RECOVERY POTENTIAL ASSESSMENT OF WAVY-RAYED LAMPMUSSEL (*Lampsilis fasciola*) IN CANADA

Wavy-rayed Lampmussel (Lampsilis fasciola) *© Environment Canada*

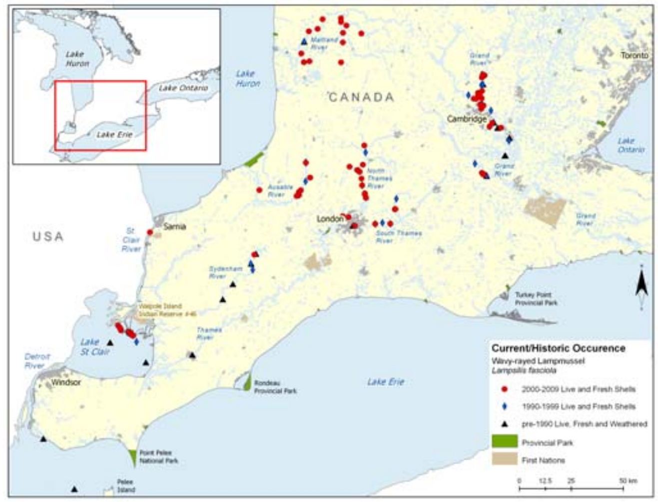

Figure 1. Distribution of Wavy-rayed Lampmussel in Canada.

Context :

The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) assessed the status of Wavy-rayed Lampmussel in October 1999. The assessment resulted in the designation of Wavy-rayed Lampmussel as Endangered. Wavy-rayed Lampmussel was subsequently listed on Schedule 1 of the Species at Risk Act *(SARA) when the Act was proclaimed in June 2003. In April 2010, the status was reassessed as Special Concern. The reason for this designation was that surveys since the first assessment identified a large, previously unknown reproducing population in the Maitland River and that there is evidence that some of the populations are reproducing.*

A species Recovery Potential Assessment (RPA) process has been developed by Fisheries and Oceans Canada (DFO) Science to provide the information and scientific advice required to meet the various requirements of the SARA, such as the authorization to carry out activities that would otherwise violate the SARA as well as the development of recovery strategies. The scientific information also serves as advice to the DFO Minister regarding the listing of the species under SARA and is used when analyzing the socio-economic impacts of adding the species to the list as well as during subsequent consultations, where applicable. This assessment considers the scientific data available with which to assess the recovery potential of Wavy-rayed Lampmussel in Canada.

SUMMARY

- The current distribution of the Wavy-rayed Lampmussel includes the Ausable, Grand, Maitland and Thames rivers as well as the St. Clair River and delta (Figure 1).

- Wavy-rayed Lampmussel is thought to be extirpated from Lake Erie, Lake St. Clair proper (excluding St. Clair River delta) and the Detroit River, as well as the Sydenham River where it has not been recorded since 1971 despite substantial sampling.

- Gills of the appropriate host fish are the required habitat for the glochidial life stage.

- Adult Wavy-rayed Lampmussel are generally found in small to medium, clear, hydrologically stable rivers, around shallow riffle areas, but are also known to inhabit lacustrine areas. It is generally found on sand or gravel substrates, at times stabilized with cobble or boulders usually at depths of up to 1 m. Juvenile habitat requirements are inferred from the adult life stage.

- For the Grand River population, to achieve a 99% probability of persistence over 250 years, given a 15% chance of partial catastrophe per generation, a population with 1500 female adults is required. If the chance of catastrophe was a 15% chance of full catastrophe per generation, a population with 83 000 female adults is needed

- For the Thames River population, to achieve a 99% probability of persistence over 250 years, given a 15% chance of partial catastrophe per generation, a population with 31 adult females is required. If the chance of catastrophe was a 15% chance of full catastrophe per generation, a population with 420 female adults is needed

- Assuming 15% probability of partial catastrophe; and growth rates of 1.08 and 1.18 respectively, population modeling indicates that in the absence of both recovery efforts and additional harm, populations between 2-20% of the recovery target have a 95% chance of reaching the target in 46-85 years (Grand), or 18-30 years (Thames).

- Population dynamics were most sensitive to changes in adult survival. Recovery time is reduced by approximately half with a 10% increase in adult survival.

- The greatest threats to the survival and persistence of extant Wavy-rayed Lampmussel populations are related to increased levels of contaminants and toxic substance, increases in nutrient loading, increases in turbidity and sediment loading, introduction of exotic species and habitat removal and alteration. Due to the obligate nature of the mussel reproductive cycle, any threat leading to the separation of mussel and fish host during reproduction can be detrimental to the mussel population. Secondary threats include predation and harvesting, and recreational activities.

- The growth rate of Wavy-rayed Lampmussel populations is most sensitive to the survival of adults. Harm to vital rates of the Grand River population should be less than 14% for glochidial survival or 14% for adult fecundity or 9% for juvenile survival or 6% for adult survival. Harm to vital rates of the Thames River population should be less than 33% for glochidial survival or 33% for adult fecundity or 22% for juvenile survival or 14% for adult survival.

