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Biodiversity of freshwater mussels in the lower Great Lakes Drainage Basin

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MANAGEMENT PERSPECTIVE

North America is home to the richest freshwater mussel fauna in the world. Over the past century, however, mussels have suffered severe declines in diversity and abundance due to commercial harvesting, human alterations of aquatic habitats, water pollution and, most recently, the invasion of the zebra mussel. In the United States, freshwater mussels have been protected under endangered species legislation for nearly 30 years. A national strategy for the conservation of native mussels was drafted in 1995, and recovery plans are in place for 42 of their 57 listed species. With the formation of the Mollusc Working Group (MWG) in 1995, the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) officially recognized mussels as one of the most threatened groups of invertebrates in Canada. The MWG is charged with preparing a national list of mollusc species at risk and preparing status reports on them. Two of the authors of this report (J.L. Metcalfe-Smith and G.L. Mackie) are members of the MWG.

This project examined trends in the biodiversity of freshwater mussels in the lower Great Lakes drainage basin over the past 140 years. The data revealed a pattern of species losses and changing community composition throughout the basin, particularly in the formerly species-rich Lake Erie and Lake St. Clair drainages. River systems that once supported numerous species characteristic of a wide variety of habitats are now dominated by fewer siltation- and pollution-tolerant species. One of the most significant contributions of the project was a list of candidate species to be considered for national status designation by COSEWIC.

As a result of the 1992 Convention on Biological Diversity, biodiversity has become one of Environment Canada's top issues. The Canadian Biodiversity Strategy requires the federal government to participate in and support COSEWIC. This project specifically addressed one of the departmental priorities by providing biodiversity objectives based on the mussel fauna for ten waterbodies in the study area. The project also supports the Canada-Ontario Agreement Respecting the Great Lakes, which has called for an inventory of the diversity of biota in the Great Lakes.

ABSTRACT

Severe declines in the diversity and abundance of freshwater mussels have been documented over the past century in the United States. Although similar trends might be expected in Canada, freshwater mussels (and aquatic invertebrates in general) have received little attention to date. This imbalance was addressed in 1995, when the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) recognized freshwater mussels as one of the most threatened groups of invertebrates in Canada and formed the Mollusc Working Group to assess the conservation status of Canadian mollusc species at risk. The lower Great Lakes drainage basin, which historically supported the most diverse and unique mussel fauna in Canada, was given first priority for the study of mussel biodiversity. The objective of this project was to develop a computerized, GIS-linked database on the historical distributions of freshwater mussels in the lower Great Lakes drainage basin, and use this information to assess the conservation status of mussel species and communities throughout the study area. Over 4000 collection records obtained from numerous sources, including natural history museums, the primary literature, government reports and university theses, and spanning a 140-year period from 1860 to 1996, were compiled and examined together for the first time. Distribution maps were prepared for the 41 species native to the study area; biodiversity objectives based on species richness were developed for ten of the major waterbodies; historical and recent data were compared to determine if diversity is declining; a list of candidate species to be considered for national status designation by COSEWIC was prepared; and species-rich areas that should be protected were identified. Comparisons of historical and recent data revealed a pattern of species losses and changing community composition throughout the basin, particularly in the formerly species-rich Lake Erie and Lake St. Clair drainages. River systems that once supported numerous species characteristic of a wide variety of habitats are now dominated by fewer siltation- and pollution-tolerant species of the Subfamily Anodontinae. The data suggest that fully 40% of the 41 native mussel species would fall into the Extirpated, Endangered or Threatened risk categories as defined by COSEWIC. The results of this study show that conservation efforts are urgently needed to maintain and recover these unique components of aquatic biodiversity.

INTRODUCTION

North America is the world centre for the evolutionary radiation of freshwater bivalves (Barr 1996), and the greatest diversity of freshwater mussels, nearly 300 species, occurs on this continent. Over the past century, this rich fauna has been decimated by commercial harvesting, habitat destruction, water pollution and, most recently, the invasion of the exotic zebra mussel *Dreissena polymorpha* (Biggins *et al.* 1995). In a recent assessment by the American Fisheries Society (Williams *et al.* 1993), 72% of native mussel species were listed as extinct, endangered, threatened or of special concern and only 24% as currently stable. Similarly, The Nature Conservancy recognizes 55% of the mussel fauna as imperiled, in contrast to only 7% of birds and mammals. No other widespread animal group in North America approaches this level of faunal collapse.

The vulnerability of native mussels to anthropogenic impacts can be attributed in part to a unique life history trait: they have an intermediate larval stage that is an obligate parasite on fish (Neves 1993). Female mussels brood their young from the egg to the larval stage in their gills, then expel the larvae, termed glochidia, into the water where they must attach to the gills or fins of an appropriate fish host in order to complete their metamorphosis. After a period of encystment ranging from 1 to 25 weeks, depending on the species (Cummings and Mayer 1992), the juvenile mussel detaches from its host and falls to the substrate to complete its development into a free-living adult. Some species may successfully use a variety of fishes, but the majority are host-specific to some degree (Neves 1993). It is because of this dependency that mussels are so sensitive to perturbations of the freshwater ecosystem (Bogan 1993). Not only are they threatened by disturbances that impact them directly, but also those that affect their host fish populations. In several cases, mussel species have become functionally extinct due to the disappearance of host fish (Bogan 1993).

According to Williams *et al.* (1993), the single most important cause of the decline of freshwater mussels during the last century is the destruction of their habitat by siltation, dredging, channelization, the creation of impoundments, and pollution. In come cases, dams have resulted in the loss of 30% to 60% of the mussel fauna, mainly due to the elimination of host fish. Erosion due to deforestation, poor agricultural practices and the destruction of riparian zones, causes an increase in siltation and shifting substrates that can smother mussels. As noted by Bogan (1993), domestic sewage, effluents from paper mills, tanneries, chemical industries and steel mills, acid mine runoff, heavy metals and pesticides have all been implicated in the destruction of mussel fauna.

