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Assessing Characteristics of Recovery: a case study using the Endangered Wavyrayed Lampmussel (*Lampsilis fasciola*, Rafinesque 1820)

Évaluation des caractéristiques de rétablissement : une étude de cas de la lampsile fasciolée (*Lampsilis fasciola*, Rafinesque 1820), espèce en voie de disparition

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Abstract

The Wavyrayed Lampmussel (*Lampsilis fasciola*, Rafinesque 1820) is a small sexually dimorphic mussel characterized by its round shape and fine, broken wavy green rays. This species historically occurred in western Lake Erie, Lake St. Clair, and the Maitland, Ausable, St. Clair, Sydenham, Thames, Detroit and Grand Rivers. Habitat degradation, damming activity, declining water quality resulting from rural farming practices and increasing urban pressures as well as the invasion of the zebra and quagga mussel have lead to large scale declines in the range and abundance of this species. Current populations are known only from a small portion of the Lake St. Clair delta and the Ausable, Grand, Thames and Maitland Rivers. The Wavyrayed Lampmussel was declared Endangered by the Committee on the Status of Endangered Wildlife in Canada in 1999. This report attempts to determine a suite of characters that can be effectively used to monitor recovery of this species across its Canadian range. We recommend that recovery be evaluated at a population level for each of the 6 remaining populations using a hierarchical approach incorporating individual, population and species levels criteria.

Résumé

La lampsile fasciolée (*Lampsilis fasciola*, Rafinesque 1820) est une petite moule dimorphique qui se caractérise par sa coquille ronde marquée de rayures vertes, fines et sinueuses. Cette espèce se retrouvait autrefois dans l'ouest du lac Érié, dans le lac St. Clair, ainsi que dans les rivières Maitland, Ausable, St. Clair, Sydenham, Thames, Detroit et Grand. La détérioration de son habitat, la construction de barrages, la diminution de la qualité de l'eau résultant des pratiques agricoles et l'accroissement des pressions urbaines, ainsi que l'invasion de la moule zébré et de la moule quagga ont fortement rétréci son aire et diminué son abondance. Les populations actuelles sont confinées uniquement à de petites parties du delta du lac St. Clair et aux rivières Ausable, Grand, Thames et Maitland. La lampsile fasciolée a été déclarée en voie de disparition par le Comité sur la situation des espèces en péril au Canada en 1999. Le présent rapport tente d'établir une série de caractéristiques qui pourraient être utilisées pour suivre efficacement le rétablissement de l'espèce dans son aire canadienne. Nous recommandons d'évaluer le rétablissement au niveau de chacune des six populations qui restent, à l'aide d'une démarche hiérarchique incluant des critères aux niveaux de l'individu, de la population et de l'espèce.

Context

The following case study was prepared as a contribution to the national workshop on “The Development of a Framework on Characteristics of Recovery” held in Ottawa in August 2005 (DFO 2005). The purpose of the workshop was to examine a wide array of species including marine, freshwater, vertebrate, invertebrate, commercially harvested and bycatch and to develop a set of guidelines to provide consistent advice to recovery planners regarding interpretations of recovery. The Endangered Wavyrayed Lampmussel was selected as an example of a data-poor, non-harvested, freshwater invertebrate threatened primarily by habitat related activities.

Introduction

The Wavyrayed Lampmussel (*Lampsilis fasciola*, Rafinesque 1820) is a small sexually dimorphic mussel recognized by its yellow or yellowish-green rounded shell. The shell is characterized by numerous thin wavy green rays that may be narrow and individual or coalesced into wider rays in some specimens (Figure 1). Regardless of size, the rays are always wavy with multiple interruptions giving rise to the common name of this mussel. The species is commonly found in small to medium, clear, hydrologically stable rivers where it inhabits clean sand/gravel substrates in and around shallow riffle areas.

The Wavyrayed Lampmussel is considered globally secure (G4). It is considered nationally secure within the United States (N4) although it is declining throughout its range, particularly in the north where it is considered endangered in Illinois, threatened in Michigan and New York, and of special concern in Indiana. This species is considered imperiled (N1) in Canada where it was listed as Endangered in 1999 by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) and added to Schedule 1 under the *Species at Risk Act* in June 2003. The Canadian distribution is restricted to Ontario where it has likely always been a rare species (Metcalfe-Smith and McGoldrick 2003) with a historical range that included western Lake Erie, Lake St. Clair, and the Maitland, Ausable, St. Clair, Sydenham, Thames, Detroit and Grand Rivers. Current populations are known only from a small portion of the Lake St. Clair delta and the Ausable, Grand, Thames and Maitland Rivers (Figure 2).

Biologically Limiting Factors

Reproductive Attributes: The Wavyrayed Lampmussel, like all unionids, has a complicated reproductive cycle characterized by a period of obligate parasitism. This parasitic phase makes the Wavyrayed Lampmussel particularly sensitive to external factors that may indirectly affect them via their hosts (Bogan 1993).

The Wavyrayed Lampmussel is a medium sized, moderately long-lived, sexually dimorphic species. During spawning season, males release sperm into the water column and females located downstream take in the sperm via their incurrent siphons. Females brood the young from egg to larval stage in the posterior portions of the outer gills. Mature female Wavyrayed Lampmussels are characterized by distended shells, swollen along the posterior-ventral margins to allow room for expanded gill pouches (Metcalfe-Smith et al. 2000). Wavyrayed Lampmussels are long-term brooders (bradytictic) with spawning occurring in August and glochidial release occurring the following year (May through August in Virginia (Zale and Neves 1982), June through August in Canada (Woolnough 2002).

When the larvae are mature they are released by the female and must undergo a period of encystment on the gills of a suitable host. Two host species have been identified for the Wavyrayed Lampmussel in the U.S. Zale and Neves (1982) reported successful laboratory infestations of smallmouth bass (*Micropterus dolomieu*) with Wavyrayed Lampmussel glochidia while G.T. Watters (Ohio State University, cited in Metcalfe-Smith *et al*. 2000) reported success with largemouth bass (*M. salmoides*). The largemouth bass has recently been confirmed as host for the Wavyrayed Lampmussel in Canada (McNichols and Mackie 2003). Recently, researchers at the University of Guelph successfully infected mottled sculpin (C*ottus bairdi*) with Wavyrayed Lampmussel glochidia, although it is unclear whether this species functions as a host under natural conditions (K. McNichols, University of Guelph, pers. comm., September 2003).

To increase the likelihood of encountering an appropriate host and facilitate successful encystment, female Wavyrayed Lampmussels have developed specialized mantle tissue to function as a lure (Strayer and Jirka 1997). Three co-occurring mantle lure morphologies have been observed on displaying female Wavyrayed Lampmussels during field surveys of the Grand, Thames, Ausable and Maitland Rivers. The three morphologies consist of a black lure, a bright red lure, and a fish-like lure (Figure 3). It is unknown if the three lure morphologies constitute sibling species or if they are ecomorphs. Molecular phylogenetic analysis is required to resolve this knowledge gap.

When a suitable host fish touches the mantle lure the mantle flaps are retracted into the shell, placing pressure on the marsupia and causing the release of the mature larvae (glochidia). The structure of the lure (e.g., eyespots and pigmentation consistent with a small minnow-shaped fish in the fish-like lure morph) and the method of glochidial release are consistent with a host species which is a visual predator. This indicates that water clarity likely plays a critical role in the successful completion of the reproductive cycle of the Wavyrayed Lampmussel.