- There remain numerous sources of uncertainty related to Wavy-rayed Lampmussel life history, juvenile habitat requirements, host distribution and abundance, and host-mussel distribution overlap. A thorough understanding of the threats affecting the decline of Wavy-rayed Lampmussel populations is also lacking. Numerous threats have been identified at the mussel community level, but the threat likelihood and impact at the species level is currently unknown. Numerous modeling parameters specific to Wavy-rayed Lampmussel are currently unknown, such as glochidial survival, glochidial attachment rates, juvenile survival, and population growth rates.

BACKGROUND

In October 1999, the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) designated the Wavy-rayed Lampmussel (*Lampsilis fasciola*) as Endangered. Wavy-rayed Lampmussel was subsequently listed on Schedule 1 of the *Species at Risk Act* (SARA) when the Act was proclaimed in June 2003. In April 2010, the status was reassessed as Special Concern (COSEWIC 2010). When COSEWIC designates an aquatic species as Threatened or Endangered and Governor in Council decides to list it, or when a species is down-listed, the Minister of Fisheries and Oceans Canada (DFO) is required by the SARA to undertake a number of actions. Many of these actions require scientific information such as the current status of the population, the threats to its survival and recovery, and the feasibility of its recovery. This scientific advice is developed through a Recovery Potential Assessment (RPA). This allows for the consideration of peer-reviewed scientific analyses in subsequent SARA processes, including permitting on harm and recovery planning. This RPA focuses on Wavy-rayed Lampmussel in Canada, and is a summary of a Canadian Science Advisory Secretariat peer-review meeting that occurred on 26 May 2010, in Burlington, Ontario. Two research documents, one providing background information on the species biology, habitat preferences, current status, threats and mitigations and alternatives (Bouvier and Morris 2010), and a second on allowable harm, population-based recovery targets, and habitat targets (Young and Koops 2010) provide an in-depth account of the information summarized below. Proceedings are also made available that document the activities and key discussions of the meeting (DFO 2010b).

Species Description and Identification

The Wavy-rayed Lampmussel (*Lampsilis fasciola*, Rafinesque 1820) is a small, sexually dimorphic mussel with a smooth, yellow shell covered with dense wavy green rays of varying widths. Females are easily distinguished from the males with a distended shell shape. Wavy-rayed Lampmussel is medium-sized, generally 75-100 mm long. Wavy-rayed Lampmussel can be confused with the Plain Pocketbook (*Lampsilis cardium*), although the Wavy-rayed Lampmussel is generally smaller, relatively thicker and more regularly ovate.

ASSESSMENT

Current Species Status

Ausable River

The Ausable River population was discovered in 1993. Increased sampling efforts over the following 12 years yielded only three additional individuals; two individuals found in a timed-search in 2002 and one juvenile found during an observational study in 2005. In 2006, DFO and Ausable-Bayfield Conservation Authority (ABCA) completed quadrat surveys and found 18 animals at five sites. An additional timed-search survey was completed in 2008 where one live individual was found (ABCA, unpubl. data). The distribution of the Wavy-rayed Lampmussel includes reaches in both the Little Ausable River (3 km) and the main stem (84 km). The Area of Occupancy (AO) for the Ausable River population was calculated to be approximately 0.7 km^2.

Grand River

The Grand River Wavy-rayed Lampmussel population is one of the healthiest Canadian populations. It appears that this population has recovered from poor water quality conditions present in the 1970s and early 1980s. Sampling on the Grand River from 1995 to 1998 resulted in 22 live animals, 38 fresh whole shells, and seven fresh half-shells from 11 sites, including two sites on the Nith River and one on the Conestoga River (both tributaries of the Grand River). Various mussel collections from 2001-2006 resulted in the capture of 73 live individuals, 20 fresh whole shells, and seven fresh half-shells. In addition, two relocation studies completed in 2006 noted 248 live individuals, while a mark-recapture study (one plot sampled 13 times between May and October) noted 88 unique individuals. Wavy-rayed Lampmussel occurs from Inverhaugh (north of Waterloo) downstream to Glen Morris (south of Cambridge). Wavy-rayed Lampmussel has also been found in three Grand River tributaries: 13.5 km of the Conestogo River, 30 km of the Nith River, and the lower portion of the Speed River (10 km). Based on these known distributions, the AO has been calculated as 7.5 km^2.

Maitland River

Wavy-rayed Lampmussel occurs in all four branches of the Maitland River watershed. Sampling completed in 1997-1998 yielded three live animals, as well as three whole shells. Additional timed-search sampling between 2003-2004 recorded 21 live individuals at nine sites. In 2008, Wavy-rayed Lampmussel was found at three of these previously sampled sites, as well as one additional site. The trajectory of the Maitland River population is unknown due to a lack of historic distributional data. Wavy-rayed Lampmussel has been noted to occur over a 23 km stretch in the Middle Maitland River, 15 km in the Little Maitland River, 54 km in the main stem, and 10 km in the South Maitland River. The AO for the Maitland River is approximately 3.2 km^2.

