Photo: Rob Tervo

Gray Ratsnake

(Pantherophis spiloides) Carolinian and Frontenac Axis populations in Ontario

Ontario Recovery Strategy Series

Recovery strategy prepared under the *Endangered Species Act, 2007*

September 2010

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Ministry of Natural Resources

Ontario

About the Ontario Recovery Strategy Series

This series presents the collection of recovery strategies that are prepared or adopted as advice to the Province of Ontario on the recommended approach to recover species at risk. The Province ensures the preparation of recovery strategies to meet its commitments to recover species at risk under the Endangered Species Act, 2007 (ESA, 2007) and the Accord for the Protection of Species at Risk in Canada.

What is recovery?

Recovery of species at risk is the process by which the decline of an endangered, threatened, or extirpated species is arrested or reversed, and threats are removed or reduced to improve the likelihood of a species' persistence in the wild.

What is a recovery strategy?

Under the ESA, 2007, a recovery strategy provides the best available scientific knowledge on what is required to achieve recovery of a species. A recovery strategy outlines the habitat needs and the threats to the survival and recovery of the species. It also makes recommendations on the objectives for protection and recovery, the approaches to achieve those objectives, and the area that should be considered in the development of a habitat regulation. Sections 11 to 15 of the ESA, 2007 outline the required content and timelines for developing recovery strategies published in this series.

Recovery strategies are required to be prepared for endangered and threatened species within one or two years respectively of the species being added to the Species at Risk in Ontario list. There is a transition period of five years (until June 30, 2013) to develop recovery strategies for those species listed as endangered or threatened in the schedules of the ESA, 2007. Recovery strategies are required to be prepared for extirpated species only if reintroduction is considered feasible.

What's next?

Nine months after the completion of a recovery strategy a government response statement will be published which summarizes the actions that the Government of Ontario intends to take in response to the strategy. The implementation of recovery strategies depends on the continued cooperation and actions of government agencies, individuals, communities, land users, and conservationists.

For more information

To learn more about species at risk recovery in Ontario, please visit the Ministry of Natural Resources Species at Risk webpage at: **www.ontario.ca/speciesatrisk**

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Cette publication hautement spécialisée Recovery strategies prepared under the *Endangered Species Act, 2007*, *n'est disponible qu'en Anglais en vertu du Règlement 411/97 qui en exempte l'application de la Loi sur les services en français. Pour obtenir de l'aide en français, veuillez communiquer avec Pamela Wesley au ministère des Richesses naturelles au 705-755-1661.*

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DECLARATION

The Ontario Ministry of Natural Resources has led the development of this recovery strategy for the Gray Ratsnake (Carolinian and Frontenac Axis populations) in accordance with the requirements of the *Endangered Species Act,* 2007 (ESA 2007). This recovery strategy has been prepared as advice to the Government of Ontario, other responsible jurisdictions and the many different constituencies that may be involved in recovering the species.

The recovery strategy does not necessarily represent the views of all of the individuals who provided advice or contributed to its preparation, or the official positions of the organizations with which the individuals are associated.

The goals, objectives and recovery approaches identified in the strategy are based on the best available knowledge and are subject to revision as new information becomes available. Implementation of this strategy is subject to appropriations, priorities and budgetary constraints of the participating jurisdictions and organizations.

Success in the recovery of this species depends on the commitment and cooperation of many different constituencies that will be involved in implementing the directions set out in this strategy.

RESPONSIBLE JURISDICTIONS

Ontario Ministry of Natural Resources
Environment Canada, Canadian Wildlife Service - Ontario
Parks Canada Agency

EXECUTIVE SUMMARY

The Gray Ratsnake is a large snake that is native to North America and in Ontario it is only found in two locations: the Carolinian forest and Frontenac Axis. It is Ontario's largest snake and can grow to 185 centimetres in length. It has keeled scales and a powerful slender body with a wedge-shaped head. The body tends to be more square than round in cross section. Hatchling Gray Ratsnakes have a pattern of dark grey or black blotches and spots over a background of light gray. As the snake ages, this pattern fades and adults are predominantly black. The underneath of the chin and throat are usually white, often mottled with grey and black blotches. They can live up to 30 years, and reach maturity at about seven years. Mating occurs between late May and mid-June and females usually reproduce every two to three years.

The Frontenac Axis population of Gray Ratsnakes was listed as threatened in 2009 under Ontario's *Endangered Species Act,* 2007 and the Carolinian population was listed as endangered. The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) assessed the Frontenac Axis population as threatened and the Carolinian population as endangered in 2007.

The Gray Ratsnake requires a mosaic of habitat features, including forest and edge habitat. Mature females require oviposition (egg-laying) sites, typically rotten interior cavities of large deciduous trees and stumps or compost piles. This species overwinters underground in communal hibernacula and shows high fidelity to those hibernacula.

Life history features such as late age of maturity, long life span, biennial reproduction and intermittent juvenile recruitment predispose Gray Ratsnake populations to major demographic fluctuations when subjected to disturbances and do not allow for a natural capacity to rapidly rebound from demographic low points.

Threats to the Gray Ratsnake include habitat degradation, fragmentation and loss, direct mortality, road mortality and disturbance or destruction of hibernacula. Knowledge gaps relate to population persistence and viability measures, efficacy of mitigation measures and juvenile and neonate ecology. A number of recovery actions have been completed or are underway and range from stewardship and outreach activities to habitat and genetic research.

The recovery goal for the Gray Ratsnake in Ontario is to retain the current distribution, population size and connectivity among extant sub-populations within the Frontenac Axis population of eastern Ontario and to achieve self-sustaining sub-populations in the Carolinian population by increasing the distribution and size of the population.

Protection and recovery objectives that guide the approaches to recovery are to:

1. Develop and implement a coordinated monitoring plan focused on population indices and distribution, habitat stresses and efficacy of recovery actions;

2. Conduct research to fill knowledge gaps including ecological studies of habitat, genetic connectivity and the impacts of various threats;
3. Describe and map habitat required to meet recovery goals for each of the Ontario populations;
4. Protect and manage the habitat of the species and mitigate priority threats; and
5. Improve the delivery and evaluation of stewardship and communications to increase awareness, land stewardship, application of best management practices and citizen science efforts.

A number of approaches are identified for each of these objectives.

