wide zone around the outer perimeter of the first two PIC operations (Fig. 1). About 23,000 of the baits were Merial Fishmeal Polymer (FP) baits containing Raboral® V-RG. The remaining 27,000 baits were Ontario Slim baits (manufactured by Artemis Technologies Inc., Guelph, Ontario). These also contained liquid V-RG vaccine (the bulk vaccine was purchased from Merial Inc.). Target bait density was 70 baits/km^2 with flight line spacing of about 1 km.

Following notification of the third case of raccoon rabies, about 31,300 Raboral® V-RG FP baits were deployed aerially (on 27 September 1999) in a 450 km^2 area north of the location of the third case of raccoon rabies (Fig. 1). Bait density and flight line spacing were the same as on 8 September 1999.

RESULTS

PIC Operation # 1—Domville area

Twenty-seven different trappers utilized 24,973 trap-nights to capture 2,258 animals during the first PIC program from 16 to 30 July 1999 (Table 1). The total included the 487 raccoons and 93 skunks

TABLE 1. Trapping effort for the first point infection control program at Domville, Ontario, 16–30 July 1999.

Zone	Number of trappers	Number of trap-nights	Different raccoons	Recaptured raccoons	Different skunks	Recaptured skunks	Cats vaccinated
PR zone[a] (days 1–7)	8	6,188	423	0	83	0	98
TVR zone[a] (days 1–7)	7	4,627	255	77	86	37	68
PR zone (days 8–14)	12	4,000	64	0	10	0	0
TVR zone (days 8–14)	15	10,158	512	156	113	56	115
Total euthanized			487	0	93	0	0
Total vaccinated			767	233	199	93	281
Totals	27 (d)[a]	24,973	1,254	233	292	93	281

[a] d = different trappers; PR zone = population reduction zone; TVR Zone = trap vaccinate-release zone.

from the PR zone (75 km^2 area) that were euthanized and submitted to the CFIA for rabies testing. All were negative for rabies by FAT. About 89% (423/487) of the raccoons from the PR zone were captured during the first seven nights of trapping (14 nights in total) (Fig. 2). Estimated raccoon density in the PR zone prior to control was 7.1 ± 0.4/km^2 ($\bar{x}$ ± SE). Post control raccoon density was 0.6 ± 0.3/km^2. About 91% of the raccoons in the PR zone were euthanized.

A total of 767 different raccoons, 199 different skunks and 281 cats (including those in the PR zone) were trapped, vaccinated (intramuscularly with Imrab 3) and released in the TVR zone (225 km^2 area) (Table 1). A total of 105 non-target animals were captured and released including 35 rabbits (Leporidae), 19 woodchucks (*Marmota monax*), 9 muskrats (*Ondatra zibethicus*), 6 gray squirrels (*Sciurus carolinensis*), 11 porcupines (*Erethizon dorsatum*), 8 fishers (*Martes pennanti*), 6 turtles (Emydinae), 2 rats (*Rattus* sp.), 2 mice (Sigmodontinae), 1 fox (*Vulpes vulpes*), 1

