Mitchel Stimers
Department of Geography
Kansas State University
118 Seaton Hall
Manhattan, Kansas 66502

Abstract

The introduction of non-native species has been one of the most damaging human impacts on specific ecosystems and the environment in general. Invasive species, such as the Zebra Mussel *(Dreisenna polymorpha)*, are often introduced into an ecosystem inadvertently, but with negative and far-reaching effects on native species. *D. polymorpha*, since its introduction, has exhibited a devastating propensity for altering the trophic state of lakes and rivers, and has rapidly populated many waterbodies throughout North America. Two rules added to a genetic algorithm rule-set prediction (GARP) model reflect the temporal dimension and the spatial extent of spread. Utilizing GARP, TableCurve, and GIS, I modeled several possible scenarios. Results of the models illustrate the potential for *D. polymorpha* to continue spreading deeper into the United States as well as the difficulty in predicting the spread of an invasive species.

Keywords: Zebra Mussels, Invasive Species, GIS, GARP

<u>Introduction</u>

The introduction of non-native species has been one of the most damaging impacts on river and environmental systems in general (Elton 1958). Invasive species are often introduced into an ecosystem inadvertently, but with negative and far-reaching effects on native species. Zebra Mussels *(Dreisenna polymorpha)*, first discovered in Lake St. Clair (located in Ontario, Canada, about 10 kilometers northeast of Detroit, Michigan) 1988, were introduced when a transatlantic ship from Europe emptied its ballast tanks in port (Herbert *et al*. 1989; Griffiths *et al*. 1991). Although not discovered until 1988, they are thought to have arrived in 1986 (Gist *et al*. 1997). In the nineteen years since, the non-native species has invaded the entire Upper Mississippi River system, a large number of its tributaries, many inland lakes, and has nearly eliminated most native mussel species in the Great Lakes (Allen *et al*. 1999; Chakraborti *et al*. 2002; U.S Fish and Wildlife Service 2003). Since its introduction, *D. polymorph* has rapidly populated many water bodies throughout North America (Chakraborti *et al*. 2002), exhibited a devastating propensity for altering the trophic state of lakes and rivers (Caraco *et al*. 1997), greatly reduced native mussel populations (Nalepa *et al*. 2001), and caused large changes in fish populations (Strayer *et al*. 2004). It has been suggested that *D. polymorpha* has the potential to invade most of the waterways in the United States as well as southern Canada (Johnson *et al*. 1996). The Zebra Mussel competes aggressively for food with native species, and due to its rapid rate of reproduction (Mackie 1993) and domination of the bottom of waterbodies, reproduction becomes difficult for native species.

Mitigation efforts to control the spread of *D. polymorpha* have been undertaken, but have proven difficult, and too often, ineffective. Several types of traps have been developed to capture mature adults, but the effects of these have been minimal. Recently, a microscopic particle containing potassium chloride and other inert chemicals has been developed that when ingested by *D. polymorpha* led to death in 60 percent of a test population; the substance, if not ingested, eventually breaks up in the water and dissipates, causing no harm to other species (Harder 2006).

The adaptive ability of the Zebra Mussel, its lack of predators in some areas, and its apparent ability to inhabit virtually any water body make it difficult to control (Chase and Bailey 1999; Ricciardi 1998). Effective modeling of the potential for spread has become an important mitigation tool in combating *D. polymorpha*, but there are many variables that contribute to its success or failure, which has limited the use of modeling.

Native mussel species have great importance to local ecosystems. Typically not eaten by humans, but a major food source for otters, muskrats, raccoons, and ducks, they are a vital link in the food chain (United States Fish and Wildlife Service 2003). In reducing native mussel numbers, *D. polymorpha* has caused serious problems for wildlife management authorities, and could further endanger species in some areas. For example, in the Great Lakes, *D. polymorpha* readily attaches onto crayfish, inhibiting their ability to feed, escape predation, molt, and reproduce. The crayfish is an important part of the aquatic food chain, and a decline in their numbers will have far-reaching effects on the aquatic ecosystem (Brazner *et al*. 2000).