It is recommended that the area prescribed as Gray Ratsnake habitat in a habitat regulation include all known hibernacula and the area within a 150 metre radius of them; and all known oviposition sites and the area within a 30 metre radius of them. In addition, for the Carolinian population, the area prescribed as habitat in the regulation should also include all natural features (e.g., woodlands, wetlands, hedgerows, meadows) within five kilometres of known hibernacula, oviposition sites and locations at which a Gray Ratsnake has been observed (accurate to 100 metres). For the Frontenac Axis population, a map based on quantified measures of preferred habitat including indices of suitable habitat, road density, measures of connectivity and likelihood of supporting existing populations is included in the strategy. It is recommended that cells in the map with suitable habitat (cell value of 0.5 or greater) be prescribed as habitat in a habitat regulation for the population. This area is roughly bordered by Highway 7 in the north, the St. Lawrence River in the south, Highway 38 and in the west and Highway 29 in the east.

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1.0 BACKGROUND INFORMATION

1.1 Species Assessment and Classification

COMMON NAME: Gray Ratsnake

SCIENTIFIC NAME: *Pantherophis spiloides*

SARO List Classification:
Gray Ratsnake (Carolinian population) – Endangered
Gray Ratsnake (Frontenac axis population) – Threatened

SARO List History:
Gray Ratsnake (Carolinian population) – Endangered (2009)
Gray Ratsnake (Frontenac axis population) – Threatened (2009)
Eastern Ratsnake – Threatened (2004)

COSEWIC Assessment History:
Gray Ratsnake (Carolinian population) – Endangered (2007)
Gray Ratsnake (Great Lakes/St. Lawrence population) – Threatened (2007)
Eastern Ratsnake – Threatened (2000 and 1998)

SARA Schedule 1:
Gray Ratsnake (Carolinian population) – Endangered (March 5, 2009)
Gray Ratsnake (Great Lakes/St. Lawrence population) – Threatened (March 5, 2009)

CONSERVATION STATUS RANKINGS:
GRANK: G5 NRANK: N3 SRANK: S3

The glossary provides definitions for the abbreviations above. The Gray Ratsnake is also known as Black Ratsnake, Black Rat Snake, Gray Rat Snake and Eastern Ratsnake and by the scientific names of *Pantherophis obsoletus*, *Elaphe obsolete* and *Elaphe spiloides.*

1.2 Species Description and Biology

Species Description

The Gray Ratsnake is Ontario's largest snake. It reaches sexual maturity at an average of 105 centimetres in length and can grow to 185 centimetres in length. The average diameter of the snake's body is 4 centimetres at the widest point. It has keeled scales and a powerful slender body with a wedge-shaped head. The body tends to be more square than round in cross section. The anal plate of the Gray Ratsnake is divided. The Gray Ratsnake is highly variable in colouration and pattern depending upon the age of the snake. Hatchling Gray Ratsnakes have a pattern of dark grey or black blotches and spots over a background of light gray. As the snake ages, this pattern fades and

adults are predominantly black. Slight traces of the juvenile pattern often remain even in the adult Gray Ratsnake, resulting in small specks of white and occasionally even tinges of red and brown scattered throughout the scales. The underside of the chin and throat are usually white, often mottled with grey and black blotches.

Some adults attempt to protect themselves by coiling their body and vibrating their tails in dead leaves to simulate a rattle. If the snakes continue to be provoked they will strike. Gray Ratsnakes produce a foul-smelling musk as a deterrent, releasing and spreading it on a predator if they are picked up.

Species Taxonomy

The taxonomic classification of Gray Ratsnake has changed over the years resulting in a number of different common names and scientific names for the species. At present the accepted common name is Gray Ratsnake and the accepted scientific name is *Pantherophis spiloides* (Gibbs et al. 2006). Several genetic studies over the past decade have been conducted (Burbrink 2001, Burbrink et al. 2001, Utiger et al. 2002, Gibbs et al. 2006, Burbrink and Lawson 2007, Collins and Taggart 2008, Pyron and Burbrink 2009). Research indicates that although the two Canadian populations are genetically different, the Carolinian population is a subset of the Frontenac Axis population (Gibbs et al. 2006) and therefore this distinction should not affect conservation of the species.

Species Biology

Gray Ratsnakes are estimated to live up to 30 years and they become sexually mature at approximately seven years (COSEWIC 2007). The mating season in Ontario runs from late May to mid-June. Females usually produce a clutch of 10 to 15 eggs every two to three years, but may produce clutches for two or three years in a row (COSEWIC 2007). Gray Ratsnakes thermoregulate through behaviour. Since they are at the northern limit of their range in Ontario this is an important underlying feature of habitat selection and use (COSEWIC 2007). Home range size is on average 18.5 hectares and Gray Ratsnakes migrate between hibernacula and home ranges (COSEWIC 2007). Overwinter dormancy normally persists for up to seven months (October to April) each year (Blouin-Demers et al. 2000; Blouin-Demers and Weatherhead 2001b). Gray Ratsnakes overwinter communally in traditional underground hibernacula. It is possible that undisturbed hibernacula have been continuously occupied for hundreds of years. It is not known where juveniles hibernate before they begin to attend communal hibernacula at about seven years of age (Prior et al. 2001), but preliminary data suggest that some hibernate singly in rock fissures (Blouin-Demers et al. 2007).

Gray Ratsnakes exhibit relatively fluid gene flow across the entire Frontenac Axis which is indicative of significant relationships among local populations (Lougheed et al. 1999). Recent evidence of multiple paternity in Gray Ratsnakes (Blouin-Demers and Gibbs 2003; Blouin-Demers et al. 2005) suggests that some gene flow is realized by mating among members of different hibernacula. Juvenile dispersal also contributes to this gene flow (Blouin-Demers and Weatherhead unpublished data).

1.3 Distribution, Abundance and Population Trends

Gray Ratsnakes are restricted to North America. In the United States they are widely distributed and can be found where appropriate habitat occurs across much of the eastern half of the country. In the southern parts of their range they may be relatively abundant. In the east, they are found from southwestern New England south to central Georgia, while in the midwest they occur from southwestern Wisconsin south to southern Oklahoma, northern Texas and northern Louisiana (COSEWIC 2007).

In Canada, Gray Ratsnakes are only found in Ontario. In Ontario, the Gray Ratsnake is found in two regions (Figure 1) (COSEWIC 2007). The Carolinian forest region, along the north shore of Lake Erie in southwestern Ontario, has two extant disjunct sub-populations (the Big Creek sub-population in Norfolk and Elgin counties and the Oriskany Sandstone sub-population in Haldimand County) and other sub-populations to be confirmed in Skunks Misery (Middlesex and Kent counties) and the Niagara area. These sub-populations are highly isolated and appear to be quite small. The Frontenac Axis region in southeastern Ontario has one population that extends across the United States border into upper New York State. The entire Frontenac Axis population is disjunct from the populations in the eastern and central United States. Populations in Ontario are on the northern edge of the species' distribution, geographically peripheral to the species' central range.

