1994

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Recommended Citation

Baker, P., Baker, S., & Mann, R. L. (1994) Potential range of the zebra mussel, Dreissena polymorpha, in and near Virginia. Marine Resource Advisory No. 51. Virginia Institute of Marine Science, College of William and Mary. https://dx.doi.org/doi:10.25773/v5-fak4-f789

Potential Range of the Zebra Mussel *Dreissena polymorpha*, In and Near Virginia

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This document was published by Virginia Sea Grant's Marine Advisory Program, School of Marine Science, Virginia Institute of Marine Science, College of William and Mary, Gloucester Point, Virginia 23062.

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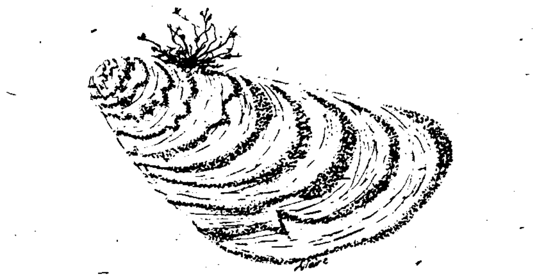
Virginia Sea Grant Marine Resource Advisory No. 51
Virginia Sea Grant Advisory No. VSG-93-04
Virginia Institute of Marine Science Contribution No. 1822

INTRODUCTION

The following document is from the proceedings of a 1993 zebra mussel workshop, conducted in Baltimore, Maryland. At the workshop, forecasts were presented concerning the future of zebra mussels, Dreissena polymorpha, *in the mid-Atlantic states.*

This publication is devoted to predictions of the probability of invasion by the zebra mussel, *Dreissena polymorpha* (and the quagga mussel, *Dreissena* sp.) to specific bodies of water in Virginia. Probability of invasion is divided into *risk* and *susceptibility. Risk* refers to the chance, relative to other sites, that a body of water will be inoculated with *Dreissena,* in sufficient number to establish a population. Inoculation can occur by natural dispersal, but in the mid-Atlantic region is most likely to-occur though accidental introduction by humans, especially via boat traffic. *Susceptibility* of a body of water refers to the probability, based on known physiological requirements, that *Dreissena* could survive and reproduce. In this publication predictions are made, concerning both risk and susceptibility, for several bodies of water in Virginia.

Original *Dreissena* populations are native to freshwater or brackish portions of estuaries, with bidirectional water flow, in eastern Europe and central Asia (Staczykowska, 1977), and most subsequent invasions have occurred in lakes and freshwater portions of estuaries (Shtegman, 1968; Wolff, 1969; Staczykowska, 1977; Griffiths *et al.,* 1991). Freshwater portions of estuaries, and natural and artificial reservoirs in the mid-Atlantic region of the United States (here defined as drainages east of the Appalachian Mountains between New York and South Carolina) are therefore at risk from invasion by *Dreissena,* given correct water quality parameters, *Dreissena* populations cannot be maintained at high levels in freshwater rivers without an upstream reservoir or lake, because it has planktonic larvae and postlarvae stages. This topic is discussed at greater length in *Criteria for Predicting Zebra Mussel Invasions in the Mid-Atlantic Region,* a Virginia Sea Grant Publication, which can be obtained from the Virginia Institute of Marine Science.



A zebra mussel is a small, striped mollusk capable of raising havoc. (Although the mollusk can grow up to two riches, it is usually much smaller — fingernail size.) zebra mussels have cost millions of dollars in the Great Lakes region where they rapidly colonized water-intake pipes, boats, docks, piers, and other structures. *Dreissena polymorpha* was inadvertently delivered to U.S. waters around 1986 through the discharge of European shipping ballast water. -ed.

TEMPERATURE-LIMITED SYSTEMS

None of the systems in the mid-Atlantic region fall below the minimum temperature requirements for *Dreissena* reproduction (refer to *Criteria for Predicting Zebra Mussel Invasions in the Mid-Atlantic Region),* but most estuaries and lowland reservoirs in South Carolina and Georgia have summer temperatures that may exceed *Dreissena* tolerances, based on reported European limits (Strayer, 1991), and reported physiological limits of zygotes and adults (Sprung, 1987; McMahon and Alexander, 1991). Reported European temperature limits for *Dreissena* may be based on geography as much as temperature, however, since the Mediterranean Sea acts as a southern barrier. The movement of *Dreissena* down the Mississippi River, tracked recently as far as Vicksberg, Mississippi (New York Sea Grant, 1993), should be closely monitored as a natural test of temperature tolerance of this species in North America.