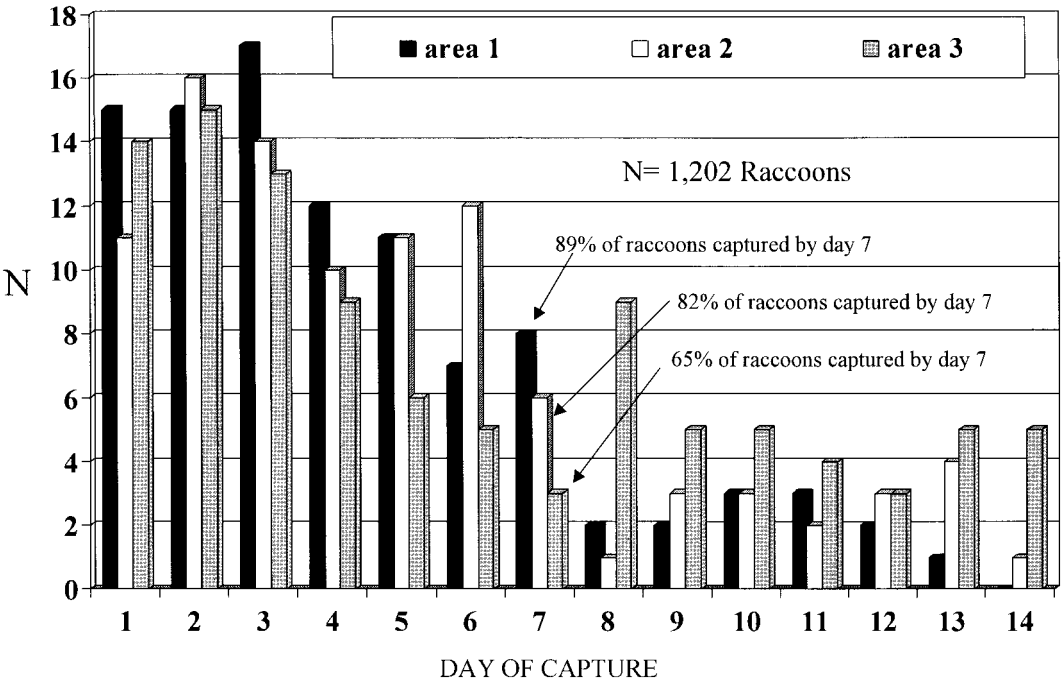

FIGURE 2. Number of raccoons captured per night in relation to total raccoon captures during 14 nights of trapping in the first three point infection control programs in Ontario, Canada, July–August 1999.

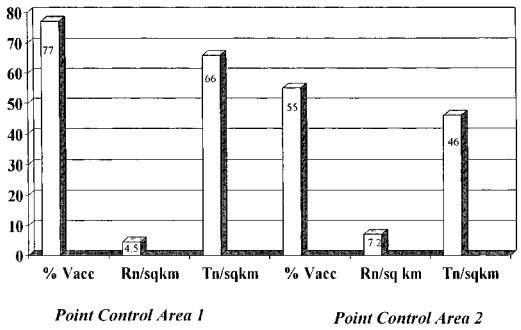

FIGURE 3. Comparison of the percentage of raccoons vaccinated, raccoon density and trapping efforts between the first two point infection control programs in Ontario, Canada during July–August 1999. % Vacc = percent vaccinated; Rn/sqkm = Raccoons per square kilometre; Tn/sqkm = Trap-nights/km^2.

frog (Ranidae), 1 mink (*Mustela vison*) and 4 birds.

The estimated raccoon density in the 225 km^2 TVR zone was about 4.5 ± 0.4/km^2. About 77% (767/1003) of the estimated raccoon population in the TVR zone was vaccinated using a trapping effort of 66 trap-nights/km^2 (Fig. 3).

PIC operation # 2—Jellyby area

Seventeen different trappers utilized 18,946 trap-nights to capture 1,966 animals during the second PIC program from 28 July to 10 August, 1999 (Table 2). That included the 385 raccoons and 116 skunks from the PR zone (75 km^2 area) that were euthanized and submitted for rabies testing. All were negative for rabies by FAT. About 82% (315/385) of the raccoons from the PR zone were captured during the first 7 nights of trapping (14 nights in total) (Fig. 2). Estimated raccoon density in the PR zone prior to control was about 6.5 ± 0.6/km^2. Raccoon density as a result of the PR program declined to 1.1 ± 0.5/km^2. About 83% of the raccoon population in the PR zone was euthanized.

A total of 785 different raccoons, 223 different skunks and 290 cats (including those in the PR zone) were trapped, vaccinated (with Imrab) and released in the TVR zone (200 km^2 area) (Table 2). A total of 96 non-target animals were captured and released including 27 rabbits, 13 squirrels, 12 porcupines, 12 muskrats, 12 fishers, 8 woodchucks, 4 birds, 2 weasel (*Mustela* sp.), 1 turtle, 1 rat, 1 beaver (*Castor canadensis*), 1 coyote (*Canis latrans*), 1 dog (*Canis* sp.), and 1 mink.

The estimated raccoon density in the 200 km^2 TVR zone was about 7.2 ± 0.5/km^2. About 55% (785/1440) of the estimated raccoon population in the TVR zone was vaccinated using a trapping effort of 46 trap-nights/km^2 (Fig. 3).

PIC Operation # 3—Oxford Station area

Nineteen different trappers utilized 8,756 trap-nights to capture 1,143 animals during the third PIC program from 20 September to 4 October, 1999 (Table 3). That included the 330 raccoons and 128 skunks from the PR zone (75 km^2 area) that were euthanized. About 65% (214/330) of the raccoons from the PR zone were captured during the first 7 nights of

TABLE 2. Trapping effort for the second point infection control program at Jellyby, Ontario, 28 July–10 August 1999.