The species' geographic distribution in Ontario is estimated to have been reduced by as much as 75 percent over the past 100 years with a concomitant reduction in population size. Anecdotal evidence based on reduced sightings over the past 50 years in the southwestern Ontario portion of the species' range further indicates that population size is continuing to decline. Long-term mark-recapture data from two areas on the Frontenac Axis (St. Lawrence Islands National Park and Queen's University Biological Station) have indicated that populations are declining, even in protected areas (Weatherhead et al. 2002).

Communal hibernacula are known to have as many as 60 individuals each and there are assumed to be hundreds of active hibernacula across the Frontenac Axis region. The Gray Ratsnake population density estimate at Queen's University Biological Station is 0.261 mature snakes per hectare (Blouin-Demers and Weatherhead 2002b).

No estimates of the number of hibernacula or population abundance for Gray Ratsnake in southwestern Ontario have been made. Consensus among members of the Gray Ratsnake Recovery Team suggests that at least 75 percent of the species historical distribution has been eliminated from southwestern Ontario.

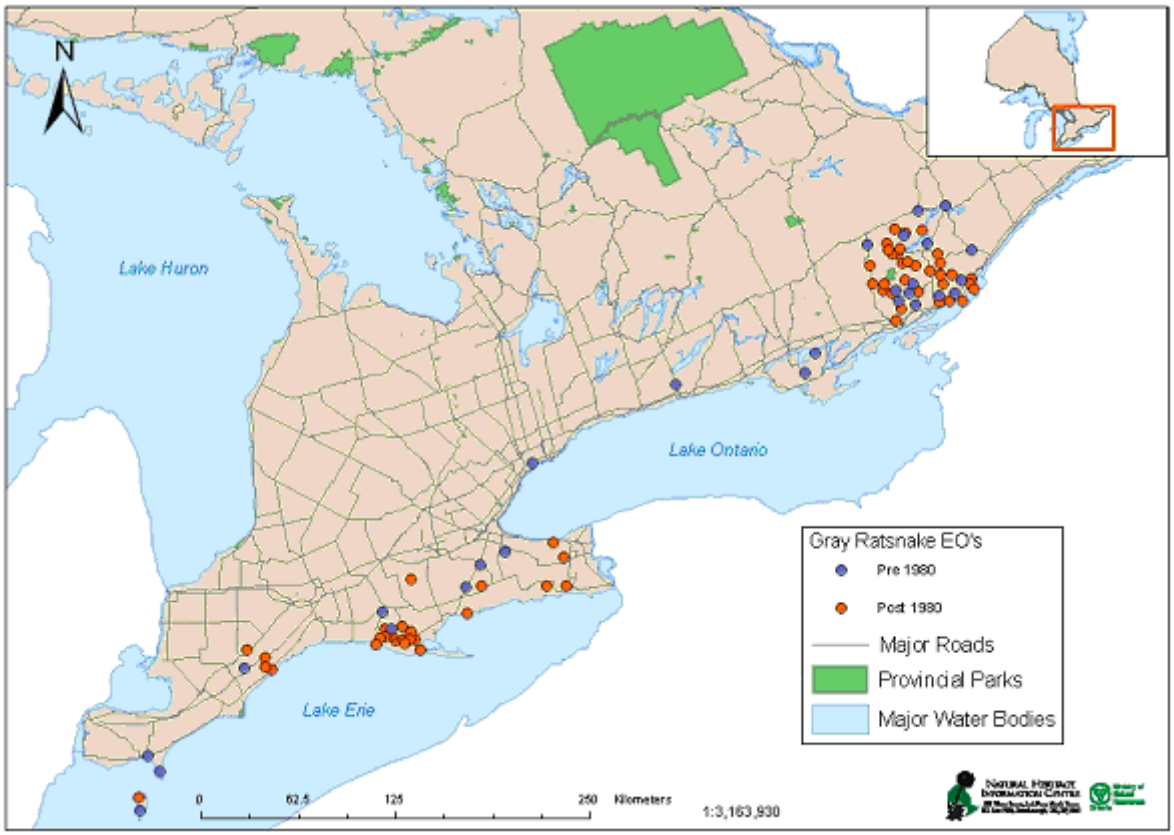

Figure 1. Recent (1980-2005) and historic (pre-1980) element occurrences (EOs) of Gray Ratsnake in Ontario (Natural Heritage Information Centre 2005)

1.4 Habitat Needs

Gray Ratsnakes are typically associated with deciduous forest, though they appear to be capable of utilizing a broad range of habitat types. They exhibit a strong preference for 'edge habitats' where open habitats (such as old field, meadow, rocky outcrops or marshes) and deciduous forest vegetation communities meet (Blouin-Demers and Weatherhead 2001a, b, c, 2002b). It is important that individuals are able to include forest and forest edges within their home ranges. Work conducted in Maryland suggests that a landscape mosaic composed of 50 percent mixed forest and 33 percent cropland may be sufficient to support a healthy population when climate is not a limiting factor (Durner and Gates 1993). Because climate is much more challenging for snakes in Ontario, these estimates may not apply. Research in a relatively undeveloped Ontario study area (within Frontenac Axis) suggests that Gray Ratsnakes use considerably less open habitat (i.e., 3% field, 4% wetland and 10% rocky outcrops) and more forest than the snakes in the Maryland study (Blouin-Demers and Weatherhead 2001a). Analyzing known home range data, Row (2006) found that Gray Ratsnakes preferred home ranges containing forest cover of 41 to 53 percent; less than 28 percent edge habitat (defined as 10 metres on either side of forest); and less than 17 percent marsh. Average home range size in the Frontenac Axis population studied is

approximately 18.5 hectares (Blouin-Demers and Weatherhead 2001a). A habitat use analysis of juveniles in the Frontenac Axis population found that juvenile Gray Ratsnakes used their habitat randomly (Blouin-Demers et al. 2007). The authors did note the possibility that this random use of habitat may have been due to the fact that habitat in the area is very suitable for Gray Ratsnakes. No data are currently available for habitat use of neonate Gray Ratsnakes (approximately 0 – 5 years).

Mature females require oviposition (egg-laying) sites, typically rotten interior cavities of large deciduous trees and stumps or compost piles (Blouin-Demers and Weatherhead 2000). Oviposition sites maintain thermal conditions necessary for egg incubation. After eggs are laid in late June to early August, incubation is approximately 60 days, with hatching occurring in late August to early October (COSEWIC 2007). Gray Ratsnakes overwinter underground in communal hibernacula and show high fidelity to those hibernacula (COSEWIC 2007). Hibernacula are subterranean structures (e.g., rock fissures) generally located in rocky areas and must extend below the frost line to provide adequate protection from freezing (COSEWIC 2007).

