Final Report of the Sustainable Fisheries Goal Implementation Team

Invasive Catfish Task Force

Winter 2014

Invasive Species Task Force Members

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Special thanks to Mary Fabrizio and Greg Garman who authored significant portions of the report documenting the history, biology and invasiveness of blue and flathead catfishes.

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Executive Summary

The Problem

Federal Executive Order 13112, adopted in 1999, defined an invasive species as a non-native species whose introduction does or is likely to cause economic or environmental harm or harm to human health. There are several species in the Chesapeake Bay watershed that meet these criteria and pose a risk to the ecology and economy of the region; however, this report focuses on the blue catfish (*Ictalurus furcatus)* and flathead catfish (*Pylodictis olivaris*). Both catfish species are considered invasive to the Chesapeake Bay as they are not native to this region and have demonstrated negative impacts on native species and the ecology of the Bay. Flathead catfish were introduced into the James River in the late 1960s, whereas blue catfish were introduced into the James, Rappahannock, and York Rivers in Virginia during the 1970s and 1980s. The catfish were introduced to establish recreational fisheries in Virginia; however, these catfish quickly spread throughout the region into nearly every major tributary. Both blue and flathead catfishes are long lived and are predators that feed predominantly on native fishes and shellfish, which may have dire consequences for fishery industry as well as other ecological and economic interests in the Chesapeake Bay region. The expanding range and increasing population size of these catfish, particularly of blue catfish, have resource managers concerned that damage to Chesapeake Bay resources may be irreversible without management intervention.

The Need

Currently, a comprehensive management strategy for invasive catfishes is lacking. Further, there is a strong need for coordination across Chesapeake Bay management jurisdictions to work together and engage the public to effectively reduce the spread and minimize the ecological and economic harm from blue and flathead catfishes. Developing management strategies should incorporate current research studies and monitoring efforts to improve knowledge and evolve management approaches into the future.

The Invasive Catfish Task Force

The Invasive Catfish Task Force (ICTF) was established in 2012 by the Sustainable Fisheries Goal Implementation Team (Fisheries GIT) of the Chesapeake Bay Program and tasked with developing and recommending management options that could be applied Bay-wide in response to the spread of invasive blue and flathead catfish populations in the Chesapeake Bay region. The ICTF is comprised of members from the state and local fishery management jurisdictions of Maryland, Virginia, Pennsylvania, Delaware, and the District of Columbia, representatives from the Potomac River Fisheries Commission and National Oceanic and Atmospheric Administration (NOAA), academic experts from the Virginia Institute of Marine Science (VIMS), Virginia Commonwealth University (VCU), Smithsonian Environmental Research Center (SERC), and seafood marketing specialists from Maryland Department of Natural Resources and the Virginia Marine Products Board.

The ICTF met several times in-person and via teleconference to compile and evaluate existing information on blue and flathead catfishes and to discuss potential management options. The ICTF also briefed the Fisheries GIT and stakeholders on draft recommendations during the preparation of this report. The ICTF developed recommendations to address the following four objectives:

1. Slow and reduce the spread of invasive catfishes into currently uninvaded waters;
2. Minimize the ecological impacts of invasive catfishes on native species;
3. Promote a large-scale fishery to significantly reduce abundance of invasive catfishes and provide economic benefits to the region; and
4. Increase outreach and education and broadcast the message that blue and flathead catfishes are not native to the Chesapeake Bay and negatively impact native ecosystems. Outreach is also needed to emphasize that public assistance is needed to avoid additional unauthorized introductions within the Bay watershed.

Recommendations

Recommendation 1: Removal from Priority Areas

We recommend that jurisdictions (federal, state and local) work together to design and implement targeted fishery-independent (non-commercial market) removals of invasive catfish in areas of significant ecological value (i.e. spawning and nursery habitat areas for anadromous species). Well-planned, intensive, and repeated removals of invasive catfishes may have the potential to reduce populations and lessen their impacts on important native species. We further recommend these removals be conducted as pilot projects or studies to develop, test, quantify, and evaluate removal methods for invasive catfishes. As part of this effort, we recommend that jurisdictions identify areas of significant ecological and economic value for native fish and shellfish species and their habitats and consider preventative measures to reduce the risk of invasive catfish introductions and expansion in these areas.

Recommendation 2: Develop Commercial Fisheries

We recommended that efforts and incentives to develop a large-scale, commercial fishery be accelerated and coordinated across jurisdictions. Harvest incentives exploiting the growing populations of invasive catfishes have the potential to reduce populations while also providing economic benefits to the region. This will require more immediate and coordinated action across jurisdictions to identify markets, increase the value of the fishery, and remove factors (e.g. lack of processing facilities) that are currently limiting expansion of the existing small-scale fishery. A critical element of this recommendation is developing a fishery that is dedicated to reducing invasive catfish populations over the long term. We recommend a workshop be held with current and prospective fishers, fishery managers, and economists to identify the steps needed to expand the current fishery and make it economically feasible. We note that Washington, D.C. restaurants have been successful in promoting the blue and flathead catfish as 'local, fresh catfish' on their menus and suggest implementing similar measures throughout the Bay watershed.

Recommendation 3: Evaluate Removal Methods

We recommend jurisdictions consider options to incentivize increased harvest operations for invasive catfishes by small boat operations and electrofishing. These options could be further discussed as a part of the workshop suggested in Recommendation 2. We note that the Fishery Resource Grant Program of Virginia Sea Grant has funded studies exploring the feasibility of using electrofishing gear for harvest of blue catfish. Similar evaluations of gear efficiency could be promoted within additional organizations.

Recommendation 4: Develop Monitoring and Response Plans

We recommend jurisdictions establish monitoring programs dedicated to identifying and tracking invasive catfish distributions and population status. There are currently few dedicated monitoring and survey efforts for invasive catfishes; accordingly, we also recommend developing early detection and response programs for ecologically significant areas. In addition, invasive catfish research and management efforts in the Chesapeake Bay should be synthesized and used to improve effective implementation and refinement of the management options outlined in this report.

