An Analysis of the Recreational Angler Vector and Associated Pathways to aid in the Prevention of Invasive Species Introductions in Mid-Atlantic Waterways

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Executive Summary:

Recreational fishing is a known vector for the transport and dispersal of invasive species, with key pathways including live bait, angling gear, and boating gear. In Maryland, live bait has resulted in the establishment of non-native worms, minnows, and crayfish, zebra mussels (*Dressena polymorhpa*) and hydrilla (*Hydrilla verticillate*) are suspected to have been introduced through boating, and didymo (*Didymosphenia geminate*) is suspected to have been introduced by angling gear. These and other invasive species have the potential to cause serious ecological harm and economic impacts throughout the Mid-Atlantic Region. The objective of this proposed study is to contribute to the prevention and management of invasive species through a pathway analysis that utilizes fishing trip location data from a 2016 survey of Maryland non-tidal anglers.

Finding 1: Fishing effort is correlated with invasive species-infected waterbodies in Maryland. In 2015, an estimated 411,000 trips occurred across four waterbodies – Gunpowder River (~55,000 trips), Savage River (~33,000 trips), Potomac River (~237,000 trips), and Deep Creek Lake (~87,000 trips).

Finding 2: The fly fishing method – a known pathway for transmitting didymo between waterways – is commonly used by recreational anglers who fish the Gunpowder River and Savage River. An estimated 20,000 trips were taken to the Gunpowder River by anglers who use the fly fishing method, and about 19,000 such trips were taken to the Savage River.

Finding 3: The use of boats while fishing – a known pathway for transporting invasive species such as hydrilla and zebra mussels – is common across anglers who fish the Potomac River and Deep Creek Lake. An estimated 154,000 trips were taken to the Potomac River by anglers who use watercraft to fish, and about 63,000 such trips were taken to Deep Creek Lake.

Finding 4: Anglers who visit the four waterbodies described above and use the relevant fishing methods pathways take over 100,000 additional fishing trips to a large network of locations in Maryland. Potomac River anglers take nearly 100,000 trips to other (pathway relevant) waterbodies, Deep Creek Lake anglers – 41,000 trips, Savage River – 28,000 trips, and Gunpowder River anglers – 20,000 trips.

Finding 5: Fly fishers visiting the Savage River fish a diverse network of rivers/streams. While 65% more trips are taken to the Gunpowder River, a similar number of trips are taken by fly fishers to both, and fly fishers visiting the Savage River took 38% more trips to other rivers/streams than did Gunpowder River anglers.

Contents

Introduction:

Recreational fishing is a well-known vector for the spread of aquatic invasive species in non-tidal waterways, with anglers transporting and dispersing invasive species through the live bait, fishing gear and boating gear pathways. It is confirmed in many cases and suspected in others that these pathways have introduced invasive species into Maryland. The use of live bait by recreational anglers is the suspected pathway for introducing at least five nonnative finfish species, four non-native crayfish species, and several non-native earthworm species in Maryland (Kilian et al. 2012). Angling gear (e.g., fishing waders and boots) and boats/boating equipment (e.g., boat trailers) are suspected pathways for the introduction of aquatic plant and algae species. The Maryland Department of Natural Resources (MDDNR) Maryland Aquatic Nuisance Species Plan (MANSP) lists and describes nine "high priority" aquatic nuisance plant species that have become established in Maryland (MANSP 2016). These species include *Hydrilla verticillata* (hydrilla), *Myriophyllum spicatum* (Eurasian watermilfoil), and *Egeria densa* (Brazilian elodea), which are known to be transported between waterbodies by boats and trailers. Also listed as "high priority" is *Didymosphenia geminata* (didymo), a freshwater invasive algae species that can form thick brown mats on stream bottoms, altering the ecology of coldwater streams and negatively affecting recreational activities such as trout fishing. The transport and dispersal of didymo has been linked to the use of waders with felt-soled boots – a type of fishing gear commonly used by trout anglers (Bothwell et al. 2009).

The invasive species described above have the potential to cause serious ecological and economic impacts throughout the Mid-Atlantic region. As such, state agencies are taking preventative measures to reduce the risk of introduction and spread of "hitchhiking" invasive species into new waterways. Such measures generally involve the identification of locations where the pathway risk is high and subsequently targeting anglers accessing the water at these locations with a combination of informational displays, gear cleaning devices, and/or staff observers with expertise in invasive species identification. In Maryland, the MDDNR has teamed with Garrett College in Western Maryland, establishing a program in which boat launch stewards are stationed at key launch sites on Deep Creek Lake – a major Western Maryland boating destination – to examine trailers and boats for attached aquatic invasive species. Additionally, to help prevent the introduction and spread of didymo, the state of Maryland has banned the use of felt-soled waders and deployed 45 wader wash stations at key coldwater river/stream access points used by trout anglers. While a number of other states in the U.S. have banned felt-soled waders (e.g., Alaska, Missouri, Nebraska, Rhode Island, South Dakota), Rhode Island is the only state other than Maryland in the Mid-Atlantic region to enact such legislation. As such preventative measures require the allocation of scarce personnel time and budgets, cost-effective management can be facilitated through a vector and pathway spatial analysis highlighting "hotspots" which have the greatest risk of invasive species introductions.

The objective of this project is to examine recreational angler choice of waterbodies as a fishing destination, within the context of invasive species distribution and the use of risky fishing method pathways that facilitate the transmission of invasive species to new waterbodies. First, angler choice of fishing sites is visually represented through ArcGIS maps that highlight the location of fishing trips involving the use of one of three fishing methods pathways (fly fishing, boating, and natural bait). Data layers accounting for the use of risky fishing methods are overlain with data layers highlighting the distribution of the relevant invasive species that can be spread through the use of relevant fishing method pathways. The combination of angler fishing site choice, risky fishing method pathway used, and invasive species distribution facilitates the identification of waterbodies and geographical areas of concern. Second, individual angler movement between waterbodies through different fishing trips is examined. The focal point of this analysis is four frequently fished waterways confirmed to have invasive species present that are known to be transported through the use of fishing method pathways commonly used in these waterbodies. These four areas are the Gunpowder River (risky fishing method pathway: Fly Fishing Method), Savage River (Fly Fishing Method), Potomac River (Boating Method), and Deep Creek Lake (Fishing Method). This analysis accounts for the scale and scope of angler-specific movement between different waterbodies. The report concludes with a summary of key findings related to the potential transmission of invasive species between waterbodies.

METHODS

Survey Data

This analysis was conducted using previously collected secondary data obtained from a combination internet and mail survey of a randomly drawn sample of individuals (N= 4,285) licensed to fish in Maryland non-tidal waterways during the 2015 fishing season. The objective of this survey was to collect information on recreational angler effort, angler preferences (especially with respect to trout fishing), trip-related expenditures, and socioeconomic/ demographic information to inform and improve non-tidal fisheries management in Maryland. However, this survey generated large quantities of spatially-explicit recreational angler site choice data that could be used to describe fishing method pathway risk.

Survey development and implementation followed the Dillman Method (Dillman 2014). Individuals were contacted up to four times via the U.S. Postal Service, with approximately two weeks between mailings. Pending receipt of a completed survey, the individual was excluded from future mailings. The first mailing consisted of a personalized letter that introduced the purpose of the survey and provided a web address for accessing the survey. The second and third mail contacts were reminder postcards that included the web address for accessing the

survey. A fourth mailing – a 12-page hard copy survey booklet and business-reply mail envelope – was sent to individuals who had not responded to the first three mailings. This final hard copy mailing enabled the participation of individuals who did not have internet access and/or lacked the internet skills to complete the survey online. Of the 4,285 individuals contacted with survey mailings, 456 mailings were returned by the USPS due to an invalid home address. From the population of individuals with valid home addresses (3829), 962 individuals responded to the survey, yielding a response rate of 25.1%. This response rate is comparable to recent response rates for recreational fishing surveys following the Dillman Method or similar approaches. For example, Brinson and Wallmo (2013) implemented a large survey of saltwater recreational anglers (N= 33,673; 6 different U.S. regions) which yielded an aggregate response rate of 27% and regional response rates which varied between 21% and 38%.

Two primary sources of data from the non-tidal recreational fishing survey were used to identify the geographic locations of fishing trips. The first primary source of data on non-tidal angler fishing location was obtained from survey question 14 (Figure 1) and survey question 16 (Figure 2). In these two questions, anglers provided information on the annual number of trips and fish species targeted for up to six Maryland non-tidal fishing areas (maximum of three lakes/ponds/reservoirs; maximum of three rivers/streams). The second source for data is obtained from survey questions 4-10 (see Figure 3 below). These questions prompt anglers to provide details of a specific recent fishing trip[1], including the location of the trip (waterbody, nearby town/city), mode of fishing (e.g., boat, shore/wading), fishing method/gear used (e.g., fly fishing, live bait), and species targeted (e.g., trout). Additional information on fishing method pathway used is obtained from survey question 17 (see Appendix A).

The two survey sections that generate information on fishing trips each have unique aspects that make them useful for different purposes. An advantage of survey questions 14 and 16 is the large quantity of spatially-explicit trip information generated, both for an individual angler and across all anglers. This enables the geolocation of a large number of fishing trips across the state of Maryland. Further, given that these questions elicit up to six trip locations per angler, these questions account for the movement of individual anglers across waterbodies through multiple fishing trips. However, these questions generate limited location-specific information (limited to fish species targeted), and these questions do not generate trip-specific information.[2] Questions 4-10 (Figure 3) provides information on which elicits trip-specific information on species targeted, fishing method, and nearest city/town.

[1] Asking anglers about their most recent fishing trip is common survey approach for eliciting trip information. However, information collected through such a survey approach cannot be extrapolated to the population of anglers if aspects of the angler fishing trip (e.g., species targeted, method used, amount of expenditures) are correlated with the time of year the fishing trip occurred. To circumvent this problem to the greatest degree possible, the survey incorporated a question asking anglers to identify during which of the four seasons they took a fishing trip. The order of the seasons was randomized in the question across survey respondents, and individuals were prompted to answer a question about the first trip they took during a particular season. This mechanism minimizes bias and ensure that trip responses were received across all seasons.