ESTUARIES

Virtually all estuaries with permanent freshwater inputs in the mid-Atlantic region have tidal freshwater portions, and are potentially susceptible to invasion by Dreissena. Examples of major estuaries (more than 1000 ha. of open, permanently fresh water) between New York and North Carolina include the Hudson River; the Delaware River; the Susquehanna, Potomac, Rappahannock, Mattaponi, Pamunkey, and James Rivers in the Chesapeake Bay; Currituck and Albemarle Sounds, and Pamlico, Pungo and Neuse Rivers in North Carolina (Coupe and Webb, 1984 U.S. Army Corps of Engineers, 1984; NOAA, 1985).

Estuaries can be invaded by Dreissena in several ways, all discussed at length in *Criteria for Predicting Zebra Mussel Invasions in the Mid-Atlantic Region.* Briefly, they can be invaded overland, usually with recreational vessels, either directly to the freshwater estuarine portion, or to a lake, from where, if they become established, they will subsequently invade all downstream waters. Alternately, estuaries can be invaded from the seaward direction, with vessels traveling from other estuaries. Ballast water containing *Dreissena* larvae is a well-known vector, but under some circumstances, Dreissena-may also be introduced as adults on the hulls of vessels, if the time spent in high-salinity water is not long. This is often possible, as discussed below.

Natural terrestrial and high-salinity barriers between major estuaries and smaller estuaries have been partially eliminated by canals of the Intracoastal Waterway, and may facilitate *Dreissena* transfer between basins. For example, the Chesapeake-Delaware canal, between oligohaline portions of those respective estuaries, is at times of high freshwater runoff, fresh or nearly fresh at both ends (U.S. Amy Corps of Engineers, 1985; NOAA, 1985; Mellor, 1986), and thus represents a route for natural invasion by *Dreissena* of the Delaware estuary from the Susquehanna drainage, where it is found at present (Lange and Cap, 1992; New York Sea Grant, 1993). Two canals, the Dismal Swamp Canal and the Chesapeake and Albemarle Canal, connect the Elizabeth River estuary in southern Chesapeake Bay, Virginia, to freshwater portions of the Albemarle and Currituck Sounds in North Carolina so that freshwater portions of the two formerly separate estuaries are now a single body of water. The Alligator River and Pungo River Canal connect tidal fresh waters of Albemarle and Pamlico Sounds, respectively, in North Carolina. Similar examples can be found elsewhere along the Intracoastal Waterway. Even if there are high salinity regions that act as barriers to natural range expansion by *Dreissena,* barge and other boat traffic carrying *Dreissena* along these canals could pass relatively quickly through high salinity areas and *Dreissena* can tolerate at least several days of relatively high salinity.

Dreissena has already invaded the Hudson River estuary (Walton, 1993), and appears poised to invade the Susquehanna River estuary (Lange and Cap, 1992; New York Sea Grant, 1933). These estuaries will serve as models of the sorts of biological and economic impacts to expect in other mid-Atlantic estuaries. In addition, they will serve as reservoirs of *Dreissena* to invade adjacent estuaries, particularly on the hulls of vessels traveling between estuaries, as discussed in *Criteria for Predicting Zebra Mussel Invasions in the Mid-Atlantic Region.*

Some, but not all, of Virginia's freshwater estuarine regions are at risk of, or susceptible to, invasion and establishment by *Dreissena.* The risk of inoculation varies between estuaries, according to the level of boat traffic and other human factors. Susceptibility of establishment, on the other hand, varies according to water chemistry, independently of human use. In the following discussion for each estuary, values for pH and calcium are the maximum reported monthly averages for summer (May to September), based on existing water chemistry data.

Pocomoke River

The Pocomoke River is at low risk of inoculation, and is not susceptible to establishment of *Dreissena.* Like other estuaries on the Delaware Peninsula, it has relatively low freshwater inflow, and no major upstream reservoirs for *Dreissena* to invade. There is little commercial vessel traffic into the estuary, although the channel is maintained to Snow Hill, Maryland, and there is a marina near Snow Hill. Opportunities for inoculation, therefore, are relatively limited, relative to other Chesapeake Bay estuaries.

Water chemistry data for February 1991 near the upstream tidal limit at Snow Hill showed low pH (6.1) and calcium content (4.3 ppm) (James *et al.*, 1991). If *Dreissena* were to invade this estuary, they probably would not attain high population levels.