Recommendation 5: Evaluate Habitat Connectivity

We recommend an evaluation of the effectiveness of existing barriers to invasive catfish spread (i.e. dams) and suggest that the benefits of barrier removal be weighed against the risk of damage to areas of significant ecological value by invasive catfish range expansion. We suggest formal coordination between invasive catfish experts and the Fish Passage Workgroup of the Chesapeake Bay Program Habitat Goal Implementation Team to identify barriers and develop ecosystem-based recommendations that address the risk of additional invasions following dam or other barrier removal efforts.

Recommendation 6: Review Fishing Policies and Regulations

We recommend a cross-jurisdictional review of current fishing policies and regulations to identify and address current regulations that may facilitate the persistence and expansion of invasive catfish populations. This review should also evaluate the efficacy of communications and enforcement of the current regulations regarding the illegal transport of live fish.

Recommendation 7: Develop Communication Strategies

We recommend jurisdictions make information on invasive catfishes more accessible, consistent, and clearer to anglers and the general public. Information on invasive catfishes is difficult to find and not well coordinated across jurisdictions. Particular attention should be paid to the correct identification of blue catfish (especially), distinguishing them from native species. We suggest an immediate effort be made to convene communication experts from the Chesapeake Bay region to identify inconsistencies in messaging and develop an aggressive communication campaign to increase public awareness. This campaign should be paired with the development of a web portal that provides the public, researchers, and resource managers access to current information on invasive catfishes.

We believe that these recommendations, once implemented, will form the foundation to address the many challenges associated with the catfish invasion of the Chesapeake Bay. Furthermore, lessons learned during implementation will allow for adaptation and improvements. We suggest that the Fisheries GIT Executive Committee prioritize these recommendations and determine the most effective way for to implement the actions that result.

Introduction

Invasive species are defined as non-native species that can cause harm to the environment, economy, or to human health according to federal Executive Order 13112, signed in 1999. There are several species in the Chesapeake Bay watershed that meet these criteria and pose a risk to the ecology and economy of the region; however, this report focuses on the blue catfish (*Ictalurus furcatus)* and flathead catfish (*Pylodictis olivaris*), both considered invasive to the Chesapeake Bay as they are not native to this region and have demonstrated negative impacts on native species and the ecology of the Bay. Flathead catfish were introduced into the James River in the late 1960s, whereas blue catfish were introduced into the James, Rappahannock, and York Rivers in Virginia during the 1970s and 1980s. Both species were introduced to establish recreational fisheries in Virginia; however, these catfish quickly spread throughout the region into most major tributaries. These invasive catfishes are long-lived predators that feed predominantly on native fishes and shellfish. The expanding range and increasing populations, particularly of blue catfish, have resource managers concerned that without management intervention, damage to Chesapeake Bay resources may be irreversible.

Purpose

The purpose of this report is to offer recommendations to address the expansion of invasive catfish populations and their impacts on living resources in the Chesapeake Bay. The report provides decision-makers an overview of the invasion and recommendations necessary to develop coordinated management strategies for the blue and flathead catfish invasion within the Chesapeake Bay watershed.

Scope

Although this report specifically applies to the waters and resources in the Chesapeake Bay watershed (Maryland, Virginia, Pennsylvania, District of Columbia, and Delaware), the Invasive Catfish Task Force (ICTF) recognizes that close coordination and cooperation is required with broader regional organizations such as the Atlantic States Marine Fisheries Commission, the Mid Atlantic Panel on Aquatic Invasive Species, Aquatic Nuisance Species task Force and National Invasive Species Council.

Invasive Catfish Task Force and Objectives

The Invasive Catfish Task Force (ICTF) was established in 2012 by the Sustainable Fisheries Goal Implementation Team (Fisheries GIT) of the Chesapeake Bay Program and tasked with developing and recommending management options that could be applied Bay-wide to respond to the spread of invasive blue and flathead catfish populations in the Chesapeake Bay region. The ICTF is comprised of members from the fishery management jurisdictions of Maryland, Virginia, Pennsylvania, District of Columbia, Delaware, representatives from the Potomac River Fisheries Commission and National Oceanic and Atmospheric Administration (NOAA), academic experts from the Virginia Institute of Marine Science (VIMS), Virginia Commonwealth University (VCU), Smithsonian Environmental Research Center (SERC), and seafood marketing specialists from Maryland Department of Natural Resources and the Virginia Marine Products Board.

The ICTF met several times in-person and via teleconference to compile and evaluate existing information on blue and flathead catfishes and to discuss potential management options. The ICTF also briefed the Fisheries GIT and stakeholders on draft recommendations during the preparation of this report. The ICTF developed recommendations to address the following four objectives:

1. Slow and reduce the spread of invasive catfishes into currently uninhabited waters;
2. Minimize the ecological impacts of invasive catfishes on native species;
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4. Increase outreach and education and broadcast the message that blue and flathead catfishes are not native to the Chesapeake Bay and negatively impact native ecosystems. Outreach is also needed to emphasize that public assistance is needed to

avoid additional unauthorized introductions within the Bay watershed.

Overview of Invasive Catfishes (blue and flathead) in the Chesapeake Bay

Introduction, Distribution, and Expansion

Beginning in the 1960's, blue catfish and flathead catfish were introduced to a small number of Virginia tributaries within the Chesapeake Bay region to create additional angling opportunities. Today, both species are now established in at least 10 major tributaries across Virginia, Maryland, and Pennsylvania. Initial stocking of blue batfish occurred in the 1970s and 1980s in the freshwater reaches of the Chesapeake Bay tributaries. Following introduction, the species rapidly expanded into tidal riverine habitats and are now commonly found in oligohaline and mesohaline waters of Chesapeake Bay tributaries, including all western shore rivers in Virginia as well as several Maryland and Eastern Shore tributaries. Flathead catfish were introduced to the James River, Virginia, between 1965 and 1970 and now occur in several Chesapeake Bay tributaries, including the James, York, Potomac, and Susquehanna rivers. Unlike blue catfish, flathead catfish are habitat specialists and generally prefer nontidal and tidal freshwater and oligohaline habitats.