Zone	Number of trappers	Number of trap-nights	Different raccoons	Recaptured raccoons	Different skunks	Recaptured skunks	Cats vaccinated
PR zone[a] (days 1–7)	7	4,734	315	0	102	0	88
TVR zone[a] (days 1–7)	4	2,647	189	53	32	23	62
PR zone (days 8–14)	6	4,000 estimated	70	0	14	0	0
TVR zone (days (8–14)	11	7,565	596	172	75	27	140
Total euthanized			385	0	116	0	0
Total vaccinated			785	225	107	50	290
Totals	17 (d)[a]	18,946	1,170	225	223	50	290

[a] d = different; PR zone = population reduction zone; TVR zone = trap-vaccinate-release zone.

TABLE 3. Trapping effort for the third point infection control program near Oxford Station, Ontario, 20 September–4 October 1999.

Zone	Number of trappers	Number of trap-nights	Different raccoons	Recaptured raccoons	Different skunks	Recaptured skunks	Cats vaccinated
PR zone[a] (days 1–7)	7	4,039	214	11[a]	89	0	113
TVR zone[a] (days 1–7)	5	2,959	207	37	71	38	140
PR zone (days 8–14)	7	1,758	116	0	39	0	32
Total euthanized	—	—	330	0	128	0	0
Total vaccinated	—	—	207	37	71	38	285
Totals	19	8,756	537	48	199	38	285

[a] Recaptures were ear-tagged animals that dispersed from the TVR zone; PR zone = population reduction zone; TVR Zone = trap-vaccinate-release zone.

trapping (14 nights in total) (Fig. 2). Estimated raccoon density in the PR zone prior to control was about 5.1 ± 0.4/sq km. Post PR program raccoon density was 0.7 ± 0.3/km^2. About 86% of the raccoons in the PR zone were euthanized.

A total of 207 different raccoons, 71 different skunks and 285 cats (including those in the PR zone) were trapped, vaccinated (with Imrab) and released in the TVR zone (60 km^2 area) (Table 3). A total of 36 non-target animals were captured and released including 13 rabbits, 6 squirrels, 5 porcupines, 7 fishers, 2 dogs, 1 bird, 1 beaver, and 1 mink. Raccoon density and percent vaccinated estimates for the TVR area were not calculated as the area (60 km^2) in question was deemed too small for confident estimates.

TABLE 4. Costs (Canadian) to implement three point infection control programs in Ontario, Canada, during July–October 1999.

Salary costs—37 trappers, 8 support staff	$194,500.00
Vehicle lease/gas/mileage	$25,500.00
Accommodation/meals	$21,500.00
Contracts (security/maintenance etc)	$9,600.00
Equipment	$18,000.00
OMNR District support (field lab)	$6,000.00
Incinerator costs	$8,000.00
Replenish traps	$55,000.00
Replenish supplies	$25,000.00
Total costs	$363,100.00

Trapping in the vicinity of raccoon rabies cases 4–14

Two trappers accumulated a total of 840 trap-nights during 5 to 12 January 2000. Capture success included 13 raccoons (1 ear-tagged animal), 11 skunks (5 ear-tagged) and 30 cats. All tested animals were negative for rabies by FAT.

Media/communications

The first case of raccoon rabies elicited intense media interest. Interviews were given to more than 75 different reporters during the 3 wk following the first case. A toll-free rabies hotline telephone number was available to the public for raccoon rabies related inquiries. A total of 518 calls were documented during 26 July to 19 August 1999. Those calls were related to the media (22%), suspect rabid animals (27%), general rabies information (8%), nuisance animals (11%), and other issues (32%).

Costs for PIC operations

The total cost for the three PIC control programs was about $285,000.00 Cdn. However, traps and supplies had to be replenished which brought the total cost to about $363,000.00 Cdn. This is equivalent to a cost of about $500.00 Cdn/km^2. The distribution of costs is shown in Table 4. The cost to purchase vaccine, manufacture and distribute 81,300 V-RG baits was about $241,000.00 Cdn including post baiting assessment costs, equivalent to a cost of about $200.00 Cdn/km^2.