1.5 Limiting Factors

Life history features such as late age of maturity (9 – 10 years), long life span (25 – 30 years), biennial reproduction and intermittent juvenile recruitment predispose Gray Ratsnake populations to major demographic fluctuations when subjected to disturbances (Blouin-Demers and Weatherhead 2002a) and do not allow for a natural capacity to rapidly rebound from demographic low points. For example, even minor increases in the rate of adult mortality (e.g., through deliberate killing by humans or incidental mortality on roads) may alter the reproductive capacity of a population to such an extent that it becomes highly vulnerable to extinction (Weatherhead et al. 2002, Row et al. 2007).

1.6 Threats to Survival and Recovery

The threats are the same in all areas of Ontario where the Gray Ratsnake is found, but they are more severe in Carolinian sub-populations.

<u>Habitat Degradation and Fragmentation</u>
Because Gray Ratsnakes seem to require a variety of habitat elements (forest, open habitats) within their home range the overall suitability or quality of a landscape is presumably commensurate with the relative proportion of required elements. If so, then Gray Ratsnake habitat may be degraded by (1) the loss of specific habitats (e.g., deciduous forest) from the mosaic; (2) an alteration in the relative proportions or configuration of the habitat elements; and (3) an increase in road density. It is generally accepted that roads fragment habitat due to changes in light, sound and edge features. Habitat degradation and fragmentation across the landscape may affect spatial and activity patterns of snakes and limit the capacity of a given region to support a viable

population. Retaining the appropriate habitat composition may be a key to the future persistence of the Frontenac Axis population.

The Carolinian region sub-populations persist in a predominantly agricultural landscape. As such, these sub-populations have been subjected to severe landscape-scale habitat alteration including the fragmentation and reduction of forest and the expansion of largely unsuitable habitat (e.g., intensive agricultural crops like tobacco). These landscape-scale changes are the primary cause of the reduced size and extreme isolation of sub-populations found there today. Interrupting among-site connectivity by blocking snake movements (e.g., via habitat fragmentation, land clearing, road development) or the elimination of entire hibernacula can be viewed as the first step toward population isolation and the disintegration of meta-population structure. The highly isolated nature of each of the Carolinian region sub-populations means that local populations can not be augmented through natural re-colonization or immigration and thus are susceptible to extirpation.

Habitat Loss

The loss of deciduous forest and forest-field mosaics are thought be the key cause of the decline of the species throughout the Carolinian region of southwestern Ontario. Interestingly, the availability of suitable habitat in the Frontenac Axis is thought to have increased over the past 100 years, as much previously worked farmland is now fallow. However, any gains in this respect may have been counteracted by negative trends in other factors.

Direct Mortality

Increased encounter rates with humans will inevitably lead to higher rates of mortality for Gray Ratsnakes, both by intentional mortality (e.g., intentional persecution based on the mistaken belief that snakes are dangerous) and accidental mortality [e.g., due to agricultural and construction machinery, lawnmowers, all-terrain vehicles and boats (COSEWIC 2007b, COSEWIC 2008)].

Road Mortality

In a study on a secondary road in the Frontenac Axis region (Row et al. 2007), the road was found to be a significant source of mortality for the population. Row et al. (2007) extrapolated the known mortalities to the whole population based on the size of the study area and found the estimate of total road mortality for the population increased the probability of extinction to 99 percent over 500 years. It could be extrapolated that primary roads within the Gray Ratsnake range would be an even higher source of mortality.

Disturbance or Destruction of Hibernacula

Disturbance or destruction of traditional hibernacula could cause local extinctions. Aggregate extraction, road construction and high density residential construction are common threats to hibernacula for both Gray Ratsnake populations in Ontario. Increasing recreational development across the Frontenac Axis and resulting disturbance of hibernacula may jeopardize local sub-populations. This threat may be

particularly significant across the Carolinian region of Ontario where sub-populations may rely on only one or two communal hibernacula. Only one hibernaculum has been identified in the Carolinian region, leaving overwintering populations susceptible to disturbance. Unknown hibernacula may be destroyed or disturbed before they can be identified and thus protected.

1.7 Knowledge Gaps

Survey Requirements

For the southwestern Ontario (Carolinian) sub-populations: (1) population persistence needs to be confirmed; (2) hibernacula need to be located; (3) impacts of threats on persistence need to be quantified; and (4) the level of public awareness needs to be identified. This will need some level of organized survey effort. Additional information is needed for the population in the Frontenac Axis region regarding the effect of threats and genetic connectivity.

Biological and Ecological Research Requirements

More information is needed about population level habitat requirements and what conditions allow for population viability. An understanding of neonate and juvenile dispersal and mating patterns is needed to better determine how these mechanisms contribute to gene flow and population connectivity. More information is required on factors affecting egg mortality (e.g., availability of nests, egg parasitism and predation). The efficacy of mitigation and restoration practices is not known and should be designed (where necessary) and evaluated.

Threat Clarification Research Needs

It is important to know why Gray Ratsnake numbers are declining in protected areas. As indicated above, the relative impact that various threats have on population persistence should be quantified across all Ontario populations. The validity of methods for reducing significant threats is not well known. The extent to which habitat fragmentation and habitat composition impact population persistence needs to be thoroughly evaluated; this information may be used to guide management activities to retain habitat in some areas (e.g., Frontenac Axis) and restore habitat in others (e.g., Big Creek).

1.8 Recovery Actions Completed or Underway

- Systematic and on-going population monitoring is occurring at three locations in the Frontenac Axis: Queen's University Biological Station (22 hibernacula); St. Lawrence Islands National Park (5 hibernacula); and Murphys Point Provincial Park (2 hibernacula).
- Long-term research into habitat use and genetic structure continues at Queen's University Biological Station.