A geospatial model developed by VCU suggests that blue catfish distribution has the potential to nearly double from 136 watersheds (12-digit HUCs) to 242 watersheds in the Chesapeake basin (Figure 1). Flathead Catfish are also expanding their distribution in the region (Figure 2).

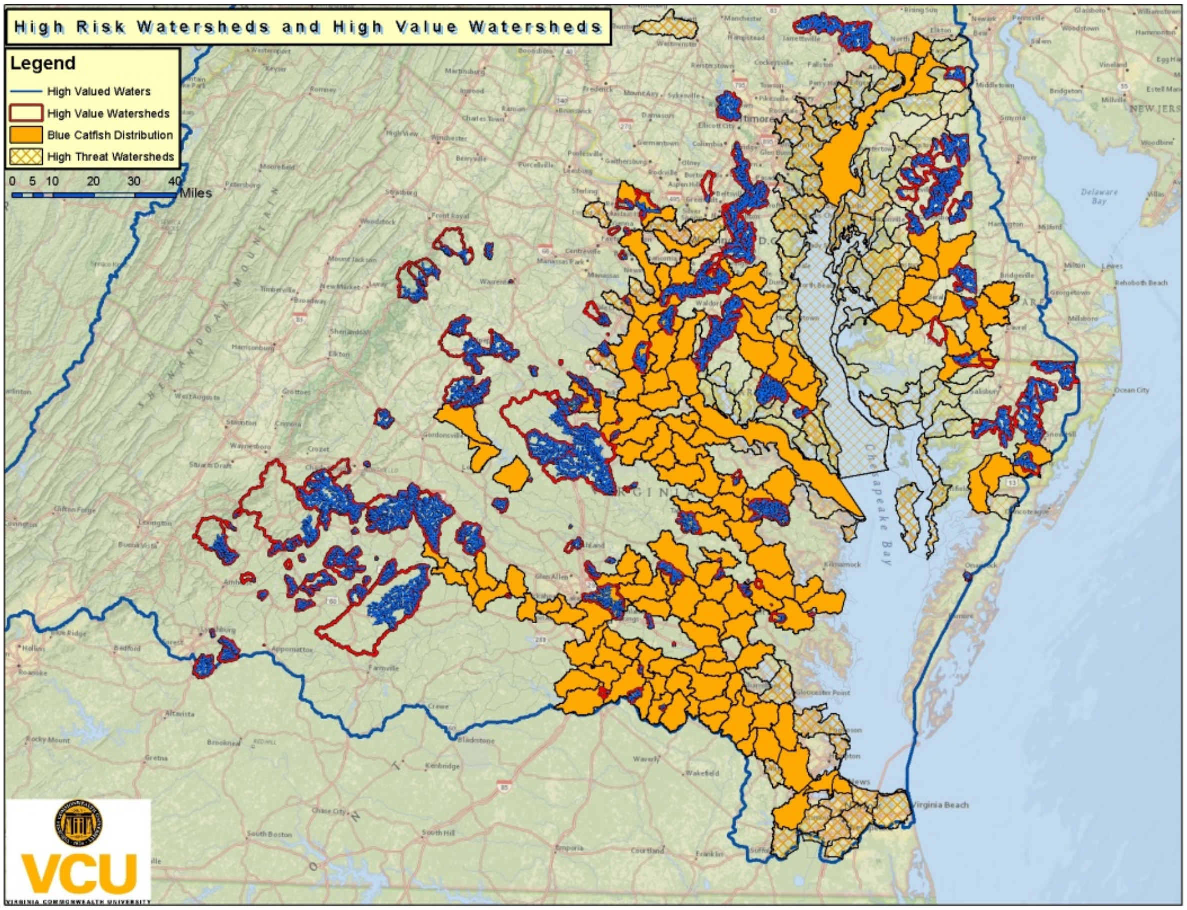

Figure 1. Current (solid polygons) and forecasted (cross-hatched polygons) distribution of blue catfish in Chesapeake Bay waters. Geospatial units are 12-digit watersheds (HUCs). Data are compiled from several sources, including VCU, VIMS, VDGIF, and MD DNR; data were current as of 1 April, 2013.

