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The Zebra Mussel Invasion of the Inland Waters of Michigan: Refinement of Predictive Models and the Development of a Demonstration Pilot Self-Help Program

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INTRODUCTION:

In 1993 the first systematic widespread sampling of inland waters in North America for the presence of zebra mussels (*Dreissena polymorpha*) was initiated to assess the incidence of overland dispersal into inland freshwater systems in the Lower Peninsula of Michigan (Johnson 1993). The 33 lakes targeted for this survey were considered to be at high risk of zebra mussel invasion due to large size, close proximity to infested waters, or the presence of public access sites, characteristics which typify lakes with higher levels of Transient Boating Activity (TBA). Zebra mussels were detected in 10 of these lakes, thus providing a limited initial assessment of its inland range expansion.

The sampling programwas continued in 1994 with the goal of expanding the scale of zebra mussel monitoring in inland lakes to construct a basis for refining inferences on the rates, direction, and spatial patterns of the spread of zebra mussels that were generated last season. Existing inland populations were monitored with the objective of investigating the early population dynamics of zebra mussel invasions and deriving predictive models of the timing and magnitude of future population growth and associated impacts.

A pilot volunteer monitoring program was developed to provide a model for the creation of a large-scale program for long-term detection and monitoring of the invasion of inland waters by non-indigenous nuisance species. The program sought out citizen involvement in active zebra mussel monitoring using simple, low cost methodology as a means of demonstrating the efficacy of volunteer efforts in gathering scientifically useful data. Goals for the program were 1) to develop a monitoring network which could be expanded in future years to involve more citizens and lake associations and 2) to complement the 1994 professional sampling program.

METHODOLOGY:

Our fundamental approach was the use of veliger detection methods that appeared to be successful in detecting sparse zebra mussel populations in the 1993 monitoring program. Plankton sampling for the presence of zebra mussel veligers was employed extensively (50 lakes). Settling plates were also deployed in 13 lakes with confirmed adult populations. Training sessions on plankton sampling techniques were conducted to train 20 volunteers from 16 lake associations for the pilot "self-help" zebra mussel monitoring program. A simple, standardized protocol for adult detection was developed using a pontoon boat inspection technique and was deployed to an additional 48 lake associations.

Overall, a total of 69 (Table 1) lakes in Michigan were involved in active zebra mussel surveys this season. Multiple monitoring methods were used at many of these lakes (i.e. plankton sampling and volunteer pontoon boat monitoring).

RESULTS AND DISCUSSION:

Inland Lake Invasion Summary

Overall, as of January 1995, a total of 26 Michigan inland lakes have displayed some evidence of zebra mussel infestation, 15 with confirmed populations of adult zebra mussels.

A total of 15 new inland lake infestations were documented in 1994. Seven new zebra mussel infestations were detected by this season's monitoring program (two with veligers-only, five with adults). An additional eight infestations were detected incidentally. Twelve of all new 1994 infestations have confirmed adult populations (Table 2). The remaining two lakes are veliger-only detections (Table 3). Most new populations detected this season were located in the southern portion of the state. Oakland county had four new detections, Washtenaw county had two, and the Lenawee-Jackson County area south of Jackson had four.

The professional survey failed to detect zebra mussels in three lakes where mussels were incidentally detected this season (Gull Lake, Kalamazoo County; Portage Lake, Washtenaw County; and Hamlin Lake, Mason County). These false negatives suggest that a more frequent monitoring regime using the plankton sampling technique is required to detect veliger populations that may be extremely sparse and fluctuating both temporally and spatially. The large scale of the program logistically prohibited spatially comprehensive and frequent sampling efforts in any one lake, thus enhancing the possibility of failing to detect mussels where they actually exist. Adults in the Gull Lake population, for instance, have been found thus far only in the south bay of the lake, an area where plankton samples had not been taken due to the limited protocol of 3 samples/lake.