Thames River

Wavy-rayed Lampmussel has been identified from the North, South and Middle Thames rivers and in two tributaries of the North Thames branch: Fish and Medway creeks. Surveys conducted in 2004 indicated that the North Thames River contains one of the healthiest populations remaining in Canada. The species currently occupies all of its known historic range in the Thames River and size/age distributions indicate that recruitment is occurring throughout most of the sites. In addition, sampling completed from 2006-2008 noted 75 live individuals, while a mark-recapture study (one plot sampled 14 times between May and October) noted 138 unique live individuals. Wavy-rayed Lampmussel occurs over 65 km of the North, South and Middle branches of the Thames River upstream of the city of London. The AO for the Thames watershed is estimated at 2.5 km^2.

Sydenham River

The most recent record of a live individual in the Sydenham River dates back to 1971 when a single individual was recorded. The Sydenham River was intensively sampled from 1997-2003 (over 600 person·hours) and not a single live individual was recorded, which provides support for the belief that the Wavy-rayed Lampmussel is extirpated from this system. The historic distribution of the Wavy-rayed Lampmussel included 42 km of the middle reach of the East Sydenham River.

St. Clair River Delta

Although the Lake St. Clair population of Wavy-rayed Lampmussel has been decimated since the introduction of the Zebra Mussel to the Great Lakes, a population was found to persist in the St. Clair River delta. The population can be found over 12 km^2 of the shallow nearshore areas of the delta within the territory of Walpole Island First Nations. Sampling from 1999-2005 resulted in the capture of 34 live individuals. Based on these surveys, it appears that the St. Clair River delta population is the last historic lake population to persist. The AO for the St. Clair River delta has been calculated as 5.5 km^2.

Lake Erie and Connecting Channels

Wavy-rayed Lampmussel was reported from Lake Erie in 1967 and 1980, but was not found in subsequent surveys including an extensive survey of 17 sites. A small remnant population may still exist in Lake Erie but it is unlikely that a significant population exists due to the establishment of Zebra Mussel in this system. A single Wavy-rayed Lampmussel was recorded from the St. Clair River in 2001 when it was found in a ponar sample. This is the only known Wavy-rayed Lampmussel sample from this area. Extensive mussel community surveys by SCUBA divers were completed in the Detroit River in 1982-83, 1992 and 1994 and no Wavy-rayed Lampmussel was recorded.

Population Status

To assess the Population Status of Wavy-rayed Lampmussel, each population was ranked in terms of its abundance (Abundance Index) and trajectory (Population Trajectory). The Abundance Index was based on quantitative density estimates and estimates of population size that are currently available. Density estimates were subsequently multiplied by the AO to obtain the Estimated Population Size. The Estimated population sizes were then used to determine the current Abundance Index for each population. The Population Trajectory was assessed based on the best available knowledge about the current trajectory of the population. Certainty has been associated with the Abundance Index and Population Trajectory rankings and is listed as: 1=quantitative analysis; 2=standardized sampling; 3=expert opinion. The Relative Abundance Index and Population Trajectory values were then combined in the Population Status matrix to determine the Population Status for each population. Each Population Status was subsequently ranked as Poor, Fair, Good, Unknown or Extirpated (Table 1). The Certainty assigned to each Population Status is reflective of the lowest level of certainty associated with either initial parameter. Refer to Bouvier and Morris (2010) for the complete methodology on Population Status assessment.

Table 1. *Population Status of all Wavy-rayed Lampmussel populations in Canada, resulting from an analysis of both the Abundance Index and Population Trajectory. Certainty assigned to each Population Status is reflective of the lowest level of certainty associated with either initial parameter (Relative Abundance Index or Population Trajectory).*

Population	Population Status	Certainty
Ausable River	Poor	3
Grand River	Good	2
Maitland River	Poor	3
Thames River	Fair	2
St. Clair River delta	Poor	3
Lake Erie and connecting channels	Extirpated	2
Sydenham River	Extirpated	1

Habitat Requirements

To fully understand the habitat requirements of the Wavy-rayed Lampmussel, we must first understand the unique life cycle of freshwater mussels. During the spawning period, males located upstream release sperm into the water column. Females subsequently utilize their gills to filter the sperm from the water column, and the sperm is deposited in the posterior portion of the female gill, in a specialized region, where the ova are fertilized. The fertilized ova are held until they reach a larval stage. Mature females are characterized by a swelling of the posterior-ventral margin. Wavy-rayed Lampmussel is considered a long-term brooder because it generally spawns in August and glochidial release does not occur until the subsequent year.

Glochidium

Females release mature larvae (glochidia) which must encyst on the gills of an appropriate host fish. Smallmouth (*Micropterus dolomieu)* and Largemouth Bass (*M. salmoides*) have been identified as suitable hosts for the Wavy-rayed Lampmussel. Females have developed specialized mantles, which mimic lures to attract host fish. Four lure types have been identified in the Ausable, Grand, Thames and Maitland rivers. When the fish comes in contact with the mantle, it retracts into the shell, resulting in a sudden release of glochidia and subsequent glochidial attachment on the fish gills. Glochidia will remain encysted until they metamorphose into juveniles. This process may last from a few weeks to several months. Encystment is an obligate step in the life cycle of the Wavy-rayed Lampmussel, and development will not occur in the absence of this phase. The gills of the appropriate host fish can be considered a habitat requirement for the glochidial life stage of the Wavy-rayed Lampmussel.