[2] In the case that an angler recorded one fishing trip to a fishing location, the species targeted would be specific to that trip.

14. **Please list the three Maryland Non-Tidal Rivers/Streams where you went fishing the most in 2015. For each waterbody, also list the county, # of trips, and species targeted.**
(If you did not fish in a Maryland Non-Tidal River/Stream in 2015, please skip to question 15.)

Non-Tidal River/Stream	County (list multiple, if necessary)	# of trips	Species Targeted (list multiple, if necessary)

Figure 1. Question 14 in Maryland Non-Tidal Fishing Survey: The three Maryland non-tidal rivers/streams where an angler went fishing the most in 2015. For each of the three Maryland non-tidal rivers/streams, an angler is also asked to provide county, number of trips, and species targeted.

16. **Please list the three Maryland Lakes, Ponds, or Reservoirs where you went fishing the most in 2015. For each waterbody, also list the county, # of trips, and species targeted.**
(If you did not fish in a Maryland Lake, Pond, or Reservoir in 2015, please skip to question 17.)

Lake, Pond, or Reservoir	County	# of trips	Species Targeted (list multiple, if necessary)

Figure 2. Question 16 in Maryland Non-Tidal Fishing Survey: The three Maryland non-tidal lakes/ponds/reservoirs where an angler went fishing the most in 2015. For each of the three Maryland lakes/ponds/reservoirs, an angler is also asked to provide county, number of trips, and species targeted.

4. During which seasons did you fish in Maryland Non-Tidal waterways? (check all that apply)

- ☐ Winter 2015 (Jan. 2015 – Mar. 2015)
- ☐ Spring 2015 (Apr. 2015 – June 2015)
- ☐ Summer 2015 (July 2015 – Sept. 2015)
- ☐ Fall 2015 (Oct. 2015 – Dec. 2015)

☆ **BEFORE PROCEEDING,** look back to Question 4 and identify the first season you checked, from Left to Right. We are interested in details of the FIRST Maryland Non-Tidal fishing trip you took during this specific season. On the rest of this page, think back to this trip when answering questions.

5. During which month was this fishing trip? (see ☆ above for instructions) _____

6. Name of the waterbody and nearest city/town where you fished

_____ Waterbody _____ Nearest city/town

7. Including yourself, how many people went on this fishing trip? _____

8. How many nights were you away from home on this trip? (if none, enter "0") _____

9. Which fishing types and methods did you use on this trip? (check all that apply)

- ☐ Natural Bait
- ☐ Artificial Lures
- ☐ Fly Fishing
- ☐ Ice Fishing
- ☐ Watercraft (with motor)
- ☐ Watercraft (without motor)
- ☐ Shore/Wading

10. Which fish species did you target on this trip? _____

11. When thinking about this previous fishing trip, please indicate how much you agree or disagree with the following statements.

	Strongly Disagree	*Disagree*	*Neutral*	*Agree*	*Strongly Agree*
Catch (ex: size, # of fish) met or exceeded my expectations	☐	☐	☐	☐	☐
Environmental quality met or exceeded my expectations	☐	☐	☐	☐	☐
Fishing was the primary reason for taking a trip to this area	☐	☐	☐	☐	☐
I plan on taking a fishing trip to this location again	☐	☐	☐	☐	☐

12. For the same trip as above, please enter the dollar amount of your share of expenditures for each category below. Please be as accurate as possible – If unsure, provide your best estimate. If you made no expenditures for a category, please enter a "0".

Transportation (ex: gas & tolls)	$ _____	Restaurant/ Takeout	$ _____	Guide Fees	$ _____
Boat Expenses (ex: gas & launch fees)	$ _____	Entertainment	$ _____	Lodging	$ _____
Groceries/Snacks/ Drinks	$ _____	Bait, Lures, & Tackle	$ _____	Other	$ _____

Figure 3. Questions 4-12 in Maryland Non-Tidal Fishing Survey. These questions ask anglers to recall and provide details of a specific fishing trip.

ArcGIS Mapping Approach

The project team used ESRI ArcGIS mapping and analytics software to illustrate the geographic location of angler fishing trips, within the context of risky fishing method pathways and the geographic distribution of invasive species. The starting point analysis is the waterbody identified by an angler as the location of a fishing trip. Some waterbodies – especially still bodies of water such as lakes, ponds, and reservoirs – enable a high degree of locational precision. However, this waterbody-level analysis provides much rougher granularity for larger rivers/streams. For example, an angler stating that he/she took a fishing trip to the non-tidal Potomac River could have fished at any location along the 184 mile length of this river.

The geospatial approach used within this study involves linking the location of fishing trips to a hydrologic unit that is assigned a unique code (Hydrological Unit Code – HUC). HUCs are defined by watershed boundaries, a characteristic useful for understanding the potential spread of aquatic invasive species. HUCs begin at a coarse-grained level of precision over the United States, and from there are divided into smaller subunits – with the larger HUC number corresponding to a smaller watershed area. Maryland 8 digit and 14 digit HUCs are used for this project. The state of Maryland employs a slightly different methodology than the National System when defining HUCs – Maryland 8-digit HUCs are equivalent to National 11-digit HUCs. This report generally focuses on the MD 8-Digit/National 11-Digit Hydrologic Unit level. See below for figures with 8-digit and 14-digit HUC watersheds for Maryland.

The project team manually identified all fishing trip locations and then linked these locations to the appropriate HUC. All reported fishing locations within each watershed are aggregated together – to the extent possible – to be analyzed at the watershed level. However, as discussed earlier, the trip-specific information obtained from survey questions 4-10 (Figure 3) that includes information both on waterbody and city/town visited enabled a more precise identification of fishing trip location. This was especially the case when the trip was taken to a lengthy river/stream near multiple cities/towns. For this trip-specific information, the waterbody was identified first, and the specific location of the waterbody visited on the trip was identified using the city/town listed in the question. For the data from questions 14 and 16, only a waterway and a county were provided. This limited the usability of this data when the goal was to precisely identify trip location.

It was generally straightforward to manually locate lakes/ponds/reservoirs; this was based on whichever HUC the waterbody described was located in. If the lake/pond/reservoir were split into multiple HUCs – which was uncommon – the waterbody was geolocated into the HUC that the majority of the waterbody was located in. For river/stream fishing trip location data, where possible, HUCs were used that encompassed the entire length of a river/stream within the county listed by the angler. Where this was not possible (i.e., when the precise HUC visited could not be identified from the angler response), trips within that county were evenly

distributed between all possible HUCs that encompassed or bordered the waterway and were within the desired county.

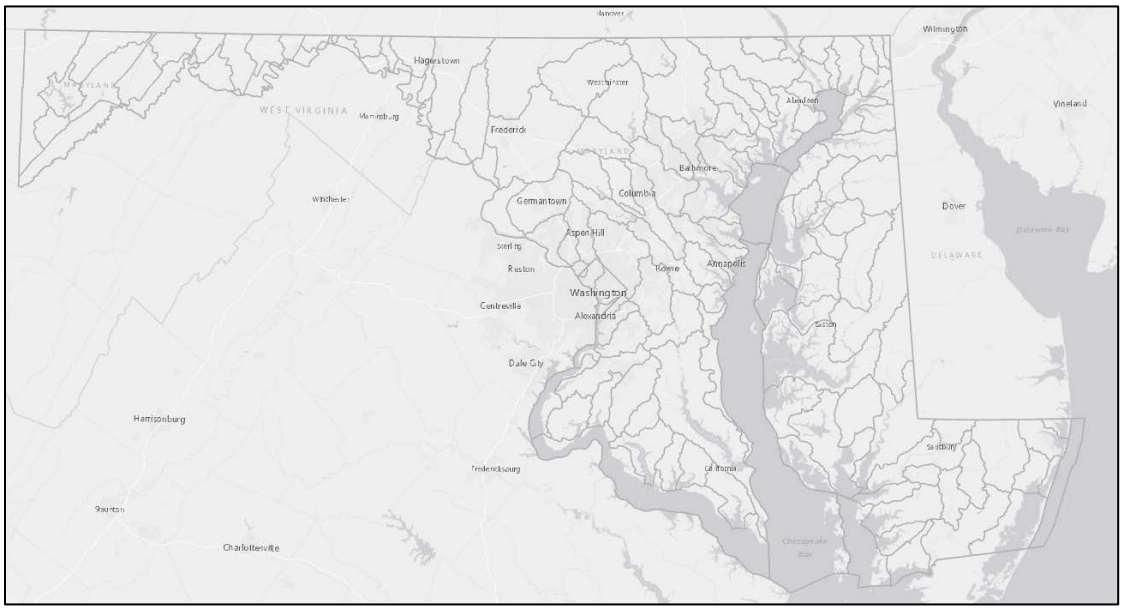

Figure 4: Hollow-outline map showing Hydrologic Unit 8-digit Codes for Maryland. This is equivalent to the National 11-digit Hydrologic Unit Code