Patterns of Dispersal

Secondary dispersal from established inland populations is becoming a significant factor in the development of new infestations. For example, the primary invasion of Loon Lake in Oakland County precipitated four new infestations through secondary dispersal within the Clinton River system. Population density comparisons between Loon Lake and Cass Lake (which is approximately 10 km downstream of Loon Lake on the Clinton River) suggest a causal effect from veligers dispersing down the Clinton River (respective mean adult settling plate densities: 62,300 mussels/m2 vs. 18 mussels/m2). Also, 1994 peak veliger densities in the Clinton River directly upstream from where it empties in to Cass Lake from Loon Lake have been as high as 2 veligers/l (D. Hunter, 1994). Additional secondary infestations derived from the initial Loon Lake invasion in the Clinton River watershed have been detected in Silver Lake, Sylvan/Otter Lake, and Orchard Lake.

Secondary downstream dispersal was demonstrated over a longer stretch of river by the appearance of adult zebra mussels in Barton Pond in Ann Arbor, an impoundment of the Huron River system. Barton Pond is approx. 20 km downstream of infested Portage Lake in Washtenaw County, the probable source of the Barton Pond infestation. Thus it is reasonable to expect the leading front of infestation to progress rapidly downstream in the future, reaching Ford Lake (Washtenaw County) joining the existing population in Belleville Lake (Wayne County) within the next year or two. Also, the presence of adult zebra mussels in the upper reaches of two other river systems in southern Michigan (Raisin, and St. Joseph Rivers) indicates that much of these systems will become infested in the coming years.

Overall, within-watershed secondary dispersal appears to be responsible for 5 of the 25 documented inland zebra mussel infestations in Michigan and 4 of the 13 new infestations detected in 1994. Of greater significance in evaluating dispersal patterns are the number of discrete inoculation events that precipitate primary invasions. 20 inland zebra mussel detections fall into this category.

Improved inferences concerning patterns and rates of overland dispersal are now possible given the data from two seasons of zebra mussel monitoring. New discrete

infestations representing separate inoculation events were detected this season in 6 of 22 uninfested lakes from the 1993 monitoring sample (Portage Lake, Washtenaw County; Devil's Lake, Lenawee County; Kent Lake, Oakland County; Lake St. Helen, Roscommon County; Gull Lake, Kalamazoo County; and Hamlin Lake, Mason County), which is an annual infestation rate of 27% within this original sample. This figure is relevant only to lakes that meet the "high risk" criteria (large size, public access, and high incidence of TBA) that guided the sample selection and is thus probably considerably larger than the actual inland lake invasion rate. Nevertheless, the data clearly shows that zebra mussels are continuing their range expansion at a rate that will infest a considerable number of inland lakes in Michigan within the next decade.

Population Dynamics

1994 surveys failed to detect zebra mussel adults or veligers in six lakes where veligers were detected in 1993 (Table 3). Also, veliger densities displayed no significant change in an additional three lakes between 1993 and 1994 (Burt Lake, Cheboygan County; Houghton Lake, Roscommon County; and Belleville Lake, Wayne County; all densities < 0.001/l). This observation suggests that at least in some cases, zebra mussels may have trouble successfully reproducing and persisting at low population densities. However, an alternate explanation for this observation is that limited sampling efforts (one visit/lake this season) at these lakes may have missed peaks in veliger abundance, hence failing to detect any larvae that may have been present. Future monitoring of the infestation status of these nine lakes is essential to the resolution of this issue.

Population growth in the 14 lakes with known adult populations thus far appear to be consistent with the explosive patterns of growth witnessed in Lake Erie in the late 1980's - 90's. Mean 1994 settling plate population density in Loon Lake was 62,300 mussels/m2. Moreover, qualitative observations of newly detected adult populations in Portage and Devil's Lakes indicate a substantial increase within the span of one season, with pontoon boat densities approximating 500/24' boat in Devil's Lake. In addition, both Vineyard and Clark Lakes (Jackson County) have advanced infestations characterized by high population densities.