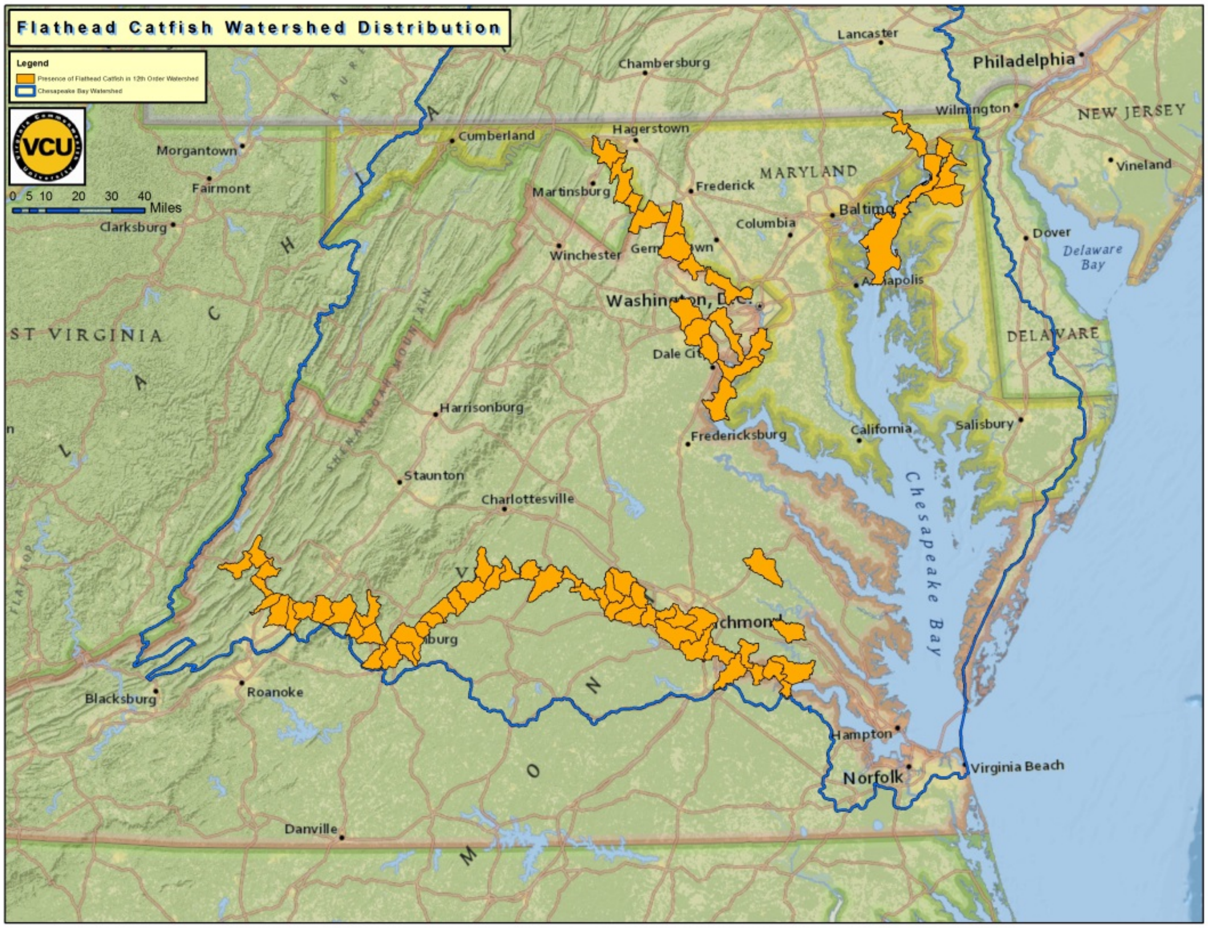

Figure 2. Current distribution of flathead catfish in Chesapeake Bay waters. Geospatial units are 12-digit watersheds (HUCs). Data are compiled from several sources, including VCU, VIMS, VDGIF, and MD DNR; data were current as of 1 April, 2013.

Biological characteristics, such as tolerance for a wide range of environmental conditions, may further enhance the spatial expansion of newly established nonnative populations. For instance, blue catfish can tolerate salinities of 14 parts per thousand (ppt) or higher, which allows them to expand into estuarine reaches of tidal tributaries (Schloesser et al. *2011*; Bringolf et al. 2005). The high salinity tolerance of these catfishes is not unique; channel catfish, another nonnative to Atlantic Slope rivers, also have a high salinity tolerance (Jenkins and Burkhead 1993). Unlike blue catfish and flathead catfish, this species has been established for over a century and is, therefore, unlikely to spread beyond its present range (Jenkins and Burkhead 1993). Range expansion of the blue catfish in Virginia tributaries has been previously assisted by high river flows and episodic flooding (Edmonds 2003; Schloesser et al. 2011). Further range expansion of blue catfish may ensue when similar conditions co-occur (high abundance, high river flows). In Maryland, the unauthorized stocking or transportation of live fish by anglers appears to have aided the spread of blue catfish among tidal tributaries of the upper Bay. Similarly, redistribution of flathead catfish by anglers appears to play a major role in their dispersal in the Chesapeake Bay watershed. Flathead catfish are not as abundant as blue catfish (except in Pennsylvania where flathead catfish populations are a primary concern) and thus, populations may not yet exhibit dispersive movements in response to environmental cues.

Ecological Impacts

Flathead catfish and blue catfish are both considered invasive species, as recent studies have suggested environmental and economic harm to the Chesapeake Bay region as a result of these species introductions. The timing, sources, and possible implications of introduced blue catfish in Chesapeake Bay waters have been described recently by Schloesser et al. (2011). A similar synthesis concerning flathead catfish in this region is lacking.

Blue and flathead catfishes share several biological characteristics that are believed to enhance the likelihood of their establishment in new environments. These include a diverse diet (including other fish), adult trophic status as apex predators, long life span, large body size, ability to tolerate a wide range of salinity, and parental care of young (Table 1; Morris and Whitfield 2009). These characteristics aid successful establishment of the non-native species and often lead to environmental harm to native species and their habitats.

Table 1. Common predictors of invasiveness for blue and flathead catfishes (adapted from Morris and Whitfield 2009). Propagule pressure refers to the density of individuals introduced, the number of introduction events, and the frequency of introductions.

Predictor	Blue Catfish	Flathead Catfish
Prior invader	X	X
Large native range	X	X
Environmental tolerance	X	X
Long life span	X	X
Large body size	X	X
High adult trophic status	X	X
Broad diet	X	
Fast growth		X
High fecundity	X	
Parental care	X	X

Invasive catfishes in Chesapeake Bay tributaries negatively interact with native fish and shellfish through predation and competition for habitat and resources. Ecological impacts from these interactions may include declines in native resident (Bonvechio et al. 2011) and anadromous (McAvoy et al. 2009) fishes. Blue catfish in these tributaries have a highly diverse diet and consume crustaceans, worms, bivalves (including native freshwater mussels), and fish, such as Atlantic Menhaden, American Shad, Blueback Herring, Bay Anchovy, and other blue catfish. The diet of flathead catfish tends to be dominated by smaller sized fish (>20 cm total length (TL) or >16.8 cm fork length (FL); Chandler 1998). Because both catfish species consume fish, and several fish species that use Chesapeake Bay tributaries are the subject of restoration or stock rebuilding efforts (e.g., *Alosa* spp.), blue and flathead catfishes have the potential to exert severe ecological harm to the region. Recent studies based on stable isotope analyses suggest that adult blue catfish and flathead catfish in these systems are novel apex predators that feed extensively on important fishery resources, including native resident and anadromous fishes (MacAvoy et al. 2009).