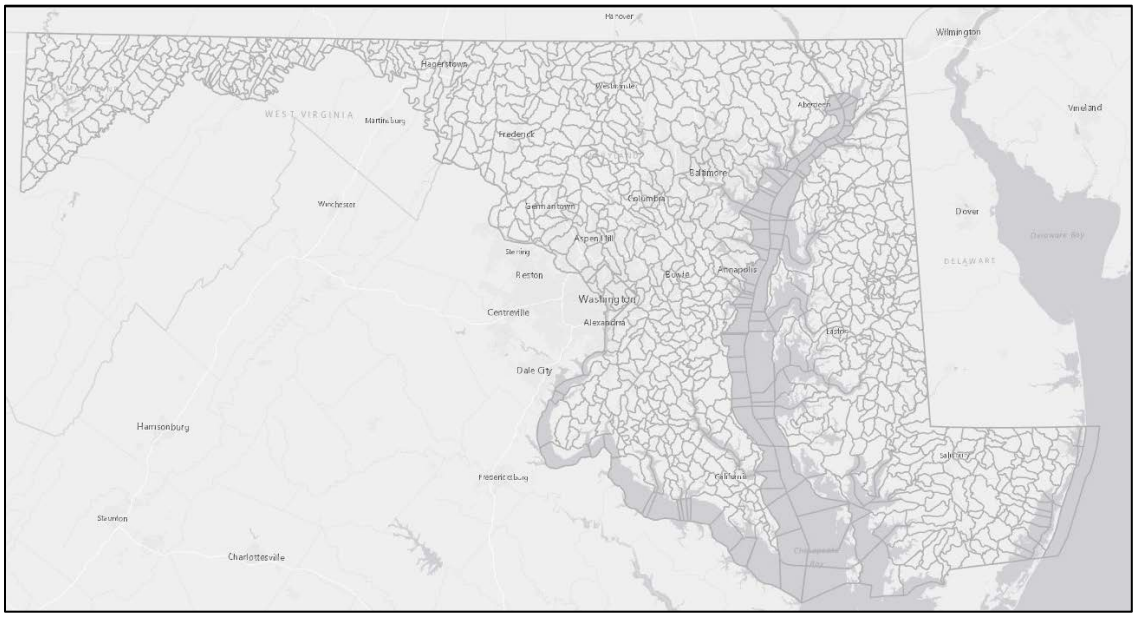

Figure 5: Hollow-outline map showing Hydrologic Unit 14-digit Codes for Maryland

Identifying Key Fishing Location Hubs and Angler Movement Between Waterways

This analysis examines the distribution of trips across different waterbodies in Maryland by a single angler, conditional on the angler having taken a trip to a "waterbody of concern". Factors considered in identifying waterbodies of concern include the number of fishing trips taken to that waterbody, relevance to regional economies (assessed in terms of annual fishing trip expenditures), and the documentation of aquatic invasive species in that waterbody and/or a management priority to prevent additional or future invasive species introductions. After a review of all waterbodies in Maryland per the above criteria, four waterbodies of concern were identified: These waterbodies are listed below.

Gunpowder River –

- Estimated 2015 Annual Fishing Effort – 54,900 trips (2nd among MD rivers)
- Estimated 2015 Fishing Trip Expenditures – $4,100,000
- Key Invasive Species Pathway – Fly Fishing

Savage River –

- 2015 Annual Fishing Effort – 33,300 trips (5th among MD rivers)
- 2015 Fishing Trip Expenditures – $4,300,000
- Key Invasive Species Pathway – Fly Fishing

Potomac River –

- 2015 Annual Fishing Effort – 237,000 trips (1st among MD rivers)
- 2015 Fishing Trip Expenditures – $22,500,000
- Key Invasive Species Pathway – Boating

Deep Creek Lake –

- 2015 Annual Fishing Effort – 86,500 (1st among all MD lakes)
- 2015 Fishing Trip Expenditures – $63,200,000
- Key Invasive Species Pathway – Boating

The estimated total number of annual fishing trips above was calculated by first obtaining the total number of trips to each waterbody from Figure 2 and Figure 3, and then extrapolating this out to the population of individuals licensed to fish in non-tidal waterways (174,853). Estimated annual fishing trip expenditures were obtained by multiplying the estimated annual trips to a waterbody by the mean, waterbody-specific per-trip expenditure obtained from survey question 12 (see Figure 3). Question 12 asks anglers to provide trip expenditure estimates for nine common expenditure categories (e.g., transportation, lodging, other); expenditures across these categories were summed to calculate total expenditures for that specific trip.

To assess the invasive species – related risk to a waterbody of concern, the project team sought to understand the potential frequency of use of risky fishing method pathways at that location. As survey respondents were not asked to report the fishing method used for each fishing trip, the project team developed an approach to estimate the number of fishing trips taken to each location that involved the use of a risky fishing method pathway. This approach involved calculating the total number of trips taken to a waterbody (using survey questions 14 and 16) by anglers who reported using the waterbody-relevant fishing method pathway at least once during the 2015 calendar year (see question 17 in Appendix A). The proportion of risky pathway trips was applied to the estimate of total trips obtained from Figure 1 and Figure 2 to estimate the total annual number of trips taken to a waterbody that involved the use of a fishing method pathway relevant to the waterbody of interest.

RESULTS

ArcGIS Mapping Results

Results in this section are presented visually, in a series of ArcGIS-constructed maps. Each map encompasses one or more layers of data to highlight geospatial relationships between Hydrologic Unit Areas (HUAs), trips involving the use of risky fishing method pathway, and known distribution of key invasive species. This section begins by first demonstrating a single data layer, and then proceeds to overlay the initial layer with additional layers to highlight relevant geospatial data interactions. This approach is intended to help the reader understand the visual-spatial representation of each layer before exploring more complex data relationships involving multiple layers.

The first maps presented within this section use angler responses to survey questions 14 and 16 (Figures 1 and 2) to highlight the spatial distribution of the total number of trips taken by anglers in each HUA and the number of anglers who reported taking a trip to that HUA at least once during 2015. Next, fishing effort is mapped within the context of the use of three risky fishing method pathways on a fishing trip: fly fishing gear; motorized or non-motorized boat; and live bait. In these maps, the size of dots reflect the number of trips taken to a HUA waterbody that involved the use of the waterbody-relevant risky fishing method pathway. As survey questions 14 and 16 do not elicit trip-specific information, these maps use trip-specific information obtained from survey questions 4-10 (Figure 3). Finally, data highlighting the intensity of high-risk angler interactions with a waterbody will be overlain with information on the distribution of aquatic invasive species (didymo, hydrilla, zebra mussels) relevant to that fishing method pathway.

Angler Density and Trip Effort

Figure 6 highlights angler-specific fishing effort in different Maryland waterbodies. Specifically, Figure 6 quantifies the number of anglers that reported taking a fishing trip to a waterbody in an HUA at least once during the 2015 calendar year. Thus, this is a trip-independent measure of geospatial angler fishing location choice. As an angler could record up to 6 fishing trip locations (3 trips to non-tidal rivers/streams and 3 trips to lakes/ponds/reservoirs), a single angler's site choice could be reflected up to six times in Figure 6. For example, an angler reporting taking 20 trips to Deep Creek Lake in Western Maryland and 2 trips to Loch Raven Reservoir (northwest of Baltimore) generated one recorded angler for each of the HUAs that include these waterbodies. Figure 7 accounts for the total number of angler trips to a non-tidal waterbody in Maryland, aggregated by HUA as with Figure 6. In this case, considering the same example as described for Figure 6, the Figure 7 map numerically accounts for all 20 trips to Deep Creek Lake area and all 2 trips to Loch Raven Reservoir area.

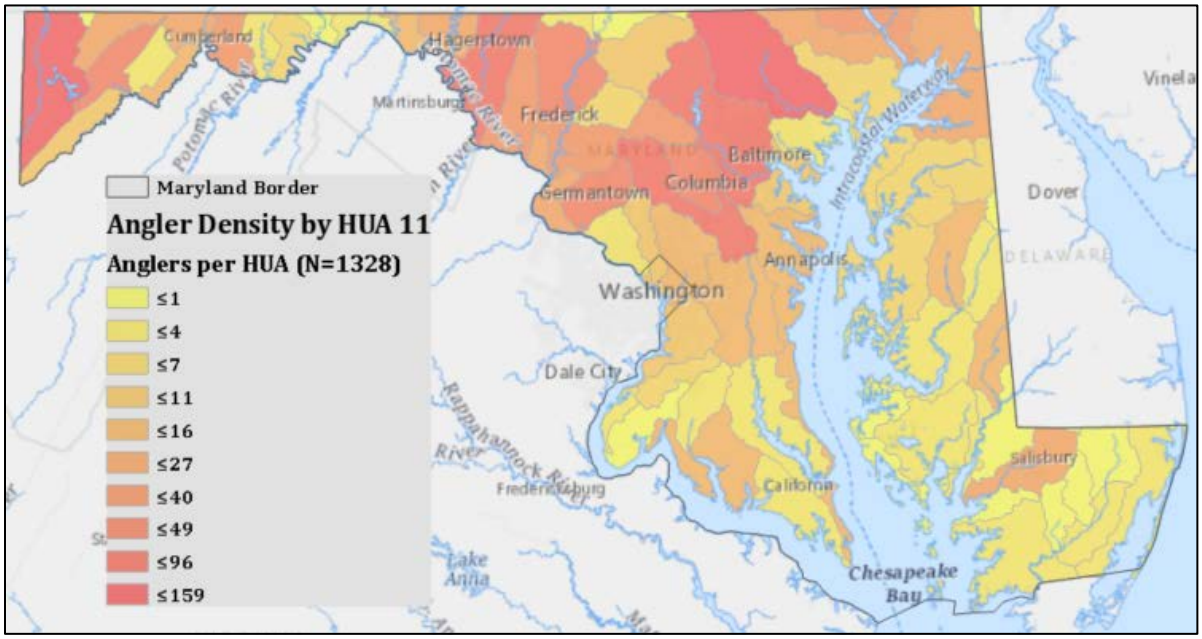

Figure 6: Number of survey respondents reporting a Maryland fishing trip to a non-tidal waterbody in 2015, aggregated at the HUA 11 scale. Data in this map are obtained from responses to survey questions 14 and 16 from Figures 1 and 2.