Potomac River

The Potomac River is at high risk of inoculation, and highly susceptible to establishment of *Dreissena.* The tidal freshwater portion of the Potomac estuary stretches from Washington, D. C., to Quantico, Virginia in most years. There are few lakes adjoining the Potomac River estuary; therefore, the invasion of the Potomac River drainage by *Dreissena* carried by recreational vessels transported from an adjoining drainage is less likely to occur than in some other systems. The Virginia portion of the Potomac/Shenandoah drainage, for example, has only about 40 public boat ramps (most of which are on rivers) compared to more than twice that number for some other Virginia drainages of similar size (DeLorme Mapping Co., 1989). Resource managers have fewer major lakes to monitor in a program to prevent the introduction of *Dreissena.* Invasion could occur via intentional, misguided introduction to a farm pond or other small impoundment, however. This possibility can be prevented only through education of landowners and users.

Inoculation of the Potomac by *Dreissena* could also occur from the seaward direction, via ballast water of the hulls of incoming vessels. Ballast water containing *Dreissena* larvae or postlarvae is a distinct risk to the Potomac estuary. Bulk cargo ships from Quebec City, Quebec, arrive in Alexandria, Virginia. 6-7 times annually (Robinson Terminal Warehouse Corp, Alexandria, VA, pers. comm.). Alexandria is the largest port in the freshwater portion of the Potomac; Quebec City is on a portion of the St. Lawrence River that has established populations of *Dreissena* (New York Sea Grant, 1993). The amount of ballast water exchanged, and the nature of the exchange, are unknown. Commercial and recreational traffic into the Potomac estuary from adjoining estuaries is very high, and the Potomac is the closest Virginia estuary to the Susquehanna River, where *Dreissena* is already present.

Water chemistry data iridicate that both pH (8.1-8.4, May to September at Washington, D. C.) and calcium content (32-40 ppm) (Prugh *et al.*, 1992) are suitable for *Dreissena* reproduction. If *Dreissena* becomes established in the Potomac estuary, all indications are that it would rapidly attain pest proportions. This region has already experienced invasion by the asiatic clam, *Corbicula fluminea,* which has attained high abundance (Phelps, 1991).

Rappahannock River

Risk of inoculation to, and susceptibility of, the Rappahannock River to *Dreissena* invasion, are moderate. The tidal freshwater portion of the Rappahannock estuary extends upstream from Fredericksburg, Virginia, to somewhere between Port Royal and Tappahannock, depending on freshwater inflow levels. Invasion of the Rappahannock could occur from upstream, where there are several reservoirs of moderate size, if they were invaded. There are 11 public boat ramps in the freshwater portion of the Rappahannock drainage (DeLorme Mapping Co., 1989), and there are also several large, privately maintained reservoirs, such as Lake of the Woods, which is surrounded by a housing development. Inoculation could also occur from the seaward direction, via fouling on the hulls of vessels moved from nearby estuaries already invaded by *Dreissena,* but both commercial and recreational movement from other estuaries to the Rappahannock is low to moderate.

The lower Rappahannock River has relatively low pH (7.8 in August, at Fredericksburg) and very low calcium (5.2 ppm) (Prugh *et al.*, 1992). Based on these data, even if *Dreissena* becomes established here, it is not predicted to have high reproductive success most years, and is unlikely to maintain pest proportions.

Piankatank River

The tidal freshwater portion of the Piankatank River is at relatively low risk of inoculation, and is not susceptible to establishment of *Dreissena.* The Piankatank, and its adjoining freshwater tidal portion, Dragon Swamp, is the largest of a number of small estuaries on the west side of Chesapeake Bay for which the drainage basins arise entirely within the coastal plain region. There are no large upstream resevoirs, and no commercial traffic into freshwater tidal portions, so the only likely mechanisms of Dreissena inoculation would be via private introductions to upstream farm ponds, or via the hulls of small pleasure vessels from other estuaries. The Piankatank has low pH (6.5 in July at Mascot) and low calcium (13 ppm) (Prugh *et al.*, 1992), so *Dreissena* would be unlikely to survive or reproduce.

Data for other small Virginia estuaries are limited, and while some (e.g. the Pocomoke, discussed above) are known to be acidic, pH and calcium of small to medium-sized impoundments upstream on these varies dramatically within the same drainage (Virginia Department of Game and Inland Fisheries, unpubl. data). No small estuary, therefore, should be considered safe from *Dreissena* invasion until water quality has been measured and determined to be unsuitable for *Dreissena* growth and reproduction.