Whereas preliminary studies have documented harm to native species, the full extent of negative impacts from catfish invasions remains poorly understood. For example, coastal rivers within North Carolina and Georgia have associated flathead catfish piscivory with declines of some native fishes, including those of recreational importance (Pine et al. 2005; Bonvechio et al. 2011). Comparable studies for invasive catfishes in the Chesapeake Bay region are lacking though recent surveys suggest that invasive catfish predation on native species such as American shad, blueback herring, alewife, and blue crabs may be spatially confined. Piscivory by blue and flathead catfishes for instance is likely to vary seasonally and regionally, depending on habitat and prey availability. On finer spatial scales, we do not know how diets may be affected by depth; for example, catfish from shallow estuarine habitats may not exhibit the same pattern of piscivory as those from deeper estuarine areas. Furthermore, ecosystem-level effects of piscivory must take into account the size dependency of this feeding behavior. In blue catfish, piscivory is strongly size-dependent such that the frequency with which fish are observed in the diet increases with in larger fish sizes. Based on electrofishing surveys in the freshwater reaches of the James River in 2010, about 46% of the population of blue catfish was <31 cm fork length (FL), 47% was between 31 and 61 cm FL, and about 7% of the population exceeded 61 cm FL (n = 6,725 fish). In freshwater reaches of the Patuxent and Nanticoke rivers in 2012-2013, about 20% of the population sampled by low-frequency electrofishing was >30 cm total length (TL) and <1% exceeded 60 cm TL (n = 320 fish) (Hines et al., unpublished data).

Nutrient enrichment has resulted in extremely high productivity in the freshwater tidal James and other bay tributaries, accommodating the presence of extremely high abundances of non-native high trophic level predators including invasive catfish.

Blue catfish are common bycatch in gillnet fisheries operating in Chesapeake Bay tidal tributaries. This may have economic consequences by reducing gear efficiency for target species. The amount and economic value of foregone harvest of the target species are currently unknown, but may be significant (Fabrizio et al. 2011).

Current Management Efforts

Regulations and Policies

In 2011, the Atlantic States Marine Fisheries Commission approved a resolution expressing concern about the impacts of blue and flathead catfish on Atlantic Coast migratory fish species. The resolution suggested that "all practicable efforts should be made to reduce the population levels and ranges of non-native invasive species" (ASMFC Fisheries Focus, 2011). Agreements between Chesapeake Bay jurisdictions and the Atlantic States Marine Fisheries Commission led to the development of various management options, the establishment of the ICTF, and the recommendation for this report. In January 2012, a policy statement (http://www.chesapeakebay.net/documents/final_catfish_policy_git_1-24-12_(with_signatures).pdf) signed by members of the Fisheries GIT Executive Committee concluded that blue and flathead catfishes are invasive and that the potential risk posed by blue and flathead catfishes on native species warrants action to examine potential measures to reduce densities and limit range expansion and to evaluate possible negative ecological impacts.

While it is illegal in all jurisdictions to transport live blue and flathead catfish for the purpose of introduction into another body of water, a coordinated management strategy for blue and flathead catfish does not exist for Chesapeake Bay management jurisdictions. Maryland Department of Natural Resources, District of Columbia, and the Potomac River Fisheries Commission officials discourage release of angler-caught fish and are asking anglers to remove and kill any blue and flathead catfish that they catch, but the Virginia Department of Game & Inland Fisheries does not support a kill-on-capture policy. The Pennsylvania Fish and Boat Commission encourages anglers to kill all flathead catfish upon capture; however, this has never been implemented as a formal regulation. Current regulations for flathead catfish in Pennsylvania include a liberal creel limit of 50 fish per day with no minimum length or seasonal limitations. A draft management plan recommending measures to increase exploitation of flathead catfish within its non-native range is currently under review in

Pennsylvania.

Commercial and Recreational Fisheries

Catfishes in the Chesapeake Bay watershed have supported recreational and commercial fisheries for several decades. Commercial fisheries for catfish are typically low valued because of the price-per-pound has remained low, around $1/lb. Consequently, commercial extraction has been minimal (about 2 million pounds/year from tributaries of Chesapeake Bay in Virginia and Maryland). Both Maryland and Virginia are exploring the potential to develop new markets and hence increase commercial value of blue catfish. Important recreational fisheries have been developed, particularly in the upper James and Potomac rivers, where populations currently support lucrative trophy fisheries. According to the 2011 National Survey of Fishing, Hunting, and Wildlife-Associated Recreation, of the 27.1 million anglers who fished freshwater, other than the Great Lakes, 7 million were fishing for catfish and bullheads (U.S. Department of the Interior, U.S. Fish and Wildlife Service, and U.S. Department of Commerce 2011). The popularity of the catfish sport fishery stems from the ease with which these fish can be taken, the lack of economic barriers to participation in the fishery (i.e., fish can be accessed from shore, with minimal investment in gear), and the palatability of the flesh. These fisheries generate millions of dollars annually through angler expenditures and have been encouraged in recent years through state-wide competitions and tournaments. Maryland and Virginia recognize anglers through angler citation programs for trophy fish whereas the District of Columbia recognizes anglers that harvest blue catfish through a newly established records program. A primary reason for introduction of these species was to develop a recreational trophy fishery for blue catfish in Virginia. The current state record for blue catfish was set on June 18, 2011 at Buggs Island Lake with a fish weighing 143 pounds. The commercial fishery has a maximum size restriction of 32 inches in an attempt to minimize impacts on the trophy recreational fishery and to comply with the consumption advisory on this species (no consumption of blue catfish over 32" from the James River; 1 meal per month of blue catfish caught from other tributaries).