While factors such as these have been causing the reduction and extirpation of mussel populations for many years (Nalepa and Gauvin 1988; Gillis and Mackie 1994), the recent introduction of the zebra mussel to the Great Lakes has led to catastrophic declines of native mussels in infested areas. Zebra mussels attach to the shells of mussels and interfere with normal activities such as feeding, respiration and burrowing (Nalepa *et al.* 1996). Ricciardi *et al.* (1996) postulate that zebra mussels kill native mussels by robbing them of the energy reserves they need to survive the winter. Zebra mussels have virtually eliminated native mussels from Lake St. Clair (Nalepa *et al.* 1996), western Lake Erie (Schloesser and Nalepa 1994) and the upper St. Lawrence River (Ricciardi *et al.* 1996).

In the United States, freshwater mussels have been protected under endangered species legislation since 1969 (Neves 1993). The U.S. Fish & Wildlife Service recently drafted a national strategy for the conservation of native mussels (Biggins *et al.* 1995), and recovery plans are in place for most of their endangered species (U.S. Fish & Wildlife Service 1996). The plight of mussels in Canada was recognized by the Committee on the Status of

Endangered Wildlife in Canada (COSEWIC) in 1995, when they expanded their mandate to include invertebrates for the first time. Working groups were formed to address the two most threatened groups of invertebrates, namely, the Mollusca (which include freshwater mussels) and the Lepidoptera (the moths and butterflies). Two of the co-authors of this report, Dr. G.L. Mackie and Ms. J.L. Metcalfe-Smith, are members of the Mollusc Working Group of the Mollusca and Lepidoptera Subcommittee. The mandate of COSEWIC is to develop a national list of Canadian wildlife species at risk and to prepare status reports on these species (Cook and Muir 1984). Recovery plans for the most endangered species are then prepared and implemented under the Recovery of Nationally Endangered Wildlife (RENEW) strategy. To date, the Mollusc Working Group has put forward draft status reports on two species of snails. Several of the provinces are independently compiling information on endangered flora and fauna, including Ontario's Natural Heritage Information Centre in Peterborough, Ontario.

The project focused on the lower Great Lakes drainage basin for two reasons. First of all, this area historically supported the most diverse mussel fauna in Canada. Forty-one of the 54 Canadian species occur here, and 22 of these are found nowhere else in Canada (see Clarke 1981). All are members of the Family Unionidae, hence the terms "mussels" and "unionids" will be used interchangeably throughout this report (the Family Margaritiferidae is not represented in the study area). The Lake Erie and Lake St. Clair drainages in particular are home to the richest mussel fauna in the country. Secondly, zebra mussels have decimated native mussels in the lower Great Lakes, leaving the rivers and streams of the drainage basin as the last refuge for many species. In his review of the freshwater Mollusca of the Mixedwood Plains Ecozone, Barr (1996) recommended that this area of southwestern Ontario be given first priority for the monitoring and study of mussel populations. Conservation measures are urgently needed to maintain and recover these unique components of aquatic biodiversity.

The objective of the project was to develop a computerized, GIS-linked database on the historical distribution of freshwater mussels in the lower Great Lakes drainage basin. The database was then used to: update the species distribution maps, which had not been done since Arthur H. Clarke published "The Freshwater Molluscs of Canada" in 1981; develop biodiversity objectives for various waterbodies within the study area; conduct time-trend analysis to determine if diversity is declining; identify the species most at risk as well as species-rich areas that should be protected; and reveal data gaps. The project directly supports the activities of the Mollusc Working Group of COSEWIC, and addresses several elements of the Canadian Biodiversity Strategy (Biodiversity Working Group 1995), i.e., maintaining viable populations of wild flora and fauna in their natural habitats, restoring individual species, and conducting biological inventories that take into consideration vulnerable, threatened and endangered species. It also supports the Canada-Ontario Agreement Respecting the Great Lakes (COA), which has called for an inventory of the diversity of biota in the Great Lakes.

MATERIALS AND METHODS

Study Area

The study area consisted of the lower Great Lakes, i.e., Lake St. Clair, Lake Erie and Lake Ontario, their connecting rivers, and all watersheds draining into the lakes within the boundaries of the Province of Ontario (Map 1).

Data Compilation

Data sources for the project included the primary literature, natural history museums, federal, provincial and municipal government agencies (and some American agencies), conservation authorities, Remedial Action Plans for the Great Lakes Areas of Concern, university theses and environmental consulting firms. In all, approximately 70 individuals from various agencies were contacted for information (Table 1). All papers, reports and unpublished material from which data were taken are listed in the References section.

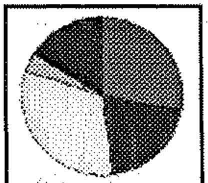

Figure 1

Mussel collections held by natural history museums in the Great Lakes region were the primary sources of information, accounting for over two-thirds of the data acquired (Fig.1). Data format varied considerably from museum to museum. The only records available in computerized format were those of the Ohio State University Museum of Zoology (OSUMZ). Records from the Canadian Museum of Nature (CMN) were computerized at our request, and all uncatalogued specimens from the study area were included. Both museums charged a fee for these services. Data from the Rochester Museum and Science Center (RMSC) were available in hard copy. The only way to retrieve data from the Royal Ontario Museum (ROM), Buffalo Museum of Science (BMS) and University of Michigan Museum of Zoology (UMMZ) was to personally visit each museum and record the data directly from the collections, i.e., from the catalogue books and/or labels stored with the specimens. This was a very time-consuming task. As very little of the data from any source had been geo-referenced, another time-consuming task was to assign coordinates (lats and longs) to collection sites based on descriptions of site locations. This was necessary in order to perform GIS functions with the data. Coordinates were assigned using 1:50,000 Energy, Mines, and Resources Canada topographical maps. In some cases, coordinates were generated using the software package SPANSMAP Version 1.4 on digital base maps provided by the Geomatics Office of Environment Canada, Burlington, ON. For many species, the nomenclature has changed several times over the years. This can be particularly problematic when dealing with old museum records. To address this problem, a partial synonymy was developed (Table 2). Taxonomy for all records was standardized to the nomenclature most recently adopted by the Freshwater Mussels Subcommittee of the American Fisheries Society Endangered Species Committee (Williams *et al.* 1993). As part of our agreement with the various museums, the completed data were returned to the curators in a computerized and geo-referenced format.