Juvenile

Subsequent to metamorphoses, juvenile Wavy-rayed Lampmussel are released from the gills of the fish host and bury themselves in the substrate until they reach several years of age. The proportion of glochidia that survive to the juvenile stage is estimated to be as low as 0.000001%. A survival tactic to overcome this increased level of mortality is to produce very high numbers of glochidia. It is difficult to classify required habitat for juvenile mussels because they are difficult to detect and because they have a tendency to burrow; although, they are generally found when implementing adult mussel survey methods. Once sexually mature they emerge from the substrate surface to participate in gamete exchange.

Adult

Adult Wavy-rayed Lampmussel are typically found in clear rivers and streams, in and around riffle/run areas, where the water flow is steady. In riverine systems, they are generally found on substrate composed of sand or gravel, up to approximately 1 m deep. The last lacustrine population located in the St. Clair River delta can be found in shallow sand flats, and along shallow wave-washed shoals. Many historically-abundant Wavy-rayed Lampmussel areas are no longer suitable since the infestation of Zebra Mussel.

Residence

Residence is defined in SARA as “dwelling-place, such as a den, nest or other similar area or place, that is occupied or habitually occupied by one or more individuals during all or part of their life cycles, including breeding, rearing, staging, wintering, feeding or hibernating”. Residence is interpreted by DFO as being constructed by the organism. In the context of the above narrative description of habitat requirements during glochidial, juvenile and adult life stages, Wavy-rayed Lampmussel do not construct residences during their life cycle (DFO 2010a).

Recovery Targets

Consistent with the preconditions of SARA section 73(3), we used demographic sustainability as a criterion to set recovery targets for Wavy-rayed Lampmussel. Demographic sustainability is related to the concept of a minimum viable population (MVP; Shaffer 1981), and was defined as the minimum adult population size that results in a desired probability of persistence over 250 years (approximately 24-40 generations). The chosen MVP targets attempt to optimize the benefit of reduced extinction risk and the cost of increased recovery effort, and result in a persistence probability of approximately 99% over 250 years. Simulations included random catastrophic events (50% decline in abundance), and three catastrophe scenarios were compared: i) 5% chance of catastrophe per generation, affecting all life stages, ii) 15% chance of catastrophe per generation, affecting all life stages, iii) 15% chance of catastrophe per generation, with 4/5 events affecting only immature individuals and 1/5 affecting all life stages. Simulations indicated that MVPs for the Grand River populations are ~5200, ~197 000 adults, or ~3600 adults respectively for the three catastrophe scenarios. MVPs for the Thames River populations were ~70, ~900, and ~60 adults, respectively.

Recovery Times

In the absence of recovery efforts or further harm, a Grand River population of Wavy-rayed Lampmussel that is at 10% of its MVP target has a 95% chance of recovering within 57-72 years (depending on the frequency and magnitude of catastrophic events). Thames River populations under similar conditions were predicted to recover in 20-25 years. Time to recovery is delayed exponentially by harm to any vital rate, but especially by harm to more sensitive life stages (Figure 2). Conversely, improving survival rates by 10% can reduce the time to recovery by as much as half. Not surprisingly, recovery times varied with initial population size (Figure 3).