Research and Monitoring

There are few monitoring programs focused only on invasive catfishes including fisheries programs at VIMS, VCU, VDGIF, SERC, District of Columbia Fisheries, University of Maryland, and MDDNR. These programs use a variety of gears to sample both the nontidal and tidal portions of the major coastal rivers. Other systems in Maryland such as the Rhode West Rivers have been sampled by SERC and University of Maryland, but these surveys have not yet encountered invasive catfishes. Where invasive catfishes have been detected, sampling can be used to infer changes in spatial distribution and relative abundance, diet composition, variations in age and growth rates, and concentrations of bioaccumulating contaminants (such as Polychlorinated biphenyls, Tributyltin, and Mercury (Hg)). A full summary of current research efforts and findings is provided in Appendix A of this report.

Communication and Outreach

Very little has been done to increase awareness among anglers or the general public with regard to invasive Blue and Flathead catfishes, the threat they pose to native species, or the "No Transport" regulations in effect. Maryland has partnered with the Chesapeake Bay Program to post signs at key public access sites to raise awareness. Information on websites across the jurisdictions is difficult to find and is not consistent, although Maryland, PRFC, and DC have taken action to improve messaging on invasive catfishes and communicate the "no transport" regulations. The issue of blue and flathead catfishes in the Chesapeake Bay and the draft recommendations in this report were presented to the Mid Atlantic Aquatic Invasive Species Panel and the Aquatic Nuisance Species Task Force. Further, the ICTF has communicated with catfish charter operators in Virginia on the invasion and associated impacts. The National Park Service and NOAA have offered to include information at their sites around the Bay but the details are still under negotiation.

Recommendations

It is important to note that although blue and flathead catfishes have been in the Chesapeake Bay for 30-40 years, little has been done to manage these species. We are still working to understand their biology and ecology and will need to test and evaluate the proposed management strategies for efficacy. The selection of appropriate management actions (e.g. prevention, eradication, control) in response to invasive fish species is often dependent on the life history characteristics of the species, size of infestation, and the ecology of the impacted community, (Kolar & Lodge 2001). Prevention is the most effective means to avert the risk of harmful introductions. Investment in prevention avoids many of the long-term economic, environmental, and social costs associated with invasive species. Once a species becomes established, control efforts require significant and sustained resources. Once a species has become widely dispersed in an open aquatic system like Chesapeake Bay eradication is rarely feasible or cost-effective (Sakai et al. 2001). The actions and recommendations outlined below focus on preventing additional spread of invasive catfish and the control of existing populations with emphasis on options to reduce impacts on vulnerable riverine and estuarine resources.

Recommendations and the corresponding logic model (Appendix C) were developed within this context along with the anticipated long term effort that will be required to measurably change the current condition and realize the desired ecological outcomes. Each of the recommendations will require extensive discussion prior to implementation, broad cooperation among agencies, and a willingness to adapt strategies to new information as it becomes available (adaptive management). The following section includes ICTF context and findings used to formulate recommendations, the specific recommendations, and an analysis of the pros and cons of each recommendation. Recommendations are not listed in priority order.

Recommendation 1: Removal from Priority Areas

High abundance of invasive catfishes in the Chesapeake Bay region may be causing ecological harm by exerting predation pressure on native species such as blue crab, blueback herring, and Atlantic menhaden, and by competing with native predators. Invasive catfishes can also cause economic harm through interference with commercial fishing operations. Catfishes may be captured by commercial gear that targets economically-valuable species such as striped bass and may lead to a significant increase in the amount of time required to remove and handle this unintended bycatch.

We recommend that jurisdictions work together to design and implement targeted fishery-independent removals of invasive catfish in places of significant ecological value (i.e. spawning and nursery habitat areas for anadromous species). Well-planned, intensive, and repeated removals of invasive catfishes may have the potential to reduce populations and lessen their impacts on important native species. We further recommend these removals be conducted as pilot projects or studies to develop, test, quantify, and evaluate removal methods for invasive catfishes. Existing GIS tools such as the Catfish Portal, Coastal GEMS, the Fish Passage Prioritization Tool and Maryland GreenPrint can be used by experts to identify prospective removal areas.

A recent GIS-based analysis by VCU (Figure 3) identified 64 high-value Chesapeake Bay watersheds in Virginia and Maryland (i.e., below Conowingo Dam) that were at risk for establishment of blue catfish populations (n=9) or that already have established populations (n=55). These watersheds could be candidates for removals and increased preventative measures.