TABLE 5. Prevalence of reported rabies cases following confirmation of raccoon rabies in selected states of the USA.[a]

Year	1990	1991	1992	1993	1994	1995	1996	1997
New York	242[b]	1,030	1,720	2,747	1,585	1,162	1,081	1,266
Vermont					143[b]	179	135	113
Maine					10[b]	101	131	227
Connecticut		122[b]	831	762	748	353	274	544
Rhode Island					153[b]	324	39	42
New Hampshire			10[b]	143	221	152	55	49
Massachusetts			42[b]	698	734	401	115	282

[a] Data from MMWR (Morbidity Mortality Weekly Reports, 1990–97).
[b] First year that raccoon rabies was confirmed in the state.

DISCUSSION

Ontario has the unwanted distinction of being the first Province to confirm the raccoon variant of rabies in Canada. It is unknown how the disease made its way into the Province. In all likelihood, the first three cases probably represented a natural extension of an epizootic that was present in the Ogdensburg, St. Lawrence County area of New York State during 1998–99. In fact, 203 cases of rabies involving raccoons and skunks were reported in St. Lawrence County during the 18 mo period (1 January 1998-30 June 1999) immediately preceding the outbreak in Ontario (Trimarchi, 1998, 1999). The front of a raccoon rabies epizootic can progress 60 km or more during 1 yr, lending further support to the theory of natural progression of the disease (Winkler and Jenkins, 1991). Only the St. Lawrence River separates Ogdensburg and the area of Ontario where raccoon rabies was found. The river is only about 1 km wide at that point and we have 6 documented instances of ear-tagged raccoons moving from Ontario to New York. However, one cannot discount the role that proactive TVR programs on the Ontario side of the Niagara and St. Lawrence Rivers, initiated in 1994 and 1995 respectively, played in slowing the progression of the disease (Rosatte et al., 1997). Raccoon rabies was present in St. Lawrence County, New York, during 1998–99, and the TVR programs may have delayed the progression of the disease into eastern Ontario. As well, raccoon rabies has been in Niagara County, New York, since the mid 1990's and despite evidence that raccoons travel across the Niagara River (through re-capture of ear-tagged raccoons), the disease has yet to be confirmed in Niagara Falls (Ontario).

Despite the evidence for natural progression of the disease into Ontario, human assisted transport of raccoons cannot be discounted as being responsible for the first cases of raccoon rabies in the Province. In Massachusetts, the disease apparently jumped 100 km from Connecticut due to raccoons being transported by refuse trucks (Wilson et al., 1997). In Ontario, there have been 15 reported instances during 1996–98 where raccoons were transported via tractor trailers from the raccoon rabies enzootic area of the United States into the Greater Toronto area of Ontario. Although it is illegal to relocate raccoons by provincial legislation in Ontario under the Fish and Wildlife Conservation Act, many animal control agencies as well as the general public still relocate raccoons.

The key to the successful implementation of the PIC programs was the fact that a raccoon rabies contingency plan had been in place since 1993 (Rosatte et al., 1997). This allowed for the rapid deployment of staff as soon as the first case was confirmed as the raccoon variant of rabies. Intergovernmental communications worked exceptionally well so that all agencies were in-

formed of the plan to contain the case the day that the plan was implemented. The communication links that were in place were so effective that trappers were at the site within 24 hr of confirmation of the first case. This rapid response was critical to allow for the removal of any animals that may have been incubating the disease (as well as other clinical animals) and prevent the spread of raccoon rabies to the rest of Ontario.

Efficacy of the PIC strategy

If population reduction is to be an effective raccoon rabies control tactic, a significant portion of the vector population must be removed so that the potential for transmission from infected to susceptible individuals is minimal. An estimated 83% to 91% of the raccoons in the PR zones around the three raccoon rabies case locations were euthanized. As a result, raccoon density in the PR zones decreased significantly from 5.1–7.1/km^2 to 0.6–1.1/km^2. This minimal density is probably below that necessary for raccoon rabies to persist.

There is also a good chance that there were few clinically rabid raccoons in the containment area. This is due to the fact that there was a very intensive trapping campaign for 14 continuous nights. With 44 trappers (and many support staff) in the target area for that period of time, any abnormally behaving raccoons should have been encountered. All residents in the area were aware of the program and were on the look-out for rabid raccoons. Therefore, chances are good they would have noticed any additional rabid raccoons.