The threat *D. polymorpha* poses to native mussel species is not the only problem. As mentioned above, *D. polymorpha* is a very rapid reproducer, and as such, causes

several problems as a result of their large populations. Power plants are especially sensitive to *D. polymorpha*, as they are notorious for colonizing around intake pipes and turbines, and causing a wide range of mechanical malfunctions that must be constantly dealt with, at great expense (Nalepa and Schloesser 1993; MacIssac 1996). *D. polymorpha* has the dubious distinction of being the first biological invader in North America to infect and disturb municipal water systems. In 1994 in Wisconsin alone, repair and remediation due to *D. polymorpha* infestations cost an estimated four million dollars (Padilla 1996). Considering all the negative effects of this species, the need to effectively and accurately model their spread is clear.

The main method by which *D. polymorpha* infects new channel segments of riverways is transport of adults and larvae by current and wind-driven action (Johnson *et al.* 1996; Padilla *et al.* 1996; Gist *et al.* 1997). While transfer by other means such as aquatic birds is possible, Johnson *et al.* (1996) have shown them to be of very little consequence. Infection of new riverways is rapid and very difficult if not impossible to stop, however, infection of inland lake bodies is a much slower process. The larvae or adult must be transported by humans, and deposited into a new waterbody within a few weeks (Johnson *et al.* 1996), and relatively large amounts of veligers (larvae) or adults must be close together for *D. polymorpha* to effectively reproduce (Ricciardi *et al.* 1998). Padilla *et al.* (1996) studied the spread of *D. polymorpha* by examining boat movement patterns. They concluded that recreational boat traffic (trailered watercraft) is the main cause of spread across waterbodies. *D. polymorpha* uses small, thread-like structures called byssal threads to attach itself to hard objects such as boat hulls. Attachment to watercrafts can occur in a very short timespan, and the substance excreted through the

byssal thread and used in attachment is extremely strong (Brazner *et al.* 2000). The Fish and Wildlife Service actively inspects boats and trailers being removed from infected areas to enforce regulations relating to cleaning equipment in order to slow overland spread.

Predictive models can be used to help managers efficiently allocate resources to mitigate against further spread. Modeling attempts have been made to include variables such as water temperature, availability of a food source, substrate composition, and acidity level of the water body in developing working representations of *D. polymorpha* spread (e.g., Ramcharan *et al.* 1992; Haltuch *et al.* 2000; Chakraborti *et al.* 2002; Ricciardi 2003; Strayer and Malcom 2006; Griebeler and Sietz 2007). However, there are several problems that inhibit the development of a truly accurate predictive model of spread. Ramcharan *et al.* (1992) found that using average values over a large area, as they did in their study of the Great Lakes, proved problematic due to the, "heterogeneity in the chemical and physical environments of these basins" (p. 2619). According to their findings, using sub-units of a larger lake or river system rather than averages across the entire system may yield better results. Haltuch *et al.* (2000) noted that incorporating regression modeling can provide a fairly accurate prediction of *D. polymorpha* spread using substrate (waterbody floor) composition alone. They added that the addition of variables such as nutrient concentrations, predator populations, and chemical profiles could enhance the predictive capabilities of the models developed, but these data are difficult to collect, and thus, not widely available. Chakraborti *et al.* (2002) echo this sentiment in their research conclusions by stating that data limitations prevented them from increasing the performance of the model, specifically in relation to its performance

on various spatial and temporal scales. Finally, Ricciardi (2003) stated that a major limitation to developing effective models is the lack of available datasets. His study concluded that a good historical record of the invasion of a species is key to understanding their movement and predicting their spread.