Mattaponi and Pamunkey Rivers

The Mattaponi and Pamunkey Rivers, which unite at West Point, Virginia, to form the York River estuary, are both at moderate risk of inoculation by *Dreissena,* and are moderately susceptible to establishment of this species. The York River is rarely fresh or oligohaline, even at West Point (NOAA, 1985), so freshwater portions of the Mattaponi and Pamunkey are normally, distinct from each other. Small tributaries of the two subestuaries are very close to each other, though, and could be host to brief overland transmigration by animals such as turtles (see *Criteria for Predicting Zebra Mussel Invasions in the Mid-Atlantic Region).*

Inoculation of either estuary by *Dreissena* could occur from upstream resevoirs which had been previously invaded overland. The Mattaponi River has several upstream reservoirs of moderate size and recreational use, such as Ni River Reservoir, and Caroline Reservoir, and in the Pamunkey drainage there is the relatively large Lake Anna (discussed separately in this chapter in the section on lakes). There are about 12 and 15 public boat ramps in the Mattaponi and Pamunkey drainages, respectively (DeLorme Mapping Co., 1989). Inoculation of the estuaries could also occur via *Dreissena* attached to hulls of vessels incoming from other, already invaded estuaries, but probability of invasion by this method is low, due to the relatively limited traffic, compared to other major estuaries. Barges with wood chips travel between the upper York River and other estuaries; but the major moorage site, in the lower Pamunkey, is rarely fresh, and the salinity regime probably is suboptimal for reproduction of *Dreissena.*

Both rivers are slightly acidic and have low calcium, and are thus only marginal for *Dreissena* growth and reproduction. Near Beulahville, pH of the Mattaponi in July is about 6.9, while calcium content is only about 3.7 ppm. Near Hanover, pH of the Pamunkey in June is about 6.9, with a calcium content of about 9 ppm (Prugh *et al.,* 1992). Even if *Dreissena* becomes established, it is unlikely that they would attain pest proportions in either estuary.

JAMES RIVER

The James River is at high risk of inoculation by *Dreissena,* and is highly susceptible to subsequent establishment of large populations. The freshwater tidal portion of the James River extends downstream from Richmond to Jamestown, and includes large portions of the Chickahominy and Appomattox Rivers, with over 8000 ha of open freshwater. The James River drainage has many large reservoirs with heavy recreational use (high risk of inoculation), and some of these reservoirs could support *Dreissena* populations. Examples include Briery Creek Reservoir, Lake Chesdin, Swift Creek Reservoir, Lake Moomaw, and Little Creek Reservoir. (Lake Chesdin, the largest of these, is discussed separately under the section on lakes.) The danger of introduction via vessel hulls or trailers increases with the amount of recreational use, and the James River drainage has over 90 public boat ramps, mostly on lakes (DeLorme Mapping Co., 1989). In addition, there are annual professional bass fishing tournaments on the tidal freshwater portions of the James and Chickahominy Rivers, with many vessels trailered in from other states, where they may have been in *Dreissena* infested waters only a day or two previously.

The risk of inoculation from the seaward direction is also high, via both ballast water and the hulls of incoming vessels. Large vessels containing varying amounts of ballast water regularly visit the Port of Richmond from freshwater European ports (Meehan Overseas Terminal, Inc., 1991), some of which have large *Dreissena* populations. Whether freshwater ballast containing *Dreissena* larvae is acquired in Europe and released, undiluted by seawater, in Richmond, is unknown, but it appears probable. Barge and other vessel traffic between industrialized areas of the James River and other estuaries in Chesapeake Bay is heavy. There is also heavy recreational traffic from other estuaries.

Conditions for *Dreissena* reproduction are favorable throughout much of the estuary, and two other non-native bivalves, *Corbicula fluminea* and *Rangia cuneata,* have already successfully invaded freshwater and oligohaline portions of this estuary (Diaz, 1977, 1989). The native bivalves *Mytilopsis leucophaeata* (a close relative to *Dreissena), Sphaeriuum transversum,* and *Pisidium casertanum* are also common in oligohaline and freshwater portions of the James River (Diaz, 1977). Near Cartersville, pH in August is 8.1, and calcium content is about 22 ppm (Prugh *et al.,* 1992), both within the minimum requirements for *Dreissena* reproduction.

ELIZABETH RIVER AND ALBEMARLE SOUND

Tidal freshwaters of southeast Virginia, including the Elizabeth River and parts of the Albemarle Sound system, are at risk of inoculation by *Dreissena*, and some regions within this area are susceptible to establishment of the species. The Elizabeth, Nansemond, and Lynnhaven Rivers in southeast Virginia, Currituck Sound and the Pasquotank River in North Carolina (Albemarle Sound), and many lesser bodies of water, form an extremely complex estuarine and freshwater system, because of the Intracoastal Waterway and many lesser canals. The northernmost portion of Currituck Sound is Back Bay, in Virginia; other connected bodies of water include Lake Drummond (Dismal Swamp), Lafayette River (Norfolk), Rudee Inlet (Virginia Beach), and various small lakes in the cities of Virginia Beach, Chesapeake, Norfolk, and Suffolk. The freshwater portions of the Elizabeth, Nansemond, and Lynnhaven Rivers are relatively small, but the Chesapeake and Albemarle Canal, the Dismal Swamp Canal, and lesser waterways are usually fresh, and all of Currituck Sound and most of Albemarle Sound are oligohaline or fresh water, depending on freshwater inflow (NOAA, 1985). All of these bodies of water are intimately connected by a network of canals or ditches (refer to United States Geological Survey topographical maps), so if *Dreissena* becomes established in any part of this system it could eventually spread to all others.