An estimated 77% of the raccoons in the TVR area around the first case of raccoon rabies were captured and vaccinated against rabies. However, only 55% of the raccoons were captured and vaccinated in the TVR area around the second rabies case. This difference was expected due to a greater trapping effort in area 1 (66 trap-nights/km^2) as opposed to area 2 (46 trap-nights/km^2). Raccoon density was higher in area 2 (7.2 raccoons/km^2) compared to area 1 (4.5 raccoons/km^2). Higher raccoon density and lower trapping effort resulted in fewer raccoons being captured. The lower vaccination level may in part explain why 15 additional cases of raccoon rabies were confirmed in the TVR area of the second PIC operation during January to August 2000 (Fig. 1). During 2000, trapping effort will be increased in any TVR operations to maximize the percentage of the raccoon population that are vaccinated against rabies.

Capture results from the first two PIC programs should not be compared to control of the third rabies case. This is due to the fact that the third case occurred within an area that had been baited with V-RG. As a result, a less intensive TVR program was completed (60 km^2 area compared to 225 and 200 km^2 areas in PIC operations 1 and 2, respectively). As the third case occurred in late September, the PIC program was not completed until early October. Cooler weather and less abundant food sources tend to slow raccoon movements making them more difficult to capture. For example, in PIC operation 3, only 65% of the total animals captured were taken by the seventh of fourteen nights of trapping (compared to more than 80% during the July control programs).

Justification for PR methodologies

The use of PR as a rabies control tactic is controversial. Some publications document apparent success at controlling rabies using PR while others were unsuccessful (MacInnes, 1988; Rosatte et al., 1986). However, most studies resulting in failure used PR in a rabies epizootic/enzootic situation. In Ontario, raccoon rabies was isolated to one specific area and control was implemented with the first reported case, before the disease reached a state where it was enzootic or well established.

We feel justified in using PR (along with TVR and ORV) to control isolated cases of raccoon rabies in Ontario. In Jeffersen/St.

Lawrence counties, New York, ORV without PR or TVR was not successful at containing isolated cases of raccoon rabies during 1998/99. However, ORV has been successful in areas such as Massachusetts and New Jersey to stop advancing epizootics of the disease, as opposed to responding to a point source infection (Robbins et al., 1998; Roscoe et al., 1998).

Population reduction is the most effective means to remove animals that may be incubating rabies from the population (it is generally believed that vaccination will not work on animals in the later stages of incubation). As the morbidity period of raccoon rabies can be 2–8 days (Winkler and Jenkins, 1991) (at which time the animal may be infectious) there would have been ample opportunity for the three initial rabid raccoons to infect other animals in the area. This is evidenced by the fact that two additional cases of raccoon rabies occurred in the TVR zone around the second case during December 1999.

About 1,200 raccoons were euthanized to contain the first three reported cases of raccoon rabies. Had the disease not been contained, raccoon rabies could have spread rapidly across southern Ontario as the Province has about 1 million raccoons (Rosatte, 2000). In Connecticut, mortality rates as high as 60%–80% have been estimated for raccoons subjected to a raccoon rabies epizootic (Clavette, 1996). By euthanizing a few hundred raccoons in Ontario through the PIC programs and containing raccoon rabies to a small area, countless raccoons and other animals will have been spared certain death due to rabies. This is not to mention increased human exposures (2,000–4,000/yr) and rabies associated costs ($8–12 Million Cdn/yr).

Logic behind vaccination of skunks and feral and domestic cats

Raccoons account for the majority of animals diagnosed with rabies where the raccoon strain is established. In the USA, 50% of the total rabies cases were reported in raccoons during 1996 (3,595/7,881) (Krebs et al., 1997). In New York, raccoons accounted for 63% to 81% of the total rabies cases reported during 1991–98 (Trimarchi, 1991–1998). However, skunks also are susceptible to the raccoon variant of rabies. This is evidenced by the fact that skunks accounted for 16% to 21% of the total New York rabies cases during 1995–98 (Trimarchi 1995–1998). Therefore, as there are significant populations of skunks (Rosatte, 1987; Rosatte et al., 1991, 1992b), in addition to raccoons in Ontario, we also euthanized and vaccinated skunks in the PR and TVR areas, respectively, to prevent the spread of rabies by skunks. It is also important to remove infected skunks from the population as V-RG is not very effective at immunizing skunks against rabies. That is, ORV using V-RG would not be effective at controlling raccoon rabies in skunks.