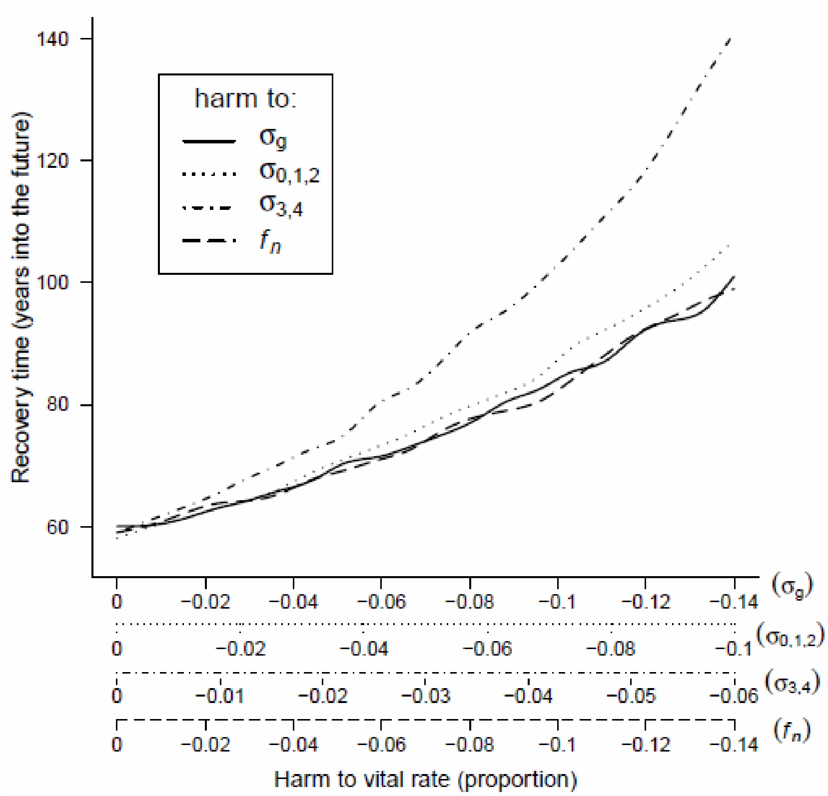

Figure 2. *Stochastic projections of mean Wavy-rayed Lampmussel recovery times for Grand River populations under additional harm. Each curve shows recovery times under harm to one vital rate or combination of rates (σ_g = glochidial survival; $\sigma_{0,1,2}$ = juvenile survival; $\sigma_{3,4}$ = adult survival; f_n = fecundity at age n). Levels of harm range from 0 harm (status quo conditions) to the maximum allowable harm as recommended in Young and Koops (2010). Simulations assume 15% probability of partial catastrophe, and a recovery target of 1504 adult females.*

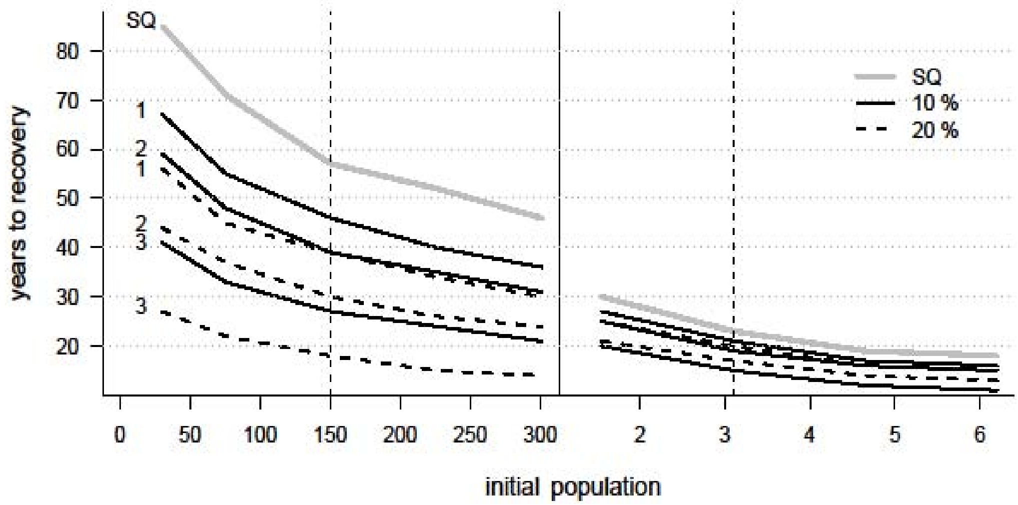

Figure 3. *Stochastic projections of mean Wavy-rayed Lampmussel recovery times for the Grand (left panel) and Thames (right panel) river populations. Figure shows predicted recovery times as a function of population size. Simulations assume 15% probability of partial catastrophe, and a recovery target of 1504 and 31 adult females for the Grand and Thames respectively. Initial populations range from 2-20% (Grand) or 5-20% (Thames) of these targets. Grey line shows recovery times in the absence of mitigation or additional harm (status quo; SQ). Numbered lines correspond to 10 or 20% improvements in glochidial survival (1), juvenile survival (2), or adult survival (3). Vertical line shows recovery times given 10% of the target.*

Threats to Survival and Recovery

In the past 30 years, species diversity and abundance of native freshwater mussels has declined throughout Canada and the United States. It appears that the two greatest limiting factors to the stabilization and growth of the Wavy-rayed Lampmussel populations in the Great Lakes are Zebra Mussel introduction and decreases in water quality (i.e., increased turbidity and suspended solids). The historic distribution of the Wavy-rayed Lampmussel in Lake St. Clair, Lake Erie and its connecting channels has been devastated by the introduction of the Zebra Mussel, and these areas no longer provide suitable habitat for the recovery of this species. There is also strong evidence that decreases in water quality, specifically increased turbidity and suspended solids, also limits the distribution of the Wavy-rayed Lampmussel. These declines in water quality are the result of activities such as dam construction, impoundments, channel modifications (e.g., channelization, dredging, snagging), and land use practices. Land use practices, such as agricultural and urban activities, lead to high silt, contaminant and nutrient loadings. In addition to these inputs, the agricultural practice of installing drainage tiles in crop fields has altered the hydrological regime in these watersheds. Due to the obligate nature of the mussel reproductive cycle, any threat leading to the separation of mussel and fish host during reproduction can be detrimental to the mussel population. Direct threats to the host, such as barriers to movement, and recreational activities, such as angling and harvesting pressures, will have cumulative effects on the mussel population. Physical loss of Wavy-rayed Lampmussel habitat through removal and alteration is detrimental to their survival. There is also evidence that predation by muskrats (*Ondatra zibethicus*) and raccoons (*Procyon lotor*) may be negatively affecting Wavy-rayed Lampmussel populations, as well as harvesting. It is important to note that these threats may not always act independently on Wavy-rayed Lampmussel populations; rather, one threat may directly affect another, or the interaction between two threats may introduce an interaction effect on the Wavy-rayed Lampmussel populations. It is quite difficult to quantify these interactions and, therefore, each threat is discussed independently.