Creation of the Database

The mussel database was created using the software program MS (Microsoft)-ACCESS Version 7.0 to store and combine data from the various sources. ACCESS is the standard database program used by Environment Canada. It is a powerful relational database that allows tables of data to be linked to other tables by means of common variables. The database can thus be queried in numerous ways, while maintaining data integrity. The mussel database consists of two tables. The first table contains information on the collection sites, including fields for: collection identification number (COLNO), organization (museum, university, etc.), name(s) of collector(s), collection date, waterbody name, primary drainage, diversity (number of species collected on that date), locality name, description of sampling location, and geographical coordinates (lats and longs). The second table contains information on the specimens, including fields for: catalogue number (for museum specimens), genus and species, number of specimens collected live and dead, and COLNO. COLNO is the common variable that links the two tables. The database can be queried in several ways, e.g., by species to determine distributions, or by site to determine patterns of diversity and species composition. Trends over time can also be assessed. Queries of selected data from the ACCESS database can be imported into SPANSMAP to generate maps illustrating a wide range of results, such as species distributions and the locations of high diversity sites. The software also allows the user to "zoom in" for higher resolution.

Limitations of the Data

According to Steedman *et al.* (1996), a "...key use of historical information is to help calibrate present expectations regarding the productivity, diversity, and stability of the natural systems upon which humans depend." In the context of the present project, historical information will be used to provide realistic targets for the diversity of the mussel fauna of the various lakes, rivers and streams throughout the study area. In the absence of healthy, relatively undisturbed ecosystems from which targets can be derived directly, historical information is the only option. Unfortunately, historical data such as these, which were gathered over a 140-year period for various unrelated purposes rather than with "strategic foresight", are fraught with inconsistencies. Steedman *et al.* (1996) cautioned that historical information is generally of low resolution, and should only be used to specify qualitative generalizations about past ecosystem states and processes. Nevertheless, they concluded that historical information has significant potential to direct aquatic habitat management in the Great Lakes. The specific limitations that apply to the current data set are described below:

(1) *Collection sites not adequately described*: For some collection sites, geographical coordinates could not be assigned precisely, and in some cases not at all. As long as the name of the waterbody was provided, the data could be used to develop biodiversity objectives or determine species composition for that waterbody. However, data for which no coordinates could be assigned were obviously excluded from any mapping applications.

(2) *Collection dates missing*: Collection dates were missing from many of the older museum records. As many of these records were considered too important to omit, "most probable" collection dates were assigned based on the period during which the collector was active. In cases where an individual did most of his or her collecting within a single decade, the first year of the decade was arbitrarily assigned to the record. As the majority of missing collection dates were well before the cut-off date of 1960 used in the time trend analysis (see below), these estimates should have little if any effect on interpretation.

(3) *Collection of live vs. dead specimens*: The number of specimens collected live vs. dead was not always recorded. With the exception of the OSUMZ, this was particularly evident with the museum records. Some other data sources, particularly the academic surveys of recent years, did make this distinction. When the information was available, the numbers of specimens collected live and dead were entered separately in the corresponding fields. When the information was not available, the specimens were assumed to have been collected dead, i.e., as empty shells. Based on personal experience with the collections of the ROM, UMMZ and BMS, however, the majority of museum specimens were in excellent condition and would be considered "fresh dead". We submitted shells in similar condition to a recognized expert (Dr. D.L. Strayer, Institute of Ecosystem Studies, Millbrook, NY) for examination, and he estimated that the animals would have been living within the past 1 to 3 years. For the purpose of this project, all records were given equal value and treated as an "occurrence"

from a given location. We recognize that this assumption could lead to underestimates of changes in species composition and species losses. However, it will not affect the setting of biodiversity objectives, because even the occurrence of a weathered shell in a particular waterbody is evidence that the waterbody was at one time capable of supporting the species.

(4) *Variable sampling effort*: Sampling effort varied greatly, ranging from amateurs picking up a few shells for their collections to Ph.D. students conducting intensive sampling for their thesis research. The number of species collected from a given site is, of course, related to the effort expended. Furthermore, the probability of encountering a common species is probably good regardless of effort, whereas the probability of encountering a rare species increases significantly with additional effort. For example, Strayer *et al.* (1996) determined that species with population densities sparser than 0.01-0.1 m^{-2} may escape detection with efforts of up to 10 person-hours using randomly-placed quadrats. Clearly, bias due to sampling effort is of greatest concern when evaluating trends for the less common species. A measure of sampling effort was usually available for the academic surveys, which generally took place after about 1960. However, no information of this nature was available for the museum specimens, which constitute the major portion of the data. Intuitively, one would expect the academic surveys to involve greater efforts than the amateur collections. The fact that the percentage of sites where only one species was collected was higher before 1960 (60%) than after 1960 (40%) supports this hypothesis. However, it is always possible that an amateur spent a great deal of time at a given site trying to locate one particular species missing from his or her collection. Sampling effort bias has implications for identifying the species most at risk, and will be considered in detail in that section of the report.

RESULTS AND DISCUSSION

Species Distributions

The database currently consists of nearly 4200 records collected from approximately 1500 sites between 1860 and 1996. A record is defined as the occurrence of a given species at a given location on a given date. Map 2 shows the locations of all collection sites represented in the database. A total of 41 species of unionids belonging to three subfamilies were historically found within the study area (Table 3). Cummings and Mayer (1992) describe the key distinguishing features of the subfamilies as follows: Ambleminae usually have thick and solid shells, well developed teeth, indistinct sexual differences in the shell, and are usually found in streams and occasionally in lakes or large impoundments; Anodontinae usually have thin shells, absent, reduced, or poorly developed teeth, indistinct sexual differences in the shell, and are found in ponds, lakes, or the quiet water areas of streams; Lampsilinae have thin to moderately thick shells (often with brightly coloured rays or bands), well developed teeth, apparent sexual differences in the shell, and are found in streams and occasionally in lakes or other impoundments.