Feral and domestic cats were vaccinated against rabies and released in both the PR and TVR areas of the PIC zones. This was done as cats (as well as other mammalian species) have been reported as being infected with the raccoon variant of rabies virus and could contribute to the spread of the disease to wild and domestic animals as well as humans (Vaughn et al., 1963). Cats accounted for 2%–3% of the annual rabies diagnoses in New York State during 1991–1998 (Trimarchi, 1991–1998). More importantly, in one area of Virginia, cats were responsible for initiation of 28% of the human post exposure treatments during 1992–96—57% of those were due to stray cat contact (Hensley, 1998). The importance of cat vaccination was evidenced in New Hampshire during 1994, where 655 people were exposed to one rabid cat (Brown and Szakacs, 1997). Cat vaccination was an important aspect of the PIC program as Ontario has significant feral/owned free ranging cat populations. During 1994–98, proactive TVR programs in a 1,400 km^2 area of predominantly rural Ontario farm-land habitat yielded 9,058 cat captures (Rosatte et al., 1997).

Timing for PIC tactics

In Ontario, raccoon and skunk activity declines during the autumn as ambient temperatures fall and food becomes scarce. In fact, during periods of inclement weather both species seek shelter in dens usually from November to February/March in Ontario (Rosatte, 1987, 2000; Rosatte et al., 1991). As the success of PIC tactics such as PR and TVR depend on live-capturing a significant portion of both raccoon and skunk populations, it would not be feasible to use either tactic during the winter in Ontario. This was evidenced by the poor capture success in the vicinity of cases 4–14 during January 2000.

The most effective time to use PR and TVR will be when young of the year are old enough to respond to vaccination (about 3 months of age or older—Rosatte et al., 1990) and at a time when they are mobile enough for capture. In Ontario, that time is usually between mid June and early July (Rosatte, 2000; Rosatte et al., 1992b). However, if a case of raccoon rabies occurs prior to that time a decision will have to be made as to whether it will be appropriate to use PIC methodologies. Currently, the plan is to implement full PIC operations in response to a case(s) of raccoon rabies if it occurs during 1 May to 1 November of any given year. Should a case occur during the winter months, the plan is to hire Ontario Fur Manager Federation trappers to implement a partial PR program within the immediate vicinity of the case as was done during January 2000 for cases 4–14. A full PIC operation would be implemented around that case location the following spring.

How large must the PIC zone be to contain raccoon rabies?

One rabid raccoon in New Jersey was documented as moving 13 km (Roscoe et al., 1998). How often does this occur and how wide does a control zone have to be to control raccoon rabies? The 3 PIC operations included 5 km radial PR zones, 5 km radial TVR zones, and the distribution of vaccine baits in an area that varied between 8 km and 15 km in width on the perimeter of the TVR zones. The total width of the PIC zone around any of the cases was 18 km to 25 km. Is this width of barrier sufficient to control rabies? In southern Ontario, raccoon movements are quite extensive. During one study near Niagara Falls, raccoons moved in excess of 40 km with most movements occurring in August and September (Rosatte, 2000). However, 90% of the movements were less than 25 km during 1994 (Rosatte, 2000). The odds are that the 18 km to 25 km zone should be sufficient to control the spread of raccoon rabies. There is evidence to support this statement in that a zone of vaccine-baits that was 13 km wide was sufficient to halt the spread of raccoon rabies in Massachusetts (Robbins et al., 1998). Alternatively, a 16 km wide zone using aerial distribution of vaccine-baits was not sufficient to stop the advance of raccoon rabies in Ohio (USA); to date, a 40 km wide buffer zone in Ohio has halted the disease (Smith, 1999). However, among area comparisons of success at rabies control should be done cautiously, unless topography, raccoon density, bait density, and vaccination tactics are similar among the areas.

Expected level of raccoon rabies prevalence

We speculated that in all likelihood, the first two raccoon rabies cases that occurred in Ontario during July 1999, were not isolated and others were either incubating rabies or had yet to be found in areas outside of the PIC zones. As the average incubation period (based on laboratory experiments) for raccoon rabies is about 40 days (range 7–107 days) (Winkler and Jenkins, 1991; Winkler et al., 1985; Burridge et al., 1986), it was expected that additional cases of raccoon rabies would appear along the St. Lawrence River, probably in September 1999. Our speculations were fulfilled when the third case was confirmed on 17 September 1999, just 15 km north of the first case. The 11 cases that occurred dur-

ing December 1999–January 2000 in the vicinity of the second index case probably represented infections associated with the first three cases. The 6 cases on Wolfe Island may have been a result of a rabies infected raccoon(s) dispersing from the mainland of New York State as the St. Lawrence River is only about 1 km wide at that point with regular ferry crossing service (Fig. 1).