Inoculation of the above region by *Dreissena* is most likely to occur via the heavy recreational and commercial traffic incoming from other estuaries. There are few freshwater lakes in Virginia Beach with boat ramps, so the risk of inoculation by *Dreissena* on the hulls of recreational vessels trailered from other systems is low. Conversely, there are thousands of small recreational vessels which use creeks, canals, and oligohaline portions of the many small subestuaries in this area, and there is heavy barge traffic along the Chesapeake and Albemarle Canal, part of the Intracoastal Waterway. *Dreissena* need become established only in one of the other Chesapeake estuaries and, sooner or later it will appear in Virginia Beach or the City of Chesapeake waterways, as fouling organisms on small vessel hulls.

The Chesapeake and Albemarle Canal is potentially important in aiding dispersal of *Dreissena.* Even if the canal does not serve as a reservoir for *Dreissena* recruits, it will serve as a temporary relief of osmotic stress to *Dreissena* that are fouling vessels traveling along the Intracoastal Waterway. This could prolong the survival of *Dreissena* on vessels otherwise traveling in relatively high-salinity areas.

Some regions within southeast Virginia are susceptible to establishment of *Dreissena* others are not. Back Bay, the northernmost extension of Currituck Sound, is normally fresh, but in some years, salinity can increase to as high as 10 for extended periods, although small tributary estuaries remain fresh (Norman and Southwick, 1991). The only bivalve which presently persists in Back Bay is the non-native oligohaline clam, *Rangia cuneata* (Lane and Dauer, 1991). Alkalinity and calcium levels for Back Bay are marginal for *Dreissena* reproduction (mean pH 7.7, calcium content of 10-20 ppm) (Sincock *et al.*, 1966), but the presence of Rangia infers that other species of bivalves, such as *Dreissena,* could survive there. Once established, *Dreissena* would survive high-salinity periods by persisting in freshwater tributaries.

The Dismal Swamp and the Dismal Swamp Canal, in contrast to Back Bay, have very low pH (maximum 6.7 in July) and calcium (7.2 ppm) (Lichtler and Marshall, 1979), probably much too low for the reproduction or even extended survival of *Dreissena*. The Dismal Swamp Canal therefore is unlikely to be invaded by, or serve as, a route for natural dispersal of *Dreissena,* but it remains a ready-passage for dispersal by fouling on the hulls of vessels passing between the Elizabeth River, in the Chesapeake Bay system, and the Pasquotank River, in the Albemarle/Pamlico Sound system.

Urban development in southeast Virginia has lead to the creation of many small lakes, most of which are connected by ditches or pipes to other waterways. Water quality and chemistry are unknown for most of these, but it is probable that at least some will have ideal conditions for *Dreissena.* For example, Smith and Whitehurst Lakes, in the Little Creek drainage adjacent to the Norfolk International Airport, are both modally alkaline with sufficient calcium for *Dreissena* reproduction (Virginia Department of Game and Inland Fisheries, unpubl. data). If *Dreissena* is introduced, therefore, the probability that it could become established in some part of the system is high.

TABLE 1. PREDICTED INVASION SUCCESS IN FRESHWATER ESTUARIES

Estuaries are listed approximately from north to south. *Risk* refers to the relative chance that *Dreissena* will be introduced, and *susceptibility* refers to the relative chance that *Dreissena* will attain high population levels.

Estuary	Risk	Susceptibility
Pocomoke River, MD & VA	low	low
Potomac River, MD & VA	high	high
Rappahannock River, VA	moderate	moderate
Plankatank River, VA	low	low
Mattaponi River/ Pamunkey River, VA	moderate	low
James River, VA	high	high
Elizabeth River, VA/ Albemarle Sound, VA & NC	high	high

Table 1 summarizes the information for estuaries discussed above. The relative chance of inoculation, or "Risk," is given as "high," "moderate," or "1ow," based on factors discussed above. Using available water chemistry data and published data on *Dreissena* physiological requirements, the relative threat of establishment of large populations of *Dreissena* following inoculation, or "susceptibility" is also given as "high," "moderate," or "low" "High" predicts that if *Dreissena* becomes estab lished, it will rapidly attain high population levels, and stay at those levels at least until the ecological community adjusts to the invasion. "Moderate" predicts that if *Dreissena* becomes established, it will reproduce successfully only during certain, favorable periods, and will attain pest proportions only occasionally. "Low" indicates that *Dreissena* is unlikely be able to reproduce successfully.