- Research was completed in May 2005 investigating differences in habitat use and movement patterns between juveniles and adults in the Frontenac Axis population (information published in Blouin-Demers et al. 2007).
- Natural history interpretation and outreach programs (and/or dissemination of information) led by staff are ongoing at St. Lawrence Islands National Park, Charleston Lake, Frontenac and Murphys Point Provincial Parks.
- Baseline telemetry studies at Murphys Point and Charleston Lake Provincial Parks have provided some data on movement patterns, habitat use, hibernation locations and population characteristics for these two areas. A telemetry study was undertaken at Frontenac Provincial Park during the summer of 2001 which identified potential hibernaculum areas (Solomon 2003).
- Annual hibernacula monitoring was initiated at Murphys Point Provincial Park in 2003 and is ongoing (Lunn 2009).
- An education and resource booklet (Live and Let Slither) was completed by Ontario Ministry of Natural Resources in 2001. The booklet is being distributed and is now available through Parks Canada Agency as a bilingual document.
- An education and outreach program (including supporting education materials) has been developed and is being delivered throughout Lanark-Leeds County school boards and Stewardship Councils.
- Work has begun to establish a cooperative relationship with a Lanark County property owners association to enhance Gray Ratsnake awareness, apply best management practices (e.g., retain snags for basking, create artificial nests) and identify significant habitat features. To date this group has expressed interest in becoming involved in data collection to advance recovery goals.
- Conservation easement negotiations are underway with Rideau Valley Conservation Authority for lands supporting hibernacula.
- A survey to assess public awareness related to local large snakes was conducted in the early 1990's in the Big Creek population area.
- Ontario Ministry of Natural Resources is conducting a radio-telemetry study of the Oriskany population, located near Nelles Corners in Haldimand County of southwestern Ontario. A landowner contact program has begun as part of this study.
- Norfolk Field Naturalists developed and put up a booth dealing with snakes at the Norfolk Country Fair (this results in contact with several thousand people per year)
- Norfolk Field Naturalists produced a pamphlet specific to the area on snakes
- An educational video (Black Ratsnake Conservation in Ontario) was produced and distributed by the Friends of Murphys Point Provincial Park.

2.0 RECOVERY

2.1 Recovery Goal

The recovery goal for the Gray Ratsnake in Ontario is to retain the current distribution, population size and connectivity among extant sub-populations within the Frontenac Axis population of eastern Ontario and to achieve self-sustaining sub-populations in the Carolinian population by increasing the distribution and size of the population.

2.2 Protection and Recovery Objectives

Table 1. Protection and recovery objectives

No.	Protection or Recovery Objective
1	Develop and implement a coordinated monitoring plan focused on population indices and distribution, habitat stresses and efficacy of recovery actions
2	Conduct research to fill knowledge gaps including ecological studies of habitat, genetic connectivity and the impacts of various threats
3	Describe and map habitat required to meet recovery goals for each of the Ontario populations
4	Protect and manage the habitat of the species and mitigate priority threats
5	Improve the delivery and evaluation of stewardship and communications to increase awareness, land stewardship, application of best management practices and citizen science efforts

2.3 Approaches to Recovery

Table 2. Approaches to recovery of the Gray Ratsnake in Ontario

Relative Priority	Relative Timeframe	Recovery Theme	Approach to Recovery	Threats or Knowledge Gaps Addressed
1. Develop and implement a coordinated monitoring plan focused on population indices and distribution, habitat stresses and efficacy of recovery actions				
Critical	Ongoing	Inventory, Monitoring and Assessment	**1.1** Maintain current monitoring (e.g., of hibernacula) and develop monitoring plan to further extend monitoring efforts	• All
Critical	Short-term	Inventory, Monitoring and Assessment	**1.2** Establish additional monitoring stations in the Carolinian region to fill gaps identified in the plan	• All
Critical	Short-term	Inventory, Monitoring and Assessment	**1.3** Map existing location data and determine areas to collect additional information	• Habitat loss
Necessary	Short-term and Ongoing	Inventory, Monitoring and Assessment	**1.4** Map detailed range occupancy to aid in connectivity analysis and as a surrogate for population size and update this map regularly	• Habitat loss
Necessary	Long-term	Inventory, Monitoring and Assessment	**1.5** Develop process to analyze monitoring data and to feed this information to land management agencies and stewardship programs	• All
Critical	Long-term and Ongoing	Inventory, Monitoring and Assessment	**1.6** Monitor efficacy of recovery actions and measures employed to reduce threats	• All

Relative Priority	Relative Timeframe	Recovery Theme	Approach to Recovery	Threats or Knowledge Gaps Addressed
2. Conduct research in a number of areas to fill knowledge gaps including ecological studies of habitat, genetic connectivity and the impacts of various threats				
Critical	Long-term	Research	**2.1** Determine data needs for population and habitat viability assessment (PHVA), how PHVA should be used for management and conduct analysis	• All
Necessary	Long-term	Research	**2.2** Research, evaluate and collate data on all potential restoration practices for widespread use	• Habitat loss; direct disturbance of hibernacula
Beneficial	Long-term	Research	**2.3** Determine how genetic connectivity among sub-populations is maintained. This includes the relative importance of different mechanisms such as juvenile dispersal, adult dispersal and multiple paternity	• Habitat loss; habitat degradation and fragmentation
Necessary	Long-term	Research	**2.4** Research and implement methods for reducing significant threats in strategic regions and evaluate effectiveness	• All
3. Describe and map habitat required to meet recovery goals for each of the Ontario populations				
Critical	Long-term	Research	**3.1** Refine the maps of habitat – clarify essential habitat features associated with specific life history stages (e.g., nesting and over-wintering sites); – assess the tolerance of habitat features to disturbance; – determine the permanence of habitat features to match the degree of protection; – extrapolate known individual habitat requirements to habitat requirements of viable populations	• All
4. Protect and manage the habitat of the species and mitigate priority threats				

Relative Priority	Relative Timeframe	Recovery Theme	Approach to Recovery	Threats or Knowledge Gaps Addressed
Necessary	Short-term	Management	**4.1** Develop and apply criteria for ranking habitat parcels or networks. Establish a priority list of key habitat parcels and networks for protection	• Habitat loss
Necessary	Short-term	Management	**4.2** Promote protection of high ranking habitat parcels or networks through partners (municipalities, The Nature Conservancy of Canada, Ontario Parks, Stewardship Councils) and initiate acquisition, agreements, easements, etc.	• Habitat loss
Beneficial	Short-term	Management	**4.3** Direct other types of management actions (e.g., restoration) toward key priority sites	• Habitat loss
Beneficial	Short-term	Management	**4.4** Review, summarize and map all potential threats throughout the species' range, including relative significance of each (e.g., Is road kill significant across the range?)	• All
Critical	Short-term	Management	**4.5** Mitigate significant threats through appropriate strategies	• All
5. Improve the delivery and evaluation of stewardship and communications to increase awareness, land stewardship, application of best management practices and citizen science efforts				
Critical	Short-term	Communications, Education and Outreach	**5.1** Develop a communications plan whose target audiences include landowners, land-use planners, natural resource managers and other affected stakeholders	• Direct mortality
Necessary	Long-term	Communications, Education and Outreach	**5.2** Develop strategy for delivery of communication program to appropriate schools, Stewardship Councils, cottage associations, etc.	• Direct mortality
Necessary	Long-term	Communications, Education and Outreach	**5.3** Refine and promote best management practices and land use guidelines for landowners and stewards	• Habitat loss; direct disturbance of hibernacula