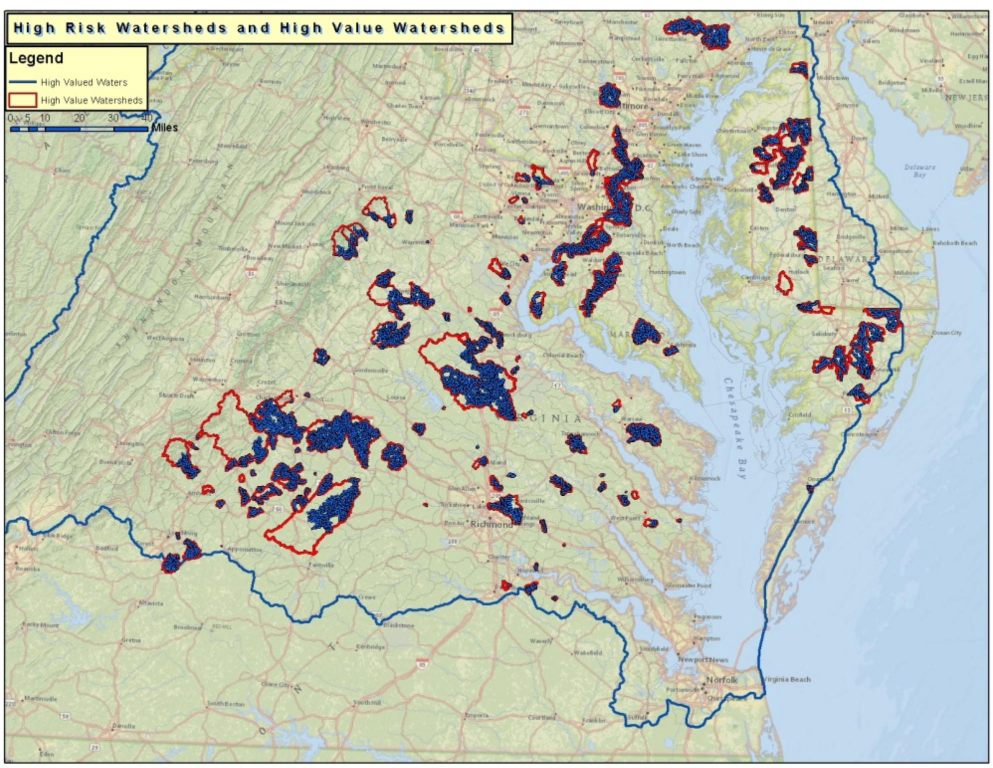

Figure 3. Ecologically significant watersheds (red polygons) and streams (blue lines) in the Chesapeake Bay that occur within watersheds at high-risk by catfish invasions. Geospatial units are 12-digit watersheds (HUCs). Data were compiled by VCU from various sources.

In these high-risk areas, the goal is not to eradicate the invasive catfishes, but rather to limit their biomass and ecological impact. The use of electrofishing or piscicides as a control measure for invasive fishes may have the potential to reduce ecological impacts in some aquatic habitats, especially smaller systems with limited connectivity to source populations (Britton et al. 2010). For example, electrofishing removal (monthly for 33 months) reduced the abundance of invasive adult tilapia by 87% in an impoundment in northern Australia and resulted in a reduction in negative ecological impacts (Thuesen et al. 2011). Similarly, reduced abundance of an invasive mosquitofish population through removal efforts in a Spanish stream led to recovery of the two species with historical presence in the system (Ruiz-Navarro et al. 2013). Low-frequency electrofishing as a catfish removal method has the advantage of limited effects on non-ictalurids. Control projects of this type require a long-term commitment of resources to maintain low populations and monitor effectiveness of the program. Following removal operations, temporary deployment of constructed or non-physical barriers in smaller creeks may be beneficial to exclude adult invasive fish species (Noatch & Suski 2012). For example, excluding predatory invasive catfishes from tidal spawning habitats for native shad (*Alosa* spp.) during spring months may increase spawning success in those systems.

Previously, VDGIF regional biologists used electrofishing in an attempt to eradicate invading blue catfish from the Piankatank River, Virginia. Although that effort failed, in part from limited departmental support, the upper Piankatank system (Dragon Run) may still be a candidate for a renewed removal pilot study in Virginia. Similarly the Patuxent River in Maryland and other Eastern Shore tributaries may serve as a test bed for removals and are currently under consideration

Pro: Targeted removals may help mitigate impacts of invasive catfishes on native species in select tributaries.

Con: Removals could be costly and may not significantly reduce numbers or ecological outcomes for native species. Disposal of removed fish may be problematic. One potential solution is to donate the fish to local food banks as this method has been used in other nuisance or invasive species control programs (e.g., the Hunters for the Hungry, Target Hunger Now). Catfish removal programs may also spur conflicts with the recreational anglers.

Recommendation 2: Develop Commercial Fisheries

Debates concerning the appropriate management options for invasive species typically focus on documenting economic and ecological impacts and (if warranted) identifying feasible eradication or control measures (Sakai et al. 2001). In the case of introduced blue and flathead catfish in Chesapeake Bay, negative economic consequences may be mitigated—at least in part—by revenues generated from recreational and commercial fisheries for these species (Shogren & Tschirhart 2005).

We recommended that efforts and incentives to develop a large-scale, commercial fishery be accelerated and coordinated across jurisdictions. Harvest incentives exploiting the growing populations of invasive catfishes have the potential to reduce populations while also providing economic benefit to the region. This will require more immediate and coordinated action across jurisdictions to identify markets, increase the value of the fishery, and remove factors (e.g. lack of processing facilities) that are currently limiting expansion of the existing small-scale fishery. A critical element of this recommendation is developing a fishery that is dedicated to reducing invasive catfish populations over the long term. We recommend a workshop be held with current and prospective fishers, fishery managers, and economists to identify the steps needed to expand the current fishery and make it economically feasible.

To increase exploitation, the ICTF recommends developing a market for Chesapeake Bay blue catfish through marketing campaigns that promote the fishery as healthy and local. The Blue Ocean Institute has listed Blue Catfish from the Chesapeake Bay region as a seafood source (http://blueocean.org/seafoods/). Current data on mercury and methyl mercury concentrations in blue catfish indicate that these fish generally have levels below the EPA human health screening level, and current consumption advisories are no different than those applicable to striped bass. The ICTF recognizes that both Maryland and Virginia have efforts underway to develop markets and suggests these efforts continue with coordination across jurisdictions. We note that Washington, D.C. restaurants have been successful in promoting blue and flathead catfishes as 'local, fresh catfish' on their menus and suggest implementing similar measures throughout the Bay watershed.

Pro: Developing a commercial market may help raise the value of catfish and encourage additional fisheries to targeting invasive catfishes through the Bay. In turn, this harvest may reduce catfish abundance and decrease bycatch interference in other commercial fisheries. Such actions that rebuild and sustain native species (and associated fisheries) provide long-term economic gain.