An exception to this trend is the surprisingly slow development of the infestation in Cass Lake (Oakland County) as compared to the directly adjacent and downstream Sylvan Lake infestation. Zebra mussels on native Unionids are more numerous in Sylvan Lake than in Cass Lake by a factor of 3(Hunter, 1994), despite the probability that the Cass infestation predated and precipitated the Sylvan infestation and the similarity of veliger densities observed from plankton samples taken from both lakes this season. This suggests that lake-specific factors such as limnological parameters may slow zebra mussel population growth in some cases.

The inadvertent inoculation of Orchard Lake with veligers in 1993 created a research opportunity of great theoretical and practical importance from which the infestation potential of a specific quantity of veligers could be investigated. In late spring and summer of 1993, Orchard Lake received approximately 3.311 x 108 l of veliger contaminated water (G. Appel, pers comm.) from Cass Lake via a lake level control pump between the two lakes (normal water flow is into Cass Lake from Orchard). Based on a conservative density estimate of 0.0005 mean veligers/liter in Cass Lake in 1993 (Cass samples from 5/93 : 0.005 veligers/l), at least 165,500 veligers were pumped into Orchard Lake last season. 1994 Orchard Lake samples taken before the pump commenced operation detected veligers at a density of 0.005/l, suggesting the presence of a breeding population of adult zebra mussels in Orchard Lake. Hence the magnitude of veliger

inoculation into Orchard Lake in 1993 was apparently sufficient to precipitate a new infestation (barring inoculation from other sources, eg. recreational boating).

Dispersal Inferences

TBA appears still to be a major dispersal vector for zebra mussels. All new detections in 1994 occurred in larger lakes with public access sites. Regional "hotspots" of new invasions appear to be in areas heavily used by Great Lakes boaters. One such area is in the Jackson - Lenawee County area, where 4 new infestations were detected this year. Two of these detections (Vineyard and Clark Lakes) were incidental and are characterized by relatively high adult population densities. No new detections were recorded in private lakes without public access sites this season through either the sampling program or incidental detections.

Additional evidence also suggests that the role of the boating activities of lakefront residents in dispersing zebra mussels to inland lakes should not be minimized. Vineyard Lake, for instance, has only a rudimentary dirt boat ramp in shallow water, apparently unsuitable for the larger boats likely to be coming directly from the Great Lakes. Personal communications with residents of these lakes suggests that a substantial proportion of lakefront property owners on Vineyard Lake (as well as lakefront owners in the in the Jackson - Lenawee region) have permanent residences in the Toledo area. If lakefront property owners are a high risk dispersal vector, then it is reasonable to suspect that lakes characterized by a high proportion of lakefront residents with permanent residences near heavily infested Great Lakes waters would experience zebra mussel inoculation events more frequently through the transient boating activity of residents.

Comparisons between two inland lake-dense regions proximate to the highly infested Lake Erie - Lake St. Clair system reveals that the Jackson-Lenawee Region is characterized by a slightly higher number of likely discrete inoculation events than Oakland County (4 vs. 3). Moreover, plankton sampling efforts able to detect cryptic veliger-only infestations were much more concentrated in Oakland County (18 lakes) than in the Jackson-Lenawee region (1 lake). Thus a number of as of yet undetected cryptic zebra mussel populations similar to Oakland County's Walled and Kent Lakes (which represent two of Oakland County's three discrete inoculation events) may exist undetected in the Jackson-Lenawee region, thus expanding the difference in inoculation frequency between the two regions.

Most lakes exhibiting evidence of zebra mussel infestation have official state, county or township public access sites (18 of 27), indicating that this variable is a significant element in the construction of zebra mussel invasion susceptibility profiles for inland lakes. Moreover, five of the nine infested lakes with no public access sites were likely infested by secondary downstream dispersal and are probably not discreet inoculation events. Of the remainng four lakes, three have either unofficial public access sites (Walloon Lake) or high volume private access sites (commercial boat launches and marinas.) However, the observed geographic spatial patterns of invasions thus far continue to suggest that other dispersal vectors cannot be ignored, particularly the boating habits of lakefront residents.