A total of 872 raccoons and 209 skunks were removed from the PR zones surrounding the locations of the first two raccoon rabies cases. All of those were negative for rabies (by FAT) upon testing at the CFIA Rabies lab in Nepean. That was expected as we were dealing with the first reported cases of raccoon rabies in Ontario and one would not expect any of the PR animals to be positive for rabies. That is because if the average incubation period for raccoon rabies is about 40 days, other raccoons infected by the initial cases would not have yet developed clinical rabies (Winkler and Jenkins, 1991). As the first 3 cases of raccoon rabies in Ontario may have represented the initial stages of an epizootic, few rabies positive animals would have been expected to follow (unless a rabies control program was not implemented).

Cost effectiveness of raccoon rabies control

The cost of the three PIC programs was about $363,000.00 Cdn. The cost to deploy 81,300 V-RG baits (including post baiting evaluation costs) was about $241,000.00 Cdn. Those costs are justified as by containing the spread of raccoon rabies, annual savings to Ontario are estimated at $8–12 million Cdn. Savings were estimated using the fact that rabies associated costs in New Jersey doubled when raccoon rabies entered the state (Uhaa et al., 1992). Rabies associated costs in Ontario before raccoon rabies was reported were estimated at about $6 million annually (excluding pet vaccination costs). Preventing the disease from becoming epizootic/enzootic in Ontario will result in fewer human rabies post exposure treatments (2,000–4,000 treatments/yr). This estimate is conservative considering that in Massachusetts, human rabies post exposure treatments went from 1.7/100,000 people in 1991 before the disease entered the state to 45/100,000 people in 1995 when raccoon rabies was epizootic (Kreindel et al., 1998). Controlling raccoon rabies in Ontario will also result in 1,500–2,000 fewer rabies cases/yr. This is based on the prevalence of the disease in neighboring states such as New York (Trimarchi, 1991–1998).

Although the PR and TVR programs were more expensive than the aerial distribution of V-RG baits ($500.00 Cdn/km^2 versus $200.00 Cdn/km^2), we will continue to use PIC methodologies utilizing all three tactics. The reason for this is that PR removes animals from the population which are incubating rabies. Vaccination will be unsuccessful for animals that are already infected with rabies. If those incubators of rabies are not removed, rabies could spread beyond the PIC zone. In addition, when using TVR, development of an immune response following intramuscular vaccination is high as the vaccine is injected directly into the animal (Rosatte et al., 1990). With ORV, raccoon contact with the liquid vaccine in the bait is not guaranteed, therefore making for a lower probability of development of an immune response compared to IM vaccination. The efficacy of Imrab 3 (used in TVR operations) at stimulating a humoral immune response in raccoons when delivered via intramuscular injection has been documented at about 95% (Rosatte et al., 1990). Currently, a higher proportion of a free-ranging raccoon population can be immunized using TVR methodologies than by ORV with baits (Rosatte, 2000; Rosatte et al., 1992a; Roscoe et al., 1998). However, it must be remembered that TVR is only logistically feasible in areas of about 1500 km^2 or smaller due to labor, time and equipment requirements to trap areas of that size.

Use of ORV and future plans for raccoon rabies control in Ontario

The most feasible approach to immunize raccoons over large areas is through aerial deployment of baits containing oral rabies vaccine (MacInnes, 1988; Uhaa et al., 1992; Rosatte et al., 1993, 1998; Roscoe et al., 1998). While TVR may be more effective over small areas, that tactic is too labor intensive for large-scale operations. In fact, a 700 km^2 area in Niagara Falls, Ontario, that took 4.5 mo to TVR using seven trappers, could have been aerially baited in a few hours. The only vaccine currently available for the oral immunization of raccoons in the wild is Raboral® V-RG (Rupprecht et al., 1986). The immediate plan in response to the first three reported raccoon rabies cases in Ontario was to deploy about 81,300 baits containing V-RG in an 8–15 km wide buffer zone immediately outside of the TVR zones during September 1999 (Fig. 1). Bulk V-RG was acquired during 1999/2000 to manufacture about 900,000 baits for future deployment in 2000 to contain any additional cases of raccoon rabies.