Lakes and Reservoirs

All major rivers and many small rivers in the mid-Atlantic region have large artificial impoundments. It is unlikely that *Dreissena* could become established in a river system by a single inoculation into the river itself, but once they become established in a reservoir, they would then spread to downstream reservoirs and freshwater portions of estuaries. Only unfavorable water quality, such as low pH and low calcium concentrations, would then limit *Dreissena* population levels.

Water chemistry data were available for some Virginia lakes, discussed in alphabetical order hereafter, except where two or more adjacent reservoirs are discussed together. Water chemistry data, especially calcium levels, are incomplete for most lakes, and while risks have been assessed based on known data, it is possible that the knon data are not representative of common conditions. The role of water chemistry in *Dreissena* survival and reproduction are discussed in *Criteria for Predicting Zebra Mussel Invasions in the Mid-Atlantic Region.*

Claytor Lake

The risk of inoculation by *Dreissena* to Claytor Lake, is high, relative to other lakes, but its suscep tibility to the establishment of large populations is only moderate. Claytor Lake is a multi-purpose resevoir (recreation, hydropower) on the New River (Kanawha River), a tributary of the Ohio River. It receives heavy recreational use, with eight improved public boat ramps, as well as eight more on the New River upstream (DeLorme Mapping Co., 1989). There are thus many opportunities for accidental inoculation of *Dreissena* via the hulls of small recreational vessels. Fields Dam impounds the New River upstream of Claytor Lake, but the resevoir is probably too small (flushing rate too high) to act as a reproductive refuge for *Dreissena.* Although *Dreissena* is already present in other portions of the Ohio River basin (New York Sea Grant, 1993), the probability of its dispersing naturally upstream to Claytor Lake is low, relative to the risk posed by human-mediated invasion. Surface waters are normally quite alkaline (7.3-9.3 in June), but calcium is generally low (9-10 ppm). In some years, however, calcium levels can attain 30 ppm (Virginia State Water Control Board, unpubl. data), so the question of *Dreissena* success in Lake Claytor, should it be inoculated, would depend on the varying water chemistry.

Flannagan Reservoir

John W. Flannagan Reservoir is at high risk of inoculation by *Dreissena,* but its susceptibility to establishment of large populations is only moderate. Flannagan Reservoir is on the Pound River, a tributary of the Ohio Ever via the Big Sandy River. The reservoir has three improved public access boat ramps; there are two more just upstream on tributaries, and three more are on North Fork Pound River Lake, also upstream (DeLorme Mapping Co., 1989). There are thus many opportunities for inoculation via the hulk of small recreational vessels. Although *Dreissena* is present in other portions of the Ohio River basin (New York Sea Grant, 1993), the probability of its dispersing naturally upstream to Flannagan Reservoir is low, relative to the risk posed by human-mediated invasion. The surface waters are alkaline (pH 7.6-8.9 in June), with low to moderate levels of calcium (9-29 ppm) (Virginia State Water Control Board, unpubl. data). *Dreissena* would survive, if released into Flannagan Reservoir, but in some years reproduction may be calcium-limited.

Harwood Mills Reservoir

Harwood Mills Reservoir is one of many small multi-use (fishing, municipal water storage) reservoirs in urbanized southeast Virginia. The risk of inoculation by *Dreissena* is low, but the lake is highly susceptible to establishment of this species, should it become introduced. Harwood Mills, on the headwaters of the Poquoson River, in Newport News, has a single public boat ramp, limited to craft without internal-combustion engines. This reduces but does not eliminate the possibility of *Dreissena* inoculation via the hulls of recreational vessels. Like the majority of small municipal reservoirs in southeast Virginia, it is modally alkaline (pH 8.1 in June), with moderate levels of calcium (25 ppm) (Virginia Dept. Game and Inland Fisheries, unpubl. data). These conditions are favorable for *Dreissena* reproduction.

Of ten similar small reservoirs in that area surveyed by Virginia Department of Game and Inland Fisheries, six have water chemistry that would support high populations of *Dreissena,* three have chemistry that would support at least moderate populations, and only one (Kilby Reservoir) has water chemistry that would be unlikely to support *Dreissena* populations.