Dispersal: Adult Wavyrayed Lampmussels have very limited dispersal abilities. Although adult movement can be directed upstream or downstream, studies have found a net downstream movement through time (Balfour and Smock 1995; Villella *et al.* 2004). The primary means for large scale dispersal, upstream movement, and the invasion of new habitat or evasion of deteriorating habitat, is limited to the encysted glochidial stage on the host fish.

Characteristics of Recovery

The following discussion outlines an exploration of the characters that may prove beneficial when attempting to evaluate recovery of the Wavyrayed Lampmussel across its Canadian range. Each character has been assessed against its biological relevance to the species, the ability to determine a healthy reference condition, availability of data (current and historical) and methodology. Where possible, recovery targets for the character have been suggested.

Ecological Properties

1) *Is this character biologically relevant to the Wavyrayed Lampmussel?*

Yes. Although no specific information exists for the Wavyrayed Lampmussel, freshwater mussels play an integral role in the functioning of aquatic ecosystems. Vaughn and Hakenkamp (2001) have summarized much of the literature relating to the role of unionids and identified numerous water column (size-selective filter-feeding; species-specific phytoplankton selection; nutrient cycling; control of phosphorus abundance) and sediment processes (deposit feeding decreases sediment organic matter; biodeposition of feces and pseudofeces; epizoic invertebrates and epiphytic algae colonize shells; benthic invertebrate densities positively correlated with mussel density) mediated by the presence of mussel beds. Welker and Walz (1998) have shown that freshwater mussels are capable of limiting plankton in European rivers while Neves and Odom (1989) have indicated that mussels also play a role in the transfer of energy to the terrestrial environment through predation by muskrats and raccoons.

2) *Is there a theoretical or conceptual basis for describing a healthy condition on this character for the Wavyrayed Lampmussel?*

No, most of the work on this topic to date has focused on identifying the role of mussels in the aquatic ecosystem although Vaughn *et al.* (2004) have recently begun to examine species-specific contributions to these overall processes. No current system exists for determining a healthy state in general, or one specific to the Wavyrayed Lampmussel.

3) *Do the technology and or analytical methods exist to estimate, measure or monitor this character if the funding were provided?*

Until a theoretical or conceptual healthy condition can be described it unclear what technology or methods would be required. There is no reason to suspect that the methods used in the studies cited above could not be reasonably applied to the Wavyrayed Lampmussel if/when they are determined to be appropriate.

4) *Do data exist that could be used to estimate historic values of the character empirically or allow theoretical models to be parameterized?*

No.

5) *Is the property currently being monitored with a frequency appropriate to measure its trend, if any?*

No, not being monitored.

6) *If feasible suggest and justify briefly what a reasonable recovery target might be for this species on this property.*

Not feasible at this time.

Abundance/Biomass

1) *Is this character biologically relevant to the Wavyrayed Lampmussel?*

Yes, population abundance is an important biological character for assessing the health of freshwater mussel populations; however the quantitative criteria applied by COSEWIC are not appropriate for use as a reference for recovery. The IUCN-based abundance criteria that COSEWIC employs for species assessments are not well suited for evaluating aquatic invertebrate species which are often characterized by large population sizes, high reproductive output and low survival to the adult stage.

2) *Is there a theoretical or conceptual basis for describing a healthy condition on this character for the Wavyrayed Lampmussel?*

There is currently no *theoretical* basis for determining a healthy population level for the Wavyrayed Lampmussel. Some recent effort has been directed towards determining ecosystem and local level carrying capacities for marine shellfish populations (e.g. Smaal *et al.* 1998) but no comparable work yet exists for freshwater mussels in general or the Wavyrayed Lampmussel in particular. Current efforts at the University of Oklahoma (C. Vaughn pers. comm. 2005) are attempting to examine this character for freshwater mussel assemblages and may provide future insight.

At the present time, the only available reference condition for a healthy population level is based on estimates of historical range and current, believed to be healthy, population densities. No historical data exist for direct comparison of current population levels as virtually all historic records are from museum specimens which provide information on presence but not on abundance.

3) *Do the technology and or analytical methods exist to estimate, measure or monitor this character if the funding were provided?*

Yes, estimating population abundances of riverine mussels is a labour intensive activity but the field protocols and statistical tools exist. At its simplest, population abundance can be estimated using only a measure of the range of the species and the density over that range. While no data exist for historical abundances/densities of the Wavyrayed Lampmussel, this can be estimated by using current densities of populations that are believed to be healthy (show ample reproduction and recruitment, complete size/age distributions etc.). In the case of the Wavyrayed Lampmussel, the Upper Thames River populations can be used as surrogates for historical conditions.

Historical range can be estimated through a detailed analysis of historical occurrences and to a lesser degree through an examination of the current distribution of relic, fossil and sub-fossil shells. Metcalfe-Smith *et al*. (1998) have compiled this information for the Wavyrayed Lampmussel in the Lower Great Lakes Unionid Database (LGLUD). Current distribution data can be, and has been, obtained for the Wavyrayed Lampmussel using the timed search methods reported in Metcalfe-Smith *et al.* (2000) and Strayer and Smith (2003). Density can be estimated through application of a more complex systematic sampling design with quadrat excavations (Strayer and Smith 2003). One of the authors applied a systematic sampling design using three random starts to obtain density estimates for the Thames river populations in 2004 (TJM, unpublished data). No other direct density estimates, historical or current, exist for the Wavyrayed Lampmussel in Canada.

4) *Do data exist that could be used to estimate historic values of the character empirically or allow theoretical models to be parameterized?*

Yes. Historical and current distributions are well captured in the LGLUD and allow for determinations of historical and current areas of occupancy (AO). We have estimated the current and historic AO's by first determining the distance between the furthest upstream and downstream records in the LGLUD for both the historic and current distributions and then combining this measure with the average width of the river over this section as determined through recorded sampling locations. Together these two measures give an AO in square kilometers. Combining the AO with an estimate of density (historic or current) can provide an approximation of the abundance for any given population.

Historical densities for Lake St Clair and Western Lake Erie populations can be estimated from the work of Nalepa (1994) and Schloesser and Nalepa (1994). Although unionids have been completely eradicated from the offshore waters of Lake Erie and Lake St Clair (Nalepa 1994, Zanatta *et al.* 2002) they can still be found in few small refuges within the Lake St. Clair delta allowing current densities to be estimated from Metcalfe-Smith *et al.* (2005). No historical density estimates exist for inland rivers however, current densities for the Thames River are available from one of the authors for use with all inland river populations (TJM, unpublished data). Note that the lack of historical estimates results in any changes observed between historical and current abundances for inland rivers being reflective only of changes in AO (Table 2 and 3).

Nalepa (1994) reported that the Wavyrayed Lampmussel represented approximately 0.5% of the total unionid fauna of Lake St Clair prior to the invasion of dreissenid mussels and that the total density of unionids was approximately 2.5/m^2. Combining these values gives an estimated historical density for Wavyrayed Lampmussels in Lake St Clair of 0.00889 animals/m^2. Nalepa (1991) found total unionid densities of 10/m^2 in 1961 for the western basin of Lake Erie while Schloesser and Nalepa (1994) reported a total unionid density of 4/m^2 in 1982. Neither study reported relative contribution of Wavyrayed Lampmussels to the overall density. Assuming the percent composition was similar to Lake St Clair gives a density of Wavyrayed Lampmussels ranging from 0.0142 to 0.0355 animals/m^2. The western Lake Erie density has been used to estimate abundance of the Detroit River population (Table 2) as no specific estimates exist for this population.