Other Invading Aquatic Species

1994 surveys also documented populations of two other exotic pest organisms in inland lakes. *Bythotrephes cederstroemi*, the spiny water flea, was detected in Long Lake in Grand Traverse county, south of Traverse City (0.003/l). The Asian clam, (*Corbicula*

fluminea) was detected in Devil's Lake (Lenawee County), which brings to a total of four known inland lake *Corbicula* infestations in Michigan. (Other *Corbicula* infestations: Lake Fenton, Genesee County; Whitmore Lake, Washtenaw County; and Loon Lake, Oakland County).

PILOT VOLUNTEER PLANKTON SAMPLING PROGRAM

20 Volunteers from 16 lake associations were trained in plankton sampling methodology for a pilot demonstration volunteer zebra mussel monitoring program. Four zebra mussel-infested lakes were used as controls to test the efficacy of the program and were sampled by both volunteers and the professional survey. Volunteer sampling at three control lakes effectively replicated and complimented professional sampling. No veligers were detected in Lake Paw Paw (Berrien County) in both professional and volunteer samples. Volunteer samples at both Cass Lake (Oakland County) and Portage Lake (Washtenaw County) detected veligers at expected densities and added valuable complimentary data to the professional samples taken at both lakes. The volunteer at the fourth control lake, Burt Lake in Cheboygan County, failed to take plankton samples after being trained in sampling methodology, the only such failure of the volunteer sampling program. This particular volunteer reported in mid-August that he had not yet taken the samples, at which time he was encouraged to take them despite the fact that the optimal sampling period was past (he attended a training session in early July). As of September he had still not taken any samples.

Volunteer sampling at the remaining 12 lakes that were not included in the professional sampling schedule were very successful. All plankton samples had been successfully taken by the trained volunteers. Volunteers at two lakes had post-training questions about sampling that were resolved over the phone. The samples were then sent through the mail to be processed without any incidence of breakage or leakage. Samples were adequately preserved by the volunteers, with no sample spoilage encountered. Adequate sampling information was included with all samples (i.e. lake temperature and sample date).

Significantly, it was volunteer sampling that resulted in the detection of *Bythotrephes cederstroemi* in Long Lake, Grand Traverse County, the first known inland population of this exotic crustacean in the Lower Peninsula. No detections of zebra mussels resulted from the volunteer plankton sampling program. Overall, the program was supported with great enthusiasm from volunteers and lake associations and demonstrated that trained lay people can produce scientifically valuable information within the context of a large scale exotic species lake monitoring project.

Also, a simple volunteer pontoon boat bottom monitoring protocol was developed and distributed to 32 lake associations involved in the plankton sampling program as well as to an additional four lakes otherwise outside of the monitoring project. The protocol was also provided to an additional 12 lakes as part of the Michigan Lake and Stream Association's Advanced Self-Help Manual. This program, which involved approximately 450 volunteers across the Lower Peninsula, resulted in the detection of three new infestations.

Both volunteer monitoring methods show great potential to be employed in a large scale, low cost inland lake zebra mussel monitoring network. The success of this season's pilot program indicates that it can clearly serve as a model for more extensive volunteer exotic species lake monitoring programs.

CONCLUSIONS:

Zebra mussels are dispersing to inland lakes at a significant rate. If present trends continue, a substantial proportion of inland lakes in the Lower Peninsula will likely be infested within a decade. As the incidence of inland infestations increase, secondary dispersal through natural and human mediated vectors will likely assume a larger role in the process of inland invasions. Emerging invasion rates suggest that if reactive anti-dispersal efforts are to have any efficacy, they must be mobilized in the window of time between primary regional infestation (i.e. the Great Lakes invasion) and subsequent overland dispersal.