The key to preventing raccoon rabies from becoming enzootic throughout Ontario will be a rapid response to contain isolated cases of the disease as soon as they are confirmed. The tactic of choice will be PIC methodologies including PR, TVR and ORV with baits. If multiple cases occur over a large geographic area, a program involving the aerial distribution of vaccine baits will be implemented as PR and TVR would not be feasible in that situation.

Has raccoon rabies in Ontario actually been controlled?

When raccoon rabies enters an area, the rate of spread is usually quite rapid (40–60 km/yr) (Jenkins and Winkler, 1987; Winkler and Jenkins, 1991) and epizootic/enzootic conditions are soon achieved with resultant dramatic increases in total cases of rabies (Table 5) (Brown and Szakacs, 1997; Krebs et al., 1997; Wilson et al., 1997; Robbins et al., 1998). In Connecticut, the first case of raccoon rabies appeared in March 1991. By December 1991, 122 cases had been documented in that state (Wilson et al., 1997). The situation was ever more dramatic in New York. During 1989 there were 54 total rabies cases reported in that state. Raccoon rabies entered New York in 1990 and by 1991, there were 1,030 cases confirmed (Trimarchi, 1991). In every U.S. state where the disease has appeared (over a 1 million km^2 area), epizootic conditions were followed by enzootic raccoon rabies except in areas such as Ohio, where active control programs were implemented following the epizootic (Smith, 1999). Given the above facts, enzootic raccoon rabies in Ontario should by now have been achieved had the control program been unsuccessful. To date (31 August, 2000), 14 months following the first confirmed case, we have just 38 reported cases of raccoon rabies in the Province of Ontario. Future plans include implementing PIC programs in response to additional cases of raccoon rabies, proactive TVR programs along the Ontario/New York border and distribution of rabies vaccine baits in eastern Ontario to prevent the spread of raccoon rabies throughout Ontario.

ACKNOWLEDGMENTS

The OMNR rabies program was supported by the Rabies Advisory Committee, Dr. J. Carlson, Chairman. The program was a success due to the dedication and unselfishness of the trappers and support staff who left friends and families at a moment's notice—without them there would not have been PIC programs. They included R. Warren, D. Grieve, R. Chambers, L. Bruce, D. Harris, T. Buchanan, T. Davies, D. Antonio, L. Howes, B. Johnston, J. Price, D. Raycroft, R. Redner, J. Ritchie, B. Slack, D. Annable, C. Bak, S. Baker, L. Bishop, G. Bron, J. Fawcett, G. Fischer, G. Hutchcroft, P. Hutton, J. Hutton, R. Jollymore, R. McNish, P. Quinn, D. Reynolds, D. Robertson, S. Sayeau, C. Sayeau, K. Seabrook, L. Stead, N. Tennyson, B. Thorpe, T. Wert, R. Dillabough, T. Dunn, B. Moir, G. Pankow, D. Robertson, M. Barnett, R. Page, D. Robinson, G. Johnson and D. Coleman. B. Stevenson operated the rabies hot-

line. E. Salsberg, C. LeBer, B. McNab, C. Gardner, R. Rogers and many others played a major role in coordinating provincial, federal and municipal activities upon notification of the raccoon rabies cases. G. Holder and G. Munro, OMNR, were key in acquiring emergency funding for the program. Special thanks to D. Hayes, CFIA, Brockville, who kindly kept us updated on the rabies diagnostic situation. F. Muldoon and the staff of the diagnostic unit of the CFIA Center of Expertise for Rabies, Nepean, performed rabies diagnostic tests on submitted specimens. Kemptville District MNR staff assisted with many operational details. Special thanks to D. Alkerton who coordinated the Ontario Fur Managers Federation trappers. Figure 1 was designed by B. Pond. P. Bachmann, L. Brown, C. Nunan, R. Grace and K. MacDonald assisted with the logistics and legalities of the V-RG baiting program. R. Tinline and D. Ball, Queens University designed the flight lines for the baiting operation. Special thanks to N. Ayers and the pilots, navigators and support staff who flew the baiting missions. A. Beresford, Artemis Technologies, Guelph, Ontario, M. Escobar, Merial Inc., Athens Georgia, and L. Bigler, Cornell University, Ithaca, New York played vital roles in the acquisition of V-RG baits. P. Silva and G. Gifford, CFIA, Nepean assisted with the approval process to use V-RG in Canada. Many others too numerous to mention played a vital role in the success of the operation.

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Received for publication 17 February 2000.