Background

Preventing the introduction and spread of non-native organisms has become a top priority for Government in the United States (CCPR 2014). Early detection and rapid response systems may help prevent the establishment or spread of a species. In preventing establishment or spread of a non-native species, irreversible ecological and significant economic damage may be circumvented. Damage caused by introducing non-native organisms may reduce resiliency of an ecosystem to natural disasters. Costs from mitigating damage caused by introducing non-native organisms has been well-documented across the world and remains significant for its people.

The worldwide practice of introducing species dates back at least 1000 years (Moyle 1986). Human introductions of species to new habitats can cause great economic and ecological expense (e.g., introduction of whirling disease, Modin 1998; escape of aquaculture species, Kumar 2000; gene introgression and hybridization, Dakin et al. 2015). In aquatic habitats, sport fishes have been widely introduced, leading to 138 non-native and established species of fish in the United States (Pimentel 2005). The release of sport fish or game fish may have detrimental impacts by lowering genetic fitness of the wild population (Hill 2011), introducing disease (Bartholomew and Reno 2002), or negatively affecting the food web (Jackson 2002). Introductions of several sport fishes continue because there is no longer a high economic and ecological risk associated with their introduction. In fact, Pimentel et al. (2005) reported revenue of $69 billion per year in the U.S. because of introduced sport fish, but a conservative loss of $5.4 billion per year to control or mitigate negative effects of aquatic nuisance species. Attention is therefore paid to prevent the introduction of new aquatic species in order to minimize the future cost of control and mitigation. Prevention requires identifying aquatic species that may become a nuisance and characterizing the pathways of their introduction. Aquatic nuisance species (ANS) are invasive and can cause or have a high risk of causing economic and ecological loss (Moyle and Light 1996; Kolar and Lodge 2002; Lodge et al. 2006; Hardin and Hill 2012).

Not all introduced species will develop established populations or become an ANS. The probability that a non-native, introduced species' population will become established depends on the natural history of the organism (Sakai et al. 2001; Kolar and Lodge 2002; Lapointe et al. 2013), available suitable habitat (Shafland and Pestrak 1982), propagule pressure and loss of native biodiversity (Levine 2000; Duggan et al. 2006), and climate change (Rahel and Olden 2008). In the Chesapeake Bay watershed, there are 120 introduced aquatic species listed by USGS (2014) and most of them have established populations (Christmas et al. 1998). Only a small fraction of introduced and established species to Chesapeake Bay watershed are ANS (Christmas et al. 1998) and many introduced and established species can have beneficial or neutral impacts (Shafland 1996; Gozlan 2008). Risk assessment tools have been developed to help predict consequences of introduction and better elucidates conditions under which a species may become an ANS (e.g., McCann 1984; Kolar and Lodge 2002; Hardin and Hill 2012; FISK, Verbrugge et al. 2012; GARP model, Vander Zanden and Olden 2008).

Even a small number of ANS can have significant and profound negative effects. These negative effects include homogenization of North American fish communities (Rahel 2000) , which has changed biodiversity in many aquatic ecosystems (Sala et al. 2000). Competition and predation with ANS affects approximately half (53%) of the threatened or endangered fishes listed by the Endangered Species Act (Wilcove et al. 1998). Predation increases risk of extinction or extirpation moreso than competition (Davis 2003). The expansion of silver carp (*Hypophthalmichthys molitrix*) from the Mississippi River and Laurentian drainages into plankton-rich areas (Chen et al. 2007; Cooke et al. 2010) may threaten or cause extirpation of plankton species in otherwise plankton-rich areas (Sparataru and Gophen 1985; Cooke et al. 2010). Additional negative effects of ANS include: **1**) simplifying aquatic food webs (Mooney and Hobbs 2000; Tyus and Saunders 2000; Ricciardi 2005; Vitule et al. 2009); **2**) dramatically changing primary productivity (Nicholls et al. 1999); **3**) reducing water clarity (Kohler and Stanley 1984); **4**) spreading disease (Radonski et al. 1984; Hill 2011); **5**) deteriorating gene pools for fishes (Philipp et al. 1983; Philipp et al. 2002; Laikre et al. 2010); **6**) increasing operating costs (e.g. decontamination, gear replacement) for boaters, anglers and waterman; and **7**) increasing the transmission of pathogens that can pose human health hazards.