Metcalfe-Smith *et al.* 2005 report that Wavyrayed Lampmussels currently represent approximately 0.58% of the total unionid community in two bays of the Lake St Clair delta where the overall mussel density is between 0.086-0.097 animals/m^2. Overall Wavyrayed Lampmussel densities range between 0.000495-0.000559 animals/m^2.

No historical data exist for the inland river populations of Wavyrayed Lampmussel and it is therefore necessary to use a current population, the Thames River, as a surrogate. The Thames River populations appear to be relatively stable, occupy 100% of the known historical range in the upper watershed, show complete size/age distributions including juveniles, and show reproduction and recruitment at virtually all sites (TJM, unpublished data). Wavyrayed Lampmussels in the Thames River occur at densities ranging from 0.045 to 0.396 animals/m^2.

These values have been used to produce the population abundance estimates provided in Tables 1 and 2.

5) *Is the property currently being monitored with a frequency appropriate to measure its trend, if any?*

Yes. Under the guidance of the Ontario Freshwater Mussel Recovery Team and the Sydenham River Aquatic Ecosystem Recovery Team a detailed monitoring program for mussel species at risk is being established in Southwestern Ontario. Permanent, long term monitoring stations are being established in all of the large rivers of southwestern Ontario where this species occurs. To date 15 stations have been established in the Sydenham River (Metcalfe-Smith and Zanatta 2003 and 6 sites in the Thames River (TJM, unpublished data) with an additional 7 sites in the Ausable River planned for 2006. These sites will be monitored on a 5 year cycle which should be sufficient to capture changes in population abundance of this long-lived species (30+ years max age (Henley *et al.* 2002)). An additional 18 sites have been established within the Lake St Clair delta (Metcalfe-Smith *et al.* 2005). Although these sites were not intended to be part of the long term monitoring program, periodic re-visitation will provide the necessary trend data.

6) *If feasible suggest and justify briefly what a reasonable recovery target might be for this species on this property.*

A suitable recovery target for abundance levels would be to restore these populations to the estimated historic levels presented in Table 1. At this time there is insufficient data to suggest an acceptable abundance target at a level below those reported in Table 1.

Range/Area Occupied

1) *Is this character biologically relevant to the Wavyrayed Lampmussel?*

Yes, area occupied is a relevant character for the Wavyrayed Lampmussel. It is also the character for which the most historical data exist. The loss of this species from the connecting waters of the Great Lakes has resulted in severe habitat fragmentation and the effective isolation of the river populations. Preventing further declines in range (i.e. reductions or losses of river populations) is key to the survival/recovery of the species and will be an important measure of recovery.

2) *Is there a theoretical or conceptual basis for describing a healthy condition on this character for the Wavyrayed Lampmussel?*

As with the abundance character, there is no theoretical basis for establishing a recovery target on range/area occupied. The best indicator of recovery will be a comparison of current versus historical range.

3) *Do the technology and or analytical methods exist to estimate, measure or monitor this character if the funding were provided?*

Historical range can be estimated through a detailed analysis of historical occurrences and to a lesser degree through an examination of the current distribution of relic, fossil and sub-fossil shells. Metcalfe-Smith *et al*. (1998) have compiled this information for the Wavyrayed Lampmussel in the Lower Great Lakes Unionid Database (LGLUD). Current distribution data can, and has been, obtained for the Wavyrayed Lampmussel using the timed search methods reported in Metcalfe-Smith *et al.* (2000).

4) *Do data exist that could be used to estimate historic values of the character empirically or allow theoretical models to be parameterized?*

Yes. Historical and current range distributions are well captured in the LGLUD (Tables 1 & 2). Given the fragmented nature of these populations it is integral that recovery be assessed at an appropriate scale. Summary statistics presented in Tables 1 & 2 for the Great Lakes and Inland River groups are only presented for comparison purposes. Recovery should be assessed at a finer scale – at least the tertiary or quaternary watershed. The Thames River population (Lake St Clair drainage) is separated from the Grand River population (Lake Erie drainage) by over 400km of inhospitable lake habitat making connectivity only possible through movement of an infected host. While this movement is possible it is not considered likely. Even within the rivers populations can remain fragmented. The North Thames population is isolated from the South and Middle Thames populations by Fanshawe dam. Range expansions by any one population, as measured by an increase in overall Inland River range, may not capture population dynamics at the watershed scale and may not lead to COSEWIC downlisting or the recovery of the species.

5) *Is the property currently being monitored with a frequency appropriate to measure its trend, if any?*

Yes. When fully implemented the long term monitoring program being initiated under the direction of the Ontario Freshwater Mussel Recovery Team and several ecosystem recovery teams will provide the data necessary to assess changes in population ranges (AO). More detailed surveys will likely be required to fully quantify changes in range however these surveys will be triggered by early indicators (i.e. failing reproduction, population size shifts, lowered densities etc.) from the monitoring program.

6) *If feasible suggest and justify briefly what a reasonable recovery target might be for this species on this property.*

A suitable recovery target for area occupied would be to restore these populations to the estimated historic levels presented in Table 1. At this time there is insufficient data to suggest an acceptable abundance target at a level below those reported in Table 1.

TEK

1) *Is this character biologically relevant to the Wavyrayed Lampmussel?*

No. Very limited TEK exists for freshwater mussels in general and no specific information exists for Wavyrayed Lampmussels. Existing knowledge takes the form of anecdotal information about greater historical abundance: “they used to be everywhere when I was a kid”.

2) *Is there a theoretical or conceptual basis for describing a healthy condition on this character for the Wavyrayed Lampmussel?*

3) *Do the technology and or analytical methods exist to estimate, measure or monitor this character if the funding were provided?*

4) *Do data exist that could be used to estimate historic values of the character empirically or allow theoretical models to be parameterized?*

5) *Is the property currently being monitored with a frequency appropriate to measure its trend, if any?*

6) *If feasible suggest and justify briefly what a reasonable recovery target might be for this species on this property.*

Minimum number of individuals

1) *Is this character biologically relevant to the Wavyrayed Lampmussel?*

Yes. The Wavyrayed Lampmussel is a broadcast spawner: males release sperm into the water column which must become entrained in the female’s filtering current in order for fertilization to occur. A minimum population abundance/density is required to facilitate such a reproductive strategy (Downing *et al.* 1993). The minimum number of animals required to complete fertilization represents a minimum population size for continued existence. This number does not reflect the population size required to ensure the preservation of genetic biodiversity which is inevitably higher.

2) *Is there a theoretical or conceptual basis for describing a healthy condition on this character for the Wavyrayed Lampmussel?*

No studies exist on the minimum population density to ensure fertilization in the Wavyrayed Lampmussel. Downing *et al.* (1993) assessed the minimum required population size to support reproduction in the unionid *Elliptio complanata* in a small Quebec lake and determined a minimum local density of 10 animals/m^2 was required for any reproduction while a density of 18 animals/m^2 was required for 50% successful fertilization. These methods could be applied to develop a theoretical estimate for the Wavyrayed Lampmussel.