Methods

The prediction of the impacts of an invasive species may be possible if the impacts to the ecosystem can be quantified as a function between the invasive species and the ecosystem (Ricciardi 2003). Two recent studies have utilized variables related to survival and transport of veligers and adults, and incorporated a geographical information system (GIS) to model the spread of *D. polymorpha* (Haltuch *et al*. 2000; Chakraborti *et al*. 2002). The studies mentioned above served as a framework for this paper, with the addition of a modeling process called genetic algorithm rule-set prediction (GARP), and the statistical software package TableCurve. The goal was to model the spread of *D. polymorpha* throughout the United States in order to determine when and where entry into Nebraska, and ultimately the Platte River, will occur. The Platte River was chosen for study due to its geographic separation from currently known locations of *D. polymorpha*, as well as its importance to the natural environment in Nebraska and surrounding states. GARP accepts input from the analyst to define parameters in which the species being modeled must behave; these parameters are referred to as rules. Several rules were added to a GARP model that reflected the temporal dimension, the spatial extent of current spread, as well as temperature, and sediment composition. TableCurve plots tabular data, and derives equations to describe the patterns in the data. In this project, TableCurve was used to derive the equation that describes the rate of spread

based on the tabular data obtained from the GARP model. Utilizing GARP, TableCurve, and GIS, an attempt to model several possible scenarios is made. Results of the model serve to illustrate the potential for *D. polymorpha* to spread into the Platte River, while confirming the difficulty in predicting the spread of an invasive species.

The dataset used in this model was obtained from the National Atlas, which is maintained by the United States Department of the Interior. The years 1988 to 2004 are included in a GIS shapefile that includes point data for each known location of *D. polymorpha* colonies in the United States and Canada. Figure 1 illustrates the current spread of *D. polymorpha* in these locations, with each point on the map representing a known colony, and as shown, there were none in the Platte River as of 2004.
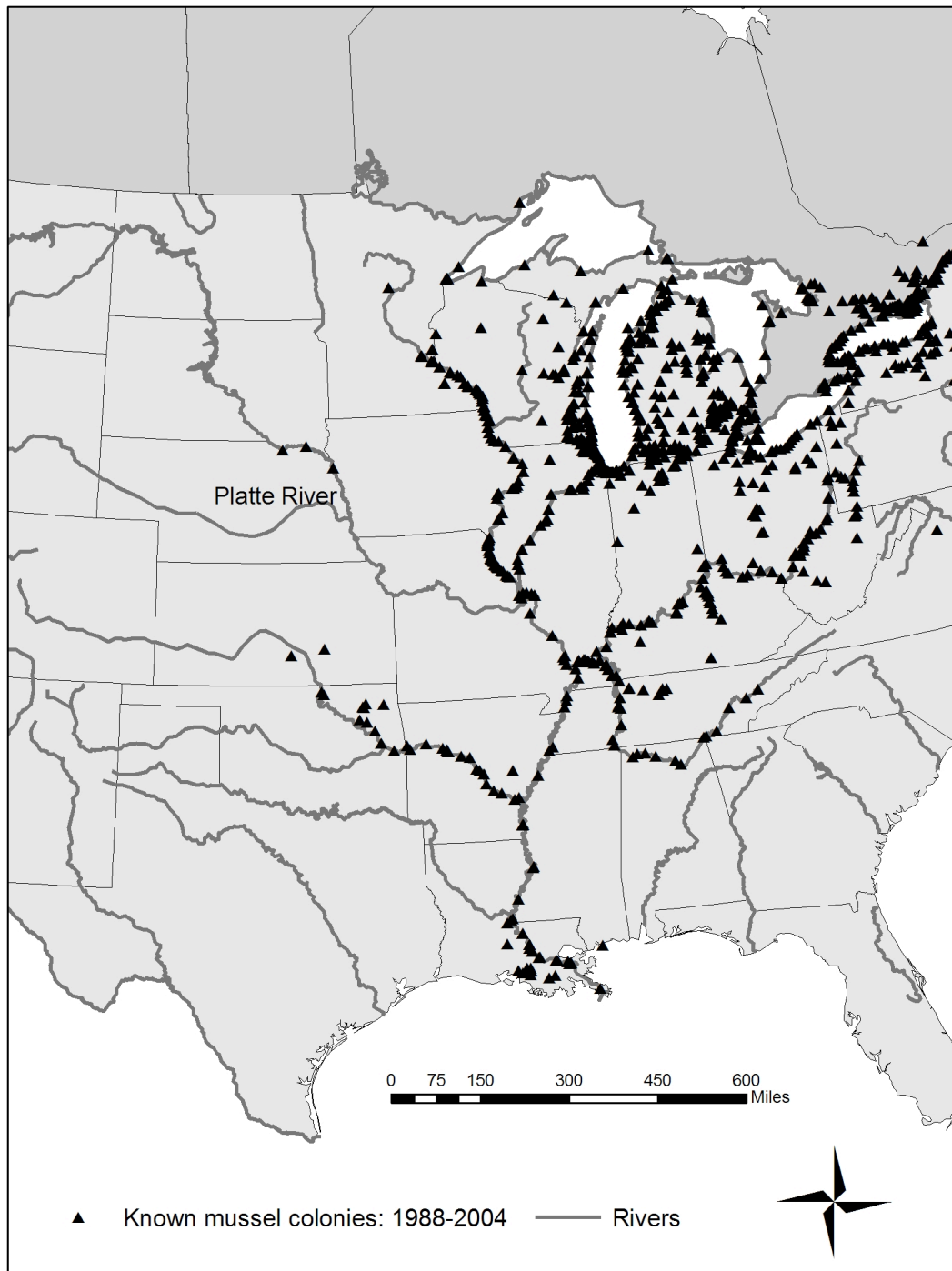
Figure 1. Extent of *D. polymorpha* in the United States and Canada through 2005.