Threat Status

To assess the Threat Status of Wavy-rayed Lampmussel populations, each threat was ranked in terms of the Threat Likelihood and Threat Impact on a population basis (see Bouvier and Morris 2010 for details). The Threat Likelihood was assigned as Known, Likely, Unlikely, or Unknown, and the Threat Impact was assigned as High, Medium, Low, or Unknown. The Threat Likelihood and Threat Impact for each population were subsequently combined in the Threat Status matrix resulting in the final Threat Status for each population (Table 2). Certainty has been classified for Threat Impact and is based on: 1= causative studies; 2=correlative studies; and, 3=expert opinion.

Table 2. *Threat Status for all Wavy-rayed Lampmussel populations, resulting from an analysis of both the Threat Likelihood and Threat Impact. The number in brackets refers to the level of certainty assigned to each Threat Status, which relates to the level of certainty associated with Threat Impact. Certainty has been classified as: 1= causative studies; 2=correlative studies; and 3=expert opinion. Gray cells indicate that the threat is not applicable to the population due to the nature of the aquatic system where the population is located. Clear cells do not necessarily represent a lack of a relationship between a population and a threat; rather, they indicate that either the Threat Likelihood or Threat Impact was Unknown.*

Threats	Ausable River	Grand River	Maitland River	Thames River
Exotic species	Medium (2)	High (2)	Medium (2)	High (2)
Turbidity and sediment loading	High (2)	Medium (2)	Medium (2)	Medium (2)
Contaminants and toxic substances	High (1)	High (1)	High (1)	High (1)
Nutrient loading	High (2)	High (2)	High (2)	High (2)
Altered flow regimes	Medium (2)	High (2)	Medium (2)	High (2)
Habitat removal and alteration	Medium (3)	Medium (3)	Medium (3)	Medium (3)
Fish hosts	Medium (2)	High (2)	Medium (2)	High (2)
Predation and harvesting	Low (3)	Low (3)	Low (3)	Low (3)
Recreational activities	Low (3)	Low (3)	Low (3)	Low (3)

Threats	St. Clair River delta	Lake Erie and connecting channels	Sydenham River
Exotic species	High (2)	High (2)	Medium (2)
Turbidity and sediment loading	Medium (2)	Medium (2)	High (2)
Contaminants and toxic substances	High (1)	High (1)	High (1)
Nutrient loading	High (2)	High (2)	High (2)
Altered flow regimes		Low (3)	Medium (2)
Habitat removal and alteration	Low (3)	Low (3)	Low (3)
Fish hosts	High (2)	High (2)	High (2)
Predation and harvesting	Low (3)	Low (3)	Low (3)
Recreational activities	Low (3)	Low (3)	Low (3)

N.B. The Threat Status represents a combination of the current Threat Impact and Threat Likelihood at a location. It does not reflect the potential impact a threat might have on a population if it was allowed to occur in the future.

Allowable Harm

Allowable harm was assessed in a demographic framework following Vélez-Espino and Koops (2009). The assessment involves perturbation analyses of population projection matrices, and includes a stochastic element. Outputs of the analyses include calculation of a population growth rate, and its sensitivity to changes in vital rates. See Young and Koops (2010) for complete details of the model and results. Modelling indicated that population growth of Wavy-rayed Lampmussel is most sensitive to perturbations of annual adult survival. It is also sensitive to the survival of glochidia, and of juveniles through the first year (Figure 4). Uncertainty in sensitivity is driven primarily by uncertainty in the survival of juveniles and glochidia.