3) *Do the technology and or analytical methods exist to estimate, measure or monitor this character if the funding were provided?*

Yes, the field and statistical techniques employed by Downing *et al.* (1993) could be applied to the Wavyrayed Lampmussel. The technique of Downing *et al.* (1993) requires that animals be sacrificed to determine fertilization success which is not an acceptable technique when working with an endangered mussel. It may be possible to determine these characteristics for a closely related surrogate species in Canada (another Lampsiline) or for a surrogate Wavyrayed Lampmussel population in the US.

4) *Do data exist that could be used to estimate historic values of the character empirically or allow theoretical models to be parameterized?*

Not at this time.

5) *Is the property currently being monitored with a frequency appropriate to measure its trend, if any?*

No, not being monitored.

6) *If feasible suggest and justify briefly what a reasonable recovery target might be for this species on this property.*

Not feasible at this time although reproduction is occurring in mussel beds in the Thames River where local (meter scale) Wavyrayed Lampmussel densities range between 1-3 animals/m^2 (TJM, unpublished data) suggesting this target may be lower for Wavyrayed Lampmussels than Downing *et al*. (1993) reported for *E. complanata*.

Productivity-recruitment

1) *Is this character biologically relevant to the Wavyrayed Lampmussel?*

Yes.

2) *Is there a theoretical or conceptual basis for describing a healthy condition on this character for the Wavyrayed Lampmussel?*

No studies of recruitment have been conducted for the Wavyrayed Lampmussel; however, Villela *et al*. (2004) examined recruitment in a closely related Lampsiline, *Lampsilis cariosa* (yellow Lampmussel, Special Concern), in the Cacapon River of West Virginia. Recruitment rates for this stable population varied between 1-4% annually.

3) *Do the technology and or analytical methods exist to estimate, measure or monitor this character if the funding were provided?*

Yes, Villela *et al.* (2004) employed standard mark-recapture techniques and the statistical models of Pradel (1996) to estimate recruitment. There is no reason why these techniques could not be implemented in Canadian rivers.

4) *Do data exist that could be used to estimate historic values of the character empirically or allow theoretical models to be parameterized?*

Detailed data do not exist at this time to estimate recruitment in Wavyrayed Lampmussel populations however these techniques could be coupled with the monitoring program described in previous sections.

5) *Is the property currently being monitored with a frequency appropriate to measure its trend, if any?*

No, not currently being monitored.

6) *If feasible suggest and justify briefly what a reasonable recovery target might be for this species on this property.*

In the absence of species specific data, the data for *L. cariosa* in the Capacon River may serve as a surrogate for a healthy Lampsiline population (1-4% annually) (Villela *et al.* 2004). It must be recognized that recruitment can be highly variable from year to year (Negus 1966; Strayer *et al.* 1981) so estimates of recruitment used to evaluate recovery must be averaged over several years.

Productivity-population growth rate

1) *Is this character biologically relevant to the Wavyrayed Lampmussel?*

Yes.

2) *Is there a theoretical or conceptual basis for describing a healthy condition on this character for the Wavyrayed Lampmussel?*

No empirical studies exist on population growth rates of Wavyrayed Lampmussels. Villela *et al.* (2004), in their study of recruitment rates of *Lampsilis cariosa*, determined that the population growth rate for this population was essentially static (Lambda = 0.993, SE = 0.076).

3) *Do the technology and or analytical methods exist to estimate, measure or monitor this character if the funding were provided?*

Yes (see Pradel 1996 ; Villela *et al.* 2004).

4) *Do data exist that could be used to estimate historic values of the character empirically or allow theoretical models to be parameterized?*

No.

5) *Is the property currently being monitored with a frequency appropriate to measure its trend, if any?*

No, not being monitored.

6) *If feasible suggest and justify briefly what a reasonable recovery target might be for this species on this property.*

At a bare minimum, for recovery to occur, population growth rates must be greater than 1.

Sex composition

1) *Is this character biologically relevant to the Wavyrayed Lampmussel?*

Yes.

2) *Is there a theoretical or conceptual basis for describing a healthy condition on this character for the Wavyrayed Lampmussel?*

Yes. Anecdotal evidence suggests healthy Lampsiline populations are characterized by a sex ratio of 1:1 and that declining populations show male biased sex ratios (Kjos *et al.* 1998).

3) *Do the technology and or analytical methods exist to estimate, measure or monitor this character if the funding were provided?*

Yes. Wavyrayed Lampmussels are sexually dimorphic and sex determination can be readily made under field conditions in a nondestructive manner in conjunction with any other sampling.

4) *Do data exist that could be used to estimate historic values of the character empirically or allow theoretical models to be parameterized?*

No, sufficient information is not contained in the historic records to develop accurate estimates of historical sex ratios. Determinations of sex ratios for currently stable populations in the US may be used as surrogates for healthy conditions in Canadian waters.

5) *Is the property currently being monitored with a frequency appropriate to measure its trend, if any?*

Yes, information on sex ratios is collected as a routine matter during all field collections. It is important to note that while information on sex ratios can be obtained from any type of sampling there are inherent biases in many sampling techniques. Male Wavyrayed Lampmussels tend to burrow deeper than females and may surface at different times of the year than females decreasing the chances of detecting males relative to females. Likewise the elaborate lures of the females can attract the attention of searchers further biasing the sex ratio towards females. Sampling to determine sex ratios for the purpose of evaluating recovery must include substrate excavation to reduce the bias associated with timed searches.

6) *If feasible suggest and justify briefly what a reasonable recovery target might be for this species on this property.*

A sex ratio of 1:1 can be used as a rough estimate of a healthy population. When considering the bias associated with varying sample methods and small sample sizes, sex ratios for Wavyrayed Lampmussels can be highly variable across sites and across rivers (McGoldrick *et al.* 2005). As populations recover and numbers of individuals increase allowing larger sample sizes it may be possible to use sex ratio as an indicator of recovery however at this time it is probably not a good candidate for assessing recovery of the Wavyrayed Lampmussel.

Age/Size composition

1) *Is this character biologically relevant to the Wavyrayed Lampmussel?*

Yes. These characters are biologically important for Wavyrayed Lampmussels for two reasons: 1) fecundity is related to age and size in freshwater mussels (Haag and Staton 2003); 2) fecundity can decline/cease in older individuals resulting in senescent populations (Downing *et al.* 1993; Haag and Staton 2003).

2) *Is there a theoretical or conceptual basis for describing a healthy condition on this character for the Wavyrayed Lampmussel?*

A healthy Wavyrayed Lampmussel population is characterized by a normal distribution of sizes/ages spanning the known size range of the species in Canada (max size approximately 100 mm).

3) *Do the technology and or analytical methods exist to estimate, measure or monitor this character if the funding were provided?*

Yes. Size distributions are easily determined in the field and these data are collected as a part of the standard protocol used during all mussel field sampling in the occupied range of the Wavyrayed Lampmussel. Age distributions can be reconstructed from size distributions providing an appropriate relationship has been determined. Henley *et al*. (2002) collected Wavyrayed Lampmussel shells from the Clinch River in Virginia and determined a size-at-age relationship through thin-sectioning following the techniques of Clark (1980) and Neves and Moyer (1988). The applicability of this relationship is questionable given the small sample size on which it is based (n=10) and the likelihood of it being watershed specific. However, the methods are certainly transferable and a similar relationship could be determined for Canadian populations.