Relative Priority	Relative Timeframe	Recovery Theme	Approach to Recovery	Threats or Knowledge Gaps Addressed
Beneficial	Long-term	Communications, Education and Outreach	**5.4** Develop (or improve) and distribute school education kits and lesson plans to schools within the range of Gray Ratsnake and other targeted school districts	• Direct mortality
Beneficial	Long-term	Communications, Education and Outreach	**5.5** Plan and develop stand alone resource presentation materials for adult audiences to be used by outreach extension volunteers	• Direct mortality
Beneficial	Long-term	Stewardship	**5.6** Develop, promote and implement citizen science program	• All
Beneficial	Long-term	Communications, Education and Outreach	**5.7** Identify training needs; develop and deliver training workshops and materials to train wildlife enforcement officers	• All

Supporting Narrative
Recovery actions should occur at multiple scales including point locations surrounding traditional sites of occupation (hibernacula, oviposition sites) and broad landscapes across which hibernacula and local populations interact. Recovery efforts should be coordinated with existing landscape conservation initiatives including Algonquin to Adirondacks (A2A), Eco-Regional Planning led by The Nature Conservancy of Canada, municipal planners, conservation authorities and local naturalists.

In order for the recovery of Gray Ratsnake to be successful in Ontario, it is recommended that a collaborative approach be implemented including the participation of government agencies, land resource managers, municipal planners, land developers and the public. Rural landscapes need to be used in ways compatible with the needs of Gray Ratsnake populations.

In the Carolinian region of southwestern Ontario, forest habitat will probably need to be actively restored (e.g., forest patches reconnected) so that Gray Ratsnakes can occupy the landscape in relative safety. By contrast, sensitive land use management and careful (restrained) land development may be sufficient to maintain large tracts of quality habitat and healthy, interacting populations on the Frontenac Axis.

2.4 Area for Consideration in Developing a Habitat Regulation

Under the ESA 2007, a recovery strategy must include a recommendation to the Minister of Natural Resources on the area that should be considered in developing a habitat regulation. A habitat regulation is a legal instrument that prescribes an area that will be protected as the habitat of the species. The recommendation provided below by the authors will be one of many sources considered by the Minister when developing the habitat regulation for this species.

The baseline research used to generate the recommendations for the species was conducted by Weatherhead and Charland (1985) and Blouin-Demers and Weatherhead (2001a, b, c, 2002b).

Both Populations
Given the high fidelity to, and the communal nature of, hibernacula, and given the importance of oviposition sites to a species that reproduces every two to three years, it is recommended that hibernacula and oviposition sites be prescribed as habitat in a habitat regulation.

Hibernacula for this species are subterranean geologic formations with surface access and cannot be easily identified by above ground features (COSEWIC 2007). In order to protect the hibernaculum itself, potential entrances and exits, and basking/staging areas used by Gray Ratsnakes in the weeks before entering hibernation in the fall and after emerging in the spring, it is recommended that an area with a radius of 150 metres from the known entrance/exit be prescribed as habitat in a habitat regulation. Blouin-Demers

and Weatherhead (2002b) observed that Gray Ratsnakes were found within 150 metres (on average) of their hibernaculum for approximately 10 to 40 days prior to or following emergence from hibernacula. Since Gray Ratsnake hibernacula have a stable structure and are used repeatedly, it is recommended that hibernacula be protected indefinitely.

Oviposition occurs in manure piles, compost piles, rotting logs and masses of dead vegetation. In order to protect the site itself and nearby basking/resting sites used prior to or following oviposition, it is recommended that an area with a radius of 30 metres (i.e., average tree height) be prescribed as habitat in a habitat regulation for the species to ensure that thermal, vegetative and lighting features are retained around oviposition sites (e.g., rotting logs). These sites are ephemeral and are only suitable for oviposition for a few years. Therefore, it is recommended that oviposition sites be prescribed as habitat until two years after the last known use of the site.

Frontenac Axis Population

The Frontenac Axis is situated on the Canadian Shield and is characterized by strongly rolling topography, frequent outcrops of bedrock, mixed deciduous-coniferous forests and many lakes, rivers and wetlands in low lying areas (COSEWIC 2007). The dominant natural subsystem is Forested Uplands, which is described as upland communities with more than 60 percent canopy cover of trees occurring on substrates with less than 50 percent rock outcrop or shallow soil over bedrock (Reschke 1990).

Favourable habitat in this region is predominately deciduous mesic forest; however, Gray Ratsnakes require a mosaic of forest and open habitats such as water, wetlands, old fields and rock outcrops (Blouin-Demers and Weatherhead 2001a) at a fine enough scale to include edge habitat within individual home ranges (about 18.5 hectares). Gray Ratsnakes travel quite extensively through the landscape and populations are comprised of networks of interacting hibernacula (i.e., individuals from different hibernacula mate) (Prior et al. 1997, Blouin-Demers and Weatherhead 2002, Blouin-Demers et al. 2005). The maintenance of healthy Gray Ratsnake populations depends upon individual snakes from neighbouring hibernacula being able to interact and thus connectivity of forest habitat is important within approximately one to two kilometres surrounding a hibernaculum (Blouin-Demers and Weatherhead 2002b). Studies have confirmed gene flow between communal hibernacula at least eight kilometres apart (Lougheed et al. 1999, Howes et al. 2009).

Row (2006) used several digital land cover maps to quantify habitat and extrapolate known habitat preferences (derived from overlaying home ranges on the land cover maps) of the Gray Ratsnake in the Queens University Biological Station (QUBS) over the rest of the habitat of the Frontenac Axis population. Suitable habitat, road density, neighbourhood size (to measure connectivity) and likelihood of supporting existing populations were all quantified and ranked for each cell. An overall suitability rank between 0 and 1 was then calculated for each cell and the resulting grid was mapped (Figure 2). Row recommended that cells with a habitat suitability value of 0.5 or greater be delineated as habitat for this species.

As this map is the result of a process using quantified data based on habitat use and preferences, it is recommended that cells on the map in Figure 2 with a value of 0.5 or greater within the range of the Frontenac Axis population of Gray Ratsnakes be prescribed as habitat in a habitat regulation.