Kerr Reservoir and Lake Gaston

John H. Kerr Reservoir, and Lake Gaston, just downstseam, are at high risk of inoculation by *Dreissena,* and at least portions of both lakes are highly susceptible to establishment of large populations of this species. Both reservoirs are large multi-use (recreation, hydropower) impoundments on the Roanoke River, astride the Virginia/North Carolina Reservoir. Just below Lake Gaston in North Carolina is the Roanoke Rapids dam and reservoir, and the Roanoke ends in Albemarle Sound, North Carolina, which has an extensive freshwater, portion. Kerr Reservoir and Lake Gaston are heavily used by recreational boaters and fishermen, with a total of about 50 public boat ramps. In addition, both are downstream of a variety of public-access reservoirs, including Philpott Reservoir, Banister Lake, Smith Mountain Lake, and Leesville Lake in Virginia, and Hyco Lake, Mayo Reservoir, and After Bay Reservoir in North Carolina, with over 80 public access boat ramps (Alexandria Drafting Co., 1981; DeLorme Mapping Co., 1989). Water chemistry in both Kerr Reservoir and Lake Gaston varies between stations, and on the basis of this McMahon (1992) considered the susceptibility of Lake Gaston to be relatively low. Both lakes, however, have semi-enclosed branches in which water chemistry may differ, and in both lakes there are modally alkaline regions (pH 6.9-9.3). Calcium levels for Kerr Reservoir were unavailable, but calcium content of the alkaline stations in Lake Gaston are about 24-44 ppm (Virginia State Water Control Board unpubl. data), and because of the proximity of the two lakes, it is safest to assume that Kerr Reservoir, more complex even than Lake Gaston, also has regions of modally high calcium.

Lake Anna

Lake Anna is at high risk of inoculation by *Dreissena* but its susceptibility to subsequent establishment of this species is low. It is on the North Anna River, a tributary of the Pamunkey, and is the largest reservoir in the Pamunkey River drainage. Lake Anna is used heavily by recreational boaters and fishermen, and is the water source for the North Anna Nuclear Power Plant. Downstream is the freshwater tidal portion of the Pamunkey River. There are 9 improved public access boat ramps on Lake Anna. Upstream of Lake Anna are Lake Orange, with one public boat ramp, and Lake Louisa, which is surrounded by a housing development (DeLorme Mapping Co., 1989). McMahon (1992) considers Lake Anna to be highly susceptible to the establishment of large *Dreissena* populations, but based on unpublished water chemistry data provided by Virginia Power (Innsbrook Technical Center, Glen Allen, VA), this seems unlikely. Although pH often rises as high as 7.9 in some branches of Lake Arms during the summer, most of the lake is modally acidic, and even, where waters are alkaline, the calcium content remains too low (maximum about 6.0 ppm) for *Dreissena* reproduction.

LAKE CHESDIN

Lake Chesdin is at relatively high risk of inoculation by *Dreissena*, but its susceptibility to establishment of this species is low. On the Appomattox River (a tributary of the James), it has several public-access boat ramps, and receives heavy recreational use from the nearby Richmond area. It has a water chemistry unsuited for *Dreissena*, however; the pH is variable (6.4-8.7), but modally acid in summer in shallow water, and calcium levels are very low (about 5-10 ppm) (Virginia State Water Control Board, unpubl. data).

LAKE GASTON (SEE KERR RESERVOIR)

LAKE MOOMAW

Lake Moomaw is a rarity in Virginia; a large reservoir at relatively low risk of inoculation by *Dreisstna*. If *Dreissena* were introduced, however, Lake Moomaw is moderately susceptible to establishment of a large population. It is on the Jackson River, in the headwaters of the James River, within a state wildlife management area, where recreational use is limited. DeLorme Mapping Co. (1989) shows no public-access boat ramps on or upstream of Lake Moomaw. The pH is modally alkaline (7.6-8.4) in shallow water in summer, with calcium levels of about 13-17 ppm (Virginia State Water Control Board, unpubl. data): marginal conditions for *Dreissena* reproduction.

LEESVILLE RESERVOIR (SEE SMITH MOUNTAIN LAKE)

PHILPOTT RESERVOIR

Philpott Reservoir is at relatively high risk of *Dreissena* inoculation, but its susceptibility to establishment of this species is low. It is on the Smith River, a tributary of the Roanoke River via the Dan River, and has 11 improved, public access boat ramps. The water is modally alkaline (pH 7.2-8.7), but available calcium data indicates very low levels (45 ppm) (Virginia State Water Control Board, unpubl. data), which would inhibit *Dreissena* reproduction. If it does become established, however, it will spread to Kerr Reservoir and Lake Gaston, downstream, which have more benign water chemistry.