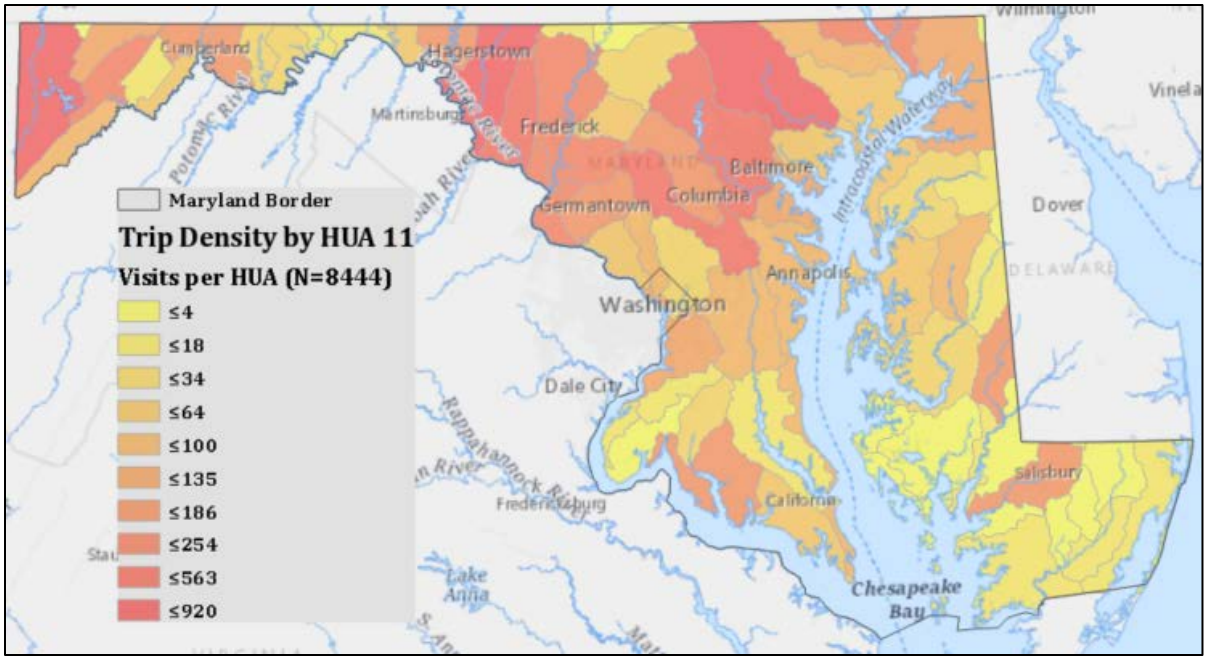

Figure 7: Total number of Maryland fishing trips to a non-tidal waterbody in 2015, aggregated at the HUA 11 scale. Data in this map are obtained from responses to survey questions 14 and 16 from Figures 1 and 2.

Fly Fishing Risk Pathway

Figure 8 incorporates pink shading to highlight MD DNR - confirmed distribution of didymo throughout Maryland, which includes the Savage River in Western Maryland and the Gunpowder River in Central Maryland. Fly fishing is a known risk factor for transmission of invasive species given the potential for didymo to attach to angler gear (especially wading boots and wading pants) during a fishing trip. Figure 9 contains the didymo distribution layer in Figure 8 and also information on the distribution on non-tidal fly fishing trips across Maryland, using data from trip-specific survey questions 4 - 10 in Figure 3. Figure 10 is a zoomed-in snapshot of Central Maryland that includes layers from Figure 8 (angler trips) and Figure 9 (MD DNR confirmed didymo observations). Note the concentration of angler trips in the Gunpowder River, which has been confirmed by the MD DNR to have didymo present. Figure 11 is a zoomed-in snapshot of Western Maryland with data layers from Figures 8 and 9. Note here the fly fishing trips occurring in Savage River, a waterbody confirmed to have didymo present.

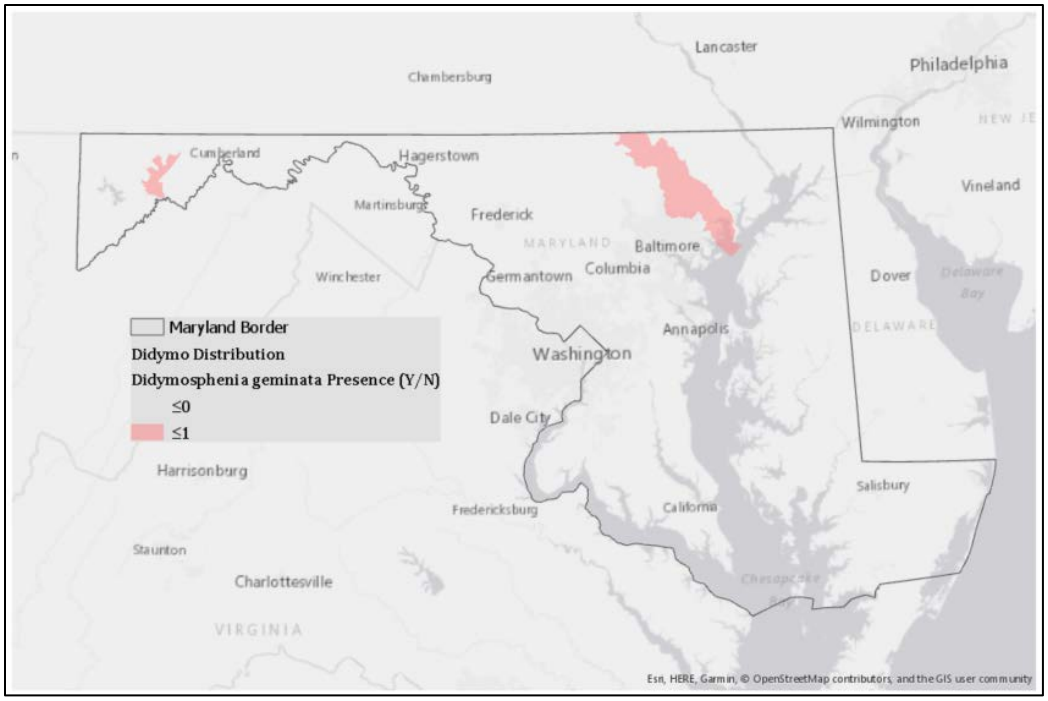

Figure 8: Location of MDDNR - confirmed observations of the aquatic invasive species didymo in pink.

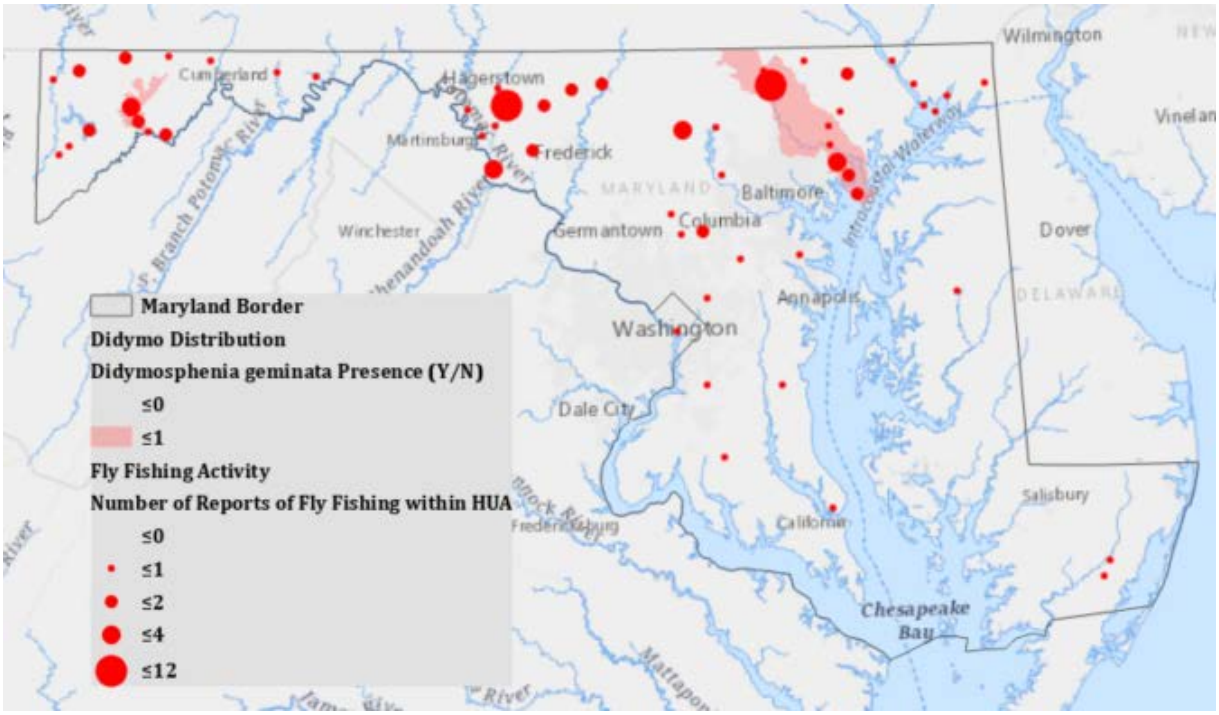

Figure 9: Location of MDDNR - confirmed observations of didymo, and the number of survey respondents reporting a non-tidal fishing trip to a HUA 11 that involved the use of the fly fishing method, using responses to trip-specific questions from Figure 3; maximum one recorded trip per respondent.

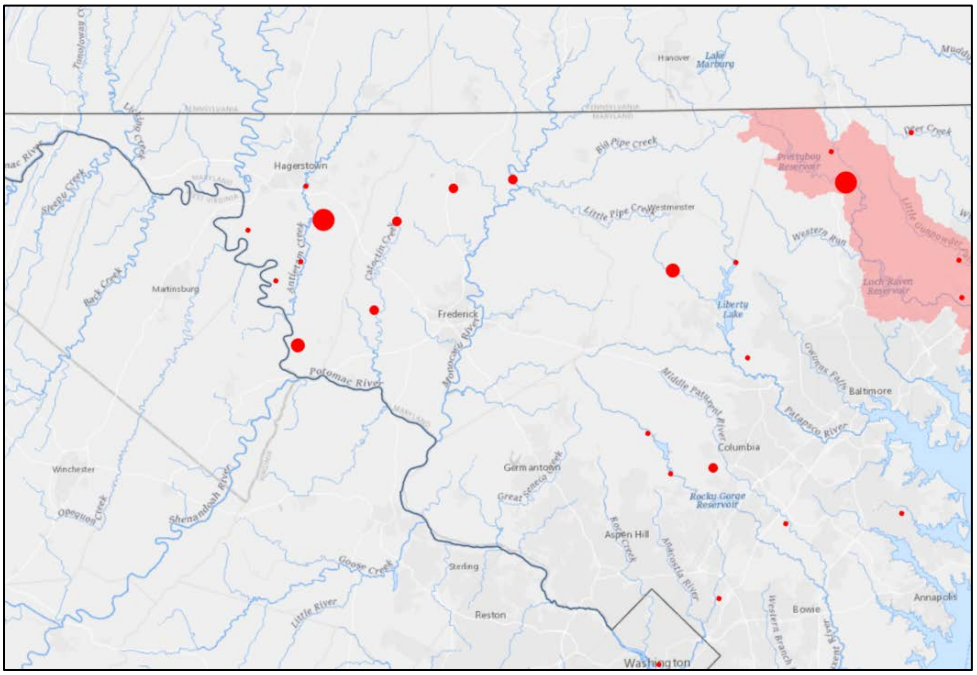

Figure 10: Non-tidal fishing trips to Central Maryland that involved the use of fly fishing gear, using responses to trip-specific survey questions 4-10 from Figure 3. Figure 10 is a zoomed-in snapshot and combination of Figure 8 and Figure 9.