Distribution maps for all species are presented in Maps 3 to 43. These maps display all known occurrences of each species between 1860 and the present. The database used to prepare the maps contains over 1200 records that were collected after the most recent previous synopsis of species distributions was published (Clarke 1981). Most of the 41 species listed in Table 3 as occurring in the lower Great Lakes are consistent with Clarke (1981); however, records for two additional species (*Epioblasma obliquata perobliqua* and *Alasmidonta undulata*) were found. It appears that *E. o. perobliqua* was not previously recognized as a Canadian species. However, Johnson (1978) reported the collection of this species from the Detroit River at Bois Blanc Isle, Essex Co., ON, based on specimens held by the UMMZ. Although these specimens have since disappeared from the museum's collection, their validity has been confirmed (Dr. J.B. Burch, UMMZ, personal communication). There are also records for this species from the American shores of Lake Erie and the Niagara River. Four records for *A. undulata* were found, including a very recent record from the Trent-Severn Waterway. Although museum records for *Anodonta implicata* (the Alewife Floater) were also found within the study area, they were considered erroneous since this species is not known to the Great Lakes region (Clarke 1981). This conclusion is supported by Strayer and Jirka (1996), who noted in their review of the pearly mussels of New York State that most museum collections contained specimens identified as *A. implicata* that were in fact large, atypical variations of *Pyganodon* spp. The original identifications had been made before malacologists had developed a clear means of differentiating these similar species.

The distributions of mussel species are a consequence of their post-glacial re-invasion routes, which followed those of their host fish (Barr 1996). Based on Mandrak and Crossman's (1992) interpretation of the dispersal patterns of freshwater fishes in Ontario, Barr (1996) divided the current ranges of freshwater mussels into two basic distribution patterns: primarily southwestern and primarily northeastern. The majority of species in the study area are southwestern (Mississippian) in origin, whereas five species are northeastern (Atlantic Coastal), and one (*Strophitus undulatus*; Map 37) may have re-invaded via both routes. *Elliptio complanata* (Map 10) is the most common northeastern species in the study area; the other four species (*A. undulata*, *Lampsilis radiata radiata*, *Obovaria olivaria* and *Pyganodon cataracta*; Maps 5, 18, 27 and 32, respectively) are mainly found in the Atlantic drainage where all except *O. olivaria* are still common. In his discussion of contemporary distribution patterns of unionids within the Mixedwood Plains Ecozone (which includes our study area), Barr (1996) characterized three range types: local (species occupying no more than 30% of the zone), widespread (species occupying 30% to 80% of the zone), and pan-regional (species occupying more than 80% of the zone). The majority of species (60%) were found to have local ranges. Barr (1996) concluded that mussel fauna of the Mixedwood Plains Ecozone consists primarily of species with local distributions, centred in the southwestern portion of the Ecozone. This is significant for two reasons. First of all, species with restricted ranges (e.g., *Cyclonaias tuberculata*; Map 9) are particularly vulnerable to loss, as a disturbance in a single watershed could have serious consequences for the species as a whole. Secondly, the southwestern portion of the Ecozone has suffered "...some of the most intense human habitat exploitation in all of Canada" (Barr 1996).

Biodiversity Objectives

The development of ecosystem-based biodiversity objectives is one of Environment Canada's priorities in response to the Canadian Biodiversity Strategy. Objectives based on the diversity of native mussel fauna provide an excellent yardstick' by which to measure the biological integrity of aquatic ecosystems for several reasons. According to Biggins *et al.* (1995), "Because of their longevity, immobility, and sensitivity to water pollution, their presence or absence is a reflection of a river's water and habitat quality". Mussels are also strongly linked to the aquatic community because of their dependency on healthy populations of host fish species. Diverse and abundant populations of mussels are therefore highly representative of unimpacted aquatic communities. As the loss or decline of mussel communities provides a warning that other aquatic species and the integrity of the ecosystem are at risk (Biggins *et al.* 1995), managing watersheds for their survival should ensure the survival of other aquatic organisms.

Species Richness

The simplest biodiversity objective is "species richness", which is defined in this context as the total number of species that a system has been known to support in the past. Species richness objectives were developed for 10 waterbodies in the study area for which a reasonable amount of data existed (Map 44). From a west to east direction, these are: Lake St. Clair and the Detroit River (105 records available), Sydenham River (446), Thames River (408), Lake Erie (1145), Grand River (968), Niagara and Welland Rivers (133), Lake Ontario (241), Trent-Severn River (62), Moira River (211) and Rideau River (86). The objectives are presented in Table 4. It is evident from these numbers that the Lake St. Clair and Lake Erie drainages have the capacity to support a much more diverse mussel fauna than the Lake Ontario drainage. Almost all 41 species have been found in the former drainages, but only 22 species have been found in the latter (see Table 3). As mentioned earlier, the distribution patterns of unionids are closely linked to the distribution patterns of their host fish. The Lake St. Clair and Lake Erie drainages were populated from the species-rich Ohio-Mississippi system when glacial melt water from that region flowed south (Clarke 1981). Mandrak and Crossman (1992) showed that the distributions of 23 fish species originating from the Mississippian refugium are limited to southwestern Ontario, and suggested that many of these species are at their thermal tolerance limit. It is possible that some of these fishes may serve as hosts for several of the rare mussel species of southwestern origin for which no hosts have yet been identified. Although Lake Ontario has only a slightly lower total fish diversity than Lake Erie, warm water habitats in Lake Ontario are extremely limited. This essentially means that there are fewer species of fish, and also fewer individuals, throughout much of Lake Ontario than Lake Erie, which effectively limits the occurrence of many mussel species. Also, because 85% of mussel species in the study area are southwestern in origin, it is most likely that their host fish will be warm-water species.

To determine if mussel diversity has declined over time, and to evaluate the current status of mussel communities throughout the study area, the biodiversity objectives were compared with species richness values for two time periods. The "historical" time period was defined as before 1960 and the "recent" time period as after 1960. The choice of 1960 as the cut-off date was somewhat arbitrary, but was influenced by the fact that approximately equal numbers of sites were sampled during each time period (679 and 797, respectively). Later cut-off dates were used in those cases where too few records existed prior to 1960 (these exceptions are noted). The results are presented in Table 4. In most cases, the biodiversity objective was greater than both the historical and recent species richness values. This would be expected, as the objective represents the combined efforts of all collectors in both time periods. However, it is apparent that diversity declined in most waterbodies after 1960, despite the fact that sampling effort actually *increased*. Interestingly, the data show that there have been no losses of diversity in the Moira and Trent-Severn Rivers, which drain into Lake Ontario. Although there is an apparent loss of species in the Rideau River, there were only 21 records available for the recent time period (1960 to 1985). A fairly intensive survey conducted by Schueler (1996) in 1995 yielded three additional species, and will contribute 52 more records to the database (the data have not yet been entered). Taken together, these results suggest that the mussel communities of the Lake Ontario drainage have not suffered the declines that have occurred in the Lake St. Clair and Erie drainages. For detailed information on the presence/absence of individual species in each waterbody during the historical and recent time periods, see Appendix I. Analysis of trends on a finer scale (i.e., over shorter periods of time) was, in our opinion, precluded by the limitations of the data that were discussed earlier.