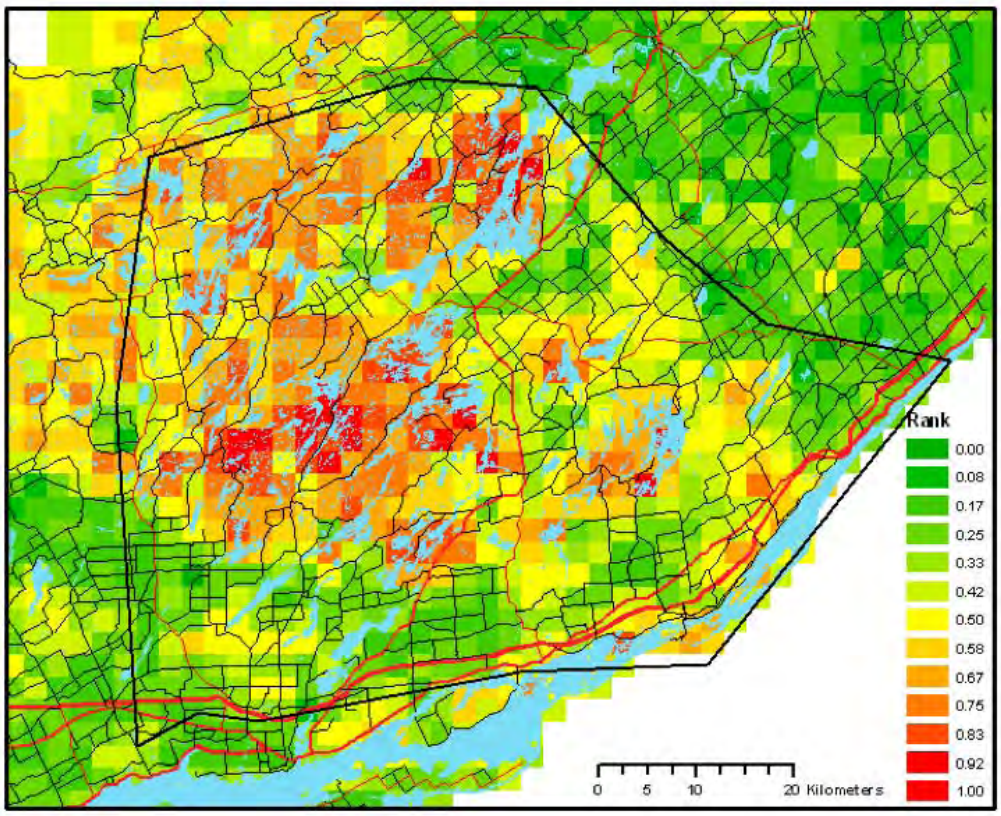

Figure 2. Rank of habitat inside 500 hectare grid squares overlaid across the Frontenac Axis. Habitat was ranked from least (0) to most (1) suitable. The black line indicates the Gray Ratsnake Frontenac Axis population range (COSEWIC 2007, from Row 2006)

Carolinian Population

The maximum distance traveled by a Gray Ratsnake from hibernaculum to nest (oviposition) site in a study by Blouin-Demers and Weatherhead (2002b) was slightly more than four kilometres; in the Frontenac Axis population the average was approximately 1 kilometre. Habitat in the Frontenac Axis region is more suitable and much less fragmented than that for the Carolinian population. Yagi and Tervo (2006) found that Gray Ratsnakes in a sub-population in the Carolinian region traveled nearly two kilometres during their study; one snake was in the process of moving away from the hibernaculum when the transponder was lost at that distance.

Given the above and that the habitat available to this population is much more fragmented than that of the Frontenac Axis population, ratsnakes in the Carolinian population likely travel longer distances and have larger home ranges than snakes in the Frontenac Axis population. Therefore, all natural features (e.g., woodlands, wetlands, hedgerows, meadows) within five kilometres of known hibernacula, oviposition sites and locations at which a Gray Ratsnake has been observed (accurate to 100 metres) are recommended to be prescribed as habitat in a habitat regulation for the Carolinian population of Gray Ratsnake.

GLOSSARY

Committee on the Status of Endangered Wildlife in Canada (COSEWIC): The committee responsible for assessing and classifying species at risk in Canada.

Committee on the Status of Species at Risk in Ontario (COSSARO): The committee established under section 3 of the *Endangered Species Act, 2007* that is responsible for assessing and classifying species at risk in Ontario.

Conservation status rank: A rank assigned to a species or ecological community that primarily conveys the degree of rarity of the species or community at the global (G), national (N) or subnational (S) level. These ranks, termed G-rank, N-rank and S-rank, are not legal designations. The conservation status of a species or ecosystem is designated by a number from 1 to 5, preceded by the letter G, N or S reflecting the appropriate geographic scale of the assessment. The numbers mean the following:

1 = critically imperilled
2 = imperilled
3 = vulnerable
4 = apparently secure
5 = secure

Element Occurrence (EO): A term used by Conservation Data Centres, including the Natural Heritage Information Centre (NHIC), to refer to an occurrence of an element of biodiversity (e.g., species or ecological community) on the landscape; an area of land and/or water on/in which an element is or was present.

Endangered Species Act, 2007 (ESA 2007): The provincial legislation that provides protection to species at risk in Ontario.

Species at Risk Act (SARA): The federal legislation that provides protection to species at risk in Canada. This act establishes Schedule 1 as the legal list of wildlife species at risk to which the SARA provisions apply. Schedules 2 and 3 contain lists of species that at the time the act came into force needed to be reassessed. After species on Schedule 2 and 3 are reassessed and found to be at risk, they undergo the SARA listing process to be included in Schedule 1.

Species at Risk in Ontario (SARO) List: The regulation made under section 7 of the *Endangered Species Act, 2007* that provides the official status classification of species at risk in Ontario. This list was first published in 2004 as a policy and became a regulation in 2008.

REFERENCES

Blouin-Demers, G., K.A. Prior, and P.J. Weatherhead. 2000. Patterns of variation in spring emergence by Gray Ratsnakes (*Elaphe obsoleta obsoleta*). Herpetologica 56:175-188.

Blouin-Demers, G., and P.J. Weatherhead. 2000. A novel association between a beetle and a snake: parasitism of *Elaphe obsoleta* by *Nicrophorus pustulatus*. Écoscience 7:395-397.

Blouin-Demers, G., and P.J. Weatherhead. 2001a. Habitat use by Gray Ratsnakes (*Elaphe obsoleta obsoleta*) in fragmented forests. Ecology 82:2882-2896.

Blouin-Demers, G., and P.J. Weatherhead. 2001b. Thermal ecology of Gray Ratsnakes (*Elaphe obsoleta*) in a thermally challenging environment. Ecology 82:3025-3043.

Blouin-Demers, G., and P.J. Weatherhead. 2001c. An experimental test of the link between foraging, habitat selection and thermoregulation in Gray Ratsnakes *Elaphe obsoleta obsoleta*. Journal of Animal Ecology 70:1006-1013.

Blouin-Demers, G., K.A. Prior, and P.J. Weatherhead. 2002. Comparative demography of Gray Ratsnakes (*Elaphe obsoleta*) in Ontario and Maryland. Journal of Zoology 256:1-10.