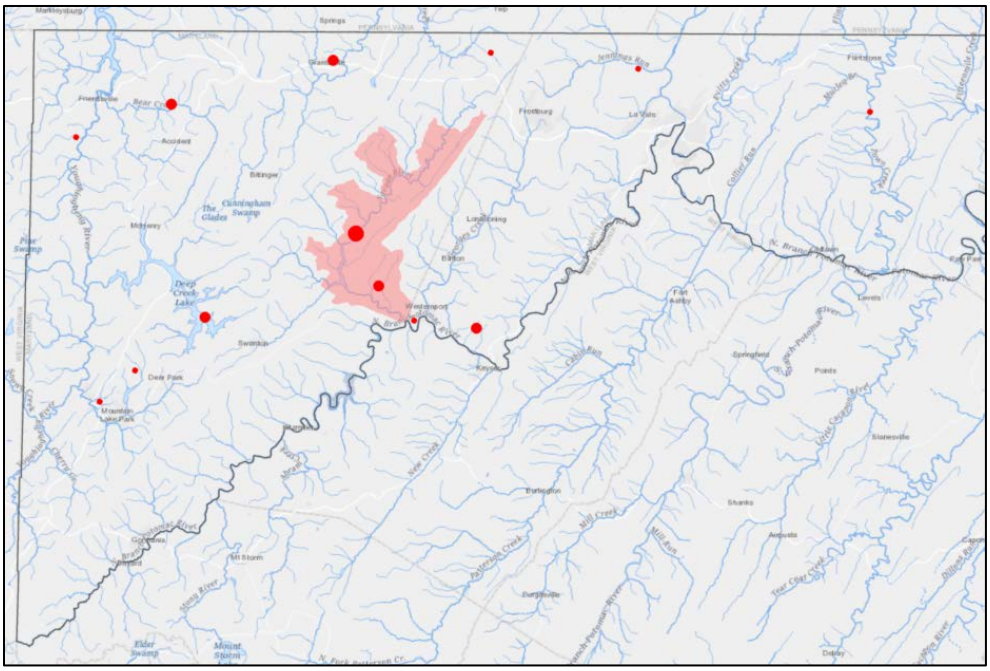

Figure 11: Non-tidal fishing trip to Western Maryland that involved the use of fly fishing gear, using responses to trip-specific questions from Figure 3. Figure 11 is a locational snapshot and combination of Figure 8 and Figure 9.

Boating Risk Pathway

Figure 12 incorporates yellow shading to highlight MD DNR - confirmed distribution of hydrilla throughout Maryland. Hydrilla is widely distributed throughout Maryland, confirmed to be present in waterbodies including the Potomac River, Great Seneca Creek, Anacostia River, Mattawoman Creek, Little Patuxent River, Patapsco River, Susquehanna river, Elk River, Sassafras River, Gunpowder River, Bush rivers, and Marshyhope River. Figure 13 incorporates blue shading to highlight the current range of zebra mussels in the state of Maryland. While zebra mussels are perhaps best known for their infestation of the Great Lakes waterbodies, their presence has been confirmed in Maryland locations including the Gunpowder River, Susquehanna River, Northeast River, Elk River and Sassafras River. Figure 14 highlights both the range of hydrilla (in yellow) and zebra mussels (in blue). Areas that contain both hydrilla and zebra mussels as confirmed by the MD DNR are highlighted in green. These two invasive species are presented together because spread occurs primarily through the movement of recreational boats across waterways. Figure 15 presents the distributions of hydrilla and zebra mussels along with a layer containing the location of fishing trips (from trip-specific survey questions 4-10 in Figure 3) involving either a motorized or non-motorized boat.

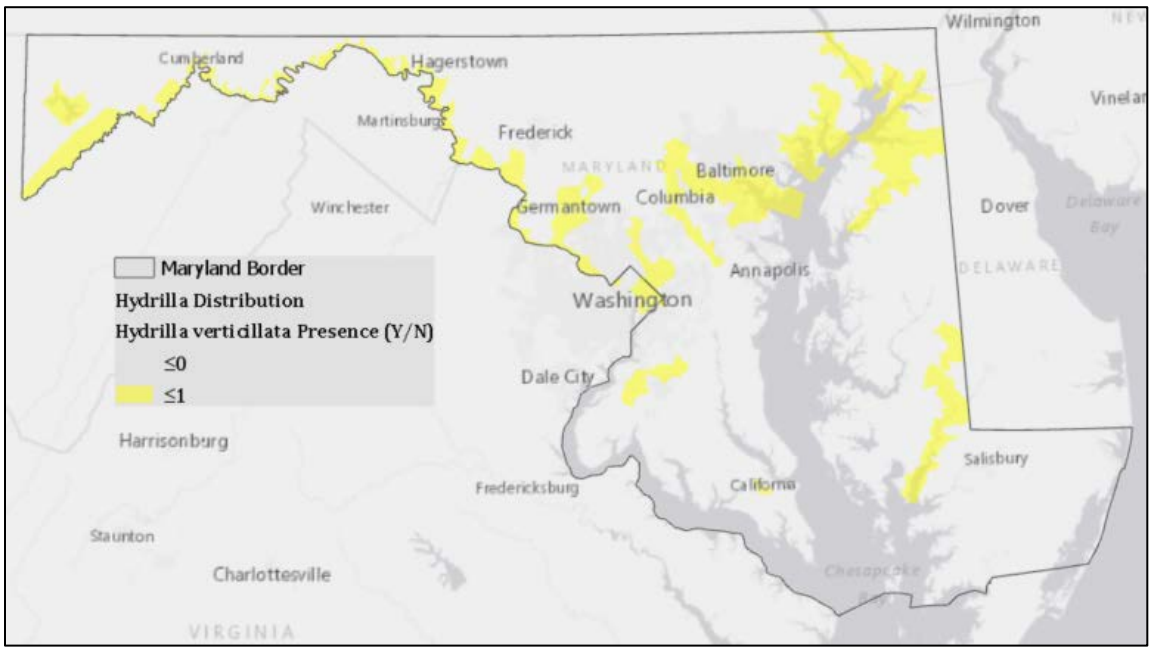

Figure 12: Location of MDDNR - confirmed observations of the aquatic invasive species hydrilla in yellow.

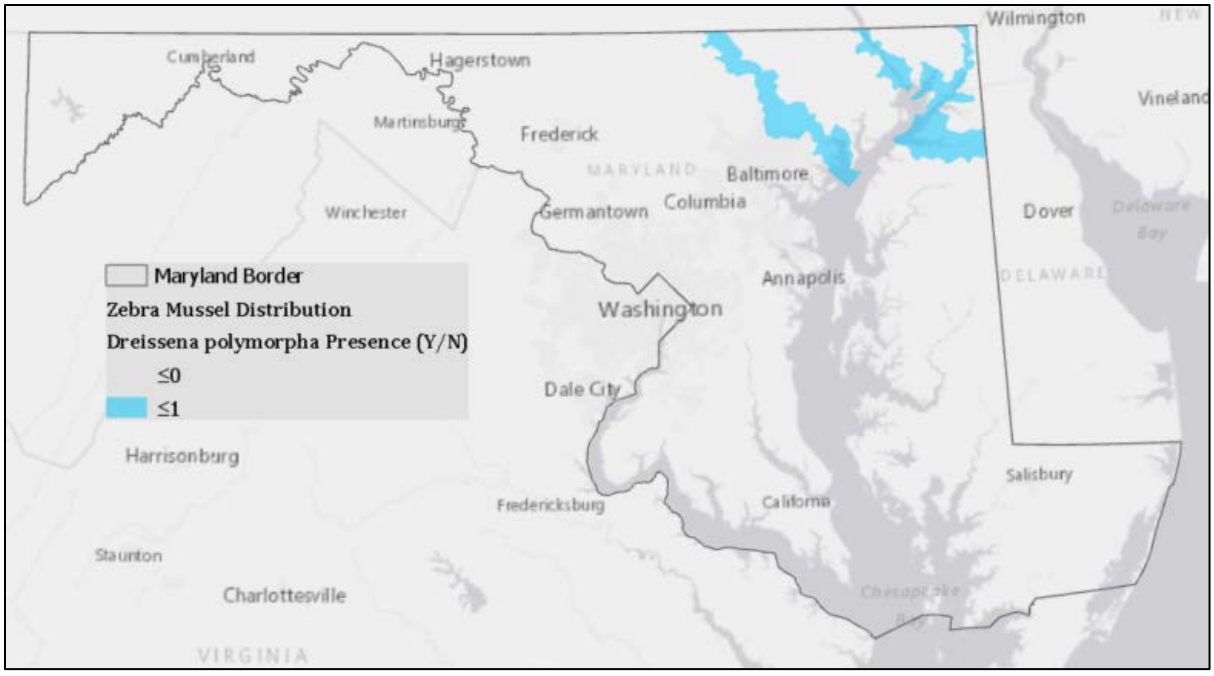

Figure 13: Location of MDDNR - confirmed observations of aquatic invasive species zebra mussels in blue.