Monitoring programs that rely on volunteer participation from lake front property owners and lake associations can be used on a large scale at minimal cost. The Pilot Volunteer Plankton Sampling Program demonstrated the potential of such efforts to succeed on a large scale while producing valuable information on the overland dispersal of aquatic nuisance invading species. This pilot program can be used as a model for similar programs at both state and nation-wide levels as zebra mussels continue their range expansion. Perhaps its greatest potential is for generating data on patterns of dispersal in Michigan that can be incorporated into anti-dispersal programs in parts of the county yet to experience the zebra mussel invasion.

Table 1: Lakes involved in zebra mussel monitoring, 1994

Lake	County	Lake	County
Baseline	Washtenaw	Lake Orion	Oakland
Belleville	Wayne	Lake Paw Paw	Berrien
Black	Cheboygan	Lake St.Helen	Roscommon
Burt	Cheboygan	Lakeville	Oakland
Cass	Oakland	Lobdell	Livingston
Corey	St. Joseph	Loch Erin	Lenawee
Crescent	Oakland	Long Lake	Grand Traverse
Crooked	Emmet	Long Lake	Cheboygan
Sylvan/Otter	Oakland	Lower Straits	Oakland
Crystal	Benzie	Loon	Oakland
Devil's	Lenawee	Maceday	Oakland
Diamond	Cass	Mullet	Cheboygan
Donnell	Cass	Orchard	Oakland
Douglas	Cheboygan	Paradise	Emmett
Duck	Calhoun	Pickerel	Emmett
Eagle	Cass	Pine	Oakland
Elizabeth	Oakland	Platte	Benzie
Elk	Antrim	Pontiac	Oakland
Ford	Washtenaw	Portage	Washtenaw
Glen	Leelanau	Sanford	Midland
Green	Oakland	Silver	Oakland
Gull	Kalamazoo	Stony Creek Imp.	Oakland
Gun	Barry	Tawas	Iosco
Hamlin	Mason	Tipsico	Oakland
Higgins	Roscommon	Torch	Antrim
Houghton	Roscommon	Union	Oakland
Hubbard	Alcona	Upper Long	Oakland
Juno/Christiann	Cass	Van Ettan	Iosco
Kent	Oakland	Vinyard	Jackson

Klinger	St. Joseph	Walled	Oakland
Lake Lapeer	Lapeer	Walloon	Charlevoix
Lake Leelanau	Leelanau	Wamplers	Jackson
Lake Louise	Charlevoix	White	Oakland
Lake Mitchell	Genesee	Wolverine	Oakland

Table 2: Inland Lakes with confirmed adult populations of zebra mussels

Lake	Year Detected	County
Barton Pond*	1994	Washtenaw
Cass	1993	Oakland
Clark*	1994	Jackson
Devils's	1994	Lenawee
Eagle	1991	Cass
Elizabeth	1994	Oakland
Gull*	1994	Kalamazoo
Hamlin*	1994	Mason
Juno/Christiann	1992	Cass
Lake St. Helen	1994	Roscommon
Loon*	1993	Oakland
Portage*	1994	Washtenaw
Silver	1994	Oakland
Sylvan/Otter	1994	Oakland
Vineyard*	1994	Jackson
Wampler's	1994	Jackson
Whitmore*	1994	Washtenaw

*Incidental detections (infestations not detected by monitoring program)

Table 3: Zebra mussel detections, veligers only: (year of detection)

Lake	Year Detected	County
Belleville	1993	Wayne
Burt	1993	Cheboygan
Crooked1	1993	Emmet
Houghton	1993	Roscommon
Kent	1994	Oakland
Orchard	1994	Oakland
Paradise1	1993	Emmet
Paw Paw 1	1993	Berrien
Pickerel 1	1993	Emmet
Walled 1	1993	Oakland
Walloon 1	1993	Charlevoix

1 zebra mussel veligers detected in 1993 but not in 1994.

Citations:

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