4) *Do data exist that could be used to estimate historic values of the character empirically or allow theoretical models to be parameterized?*

No, historical collections typically consisted of only dead specimens. Many of these specimens are contained within museum collections and are available for measurement. However, museum voucher collections are often small and do not capture the complete size distribution of the population. Small collections of dead specimens can be biased towards larger individuals who have succumb to natural mortality leading to size distributions skewed towards large size classes. Historical records for the Wavyrayed Lampmussel consist of only 12 live captures with sizes available for only 2 individuals (Metcalfe-Smith and McGoldrick 2003).

5) *Is the property currently being monitored with a frequency appropriate to measure its trend, if any?*

Yes, since 1997 detailed survey work has been conducted in areas where Wavyrayed Lampmussels are found (see references in Metcalfe-Smith and McGoldrick 2003 and McGoldrick *et al.* 2005). Length data for all live specimens and most dead shells are now collected as a matter of course whenever a species at risk is encountered, providing excellent size distribution information for current populations (Figure 4). Size distributions in the Grand, Thames and Maitland rivers as well as the Lake St Clair delta appear to be healthy with ample representation of all size classes. Note that the size distribution of the St Clair delta population is naturally shifted towards a smaller mean size suggesting that a separate length at age relationship will need to be developed for this population. Only two live animals have recently been found in the Ausable River and both animals were large relative to the other river populations (75mm, 78mm) (Metcalfe-Smith and McGoldrick 2003)

6) *If feasible suggest and justify briefly what a reasonable recovery target might be for this species on this property.*

At present, the existing Grand, Thames and Maitland River populations appear to be healthy – broad size distributions covering the entire known size range of the species, normally distributed, no bias towards small or large size classes. These size distributions can be used as suitable recovery targets for other riverine populations.

Body condition and size-at-age

1) *Is this character biologically relevant to the Wavyrayed Lampmussel?*

Yes. Body condition has been shown to be related to environmental stress, particularly the infestation rate of dreissenid mussels, in two other Canadian Lampsiline species (*Lampsilis cardium*, *Lampsilis siliquoidea*) (Metcalfe-Smith *et al.* 2005).

2) *Is there a theoretical or conceptual basis for describing a healthy condition on this character for the Wavyrayed Lampmussel?*

At this time there is no known reference condition for classifying a population as healthy based on body condition. Work is continuing in the delta area of Lake St Clair during 2005 to develop baseline body condition levels for unionids and to establish comparisons between relatively low stress areas and more highly impacted sites. It may be possible in the future to establish recovery targets based on comparisons with healthy populations in Canada or through the use of surrogates from the US.

3) *Do the technology and or analytical methods exist to estimate, measure or monitor this character if the funding were provided?*

Yes, Metcalfe-Smith *et al*. (2005) have employed standard techniques for determining Tissue Condition Indices (TCI) (Monroe and Newton 2001), fatty acid concentrations, and glycogen levels (alkaline digestion and phenol-sulphuric acid spectrophotometric method; Naimo et al. 1998; Naimo and Monroe 1999; Monroe and Newton 2001) for unionids in the Lake St Clair delta.

4) *Do data exist that could be used to estimate historic values of the character empirically or allow theoretical models to be parameterized?*

No.

5) *Is the property currently being monitored with a frequency appropriate to measure its trend, if any?*

No, not being monitored.

6) *If feasible suggest and justify briefly what a reasonable recovery target might be for this species on this property.*

Not possible at this time.

Pathologies and contaminants

1) *Is this character biologically relevant to the Wavyrayed Lampmussel?*

No. Although freshwater mussels are capable of bioaccumulating contaminants no specific contaminants have been implicated in the decline of the Wavyrayed Lampmussel. Similarly, parasite loads in unionids can be high (J. Carney, University of Manitoba, pers. comm. May 2005) and have been implicated in reproductive failure of other species (J. Carney, University of Manitoba, pers. comm. May 2005) but no evidence exists to suggest that this has played a role in the decline of the Wavyrayed Lampmussel.

2) *Is there a theoretical or conceptual basis for describing a healthy condition on this character for the Wavyrayed Lampmussel?*

No.

3) *Do the technology and or analytical methods exist to estimate, measure or monitor this character if the funding were provided?*

No.

4) *Do data exist that could be used to estimate historic values of the character empirically or allow theoretical models to be parameterized?*

No.

5) *Is the property currently being monitored with a frequency appropriate to measure its trend, if any?*

No.

6) *If feasible suggest and justify briefly what a reasonable recovery target might be for this species on this property.*

Not feasible.

Population structure

1) *Is this character biologically relevant to the Wavyrayed Lampmussel?*

Population structure is very important for the Wavyrayed Lampmussel. With the loss of this species from the offshore waters of Lake St Clair, Lake Erie and the Detroit River the remaining populations have become severely fragmented and isolated. Adult mussels are capable of relatively small movements, likely moving only a few 10's of meters per year and primarily in a downstream direction (Balfour and Smock 1995; Villella *et al.* 2004). The primary means of dispersal and connectivity between populations is through the movement of the host. However, host movement is generally small (less than 12 km Scott and Crossman 1998) and current populations are separated by large distances and instream barriers (dams, waterfalls) (Table 4).

2) *Is there a theoretical or conceptual basis for describing a healthy condition on this character for the Wavyrayed Lampmussel?*

Not applicable.

3) *Do the technology and or analytical methods exist to estimate, measure or monitor this character if the funding were provided?*

Not applicable.

4) *Do data exist that could be used to estimate historic values of the character empirically or allow theoretical models to be parameterized?*

The 10 populations identified in Table 4 represent the known historic extent of this species in Canada.

5) *Is the property currently being monitored with a frequency appropriate to measure its trend, if any?*

Yes, all currently extant populations are being or will be monitored through the long term monitoring program being established through the Ontario Freshwater Mussel Recovery Team and the other ecosystem recovery teams. The historic Great Lakes population is not currently part of this monitoring program but periodic surveys will confirm its status.

6) *If feasible suggest and justify briefly what a reasonable recovery target might be for this species on this property.*

Recovery at a population level will be achieved when all 6 currently extant subpopulations reach the levels specified under the other 11 recovery characteristics. Recovery of the Sydenham River, Lower Grand River and Lower Thames River subpopulations will occur when these populations are re-established and achieve the desired levels on the other characters. Ideally the Great Lakes population will be re-established however recovery to the desired levels is probably not possible as long as dreissenids are present.

Conclusions

No single recovery character examined during this analysis is sufficient to assess overall species status and to declare the Wavyrayed Lampmussel recovered. We feel that recovery of this species, and other freshwater mussels, must be assessed using a multi-level approach by including recovery characters from three different scales: individual, population and species.

Individual characters

The most likely individual character examined here is Body Condition. Several indicators of body condition have been identified as potential characters for the Wavyrayed Lampmussel including tissue condition indices (TCI), fatty acid levels, or glycogen content. At this time, glycogen levels appear to be the most likely character to use to indicate recovery; however, no reference conditions indicative of a healthy individual yet exist. The reference condition will have to be developed using either a surrogate species from the same watershed or using a healthy Wavyrayed Lampmussel population from another jurisdiction (e.g. the Clinch River population).

Population characters

The majority of recovery characters assessed here can be grouped as population level characters (abundance, range, minimum numbers, recruitment, population growth, sex ratios, and age and size distributions). As we have discussed, earlier historical information is lacking for many of these characters and most do not have clearly defined healthy reference conditions. Despite these limitations it is possible to develop reference points for assessing the recovery trajectory of a population. For a given population to be assessed as recovered its abundance and range must compare favourably with known or estimated historical levels; the population must be large enough, with a sex ratio close to 1, to facilitate reproduction at a level sufficient to produce recruitment (1-4% annually averaged over several years) and neutral to positive population growth. These characters must be met for a period sufficient to produce a size and age distribution that is normally distributed and not skewed towards larger older individuals.