In order to derive the equation that best expresses the rate of spread, the

TableCurve program was used, which produces a graph that best illustrates the data in

terms of (in this case) rate of spread. Using the calculated rate of spread, TableCurve then models the future spread by employing an autoregressive prediction algorithm. The rate of spread consists of time from first occurrence to present, and distance, in miles traveled. Attribute data gleaned from the National Atlas, such as gradient, channel width and length, and sediment composition were entered into TableCurve, and rate-of-spread equations were derived. These equations are then added to GARP as individual rules governing the movement of *D. polymorpha* through the model. Several iterations of the model were produced, as each one represented a possible scenario. There are literally an infinite number of scenarios GARP can produce, and as such, it was necessary to limit the number of iterations GARP performs. After completion of all model runs, the data were entered into a GIS, and displayed as point data.

Results

In 1988, five known locations of *D. polymorpha* colonies were reported. In 2004, there were 2,429 point-locations in the dataset. The rate of spread for the time period 1988 to 2004 is given by:

$$ln(y) = 8.6381 - (7.4332/x)$$

where:
 $ln(y)$ is the natural logarithm of y, the sum of known invaded locations to date
x is the year, beginning with 1 and progressing to 17 (1988 to 2004)

The GARP model presented here covers the years 2005 to 2015; roughly mirroring the time elapsed from the first discovery of *D. polymorpha* to 2004. Figure 2 illustrates the spread as predicted by the GARP model. Figure 3 shows the rate of spread to date, and Figure 4 shows the predicted rate of spread from 1988 to 2015.
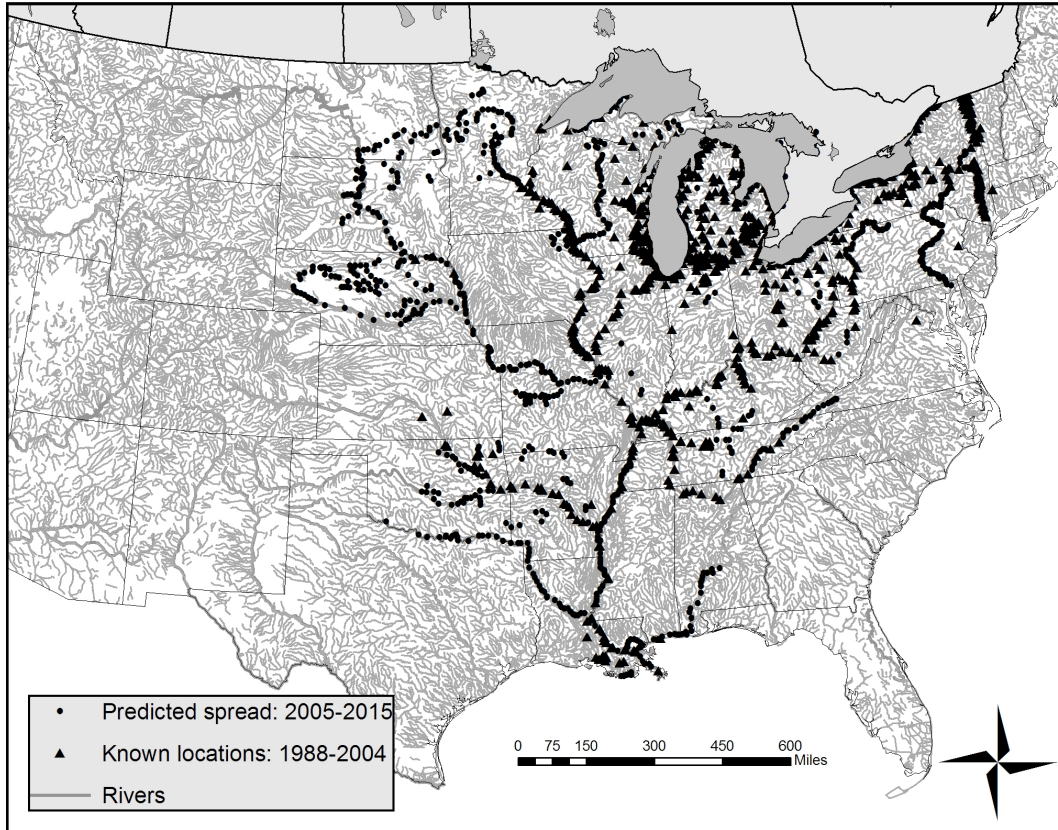
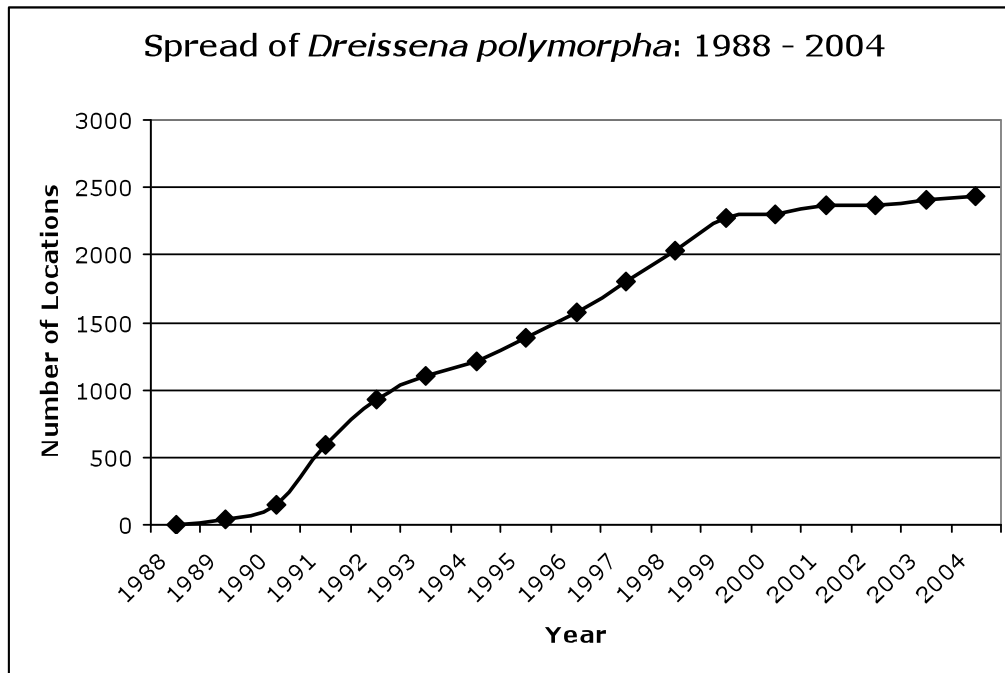Figure 2. Current and predicted spread of *D. polymorpha*, 2005 to 2015.