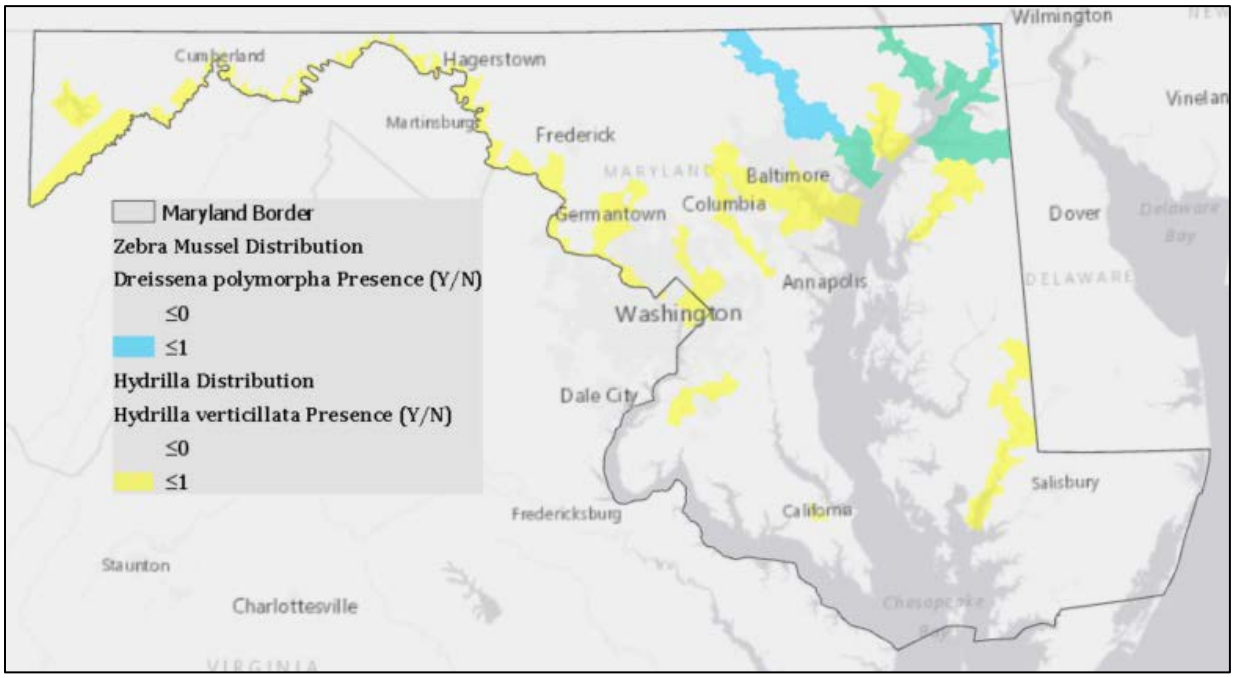

Figure 14: Location of MDDNR - confirmed observations of hydrilla in yellow and zebra mussels in blue. Areas with shaded in green are where these two species overlap.

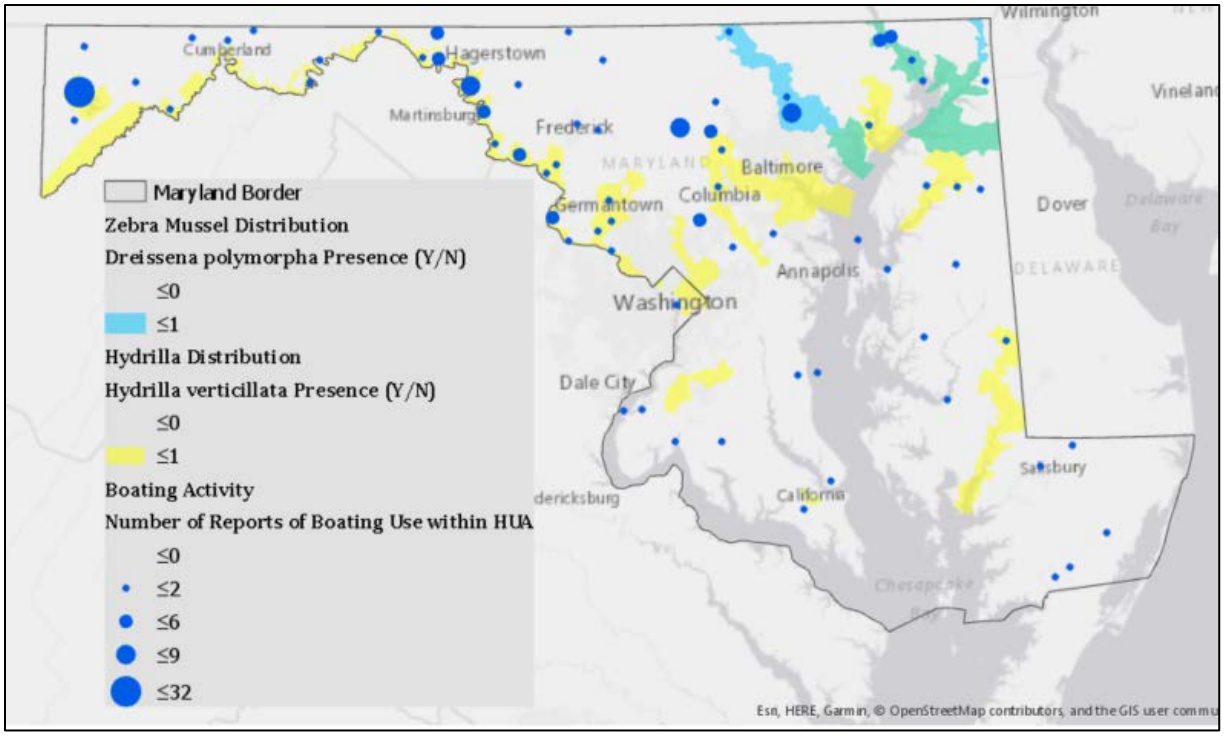

Figure 15: Location of MDDNR - confirmed observations of hydrilla and zebra mussels, with survey respondents reporting a non-tidal fishing trip to a HUA 11 that involved boating, using responses to trip-specific questions from Figure 3; max one trip per respondent

Live Bait Pathway Risk

Figure 16 illustrates the distribution of non-tidal fishing trips across Maryland that involve the use of natural bait (a proxy for the use of live bait), using data from trip-specific survey questions 4-10 in Figure 3. The use of live bait on fishing trips is a known pathway for introduction, potentially occurring through the escape or intentional discarding of live bait during or after the trip. Live bait use on fishing trips has been implicated in the distribution and establishment of multiple species of finfish, crayfish, and earthworms throughout the state of Maryland. As Figure 16 indicates, the use of natural bait is widely distributed throughout the state of Maryland. Unlike with the fly fishing and boating pathways, the spread of invasive species through the live bait pathways is unlikely to occur unintentionally through the interaction of anglers with multiple waterbodies. As such, it is of limited practical use (further constrained by limited data) to map the distribution of invasive species that could potentially be spread through the live bait fishing method pathway.

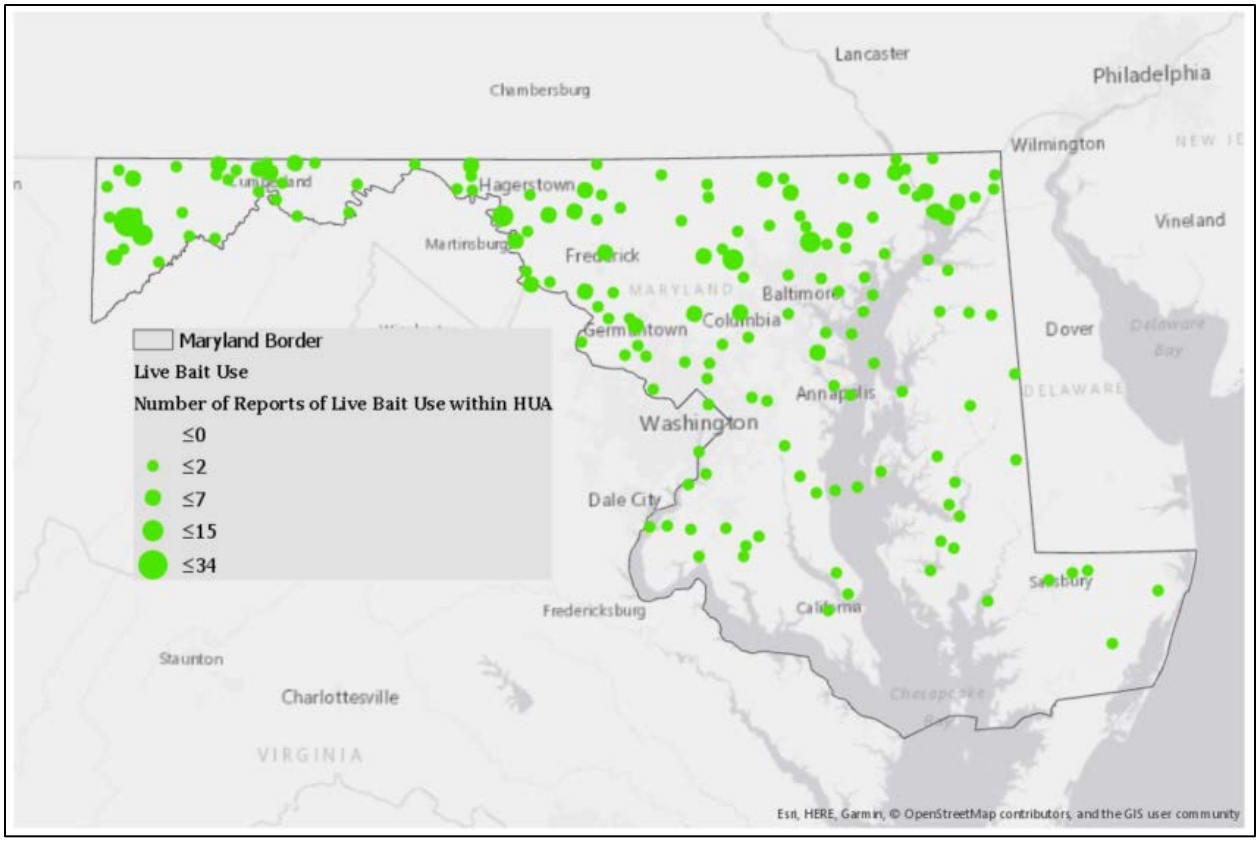

Figure 16. Number of survey respondents reporting a non-tidal fishing trip to a HUA 11 that involved the use of natural bait, using responses to trip-specific questions from Figure 3; maximum one recorded trip per respondent.