Species characters

Spatial isolation and fragmentation of the historical distribution of this species has lead us to identify 6 extant and 4 extirpated Wavyrayed Lampmussel populations. Recovery at the species level can only be determined once the population characters have been achieved at a sufficient number of populations. For COSEWIC to downlist the Wavyrayed Lampmussel to Threatened a minimum of 6 populations must be considered recovered.

Summary

Recovery of the Wavyrayed Lampmussel will be a slow process given the long lifespan and delayed reproduction observed in this species (Appendix 2). Populations will be able to hang on for years, even decades, after reproduction has ceased and they have become functionally extirpated making the determination of recovery a complicated process. Assessing recovery of this species will be hindered by a lack of historical context as a reference condition. Very limited information exists detailing historic distributions and population levels. Most historical data come from museum records giving insight into broadscale watershed-level distributions but seldom is the resolution fine enough to define within watershed distributions and in no circumstances is it ever sufficient to quantify historic population levels. A detailed, comprehensive survey of the unionids within the range of the Wavyrayed Lampmussel has only been initiated during the last 15 years with detail sufficient for abundance estimates only during the last 5 years. Furthermore, life history characters for the Wavyrayed Lampmussel have never been fully assessed for any population in Canada or beyond.

The Wavyrayed Lampmussel has been devastated through a combination of slow gradual degradation and destruction of aquatic habitat through the growth and expansion of the human population in southern Ontario and through rapid catastrophic events like the invasion of non native species. The introduction of the zebra and quagga mussels into the waters of the Great Lakes has resulted in the complete loss of the lake populations and the effective isolation of the six remaining riverine populations (Table 4) which are now suffering under the heavy agricultural burden of these watersheds. We recommend that recovery of this species be assessed individually for each of these 6 remaining populations using a hierarchical combination of individual, population and species level criteria. Recovery and downlisting of the species can only be achieved when the lower level population and individual criteria have been met.

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Table 1: Estimated historical population abundance of the Wavyrayed Lampmussel in Canada.

Waterbody	**Length of reach (km)**	**Average width of reach (km)**	**Occupied Area (km^2)**	**Max density (#/km^2)**	**Min density (#/km^2)**	**Max abundance (millions)**	**Min abundance (millions)**
L. St Clair			790	8897.5	8897.5	7.0290	7.0290
Western L. Erie			825	35590	14236	29.3600	11.7447
Detroit R.	42	1	42	35590	14236	1.4957	0.5979
Lower Grand R.	44	0.1	4.4	396825.4	30303.03	1.7460	0.1333
Nith R.	10	0.05	0.5	396825.4	30303.03	0.1984	0.0152
Upper Grand R.	60	0.05	3	396825.4	30303.03	1.1905	0.0909
Ausable R.	55	0.03	1.65	396825.4	30303.03	0.6548	0.0500
Sydenham R	48	0.03	1.44	396825.4	30303.03	0.5714	0.0436
Lower Thames R.	20	0.06	1.2	396825.4	30303.03	0.4762	0.0364
North Thames R.	30	0.05	1.5	396825.4	30303.03	0.5952	0.0455
Middle Thames R.	25	0.03	0.75	396825.4	30303.03	0.2976	0.0227
South Thames R.	10	0.05	0.5	396825.4	30303.03	0.1984	0.0152
Maitland R.	45	0.05	2.25	396825.4	30303.03	0.8929	0.0682
Great Lakes			**1657**			**37.88**	**19.37**
Inland Rivers			**17.19**			**6.82**	**0.52**
Overall			**1674.19**			**44.71**	**19.89**

Table 2: Estimated current population abundance of the Wavyrayed Lampmussel In Canada.

Waterbody	**Length of reach (km)**	**Average width of reach (km)**	**Occupied Area (km^2)**	**Max density (#/km^2)**	**Min density (#/km^2)**	**Max abundance (millions)**	**Min abundance (millions)**
L. St Clair			5	558.7	495.3	0.0028	0.0025
Western L. Erie			0	-	-	-	-
Detroit R. *	0	1	0	-	-	-	-
Lower Grand R.	0	0.1	0	-	-	-	-
Nith R.	5	0.05	0.25	396825.4	30303.03	0.0992	0.0076
Upper Grand R.	60	0.05	3	396825.4	30303.03	1.1905	0.0909
Ausable R.	12	0.03	0.36	396825.4	30303.03	0.1429	0.0109
Sydenham R	0	0.03	0	-	-	-	-
Lower Thames R.	0	0.06	0	-	-	-	-
North Thames R.	30	0.05	1.5	396825.4	30303.03	0.5952	0.0455
Middle Thames R.	25	0.03	0.75	396825.4	30303.03	0.2976	0.0227
South Thames R.	10	0.05	0.5	396825.4	30303.03	0.1984	0.0152
Maitland R.	45	0.05	2.25	396825.4	30303.03	0.8929	0.0682
Great Lakes			**5**			**0.003**	**0.003**
Inland Rivers			**8.61**			**3.42**	**0.26**
Overall			**13.61**			**3.42**	**0.27**

Table 3: Sex ratio for L. fasciola from 5 sites on the Thames River. All 5 sites were surveyed once using a timed-search method without excavation of the substrate and a second time using a stratified random design with excavation of 1 m^2 quadrats (TJM and JLM, unpublished data).

	timed searches	quadrat excavations
male	3	16
female	20	14
ratio (male:female)	0.15	1.14

Table 4: Recommended population management units based on isolation.

Population	Nearest neighbouring extant population	Separation (km)	Barrier	Comments
Grand River	South and Middle Thames R.	550	Caledonia Dam, Dunnville Dam	Separated from all other populations by 2 barriers and a large stretch of uninhabitable (dreissenid infested) lake habitat.
North Thames	South and Middle Thames R	17	Fanshawe Dam, Springbank Dam	Isolated from the South and Middle Thames population by the large Fanshawe Dam which likely serves as a barrier to movement of the host species.
South and Middle Thames	North Thames R.	17	Fanshawe Dam, Springbank Dam	See above.
Lake St Clair delta	Ausable R.	90		Large extent of dreissenid infested habitat.
Ausable River	Maitland R.	75	Falls @ Benmiller	Major natural barrier to host dispersal.
Maitland River	Ausable R.	75	Falls @ Benmiller	See above.
Sydenham River				Extirpated, possible reintroduction site.
Lower Grand River				Extirpated, possible reintroduction site.
Lower Thames River				Extirpated, possible reintroduction site.
Great Lakes				Extirpated, unlikely to be reintroduced as long as dreissenids are present

Figure 1: The Wavyrayed Lampmussel (Lampsilis fasciola): male (upper right, female (lower left). Photo courtesy of S. Staton, Fisheries and Oceans Canada.