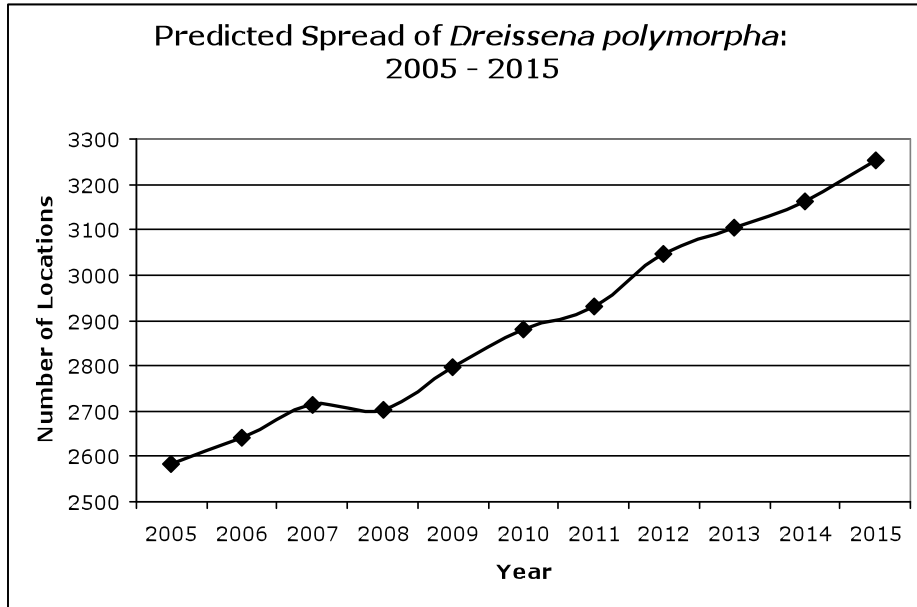Figure 3. Current spread of *D. polymorpha*, 1988 to 2004.

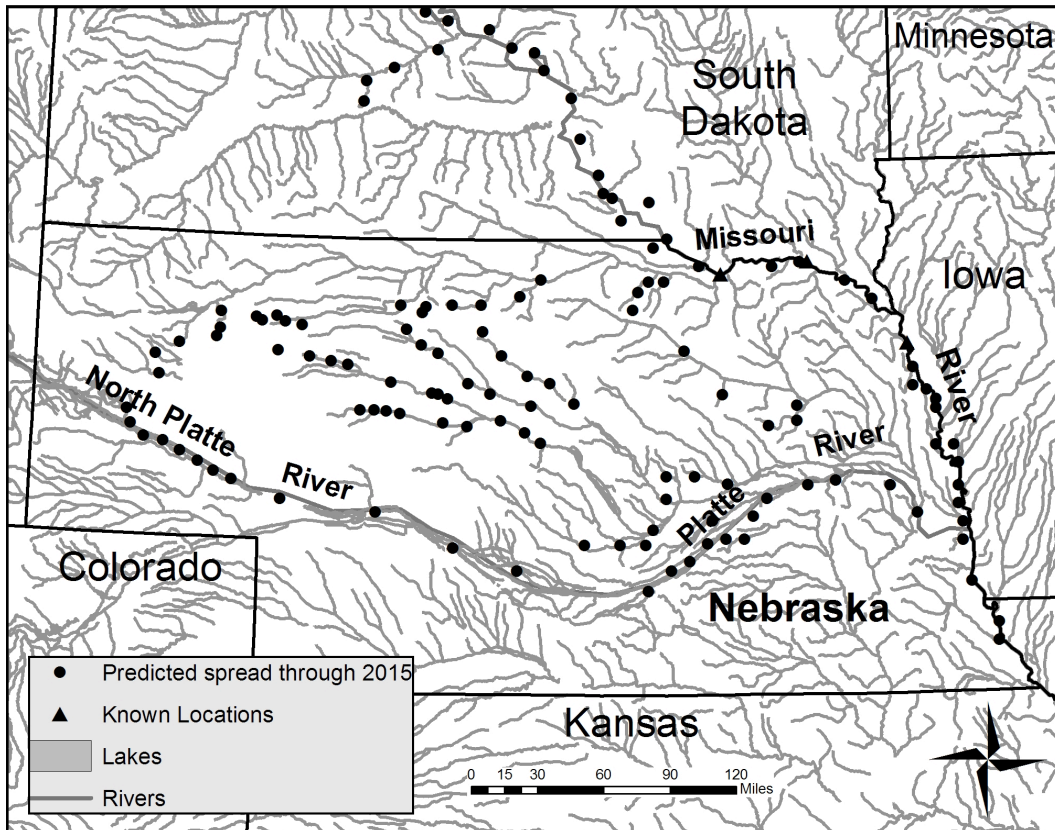Figure 4. Predicted rate of spread of *D*. *polymorpha*, 2005 to 2015.