The use of small motor boats, sailboats, pontoons, jet skis, canoes, kayaks, and other watercraft is an increasingly common pathway associated with introductions and spreading ANS. Maryland has no natural lakes, but contains several large impounded waterways that are popular tourist destinations for out-of-state visitors. Introductions associated with water craft arise when non-native, potential ANS are inadvertently carried between water bodies in bilge water, engine cooling systems, live wells, or attached/ entangled to hulls, trailers, or other surfaces. Some boaters on Maryland waters trailer their watercraft from as far south as Florida and as far west as Utah (unpubl. data, M. Lewandowski, MDDNR), which emphasizes the large geographic scope of this potential pathway. Recreational boating can also spread ANS among adjacent water bodies (Kerr et al. 2005). This pathway is believed to be responsible for the spread of problematic plants such as Eurasian milfoil (*Myriophyllum spicatum*). Eurasian milfoil is native to Europe and Asia, but is now found throughout several eastern states including Maryland. The species forms dense mats that can suppress growth of native plants and negatively affect swimming, fishing, and other recreational activities. Water craft is also the most important vector for spreading zebra mussels (*Dreissena polymorpha*) in United States. Zebra mussel was introduced with ship ballast water to North America in the 1980s, causing significant negative economic and ecological impacts to the Great Lakes region (Vitousek et al. 1996), and has been recently documented in Maryland at Conowingo Dam (lower Susquehanna River), Elk River and Sassafras River.

Other ANS that have been unwittingly transferred among waterbodies in Maryland include the invasive alga Didymo (*Didymosphenia geminata*) and Hydrilla (*Hydrilla verticillata*). Didymo was introduced into coldwater trout streams in many countries (Bothwell et al. 2009), creating unpleasant fishing experiences for anglers throughout affected areas in Maryland. To prevent spread of Didymo to other water bodies in Maryland, MDDNR banned the use of felt sole waders or felt sole wading boots in Maryland waters because of the potential for felt soles to carry the algae among streams. Hydrilla is a waterweed that is not native to the U.S. and was introduced to Florida in 1960s and later to Maryland, possibly from the aquarium trade. The species became abundant in Potomac River in the 1970's. Thick patches of *Hydrilla* create stagnancy in tidal freshwater habitats and led to navigation problems by boaters (Pimentel et al. 2005). Control of the plant using herbicides in Deep Creek Lake cost Maryland approximately $205,000 in 2014.

Not only does preventing introduction of ANS protect the affected ecosystem, but it also prevents natural spread from that ecosystem to new water bodies. Many of Maryland's water bodies are interconnected by canals that provide propagule pressure to a particular waterbody (Smith and Tibbles 1980; Daniels 2001). Increased levels of propagule pressure through canals may occur as climates and land usage change, leading to greater expansion of ANS. Climate change is expected to cause increased precipitation and stream flow in the Chesapeake Bay watershed (Najjar et al. 2010) and will serve to better connect adjacent drainages. Increased connectivity will increase probability of spread of ANS. In addition, annual averages in water temperature are more likely to increase than decrease in the Chesapeake Bay watershed (Wood et al. 2002). Increased water temperatures could facilitate establishment of introduced species or create conditions that lead to an established species becoming ANS.

In addition to naturally spreading within Maryland, ANS could spread quickly to neighboring states, creating greater need for inter-agency cooperation. The vast drainage area and interconnections with other watersheds render the Chesapeake Bay watershed susceptible to colonization by ANS between other states. The Chesapeake Bay watershed is the largest estuary in the United States (64,000 km^2), and contains major shipping routes in two of the most populous cities in the nation (Baltimore, MD and Washington, D.C.). The watershed is also interconnected with the Delaware River by the Chesapeake and Delaware (C&D) Canal and receives drainage from Washington D.C. and 6 states: Maryland, Virginia, Delaware, West Virginia, Pennsylvania, and New York. While coordinating regulations among agencies may be accomplished with federal leadership (e.g., *Channa argus*, northern snakehead), other species and pathways may not be jointly and similarly regulated (e.g., blue catfish or mandating boat cleaning before launch).

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