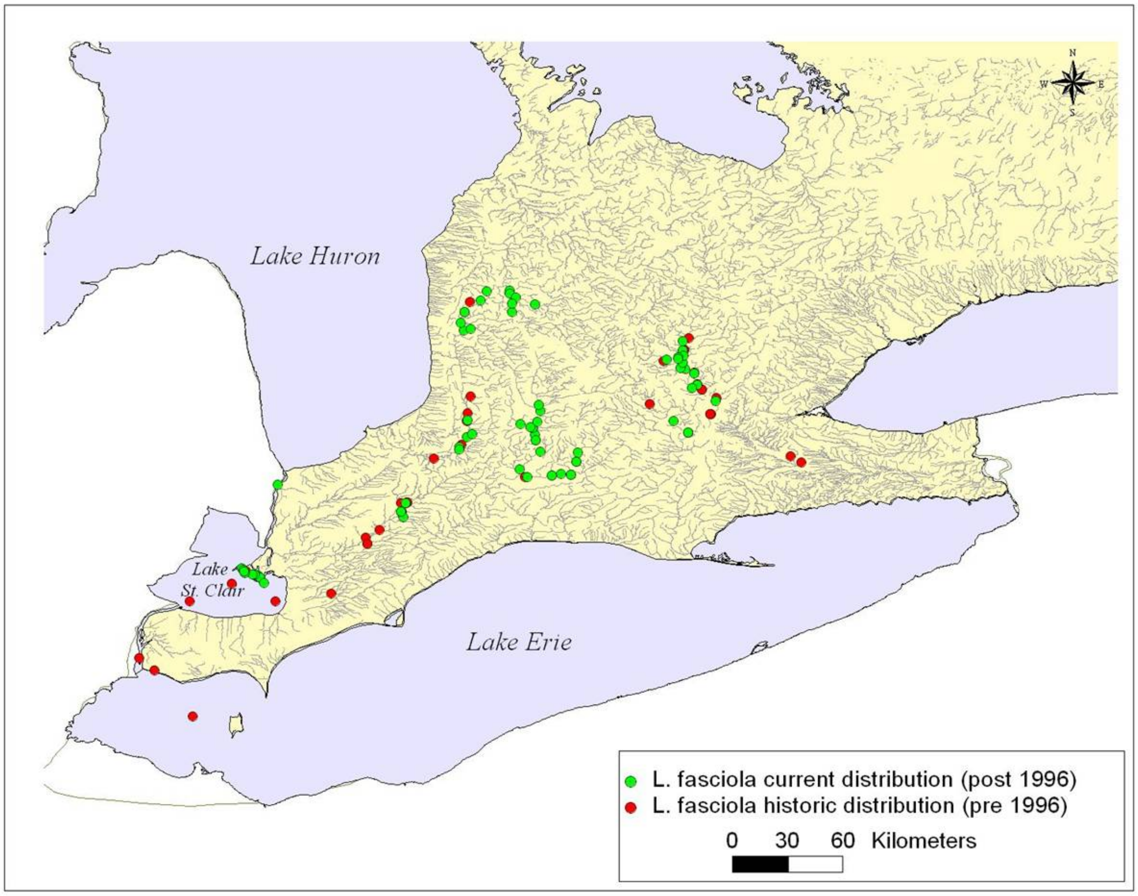

Figure 2: Canadian distribution of the Wavyrayed Lampmussel.

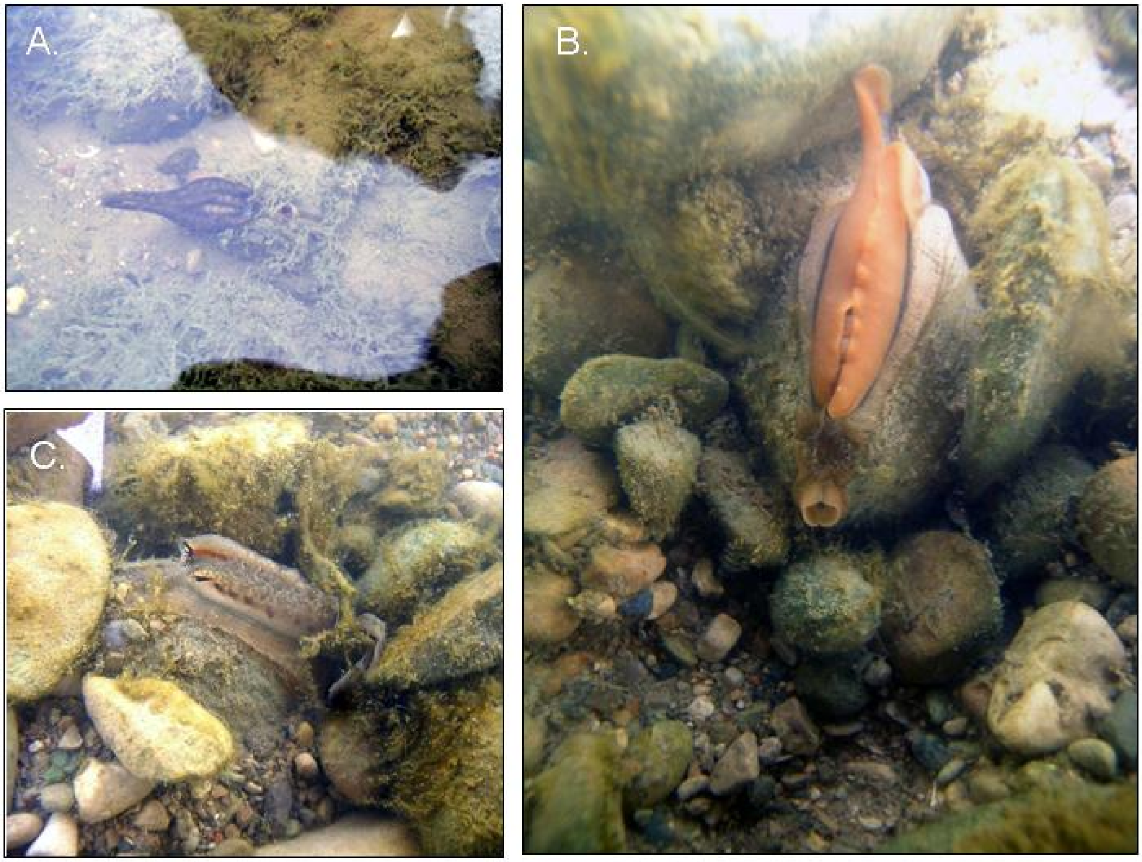

Figure 3: Three lure morphologies of the Wavyrayed Lampmussel: black (a), red (b) and fish-like (c). All three animals were observed in the North Thames River during 2004.