There is evidence that mussel diversity in the Grand, Sydenham, and Thames Rivers, which are the largest and richest river systems within the study area, has declined precipitously in recent years. Mackie (1996) recorded a total of 22 species (18 live and 4 dead) from the Grand River in 1995; Morris (1996) reported identical numbers for the Thames River in the same year; and Clarke (1992) found 25 species (23 live and 2 dead) in the Sydenham River in 1991. When compared with the corresponding biodiversity objectives, these findings represent species losses of 37 to 49% from the Grand River, 31 to 44% from the Thames River, and 24 to 30% from the Sydenham River. By the most conservative estimates, i.e., assuming that dead shells represent viable populations of a given species, the results document species losses of 24 to 37%. As these watersheds represent the last refugia for several rare species, the results portend an alarming trend toward increasing numbers of species extirpations throughout the basin and illustrate the magnitude of anthropogenic stresses on the aquatic community in general.

Changes in the Diversity and Composition of Mussel Communities Over Time

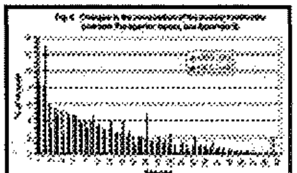
Figure 2

Community composition, which is defined as the proportion of the mussel community accounted for by each species, is a more sensitive indicator of biological integrity than species richness. Species composition indicates not only which species are present, but how common or rare they are relative to one another. Data for the entire study area were examined for changes in community composition over time, again using 1960 as the date separating historical from recent times. The proportions of records accounted for by each species in each time period are compared in Fig. 2, where species are arranged in order from the most to the least common in the earlier time period such that any differences will be clearly evident.

Major changes in composition included a shift in the order of dominance of the two most common species, with *Lampsilis siliquoidea* (species 1) accounting for the greatest proportion of records prior to 1960 and *Pyganodon grandis* (sp. 2) accounting for the most records after 1960. *L. siliquoidea* was found at 30% of the sites in both time periods; however, *P. grandis* was found at 16% of the sites before and 45% after 1960, indicating that it has become much more common in recent years. Of the 41 species examined, three species belonging to the Subf. Anodontinae, namely, *P. grandis*, *S. undulatus* (sp. 19), and *Lasmigona complanata complanata* (sp. 40), showed the greatest increases over time (8 to 13% of records, 2 to 5%, and 0.1 to 2%, respectively), while 13 species (predominantly Lampsilinae) showed decreases. Members of the Subf. Anodontinae are generally thin-shelled species that can survive in soft, silty substrates. Morris and Corkum (1996) reported that rivers in southwestern Ontario with narrow, grassy riparian zones were characterized by *P. grandis* and *S. undulatus*, whereas rivers with forested riparian zones were characterized by species of Lampsilinae and Ambleminae. They concluded that "increasingly agricultural activity is resulting in a shift towards dominance by a single common species in rivers of open riparian zones, with *P. grandis* representing over 60% of individuals in these rivers". In a related study, Morris (1994) found that *L. c. complanata* also increased significantly in abundance as the landscape shifted from forest-dominated to predominantly agricultural. These findings suggest that certain species of Anodontinae may be good biological indicators of degraded conditions.

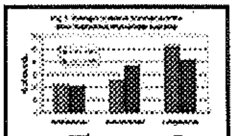

Figure 3

The Subf. Anodontinae, as a group, has significantly increased in dominance over time, and it has mainly done so at the expense of the Subf. Lampsilinae (Fig. 3). The proportion of the community accounted for by the Subf. Ambleminae has remained relatively constant. In all, 43% of species belonging to the Subf. Lampsilinae showed declines, as compared with only 25% of species of both the Anodontinae and Ambleminae. It should be noted here that apparent declines of the northeastern species *E. complanata* (Subf. Ambleminae; sp. 3), *P. cataracta* (Subf. Anodontinae; sp. 24) and *A. undulata* (Subf. Anodontinae; sp. 37) are believed to be due to a sampling artifact, as somewhat fewer sites in the Lake Ontario watershed were sampled after 1960 than before 1960. Increases were observed for 50% of the Ambleminae species, 41% of the Anodontinae and only 24% of the Lampsilinae. Mackie (1996) surveyed 70 sites in the Grand River watershed for unionids in 1995, and compared diversity and abundance with the results of historical surveys. He determined that the subfamily with the greatest percentage of species at risk in this watershed was the Lampsilinae (88%), followed by the Ambleminae (60%), with the Anodontinae being the most resilient group (only 22%). The fact that anodontines, or "floater" mussels, now dominate the mussel communities of the lower Great Lakes drainage basin is cause for concern, as increases in these generally pollution-tolerant species may herald the decline, and even loss, of other more sensitive mussel species. For example, Hoggarth *et al.* (1995) demonstrated that agricultural activities have seriously threatened the endangered purple catspaw, *Epioblasma obliquata obliquata*, in Ohio.

The next section examines in more detail the temporal changes in diversity and composition of the mussel communities of two watersheds: the Grand River, representing the Lake Erie drainage, and the Moira River, representing the Lake Ontario drainage.