Figure 5. Predicted rate of spread of *D*. *polymorpha*, into Nebraska, 2005 to 2015.

Figure 5 illustrates the spread into the Platte River, beginning in 2011. Entering Nebraska from the north, GARP predicts that spread could be facilitated through the Missouri River. Once in Nebraska, movement into the Platte is accomplished through smaller rivers, *D. polymorpha* migrates south, until the Platte is reached. One problem with the GARP prediction was the directional component associated with movement. Overland transport from northeast Nebraska to west-central Nebraska seems unlikely given the distance that would need to be covered. GARP had difficulty handling directional components properly, and therefore, tended to predict that movement would occur from downstream to upstream, which is impossible for *D. polymorpha* to accomplish without external influence (e.g., Horvath *et al*. 1996; Horvath and Lamberti 1999; and Stoeckel *et al*. 2004). In order to correct this issue, each river segment would have to be assigned a direction of flow in the attribute table, and a rule input into GARP limiting movement from upstream to downstream when using direction as a parameter for transport. This could prove difficult and extremely time consuming, as there are literally thousands of smaller rivers affecting the direction of spread into Nebraska. One solution would be to assume predicted spread is correct at the Nebraska border, and add a directional component for river channels only in Nebraska, thus increasing the accuracy of the model – but for Nebraska only. Another avenue for future research includes the consideration of boater movement patterns. Such data are not readily available, and would have to be collected for the particular river segment under study.

Conclusion

The model presented here indicates the spread of *D. polymorpha* will continue, albeit at a slower rate. These findings are consistent with those of Johnson *et al*. (2006).

Movement into the Platte River is predicted to result from transport from the north, facilitated by the Missouri River. Data from the United States Department of the Interior, containing the current extent of *D. polymorpha* infestation were entered in to a GARP model, rate of spread was calculated, entered into a GIS, and displayed as point data. The results indicate that *D. polymorpha* has the potential to further infest riverways and inland lakes in North America, leading to the Platte. Data extracted from the attribute tables, including year and sum of known locations of *D. polymorpha* colonies was entered into the TableCurve data analysis package, and the equation describing the rate of spread over time were derived. The results of the predictive algorithm extended the spread of *D. polymorpha* to 2015. The continuous function produced showed that while spread will continue, the rate at which spread is occurring would decrease.

Chakraborti *et al*. (2002) state that *D. polymorpha* has exhibited a tolerance for a wide variety of waterbody conditions, and thus has the potential to spread over an expansive geographical range. Reasons for the decline in the rate of spread reported here are not absolutely clear. Chase and Bailey (1999) posit that trapping adults and veligers upstream before they are allowed to move downstream has had at least some effect on slowing spread (for a more detailed explanation of possible reasons for the decline in rate of spread, see Johnson *et al* 2006, p. 487).

With their ability to multiply quickly, spread rapidly, and out-compete native species for resources, *D. polymorpha* has proven to be a major problem concerning United States and Canadian lakes and rivers, and it is likely the problem will continue to spread westward, and southward. Currently, the Platte River is not infected, but the GARP model presented here suggests infestation could occur as early as 2011.

Mitigation efforts to control their spread are important to reducing their numbers and minimizing the effects on native species of not just mussels, but many other animals in the food chain. Future research will hopefully produce more accurate and efficient models that can be utilized by resource managers to better understand the spreading capabilities of this invasive species.

List of Figures

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