SMITH MOUNTAIN LAKE AND IiEESVI~LE’ LAKE

Smith Mountain Lake is a large reservoir on the headwaters of the Roanoke River, and Leesville Lake is directly be-low it. Both are at high risk from inoculation by *Dreissena,* although the susceptibility of both lakes to establishment of large populations is only moderate. There are only two improved public access boat ramps into Leesville Lake, but there are more than 17 into Smith Mountain Lake, upstream. Smith Mountain Lake is also the site of a large, annual professional bass fishing tournament. The pH of both lakes in shallow water during the summer is normally high (7.6-9.1), and calcium levels are about 15-17 ppm (Virginia State Water Control Board, unpubl. data). These conditions permit reproduction of *Dreissena,* although in some years calcium content may limit population level. Downstream of these lakes are John H. Kerr Reservoir and Lake Gaston.

SOUTH HOLSTON LAKE

South Holston Lake is at relatively high risk of inoculation by *Dreissena,* and its susceptibility to subseuent establishment of large populations of this species is also high. South Holston Lake is a large multipurpose reservoir (recreation, hydropower) on the South Fork Holston River, a tributary of the Tennessee River. It is in southwest Virginia, and the majority of the lake is within Tennessee. The lake is within a few hours drive of other lakes in the Tennessee River system containing *Dreissena* (New York Sea Grant 1993). There are 16 public access boat ramps on the lake, and two more upstream on the smaller Hungry Mother Lake. The pH of South Holston Lake is relatively stable and modally alkaline (6.9-8.6 in June and July), with moderately high levels of calcium (18-30 ppm), based upon data collected largely in the 1970s (Tennessee Valley Authority unpubl. data). These conditions are favorable for *Dreissena* growth and reproduction, and once introduced, it would rapidly attain pest proportions.

WESTERN BRANCH RESERVOIR, LAKE MEADE

Western Branch Reservoir, Lake Meade, and some adjacent reservoirs are at moderate risk of inoculation by *Dreissena,* and highly susceptible to establishment of large populations of this species. Western Branch Reservoir-is the largest of seven impoundments in the Nansemond River drainage, in southeast Virginia. It is on the Western Branch Nansemond River, while Lake Meade is the largest of four impoundments on the Eastern Branch Nansemond River, but the drainages of these are very close to each other. Other lakes include Lake Prince, and Lake Burnt Mills, upstream of Western Branch Reservoir, and Lake Cohoon, Lake Kilby, and Spaetes Run Lake, upstream of Lake Meade. Western Branch Reservoir has two public boat ramps on or upstream of it, and Lake Meade has four. All lakes are used heavily for recreational fishing, but the majority of the users are local (Virginia Dept. Game & Inland Fisheries, pers. comm.). Water chemistry data shows moderately alkaline water (pH 8.2 at 2 m depth, June) with moderate levels of calcium (20-25 ppm) in all of these lakes except Lake Cohoon and Lake Kilby (no data is available for Spaetes Run Lake). Lakes Cohoon and Kilby are often acidic, and their levels of susceptibil-, ity are thus moderate or low. (Virginia Dept. Game and Inland Fisheries, unpubl. data). In the remaining four lakes, conditions are favorable for *Dreissena* reproduction. Once invasion occurred in any of those four lakes,

Dreissena would reach high population levels. Natural dispersal, perhaps-by adults attached to turtles or other amphibious organisms, could then spread *Dreissena* to the other impoundments in the Nansemond drainage.

Table 2 summarize the information for reservoirs discussed above. The definitions for “risk and “suscep tibility” are the same as for Table 1.

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TABLE 2. PREDICTED INVASION SUCCESS IN VIRGINIA LAKES AND RESERVOIRS

Reservoirs are listed alphabetically. Invasion Risk refers to the relative chance that *Dreissena* will be introduced, and *Susceptibiliyt* refers to the relative chance that *Dreissena* will attain high population levels. See also text for explanation of terms.

Lake	Drainage	Recreational Vessel Use	Other Uses	Risk	Susceptibility
Claytor Lake	Ohio	high	hydroelectric power	high	moderate
Flannagan Res.	Ohio	high		high	moderate
Harwood Mills Res. (Newport News)	Poquoson	moderate	municipal water	low	high
Kerr Reservoir	Roanoke	high	hydroelectric power	high	high
Lake Anna	Pamunkey	high	nuclear power plant	high	low
Lake Chesdin	James	high		high	low
Lake Gaston	Roanoke	high	hydroelectric power	high	high
Lake Meade	Nansemond	high		moderate	high
Lake Moomaw	James	low	wildlife mgmt. area	low	moderate
Leesville Lake	Roanoke	moderate		high	moderate
Philpott Res.	Roanoke	high		high	low
Smith Mtn. Lake	Roanoke	high		high	moderate
S. Holston Lake	Tennesse	high	hydroelectric power	high	high
W. Branch Res.	Nansemond	moderate	municipal water	moderate	high

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