The Grand River

The Grand River is a large, well-studied watershed with over 950 mussel records available from 1885 to 1996. To assess changes in community structure over time, the data were divided into 3 time periods: 1885-1960, 1961-1983 and 1983-1996. The numbers of species found in each time period were tallied, and the degree of similarity in community composition among the time periods were calculated using Pappantoniou and Dale's (1982) community overlap index "C_{lambda}" as follows:

$$C_\lambda = \frac{2\sum_{i=1}^{s} x_i y_i}{\sum_{i=1}^{s} x_i^2 + \sum_{i=1}^{s} y_i^2}$$

where x_i and y_i are the proportions that species i represents in communities x and y, respectively, and s is the total number of species. An index value of 1.0 indicates identical compositions. The results are presented in Table 5. Species losses were not evident in the Grand River until after 1983, but the most significant change in community composition occurred between the first and second time periods. This suggests that changes in species composition may be predictive of future species losses. If the pre-1960 community composition is considered to be the biodiversity objective, then the present community deviates considerably from this objective with an overlap of only $C_{lambda} = 0.64$.

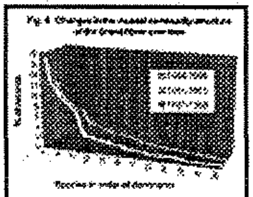

Figure 4

As illustrated in Fig. 4, the mussel community structure of the Grand River has changed over time from a community with a large number of well-represented species prior to 1960, to a community becoming increasingly dominated by fewer and fewer species until eventually some species have actually been lost. As shown in Table 6, seven species accounted for 50% of the records prior to 1960, as compared with six species in the period 1961 to 1983, and only four species in the most recent time period. Also, the community has become dominated by Anodontinae; whereas only three of the eight most common species prior to 1960 belonged to this subfamily, six species in each of the latter two time periods were floater mussels (see Table 3). *P. grandis, S. undulatus,* and *Anodontoides ferussacianus* ranked 8th, 18th and 24th in dominance prior to 1960, 1st, 2nd, and 10th between 1960 and 1983, and 1st, 6th and 4th between 1984 and 1996. In the early 1970s, Kidd (1973) reported major increases in the numbers of *P. grandis, S. undulatus* and *Lasmigona costata* in this system. Most recently, Mackie (1996) found the Grand River to be dominated by floater species, including *L. compressa, L. costata, P. grandis,* and *S. undulatus.* The decline and loss of several species of Lampsilinae, and the shift towards an Anodontinae-dominated community, suggest declining water and habitat quality throughout the system. Mackie (1996) attributed both temporal and spatial declines in diversity to several anthropogenic impacts, including agricultural runoff, roadway crossings, cattle crossings, industrial discharges and storm sewer discharges. Kidd (1973) blamed dam construction for changes in mussel distributions, especially in the lower reaches of the river. He suggested that dams may limit the migration of the mussels' host fish.

The Moira River

The authors surveyed the Moira River in the fall of 1996. The database was used to select sites that had been previously sampled, such that the data would be directly comparable. Although mussel diversity is somewhat limited in rivers of the Lake Ontario drainage, mussels were very abundant throughout the Moira River. A total of eight species was found at each of two sampling sites, which matches the highest diversity previously reported for a site on this river system. To assess changes in community composition over time, the same analyses were performed on these data as on the data from the Grand River.

It is evident from the overlap index values in Table 7 that community composition in the Moira River has changed very little from 1928 to the present. Although fewer species were found in 1996, this may not be significant as only eight sites were sampled (includes two sites sampled by Dr. F.W. Schueler, Research Associate, CMN), in comparison with 59 sites between 1928 and 1958, and 21 sites between 1960 and 1968. The mussel community of the Moira River is much "simpler" than that of the Grand River, with only three or four species accounting for 60% of the records in all time periods (Table 8). The only notable change is an increase in the dominance of *P. grandis* from 8th place prior to 1958 (not shown) to 3rd place after 1960. This is suggestive of an increase in siltation in the system, although agricultural activity is limited. Two-thirds of the watershed is on the Canadian Shield (Terry Sprague, Moira River Conservation Authority, personal communication, March 1997). In contrast, over 95% of the Grand River watershed is agricultural, with less than 5% forest cover (Mackie 1996). The relative stability of the Moira River mussel community may be partly explained by the absence of many of the more sensitive mussel species from the Lake Ontario drainage basin.

Selection of Candidate Species to be Considered for National Status Designation by COSEWIC

One of the most important goals of this project was to identify the mussel species most at risk in the lower Great Lakes drainage basin, and to prepare a list of candidate species to be considered for national status designation by COSEWIC. As only designated wildlife species can be considered for action under the RENEW strategy, it is critical to ensure that the most threatened species of freshwater mussels are officially listed. Five factors were considered in preparing the list of candidate species: their current conservation status ranks; their range, i.e., whether widespread or restricted; their vulnerability to zebra mussels; their degree of host specificity; and evidence of decline in the study area as determined from the database. The first and last factors were given the most emphasis, and host specificity was given the least. Conservation status ranks in Ontario were considered to be more important than North American or global ranks.

Factor 1 - Conservation Status Ranks

Conservation status ranks or categories are available for the mussel species of interest from three sources, namely, The Nature Conservancy (global), the American Fisheries Society (North America) and the Natural Heritage Information Centre (Ontario). The ranking systems used by each source are described in Table 9. The risk categories used by COSEWIC are included for comparison. While the terms are not unequivocal, they can be generally matched. For example, a category of "vulnerable" under COSEWIC's scheme is probably equivalent to the AFS's "special concern" category and the "G3/S3" or "rare to uncommon" ranks of The Nature Conservancy and the NHIC (the latter are affiliated and use identical ranking systems). The NHIC is in the process of developing a list of rare and endangered species of flora and fauna for the Province of Ontario. Due to their broad mandate, they cannot focus in detail on any one group of organisms. As a result, their current conservation status ranks for Ontario freshwater mussels are based on fewer data than are included in our database.

Ranks assigned to a given species by the global and North American systems generally agreed. For example, all species ranked as CS (currently stable) in North America were globally ranked as G4 to G5 (common to very common), and the three species ranked as E (endangered) or T (threatened) in North America were globally ranked as G3 or G2 (rare to very rare). However, 8 of the 11 species considered to be of special concern (SC) in North America were globally ranked as very common. The reason for this difference is not known, but it is believed that the North American ranks are based on more recent information. There were more obvious discrepancies between the provincial ranks and the other ranks. The reason for this is that many species native to the study area are at the northern periphery of their range (Barr 1996), and are naturally less common here. It should also be noted that some species that are rare in Ontario may in fact be common elsewhere in Canada. For example, the northeastern species *A. undulata* and *P. cataracta*, which are ranked as S2 to S3 in Ontario, are known to be common in the Atlantic drainage (Clarke 1981) and are therefore not significantly at risk from COSEWIC's national perspective.