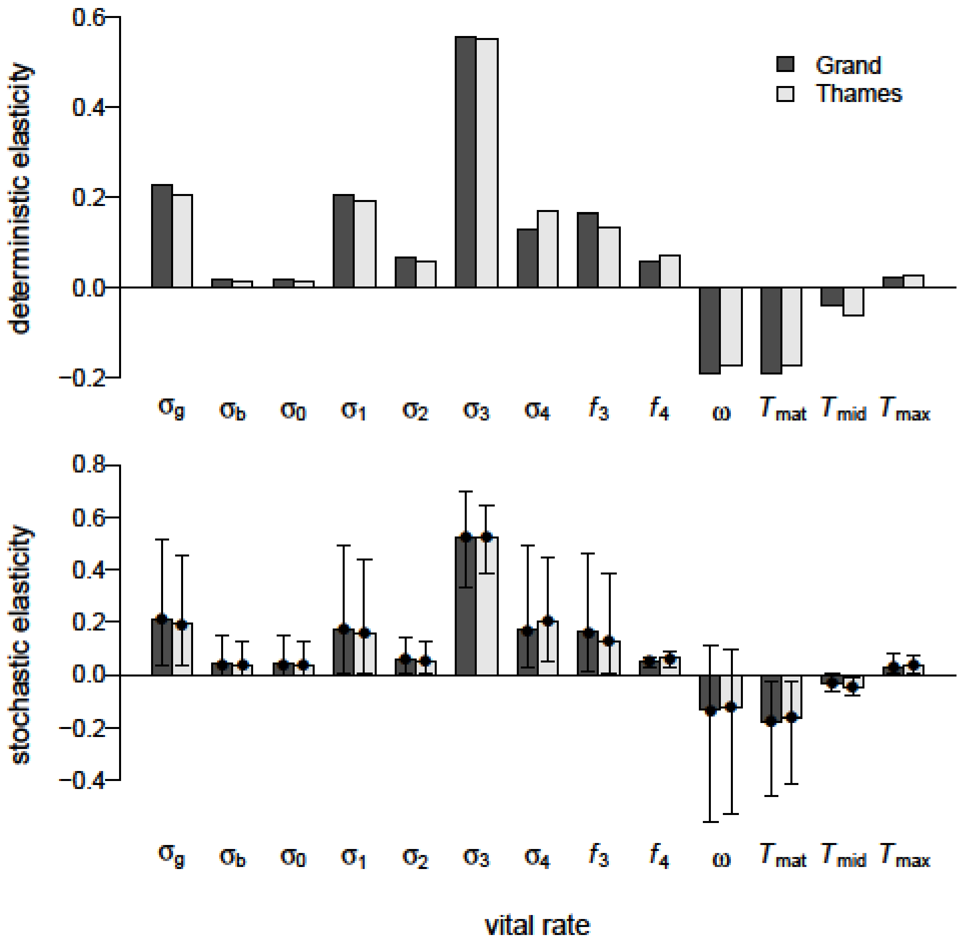

Figure 4. *Results of the deterministic and stochastic perturbation analyses showing elasticities (ε_v) of the vital rates: annual survival of stage i (σ_i), fertility of stage i (f_i), probability of overwintering on the host (ω), age at maturity (T_{max}), dividing age between early and late adult stages (T_{mid}), and maximum age (T_{max}). Stochastic results include associated bootstrapped 95% confidence intervals. See Young and Koops (2010) for parameter estimate details.*

Maximum allowable harm to annual survival of glochidia, juveniles, or adults should be limited to 14%, 9%, or 6% respectively. Reductions in fecundity should not exceed 14%. Harms that affect the survival of more than one life stage should be further restricted. If human activities are such that harm exceeds just one of these thresholds, the future survival of individual populations is likely to be compromised.

Summary of Science Advice on Allowable Harm

- When population trajectory is declining there is no scope for allowable harm.
- When population trajectory is unknown the scope for allowable harm can only be assessed once population data are collected.
- Scientific research to advance the knowledge of population data should be allowed.

- In the absence of population abundance estimates, no harm should be allowed to adult survival.
- Modeling indicates that minimal additional cumulative harm is allowable to survival of glochidia, survival of juveniles, or fecundity of adults.
- Survival of overwintering glochidia is least susceptible to harm.
- If population abundance estimates exceed MVP, cumulative allowable harm might be allowed to the level identified in the AH modeling.

Mitigations and Alternatives

Numerous threats affecting Wavy-rayed Lampmussel populations are related to habitat loss or degradation. DFO – Fish Habitat Management has developed generic mitigation measures for 19 Pathways of Effects for the protection of aquatic species at risk in the Ontario Great Lakes Area (Table 3; Coker *et al.* 2010). Additional mitigation and alternative measures, specific to the Wavy-rayed Lampmussel, related to the introduction of exotic species, disruptions to the host fish relationship and predation are discussed.

Table 3. *Threats to Wavy-rayed Lampmussel populations and the Pathways of Effect associated with each threat. 1 - Vegetation clearing; 2 – Grading; 3 – Excavation; 4 – Use of explosives; 5 – Use of industrial equipment; 6 – Cleaning or maintenance of bridges or other structures; 7 – Riparian planting; 8 – Streamside livestock grazing; 9 – Marine seismic surveys; 10 – Placement of material or structures in water; 11 – Dredging; 12 – Water extraction; 13 – Organic debris management; 14 – Wastewater management; 15 – Addition or removal of aquatic vegetation; 16 – Change in timing, duration and frequency of flow; 17 – Fish passage issues; 18 – Structure removal; 19 – Placement of marine finfish aquaculture site.*

Threats	Pathway(s)
Turbidity and sediment loading	1, 2, 3, 4, 5, 6, 7, 8, 10, 11, 12, 13, 15, 16, 18
Contaminants and toxic substances	1, 4, 5 ,6 ,7 ,11 ,12 ,13 ,14, 15, 16 ,18
Nutrient loading	1, 4, 7, 8, 11, 12, 13, 14, 15, 16
Altered flow regimes	10, 11, 12, 16, 18
Habitat removal and alteration	1, 2, 3, 4, 5, 7, 8, 10, 11, 13, 14, 15, 16, 18
Fish hosts (barriers to movement)	10, 16, 17

Exotic species

Zebra Mussel introduction and establishment could have negative effects on Wavy-rayed Lampmussel populations.