Angler Movement Between Waterbodies – Part A

Invasive species transmission risk is related to the method (i.e., pathway) in which an angler interacts with an infected waterbody and the nature of the same angler's subsequent interaction with non-infected waterbodies. The project team has identified four waterbodies – Gunpowder River (fly fishing pathway), Savage River (fly fishing pathway), Deep Creek Lake (boating pathway), and Potomac River (boating pathway) – as posing a "source" risk with respect to the transmission of invasive species into non-infected waterways. Table 1 below contains information on angler fishing effort at these four waterbodies, using information obtained from survey questions 14 and 16 (Figures 1 and 2).

Definitions:

Sub-Row Heading: "Trips Reported in Survey" (Unique Angler Site Visits) - This row provides the total number of trips from the 2015 Maryland Non-Tidal Fishing

Survey (N= 962 respondents) that fit the column criteria, and the number of unique anglers that fit the column criteria.

Sub-Row Heading: "Estimated Trips in 2015" (Unique Angler Site Visits) - This row provides the estimated total number of trips in 2015 that fit the column criteria. This number is obtained by extrapolating responses for the 962 survey responses to the population of anglers licensed to fish in non-tidal waterways 174,853. The same extrapolation procedure is used to estimate the number of unique anglers.

Column: "Trips" - This column provides the number of trips; both a count of trips from survey responses and an estimate of the total trips by the population of anglers. This column also includes the number of unique anglers visiting a site in parentheses.

Column: "Trips and Possible Pathway Use" - This column provides the number of trips taken by an angler who used the fishing method pathway at least once in 2015 (from survey questions in Appendix B); both a count of trips from survey responses and an estimate of the total trips by the population of anglers. This column also includes the number of unique anglers visiting a site at least once in 2015 who, per their responses to survey question 17 in Appendix A, used the relevant fishing method pathway at least once in 2015.

Column: "Trips to Other Waterbodies & Possible Pathway Use" - This column provides the number of trips to another waterbody in 2015, conditional upon that angler fishing in the relevant infected waterbody (in the far left column) at least once in 2015 and also using the relevant fishing method pathway of interest at least once in 2015 (per survey question 17 in Appendix A). This column also includes the number of unique anglers who took a trip to another waterbody at least once in 2015 who fished in the infected waterbody at least once and used the relevant fishing method pathway at least once in 2015. Only waterbodies relevant to the fishing method pathway are included in the counts and estimates in this column. For example, in the Gunpowder River and Savage River (Fly Fishing Pathway) rows, trips to lakes, ponds, or reservoirs are not included given the low probability of transferring didymo in these types of waterbodies using fly fishing gear. In the Potomac River and Deep Creek Lake rows, trips to rivers and streams (other than the Potomac River for Deep Creek

Lake) are not included given the infrequent use of boats on Maryland's river/streams.

Table 1. Number of trips and unique angler-site visits as reported in questions 14 and 16 (see Figures 1 and 2) in the Maryland non-tidal survey. For each of the four waterbodies of interest, the "Trips" column reflects the number of trips reported in the survey and the estimated trips taken by the population of anglers licensed to fish in Maryland non-tidal waterways in 2015. The "Trips & Possible Pathway Use" column reflects the survey-reported trips and the estimated trips taken to the waterbody of interest by the population of anglers licensed to fish in Maryland non-tidal waterways in 2015, contingent upon an individual reporting the use of the relevant fishing method pathway at least once in 2015 in survey question 17 (See Appendix A). The "Trips to Other Waterbodies & Possible Pathway Use" column reflects the survey-reported trips and the estimated trips taken to other relevant waterbodies by the population of anglers licensed to fish in Maryland non-tidal waterways in 2015, contingent upon the angler fishing in the waterbody of interest in the left column at least once during 2015 and using the relevant fishing method pathway at least once in 2015

		Trips	Trips & Possible Pathway Use	Trips to Other Waterbodies & Possible Pathway Use
Gunpowder (Fly Fishing Pathway)	*Trips Reported in Survey (unique angler-site visits)*	302 (60)	110 (30)	112 (24)
	Estimated Trips in 2015 (unique angler-site visits)	54,891 (10,906)	19,994 (5,453)	20,357 (4,362)
Savage (Fly Fishing Pathway)	*Trips Reported in Survey (unique angler-site visits)*	183 (31)	103 (20)	155 (31)
	Estimated Trips in 2015 (unique angler-site visits)	33,262 (5,635)	18,721 (3,635)	28,173 (5,635)
Potomac River (Boating Pathway)	*Trips Reported in Survey (unique angler-site visits)*	1,304 (145)	845 (83)	504 (108)
	Estimated Trips in 2015 (unique angler-site visits)	237,015 (26,355)	153,587 (15,086)	91,607 (19,630)
Deep Creek Lake (Boating Pathway)	*Trips Reported in Survey (unique angler-site visits)*	476 (96)	349 (61)	223 (33)
	Estimated Trips in 2015 (unique angler-site visits)	86,518 (17,449)	63,434 (11,087)	40,532 (5,998)

Fly Fishing Pathway

Table 1 provides information on fishing effort to different fishing sites for two key pathways for aquatic invasive species introductions – fly fishing and boating. This table reveals a high level of fishing effort in general – and fly fishing effort specifically – in the Gunpowder River. Extrapolating survey results to the population of non-tidal anglers in Maryland, there were about 55,000 trips to the Gunpowder River, the second most-often fished river/stream in Maryland. This is about 65% greater than the number of trips to the Savage River (about 33,000) - the 5th most-often fished river/stream in Maryland. The Gunpowder River and Savage River are often visited by fly fishers – i.e., anglers who reported using the fly fishing method at least once during the 2015 calendar year. About 36% of trips to the Gunpowder River and about 56% of trips to Savage River were taken by anglers who reported using the fly fishing method on a fishing trip at least once in 2015. The Gunpowder River and Savage River are more frequently visited by fly fishers relative to the proportion of visitation by fly fishers to all rivers/streams (26%). Despite the Gunpowder River receiving 65% more total fishing trips than the Savage River there were only about 6% fewer trips taken to the Savage River when only considering anglers who used the fly fishing method at least once during 2015. Further, fly fishers who fished the Savage River reported taking 38% more trips to other rivers/streams. This greater fishing effort of Savage River fly fishers in other rivers/streams, despite the similar fly fishing effort in each of these two waterbodies, has clear implications for the spread of invasive species such as didymo through the fly fishing method pathway.

Recreational Boating Pathway

Information in Table 1 reveals high levels of fishing effort in large waterways such as the non-tidal Potomac River and Deep Creek Lake that can be fished by motorized and/or non-motorized watercraft. Extrapolating survey results to the population of non-tidal anglers in Maryland, there were about 237,000 trips to the non-tidal Potomac River, the most frequently fished non-tidal waterbody in Maryland, and about 87,000 trips to Deep Creek Lake, the second-most fished waterbody and the most fished lake/reservoir in Maryland.

The Potomac River and Deep Creek Lake are frequently visited by anglers who use motorized and/or non-motorized watercraft to fish in Maryland. This includes anglers who reported using a motorized and/or a non-motorized watercraft to fish at least once during the 2015 calendar year. About 65% of trips taken to the Potomac River and 73% of trips to Deep Creek Lake were taken by anglers who reported fishing by watercraft in Maryland during 2015. Potomac River and Deep Creek Lake are more frequently visited by individuals reporting the use of the recreational boating pathway than compared to all waterbodies (49%).

Fishing effort at other waterbodies susceptible to the transmission of aquatic invasive species via the boating pathway (defined within as all lakes/reservoirs and the Potomac River) is comparable between Potomac River and Deep Creek Lake. An estimated 37,000 trips were

taken to other lakes/reservoirs by anglers reporting fishing in the Potomac River. Nearly 20,000 trips were taken by anglers to other waterbodies (i.e., Potomac River or lakes/reservoirs) by anglers who reported fishing Deep Creek Lake at least once in 2015.

Angler Movement Between Waterways – Part B

Tables 2 – 5 are specific to one of the four waterbodies of concern: Gunpowder River (Fly Fishing), Savage River (Fly Fishing), Potomac River (Boating), and Deep Creek Lake (Boating). Each of these tables list the relevant "other" waterbodies fished by anglers in 2015 who fished the table-specific waterbody and who also used the fishing method pathway of interest for that waterbody. See below for definitions of the column variables in these tables. Information in this table is obtained from survey questions 14 and 16 (Figures 1 and 2). The small number of observations across the "other" waterbodies visited prevents extrapolation of these figures out to the entire population of anglers. As such, figures in these tables consist of actual survey responses only.

Definitions:

Column A:

This column is a count of unique-angler visits to another (pathway relevant) waterbody if the angler fished the waterbody of concern at least once during the 2015 calendar year. Regardless of how many trips an angler took to another waterbody, a count of "one" is assigned to an angler with $\geq$ one trip to the other waterbody.

Column B:

This column is a summation of the number of trips taken to another waterbody by anglers who fished the waterbody of concern. For example, Column B in Table 2 contains a "2" for Jones Falls, meaning that there were 2 total trips taken to Jones Falls by anglers who: a) took a fishing trip to the Gunpowder River at least once in 2015, and b) used the fly fishing method in a Maryland waterbody at least once in 2015.

Column C:

This column is a summation of the number of trips taken to the specific waterbody of concern by anglers who fished in another waterbody. For example, Column C in Table 3 contains a "6" for Patuxent River. This means there were 6 total trips taken to the Savage River by anglers who: a) took a fishing trip to the Patuxent River at least once in 2015, and b) used the fly fishing method in a Maryland waterbody at least once in 2015.

Table 2. Fly fisher-reported trips to Gunpowder River and other Rivers/Streams. Number of trips and unique angler-site visits as reported in questions 14 and 16 (see Figures 1 and 2) in the Maryland non-tidal survey. See definitions at beginning of section for more details.