Blouin-Demers, G., and P.J. Weatherhead. 2002a. Habitat-specific behavioural thermoregulation by Gray Ratsnakes (*Elaphe obsoleta obsoleta*). Oikos 97:59-68.

Blouin-Demers, G., and P.J. Weatherhead. 2002b. Implications of movement patterns for gene flow in Gray Ratsnakes (*Elaphe obsoleta*). Canadian Journal of Zoology 80:1162-1172.

Blouin-Demers, G., and H.L. Gibbs. 2003. Isolation and characterization of microsatellite loci in the Gray Ratsnake (*Elaphe obsoleta*). Molecular Ecology Notes 3:98-99.

Blouin-Demers, G., H.L. Gibbs, and P.J. Weatherhead. 2005. Genetic evidence for sexual selection in black ratsnakes (*Elaphe obsoleta*). Animal Behaviour 69:225-234.

Blouin-Demers, G., L.P.G. Bjorgan and P.J. Weatherhead. 2007. Changes in Habitat Use and Movement Patterns with Body Size in Black Ratsnakes (*Elaphe obsoleta*). Herpetologica 63: 421-429.

Burbrink FT, R Lawson, and J.B. Slowinski. 2001. Mitochondrial DNA phylogeny of the polytypic North American ratsnake (*Elaphe obsoleta*): a critique of the subspecies concept. Evolution 54: 2107-2118.

Burbrink, FT. 2001. Systematics of the Gray Ratsnake complex (*Elaphe obsoleta*). Herpetological Monographs 15:1-53.

Burbrink, FT, and R. Lawson. 2007. How and when did Old World rat snakes disperse into the New World? Molecular Phylogenetics and Evolution 43:173-189.

Collins, J.T., and T.W. Taggart. 2008. An alternative classification of the New World rat snakes (genus *Pantherophis* [Reptilia: Squamata: Colubridae]). Journal of Kansas Herpetology 26:16-18.

COSEWIC 2007. COSEWIC assessment and update status report on the Gray Ratsnake *Elaphe spiloides* (Great Lakes/St. Lawrence population and Carolinian population) in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. vii + 33 pp.

COSEWIC 2007b. COSEWIC assessment and update status report on the Wood Turtle *Glyptemys insculpta* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. vii + 42 pp.

COSEWIC 2008. COSEWIC assessment and update status report on the Eastern Foxsnake *Elaphe gloydi* (Great Lakes/St. Lawrence population and Carolinian population) in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. vii + 45 pp.

Durner, G.M., and J.E. Gates. 1993. Spatial ecology of Gray Ratsnakes on Remington Farms, Maryland. Journal of Wildlife Management 57:812-826.

Gibbs, H.L., S.J. Corey, G. Blouin-Demers, K.A. Prior and P.J. Weatherhead. 2006. Hybridization between mtDNA-defined phylogeographic lineages of black ratsnakes (*Pantherophis sp*.). Molecular Ecology 15:3755-3767.

Howes, B.J., J.W. Brown, H.L. Gibbs, T.B. Herman, S.W. Mockford, K.A. Prior and P.J. Weatherhead. 2009. Directional gene flow patterns in disjunct populations of the black ratsnake (*Pantherophis obsoletus*) and the Blanding's turtle (*Emydoidea blandingii*). Conservation Genetics 10:407-417.

Lougheed, S.C., H.L. Gibbs, K.A. Prior, and P.J. Weatherhead. 1999. Hierarchical patterns of genetic population structure in Gray Ratsnakes (*Elaphe obsoleta obsoleta*) as revealed by microsatellite DNA analysis. Evolution 53:1995-2001.

Lunn, H.C. 2009. Gray Ratsnake 2006-2009 Summary Report: Hibernacula and Population Monitoring Murphys Point Provincial Park. Ontario Parks, South

Eastern Zone, Ministry of Natural Resources, Murphys Point Provincial Park. Unpublished report. 30pp.

Oldham, M.J., and W.F. Weller. 2000. Ontario Herpetofaunal Atlas. Natural Heritage Information Centre, Ontario Ministry of Natural Resources. http://nhic.mnr.gov.on.ca/MNR/nhic/herps/ohs.html (updated 15-01-2010).

Prior, K.A., G. Blouin-Demers, and P.J. Weatherhead. 1997. Population genetic structure in the black rat snake: implications for management. Conservation Biology 11:1147-1158.

Prior, K.A., G. Blouin-Demers, and P.J. Weatherhead. 2001. Sampling biases in demographic analyses of Gray Ratsnakes (*Elaphe obsoleta*). Herpetologica 57:460-469.

Pyron, R.A., and F.T. Burbrink. 2009. Neogene diversification and taxonomic stability in the snake tribe Lampropeltini (Serpentes: Colubridae). Molecular Phylogenetics and Evolution 52:524-529.

Reschke, C. Ecological communities of New York State. New York Natural Heritage Program. New York State Department of Environmental Conservation, Latham, New York, United States.

Row, J.R. 2006. Ranking the suitability and importance of habitat for eastern ratsnakes (*Elaphe obsolete*) in eastern Ontario. Final Report for Ontario Ministry of Natural Resources. 22 pp.

Row, J.R., and G. Blouin-Demers. 2006. Kernels are not accurate estimators of home-range size for herpetofauna. Copeia 4:797-802.

Row, J.R., G. Blouin-Demers and P.J. Weatherhead. 2007. Demographic effects of road mortality in Black Ratsnakes (*Elaphe obsolete*). Biological Conservation 137:117-124.

Solomon, L. 2003. Summary Report: Black Ratsnake Hibernacula Monitoring. Ontario Parks, South Eastern Zone, Ministry of Natural Resources. Unpublished report. 31pp.

Utiger, U., N. Helfenberger, B. Schatti, C. Schmidt, M. Ruf, and V. Ziswiler. 2002. Molecular systematics and phylogeny of Old and New World ratsnakes, *Elaphe auct.*, and related genera (Reptilia, Squamata, Colubridae). Russian Journal of Herpetology 9:105-124.

Weatherhead, P.J., and M.B. Charland. 1985. Habitat selection in an Ontario population of the snake *Elaphe obsoleta*. Journal of Herpetology 19:12-19.

Weatherhead, P.J., G. Blouin-Demers, and K.A. Prior. 2002. Synchronous variation and long-term trends in two populations of Gray Ratsnakes. Conservation Biology 16:1602-1608.

Yagi, A.R., and R. Tervo. 2006. Black ratsnake telemetry project 2001 to 2002 Oriskany sandstone area – Carolinian population final report for Ontario Ministry of Natural Resources Species at Risk, Peterborough, Ontario. 19 pp.

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