Mitigation

- Watershed monitoring for exotic species that may negatively affect Wavy-rayed Lampmussel populations, or negatively affect preferred habitat of the Wavy-rayed Lampmussel.
- Develop and implement plans to address potential risks, impacts, and proposed actions if monitoring detects the arrival or establishment of an exotic species.
- Introduction of a public awareness campaign on proper boat cleaning methods when transferring boats from an infested waterway.
- Restrict the use of boats in areas particularly susceptible to Zebra Mussel introduction and infestation (i.e., reservoirs in the Thames and Grand rivers).

Alternatives

- Unauthorized introductions
  - None.
- Authorized introductions
  - Do not carry out introduction where Wavy-rayed Lampmussel is known to exist.

Fish hosts

Increased siltation may be limiting the host's ability to visually locate the displaying mussel, impeding the transfer of glochidia from the mussel to the fish host. If decreases in visibility resulting from increased siltation are found to be a limiting factor in the reproductive success of the Wavy-rayed Lampmussel, mitigation pathways related to increased siltation should be implemented. In addition, decreases in the number of individual host fish or decreases in the area of overlap between host fish and Wavy-rayed Lampmussel may be decreasing the likelihood that a fish-mussel encounter will occur.

Mitigation

- Implement a management plan for the appropriate fish host species. This would increase the host's survival, increasing number of host individuals, creating a healthy host population and subsequently increasing the likelihood that the fish host would encounter a gravid Wavy-rayed Lampmussel.
- Immediate release of host fish if caught angling in areas where Wavy-rayed Lampmussel are known to occur.

Alternatives

- Seasonal or zonal restrictions to fishing applied for fish species known to be used as a host to the Wavy-rayed Lampmussel glochidia.

Predation and Harvesting

Muskrat and raccoon predation may have negative effects on Wavy-rayed Lampmussel populations. It should be considered that if this threat were to occur, it would be much localized, and have a relatively small impact on the Wavy-rayed Lampmussel population. In addition, human harvesting for consumption was also noted as a threat to Wavy-rayed Lampmussel.

Mitigation

- If predators were identified at a local scale to have an impact on the Wavy-rayed Lampmussel population, predator control should be considered.
- Introduction of a public awareness campaign on the negative effects of freshwater mussel consumption, in areas of higher contaminant levels, on humans.
- Increase enforcement in areas where human consumption of freshwater mussel species at risk is known to occur.

Alternatives

- None.

Recreational activities

Recreational activities such as driving all-terrain vehicles (ATVs) through streams, boating, fly-fishing, canoeing, and kayaking may negatively impact mussel beds

Mitigation

- Introduction of a public awareness campaign on the negative effects of the above-listed recreational activities on Wavy-rayed Lampmussel.

Alternatives

- None.

Sources of Uncertainty

Despite concerted efforts to increase our knowledge of the Wavy-rayed Lampmussel in Canada, there are still areas of uncertainty related to their life history, and to the factors that are limiting their existence. Areas of particular uncertainty are related to the juvenile life stage. Very little information is available regarding the preferred habitat of juvenile Wavy-rayed Lampmussel and the survival of individuals from the glochidial stage up to, and including, the juvenile life stage. Additional studies on habitat requirements are imperative to determine critical habitat for all life stages of the Wavy-rayed Lampmussel. Additional studies on the preferred habitat of this species may also help to determine possible candidate areas for relocation.

Numerous threats have been identified for Wavy-rayed Lampmussel populations in Canada, although the severity of these threats is currently unknown. There is a need for more causative studies to evaluate the impact of each threat on each Wavy-rayed Lampmussel population with greater certainty. In the literature, the threat impacts are generally discussed at a broad level (i.e., mussel community level). It is important to further our knowledge on threat likelihood and impact at the species level. Specifically, little is known about the sensitivity of Wavy-rayed Lampmussel to contaminants, toxic substances, nutrient and sediment loading. Laboratory experiments should be conducted to increase our knowledge of threshold values of Wavy-rayed Lampmussel survival. It is necessary to determine host distribution and abundance, and to quantify the amount of overlap between the mussel and host fish populations.

Many of the variables required to inform the population modelling efforts are currently unknown, or are only known for non-Canadian populations. Uncertainty in parameter estimates has resulted in large uncertainty in the population growth rates. Studies should focus on acquiring additional information on survival of both the glochidia and juvenile stages. In particular, efforts should focus on the rate of host-mussel encounter, and rate of attachment of glochidia. Population specific estimates of host-overwintering rates, and overwinter survival of glochidia are also needed, as are population specific fecundity-at-size/age relationships. Finally, the frequency and magnitude of catastrophic events are unknown.

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