	COLUMN A	COLUMN B	COLUMN C
Other River/ Stream	**Unique-angler visits to other river/stream if angler fished Gunpowder River**	**Number of trips to other river/stream if ≥ 1 trip to Gunpowder River**	**Number of trips to Gunpowder River if ≥ 1 trip to other river/stream**
Beaver Creek	1	6	2
Big Hunting Creek	2	11	14
Catoctin Creek	1	2	1
Deer Creek	2	5	5
Grays Run	1	2	4
Jones Falls	1	2	5
Little Falls	1	40	13
Little Gunpowder River	1	1	2
Little Patuxent River	1	2	3
Middle Patuxent River	2	13	15
Morgan Run	2	6	13
Patapsco River	1	2	4
Potomac River	1	4	12
Savage River	2	6	4
Susquehanna River	1	3	5
Tuckahoe Creek	1	2	1

Table 3. Angler-reported trips to Savage River and other Rivers/Streams. See definitions above.

Other River/ Stream	Unique-angler visits to other river/stream if angler fished Savage River	Number of trips to other river/stream if ≥ 1 trip to Savage River	Number of trips to Savage River if ≥ 1 trip to other river/stream
15 Mile Creek	1	3	5
Bear Creek	3	29	5
Beaver Creek	1	-	-
Big Hunting Creek	2	1	2
Casselman River	5	15	62
Friends Creek	1	4	5
Great Seneca Creek	1	6	6
Gunpowder River	2	4	6
Little Gunpowder River	1	10	3
North Branch Potomac R.	3	23	62
Patuxent River	1	5	6
Potomac River	1	1	1
Severn Run	1	4	2
Town Creek	1	10	5
Wills Creek	1	14	6
Winters Run	1	10	3
Youghiogheny River	5	14	6

Table 4. Angler-reported trips to Potomac River and Lakes/Reservoirs. See definitions above.

Other Lake/Reservoir	Unique-angler visits to other lakes/reservoirs if angler fished Potomac River	Number of trips to other lakes/reservoirs if ≥ 1 trip to Potomac River	Number of trips to Potomac River if ≥ 1 trip to other lakes/reservoirs
Big Pool Lake	5	16	84
Blairs Valley Lake	7	18	91
Broadford Lake	1	3	1
Cash Lake	1	10	3
Centennial Lake	1	20	10
Clopper Lake	1	10	5
Cunningham Falls Lake	6	33	100
Deep Creek Lake	12	45	86
Greenbrier Lake	5	22	75
Jennings Randolph Lake	1	4	26
Lake Artemesia	1	1	2
Lake Linganore	1	10	3
Liberty Reservoir	2	11	5
Little Pool Lake	2	3	3
Little Seneca Lake	9	37	65
Loch Raven Reservoir	1	2	1
Piney Reservoir	1	3	10
Piney Run Reservoir	3	8	14
Prettyboy Reservoir	1	3	1
Rocky Gap Lake	2	4	9
Rocky Gorge Reservoir	2	4	23
Smithville Lake	1	2	10
St. Mary's Lake	1	8	18
Triadelphia Reservoir	3	9	19
Urbana Lake	1	10	4
Wheatley Lake	2	15	19
Youghiogheny Lake	1	5	26

Table 5. Angler-reported trips to Deep Creek Lake and Lakes/Reservoirs or Potomac River. See definitions above.

Other Lakes/Reservoirs and Potomac River	Unique-angler visits to other lakes/ reservoirs or Potomac if angler fished Deep Creek Lake	Number of trips to other lakes/reservoirs or Potomac if ≥ 1 trip to Deep Creek Lake	Number of trips to Deep Creek Lake if ≥ 1 trip to other lakes/reservoirs or Potomac
Blairs Valley Lake	1	2	2
Broadford Lake	3	15	16
Conowingo Reservoir	1	4	10
Cunningham Falls Lake	2	4	6
Greenbrier Lake	1	7	2
Herrington Lake	1	1	1
Jennings Randolph Lake	2	9	32
Liberty Reservoir	1	3	1
Little Seneca Lake	2	12	14
Piney Reservoir	1	2	4
Piney Run Reservoir	3	40	5
Potomac River	12	86	45
Savage River Reservoir	3	5	28
Youghiogheny Lake	1	5	7

DISCUSSION

The recreational angler vector and the associated fly fishing gear, boating, and live bait pathways have been identified as a concern by managers seeking to prevent the spread of aquatic invasive species throughout the Mid-Atlantic waterways and the state of Maryland. This report details the intensity of fishing effort throughout Maryland non-tidal waterways and explores how this fishing effort interacts spatially with areas documented to have invasive species present. Two approaches are used in this report. These approaches and key findings are described below.

First, ArcGIS maps were created that identify the location of fishing trips that involved the use of fishing method pathways known to transmit invasive species to other waterbodies. These maps were combined with map layers containing known invasive species distributions to highlight areas that would be of special concern to managers. These maps show that waterbodies with invasive species present (e.g., Gunpowder River, Savage River, Potomac River, Deep Creek Lake) are subjected to relatively high recreational fishing pressure with fishing methods that serve as pathways for the transmission of these species into other waterbodies.

Further, while angling effort is high in these specific areas, the ArcGIS maps show that trips involving the use of risky, invasive species-spreading pathways are distributed throughout the state of Maryland. The "hub and spokes" issue of concentrated fishing effort in waterbodies with invasive species present, and diffuse, connected effort in non-infected waterbodies throughout Maryland, presents a challenge to managers seeking to prevent the transmission of invasive species. Preventative site-specific measures at non-infected waterbodies is likely to be impractical and expensive. Effective, efficient management would more likely involve the continuation and expansion of programs intercepting anglers at the source and providing the means to remove invasive species from fishing gear transmission (e.g., wader-wash stations) and regulatory actions that reduce the probability of transmission (e.g., banning felt soled wading boots in coldwater streams).

Second, this report provides angler-specific quantitative information on the movement of a single angler between multiple fishing locations across different fishing trips. The starting point of this analysis is at four key Maryland non-tidal fishing locations where invasive species are confirmed to be present, fishing effort is known to be high, and fishing methods commonly used at these locations are pathways for the transmission of invasive species. These four locations are the Gunpowder River (fly fishing method), Savage River (fly fishing method), Potomac River (boating), and Deep Creek Lake (boating). Each of these locations are subjected to a high amount of fishing pressure – in total, an estimated 411,000 fishing trips occurred at these four locations in 2015. A majority of these trips (62%) were taken by anglers who reported using a fishing method pathway that presents a risk of invasive species transmission that is specific to the visited waterbody. Further, a large number of fishing trips across a diversity of fishing locations were taken by individuals who fished one of the four waterbodies of concern and used a risky fishing method at least once in 2015. Estimates of these totals range from 20,000 trips to other rivers/streams for Gunpowder River anglers who use the fly fishing method to 92,000 trips to other lakes/reservoirs for Potomac River anglers who use boats to fish.

Finally, a key finding from this analysis of angler movement across waterbodies is the large network of streams visited by fly fishers who reported fishing in the Savage River. Despite that 65% more trips were taken by anglers to the Gunpowder River (relative to the Savage River), estimated trip to other waterbodies taken by Savage River fly fishers exceeds the same estimated trips taken to other waterbodies by Gunpowder River fly fishers by 38%. This suggests a high risk of Savage River fly fishers transferring didymo to other streams if didymo is unintentionally collected by fly fisher waders/boots. Helping to prevent the transfer to other streams through maintaining funding for the upkeep of existing wader-wash stations – and perhaps adding additional stations – would be a relatively low-cost preventative measure.

REFERENCES

Bothwell, M. L., Lynch, D. R., Wright, H., and Deniseger, J. (2009). On the boots of fishermen: The history of Didymo blooms on Vancouver Island, British Columbia. Fisheries, 34(8), 382-388.

Brinson, A.A. and Wallmo, K. (2013). Attitudes and Preferences of Saltwater Recreational Anglers: Report from the 2013 National Saltwater Angler Survey, Volume I. U.S. Department of Commerce, NOAA Technical Memorandum NMFS-F/SPO135, 45p

Kilian, J. V., Klauda, R. J., Widman, S., Kashiwagi, M., Bourquin, R., Weglein, S., & Schuster, J. (2012). An assessment of a bait industry and angler behavior as a vector of invasive species. Biological Invasions, 14(7), 1469-1481.

MDDNR (Maryland Department of Natural Resources). 2016. Maryland Aquatic Nuisance Species Management Plan. Annapolis. 77pp + Appendices.

Appendix A.

Fishing in Maryland Non-Tidal Waterways in 2015

17. **For this question, ONLY consider your 2015 fishing in Maryland NON-TIDAL waterways. Check ALL of the fishing types and methods you used to target each non-tidal fish below.**

	TYPE OF FISHING			FISHING METHODS			
	Artificial Lures	*Natural Bait*	*Fly Fishing*	*Shore/ Wading*	*Watercraft (with motor)*	*Watercraft (w/o motor)*	*Ice Fishing*
Bass, Largemouth	☐	☐	☐	☐	☐	☐	☐
Bass, Smallmouth	☐	☐	☐	☐	☐	☐	☐
Bass, Striped (non-tidal only)	☐	☐	☐	☐	☐	☐	☐
Bluegill/Sunfish	☐	☐	☐	☐	☐	☐	☐
Carp	☐	☐	☐	☐	☐	☐	☐
Catfish, Channel	☐	☐	☐	☐	☐	☐	☐
Catfish, Flathead	☐	☐	☐	☐	☐	☐	☐
Crappie	☐	☐	☐	☐	☐	☐	☐
Musky	☐	☐	☐	☐	☐	☐	☐
Northern Pike	☐	☐	☐	☐	☐	☐	☐
Perch, White	☐	☐	☐	☐	☐	☐	☐
Perch, Yellow	☐	☐	☐	☐	☐	☐	☐
Pickerel	☐	☐	☐	☐	☐	☐	☐
Shad	☐	☐	☐	☐	☐	☐	☐
Trout, Stocked	☐	☐	☐	☐	☐	☐	☐
Trout, Wild Brown	☐	☐	☐	☐	☐	☐	☐
Trout, Wild Brook	☐	☐	☐	☐	☐	☐	☐
Walleye	☐	☐	☐	☐	☐	☐	☐
Other _____	☐	☐	☐	☐	☐	☐	☐