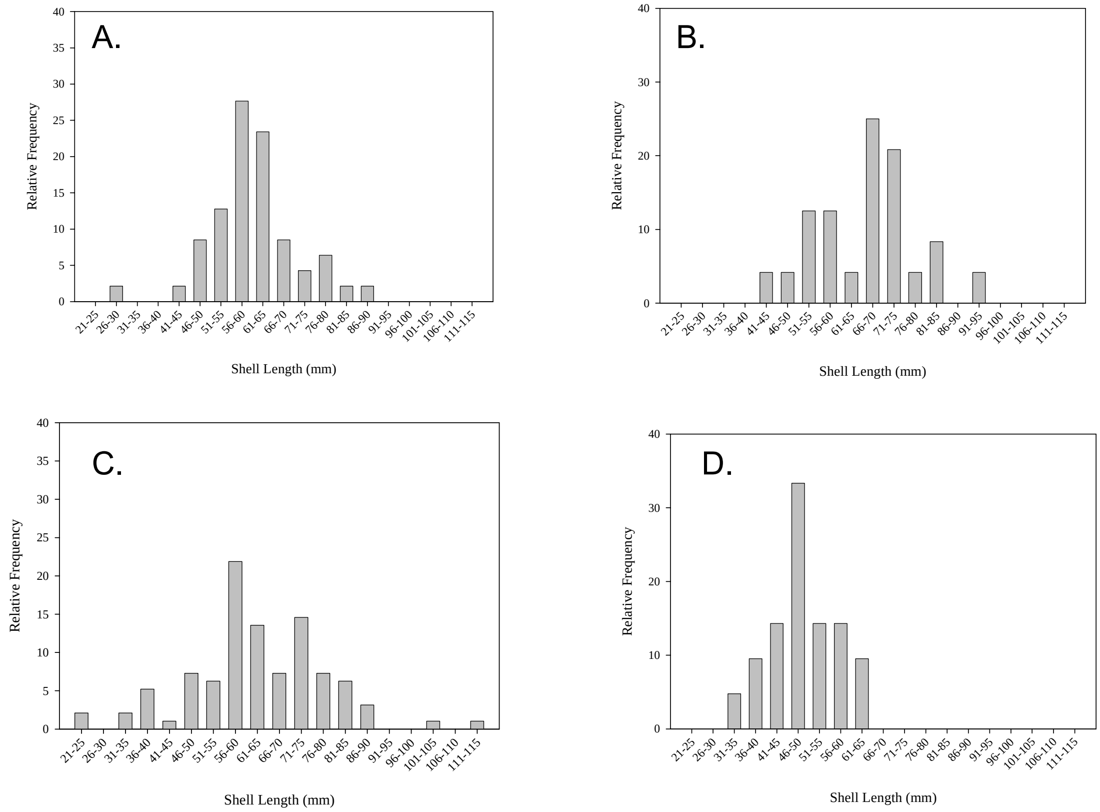

Figure 4. Size class distribution of Wavyrayed Lampmussels collected in the Grand River between 1997 and 2004 (A), Maitland River between 1998 and 2004 (B), Thames River between 1997 and 2004 (C) and delta area of Lake St. Clair between 1999 and 2004 (D). (Reproduced from McGoldrick et al. 2005).

Appendix 1: Quick reference table of recovery characters for the Endangered Wavyrayed Lampmussel (*Lampsilis fasciola*).

	Biologically relevant?	Theoretical or conceptual basis?	Technology and/or analytical methods exist?	Do data exist to estimate/model?	Currently monitored at appropriate frequency?	Recovery target
Ecological properties	Yes. Mussels are an integral part of the aquatic ecosystem structuring both water column and sediment processes.	No. Vaughn et al. are best bet but difficult to come up with a healthy condition.	Methods likely exist if we had a reference condition.	No.	No, not monitored.	Not feasible at this time.
Abundance and biomass	Yes.	Yes – very rough estimates of historical abundance.	Yes – estimates of density obtained through monitoring programs.	Yes – see table at back. These estimates use current density estimates from the Thames (min, max and avg) as well as NWRI estimates from the delta for current estimates. Historical estimates are based on Nalepa and Nalepa and Schloesser for the GL and the current Thames numbers for rivers.	Yes – mussel monitoring programs of the Ontario Freshwater Mussel Recovery Team and other aquatic ecosystem recovery teams.	Historical abundance levels.
Range/area occupied	Yes.	Yes – very rough estimates of historical range.	Yes – timed search data provide estimates sufficient to use in range definition.	Yes – see table 2 and 3.	Yes - we have a pretty good handle on the current range and it is unlikely to change rapidly without our noticing.	Historically occupied range.
TEK	No.					
Minimum number of individuals	Yes – minimum local density required to facilitate reproduction.	Conceptual work of Downing *et* al. (2003) with *Elliptio*	Yes. Techniques of Downing *et al.* (2003) could be applied to	No.	No.	Not feasible at this time but evidence of recruitment at local

	Biologically relevant?	Theoretical or conceptual basis?	Technology and/or analytical methods exist?	Do data exist to estimate/model?	Currently monitored at appropriate frequency?	Recovery target
		complanata.	Wavyrayed Lampmussel populations however the need to sacrifice animals may prohibit their use with species at risk.			Densities ≤ 3/m^2 suggest this may not be a sensitive indicator for the species.
Productivity-recruitment	Yes.	Other stable Lampsiline populations show recruitment rates of 1-4% (*L. cariosa* in Cacapon River WV)	Yes – Villella *et al* (2004).	Not currently	No.	At a minimum must be greater than 0 but can use the value of *L. cariosa* as surrogate.
Productivity-population growth rate	Yes	Must be positive.	Yes – Villella *et al.* (2004).	No.	No.	Population growth rate must be greater than one for population abundance to recover.
Sex composition	Yes	Yes – *Quadrula fragosa* habitat viability workshop report suggests sex ratio of 1:1 in healthy population with male biased ratio in imperiled populations	Yes – but must use quadrat surveys – sex ratio for wrl is highly biased towards females if only timed search data are used but much closer to 1:1 when quadrats included. Highly variable by watershed	Yes – see McGoldrick *et al.* (2005).	Yes, if monitoring program fully implemented. Must be done in all watersheds	1:1 but probably not sensitive.
Age/Size composition	Yes	Yes – normally distributed, not skewed.	Yes – easy to measure.	Yes –size distributions exist for current state but not historical. Size can be converted to age with appropriate relationships.	Yes.	Normally distributed, not skewed.
Body condition	Yes	Not a present time.	Yes – can use Tissue Condition Indices (TCI), fatty acid concentrations or glycogen levels. All are currently being employed with mussel	No.	No.	Could be developed using surrogate species or surrogate population.

	Biologically relevant?	Theoretical or conceptual basis?	Technology and/or analytical methods exist?	Do data exist to estimate/model?	Currently monitored at appropriate frequency?	Recovery target
			species at risk in the St Clair delta			
Pathologies and contaminants	No evidence this character is relevant for this species as pathologies and contaminants have not been implicated in its decline.					Not an appropriate character
Subpopulation structure	Yes			Yes – identified 6 extant subpopulations and 4 extirpated populations.	Yes.	All other recovery targets should be evaluated at the population level. Cumulative population recovery will lead to species level recovery.

Appendix 2: Summary table of population characteristics for the Wavyrayed Lampmussel (*Lampsilis fasciola*).

Population characteristic	Life history	Distribution	Abundance
Life span	33 yrs (Henley *et al.* 2002)		
Age at first reproduction	4-6 yrs (pers. comm. S. Hanlon, USFWS, 2005)		
Reproductive potential	High		
Sex ratio (M:F)	1.06:1 SD=0.762 (McGoldrick *et al.* 2005)		
Morphometric plasticity	Low		
Other species as habitat?		Yes-smallmouth bass, largemouth bass, mottled sculpin (McNichols and Mackie 2004)	
Status of habitat species?		stable	
Migratory?		No	
Diadromous/marine/or freshwater		Freshwater	
Sensitivity to contaminants	High (McGoldrick *et al.* 2005)		
Historic range		1674 km^2	
Current range		20 km^2 (1.2% of historic range)	
Edge of range?		yes	
Historic abundance (millions)			19.89 – 20.69
Current abundance (millions)			0.26 – 3.42 (minimum 85% decline)
Main reason for listing		Habitat loss – dreissenid mussel in Great Lakes, agricultural and urban impacts in rivers	
Possibility of rescue effect			Low