Factor 2 - Distribution Patterns

Species with restricted distributions are considered to be more at risk than those that are more widespread. As noted earlier, 22 of the 41 species occur only in southern Ontario (considering their Canadian distributions only). An additional six species are also found in the Red-Assiniboine drainage in Manitoba, where their current status is not known (Dr. James Duncan, Manitoba Conservation Data Centre, personal communication, November 1996). All species were assigned to one of three risk categories based on their distributions across Canada. According to Barr (1996), 60% of the mussel species in the Mixedwood Plains Ecozone have ranges that would be described as "local". However, there are "degrees" of local. For example, *Villosa fabalis* is known mainly from the Sydenham River and around Pelee Island in Lake Erie, whereas *Ptychobranchus fasciolaris* is known from Lake Erie, Lake St. Clair and several of their major tributaries. All species were assigned values of 1 (very localized) to 5 (widespread) to indicate their range characteristics.

Factor 3 - Vulnerability to zebra mussels

Zebra mussels pose a major threat to the survival of native mussels in the study area. Unionids that occur mainly in the Great Lakes themselves or in the lower reaches of the larger tributaries are most at risk from the impact of zebra mussels. All species were assigned to one of three risk categories based on their vulnerability to zebra mussels, as determined by consulting the distribution maps.

Factor 4 - Host specificity

Information on the number of recognized fish hosts for each species was obtained from two recent review papers (Hoggarth 1992; Watters 1994). Only those fish hosts known to occur in the study area (Scott and Crossman 1973) were included. According to Neves (1993), some degree of host specificity appears to be the rule rather than the exception for most mussel species. Clearly, any change in the abundance or species composition of the fish fauna could have serious effects on recruitment in co-dependent mussel populations. Not surprisingly, the most common mussel species are those that have many suitable fish hosts. For example, *P. grandis* and *L. siliquoidea*, which are the dominant mussel species in the study area, have the most known hosts (31 and 14, respectively). Conversely, 10 of the 12 species for which no hosts have yet been identified are species ranked SH, S1 or S2 in Ontario. Of the species for which hosts have been identified, fully one-third have only 1 or 2 known hosts. Although host specificity was not one of the major factors considered in the selection of candidate species, it has implications for a few species. *Utterbackia imbecillis* and *Actinonaias ligamentina* have large numbers of fish hosts (9 and 12, respectively), including common species such as largemouth bass (*Micropterus salmoides*), smallmouth bass (*Micropterus dolomieui*), bluegill (*Lepomis macrochirus*) and yellow perch (*Perca flavescens*), yet their provincial ranks are S1 and S2. This suggests that these mussel species are being limited by factors acting on them directly rather than on the fish community that supports them. Conversely, *Lasmigona costata* and *Leptodea fragilis* both rank S4, despite having only one fish host each. The explanation for this is that their hosts are two of the most widespread and abundant species in the study area, namely, the carp (*Cyprinus carpio*) and the freshwater drum (*Aplodinotus grunniens*), respectively. As carp were only introduced into Ontario in the late 1800s (Scott and Crossman 1973), *L. costata* undoubtedly has other hosts. No hosts have been identified for *O. olivaria* in Canada; however, it is known to use the shovelnose sturgeon (*Scaphirhynchus platorynchus*) elswhere. The most likely host for this species in Canada is the lake sturgeon (*Acipenser fulvescens*), which is one of the St. Lawrence Action Plan's priority wildlife species (Bouchard and Millet 1993) mainly due to the small number of spawning adults that now exist. If the lake sturgeon suffers further declines, *O. olivaria* could become functionally extinct, i.e., known only from non-reproductive populations.

Factor 5 - Evidence of Decline in the Study Area

Assessment of this factor required the analysis of occurrence records from the historical database. There are essentially two ways to evaluate trends over time for individual species. Changes in relative dominance, i.e., the proportion of total records accounted for by each species in each time period, indicate whether a certain species has increased, decreased or stayed the same in terms of its significance as a component of the community. The difficulty with this type of analysis is that some species may only *appear* to have decreased in occurrence because others have substantially increased. This approach could therefore *overestimate* the number of species for which declines have actually occurred. Another way to examine the data is to compare the proportion of sites at which a given species was found before vs. after 1960. This analysis requires the assumption that sampling effort was the same in both time periods, when in fact sampling effort increased considerably after 1960. Although only 17% more sites were sampled after 1960 than before, the number of records doubled. It is conceivable that a species found at 5% of the sites in both time periods actually declined, because more time was spent searching for it after 1960. This approach could therefore *underestimate* the number of species for which declines have actually occurred. The results of both types of analysis were considered together to determine risk. For example, species that declined based on both proportions of records and proportions of sites were considered most at risk (category 1), those that declined based on proportions of records but did not change based on proportions of sites were assigned to category 2, etc. A 20% increase or decrease was considered to be significant. The results are presented in Appendix II.

Final Selection and Prioritization of Candidate Species

Results of the risk factor analysis used to identify and prioritize the candidate species are presented in Table 10. The 41 species have been divided into three groups based on their level of risk, with Group 1 containing the species considered to be most at risk and Group 3 containing the species least at risk. Within each group, the species have been arranged in order from the most to least at risk. As previously noted, the factors given the greatest emphasis when determining risk were conservation status ranks and evidence of decline in the study area. The two factors generally agreed well, but there were some discrepancies. Of the eight species showing the greatest declines, four are considered extirpated from Ontario (*E.o. perobliqua*, *Epioblasma tortulosa rangiana*, *Epioblasma triquetra* and *O. olivaria*). Declines of the three northeastern species (*E. complanata*, *P. cataracta* and *A. undulata*) are spurious, being due to the fact that only one-third as many sites in the Lake Ontario drainage were sampled after as before 1960. The eighth species, *Ligumia nasuta,* is ranked only S3 in Ontario. Because it has significantly declined, is extremely vulnerable to zebra mussels, and was once a major component of the mussel community (5th largest number of records prior to 1960), we have assigned it a higher priority. Five species fell into Category 2 based on evidence of decline (Appendix II), and four of these (*Simpsonaias ambigua*, *V. fabalis*, *Truncilla donaciformis* and *Pleurobema coccineum*) ranked between SH and S2 in Ontario. All except *P. coccineum* were found at fewer than 20 sites after 1960. The fifth species, *L. siliquoidea*, is one of the most common and widespread species in Canada and is therefore not currently at risk. However, indications are that it has been replaced as the dominant species of unionid in the lower Great Lakes drainage basin by *P. grandis*. Eight species that ranked between SH and S1/S2 in Ontario showed no evidence of decline over time. In fact, there were four times as many records for both *C. tuberculata* and *Truncilla truncata* after 1960 as before. These are more records than could likely be accounted for by the increased sampling effort. Because of its extremely restricted range, *C. tuberculata* should probably remain a high priority species, but *T. truncata* was assigned to Group 3. The remaining six species, *Obovaria subrotunda, Obliquaria reflexa, P. fasciolaris, Toxolasma parvus, U. imbecillis* and *Lampsilis fasciola* showed either no change or slight increases in occurrence over time. As the latter three species were found at fewer than 20 sites after 1960, they may be considered more at risk than the former species. It is possible that *T. parvus* has not been extirpated from Ontario, as Clarke (1992) found a live specimen in the Sydenham River in 1991. *L.c. complanata* was found at one site prior to 1960 and 58 sites after 1960, thus it is an example of a species that is expanding its range. It should probably be ranked S5 rather than S3 in Ontario.

We recommend that the nine species of mussels in Group 2 of Table 10 be considered for national status designation by COSEWIC, in the approximate order of priority given, i.e., *Villosa fabalis, Truncilla donaciformis, Pleurobema coccineum, Ligumia nasuta, Lampsilis fasciola, Utterbackia imbecillis, Cyclonaias tuberculata, Obovaria subrotunda*, and *Ptychobranchus fasciolaris*. It is our contention that there is little to be gained by documenting the status of the seven species that are already presumed extirpated from Canada. Rather, the Mollusc Working Group should focus its efforts on officially designating those species for which there may still be time to intervene. *L. nasuta* is a case in point. This species has been decimated by zebra mussels throughout most of its range. However, the authors discovered a healthy population in a small lake in Prince Edward County in 1996. If *L. nasuta* is officially designated by COSEWIC, then funds will be accessible under the RENEW strategy for developing a recovery plan that could include protecting the small lake as a refuge for this species.

Identification of High Diversity Sites

The final objective of this project was to identify species-rich sites that could serve as refugia for representative mussel communities. The simplest way to achieve this was to plot all collection sites as per Map 2, only in this case using the diversity field in the database to generate points that varied in size in proportion to the number of species found at each site. The results are presented in Map 45. A total of 75 "high diversity" sites, which are defined as those sites having 10 or more species, were identified. Diversity was found to be greatest in Lake St. Clair and Lake Erie and in the lower reaches of their largest river systems. The greatest proportions of these sites were in Lake Erie (41%), followed by the Sydenham River (31%), the Grand River (17%), the Thames River (6%), and Lake St. Clair (2%). All sites with greater than 20 species were in Lake Erie, the Sydenham River and the Grand River. Mussel diversity in the Lake Ontario drainage was substantially lower, where the richest sites supported a maximum of eight species and were located in the Moira and Trent-Severn watersheds. The highest diversity ever reported for a single site in the study area was 25 species taken from a site on the Sydenham River in 1965. Although the Sydenham River has recently suffered the loss of some of its mussel fauna, it is still considered to be "...the richest system for Unionidae in Canada and one of the richest small river systems in North America" (Clarke 1992). Clarke (1992) also recognized the Sydenham River as an important sanctuary where native mussels might be protected from zebra mussels, and urged that the system be made an ecological preserve.

As noted earlier, the number of species found at a site is related to the amount of effort expended. The ten most diverse sites in the database are those that were sampled in the 1960s and 1970s by collectors from Ohio State University, suggesting that Dr. Stansbery and his colleagues were very thorough. Because of variability in sampling effort, sites with apparently low diversity are often situated next to sites with high diversity on Map 45. Further analysis of the data using a "cumulative diversity" approach will be required to identify the specific tributaries and reaches of the various river systems that have the greatest potential to support diverse mussel communities.

CONCLUSIONS AND FUTURE DIRECTIONS

The mussel database provides the most complete picture possible of the distributions of freshwater mussels in the lower Great Lakes drainage basin over the past 140 years. Thousands of collection records from numerous sources were compiled and examined together for the first time in order to assess the conservation status of mussel species and communities throughout the study area. Analyses of historical and recent data revealed a pattern of species losses and changing community composition throughout the basin, particularly in the formerly species-rich Lake Erie and Lake St. Clair drainages. River systems that once supported numerous species characteristic of a wide variety of habitats are now dominated by fewer siltation- and pollution-tolerant species of the Subfamily Anodontinae. The data suggest that fully 40% of the 41 native mussel species would fall into the Extirpated, Endangered or Threatened risk categories as defined by the Committee on the Status of Endangered Wildlife in Canada. Because of intensive agricultural activity, a burgeoning human population with its associated impacts, and the relentless spread of the exotic zebra mussel in this region of Canada, the status of these and many other mussel species may become worse unless measures are taken to conserve and protect them.

The mussel database will primarily be used as a resource to support the activities of the Mollusc Working Group of COSEWIC. Tasks facing the MWG include: identifying candidate species for national status designation; determining the current status of designated species, then preparing status reports on them; and, ultimately, contributing to the development and implementation of recovery plans for those species deemed to be most at risk. This report provides a list of recommended candidate species, which were derived using a detailed risk factor analysis. The list will be proposed to the MWG for discussion purposes. To address the next task, the authors will conduct field surveys throughout the study area in 1997 in order to determine the current status of species ranked as very to extremely rare in Ontario (includes all Group 2 species and several Group 3 species). The mussel database will be used to identify sites where these species were found in the past. Sites that supported diverse mussel communities, particularly those where more than one target species was found, will be given the highest priority for sampling. This work will be partially funded by the Endangered Species Recovery Fund.

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