Con: Developing a commercial market to raise the value of an invasive species may lead to pressure to manage the fishery for sustainable harvests, contradicting the initial objective of population reduction. Further, successful efforts to increase demand and market value may increase the threat of unauthorized introductions into new waters to create fisheries.

Recommendation 3: Evaluate Removal Methods

We recommend jurisdictions consider options to incentivize increased harvest operations for invasive catfishes by small boat operations and electrofishing. These options could be further discussed as a part of the workshop suggested in Recommendation 2.

As recommended by the ICTF, If may be ideal for commercial industries to begin with offering incentives to small-boat operations (2-3 people), for example free licenses for the capture and sale of invasive catfish may be provided. This may increase harvest and promote profitable small-scale operations.

Electrofishing as a commercial fishing technique has been around for many years (Fitz 1970), but for many reasons, including cost, safety, and effects on non-target species, it is not widely applied. However, in nontidal, tidal freshwater, and oligohaline reaches of larger Chesapeake Bay tributaries, the use of low-frequency (≤ 15 pps), pulsed direct current (PDC) electrofishing by commercial catfishers could lead to the harvest of large numbers of blue catfish. Whether or not commercial LFEF electrofishing could be an effective (i.e., ecologically relevant) control measure for blue or flathead catfish is currently unknown, but electrofishing has the advantage of limited by-catch (cp. gillnets) and low habitat impacts (cp. bottom trawls). Electrofishing is restricted to specific seasons (water temperatures between 18° and 25° C) and locations (≤ 2 ppt salinity) and may be subjected to variable market demand and contaminant issues similar to other fisheries. Experimental electrofishing for commercial applications would require a significant financial investment ($20K per vessel) and strict oversight by agencies, this investment may be fundable through fishery resource grants or similar programs. North Carolina currently allows recreational (but not commercial) catfish harvest by electrofishing, with specific restrictions (T. Kwak, NCSU, pers. comm.). We note that at least one proposal has been submitted to the Fishery Resource Grant Program of Virginia Sea Grant to explore the feasibility of using electrofishing gear for harvest of blue catfish. Similar evaluations of gear efficiency may promoted within other organizations.

Pro: Incentives and gear allowances may promote a fishery and help increase landings of blue catfish, reduce biomass, and reduce impacts on native species. The fishery may also provide economic opportunities.

Con: Developing a market and raising the value of an invasive species may pressure agencies to manage the fishery for sustainable harvests, contrary to the initial objective. Competing objectives could also arise between small-scale operations and recreational fishing, however, if only smaller fish are targeted by electrofishing then these conflicts should be minimal. There is also the possibility that native white catfish could be accidently removed if species identification is not emphasized. There are regulatory and legislative barriers to allowing catch of recreational fish to be sold in addition to possible safety concerns and fishery enforcement challenges, which may create challenges to implementation.

Recommendation 4: Develop Monitoring and Response Plans

Invasive catfish populations are rapidly expanding across tidal and nontidal reaches of the Chesapeake Bay watershed. As previously shown in Figure 1 and 2 blue catfish distribution and flathead catfish are expanding across the region.

We recommend jurisdictions establish monitoring programs dedicated to identifying and tracking invasive catfish distributions and population status. There are currently few dedicated monitoring and survey efforts for invasive catfishes; accordingly, we also recommend developing early detection and response programs to monitor ecologically significant areas. Research efforts in regards to the catfish invasion in the Chesapeake Bay should be synthesized and used to improve effective implementation and refinement of the management options outlined in this report.

Effective surveillance programs are essential for the management and potential control of invasive species but such programs are very expensive to maintain, especially across large areas. Opportunities to leverage existing resources (e.g. acoustic telemetry arrays) or new technologies (e.g. molecular genetics (eDNA), online data portals) should be identified and pursued as part of an overall strategy for monitoring the distribution and spread of blue catfish and flathead catfish in the region. For example, the recent development of environmental DNA (eDNA) analyses as a relatively inexpensive and accurate way to detect Asian carp and other biological invaders (Darling and Mahon 2011) in aquatic habitats could be applied to Chesapeake Bay surveillance programs for catfish and other aquatic invasive species.

Another example of surveillance is the use of smartphone apps that allows recreational and commercial fishers to upload photos and locations of captured blue catfish. SERC is using the citizen science smartphone app, called Project Noah, as one tool to study the spread of blue catfish throughout upper Chesapeake Bay. Backed by National Geographic, this app is used to collect catfish distribution information from commercial and recreational fishermen. The app is free to download and can be viewed at http://www.projectnoah.org/missions/38272048.

The concept of using recreational and commercial users to help identify and document invasive catfish distributions using mobile devices could be applied more broadly in the Bay. Therefore, we also encourage continued support to improve understanding of invasive catfish biology, their ecological impacts, and potential control mechanisms. There is still much to be known about the role of invasive catfishes as predators in the Chesapeake Bay region in spite of recently-completed and ongoing studies supported by NCBO, ASMFC, VDGIF, and others. Basic biological information about these species remains largely unknown including reproductive potential, salinity tolerance, and bio-energetic demands. Efforts should continue to improve our understanding of the mechanisms that contribute to the spread and success of invasive catfishes in the Bay region. The ecosystem is not static and there may be changes we cannot anticipate that will enhance the ability of catfish to invade other areas. Applied research efforts will also assist in the development of new tools and more effective management approaches.

Pro: Improved monitoring would provide better distribution and population status of invasive catfish species. Continued research and synthesis will allow for new tools and adaptive management strategies.

Con: Effective monitoring requires long-term commitment of resources, interagency coordination, technology development and public participation.

Recommendation 5: Evaluate Habitat Connectivity

Over 3,800 constructed impediments to fish migration (mostly low head dams) are documented on Chesapeake Bay tributaries (E. Martin, TNC, unpubl. data). Many have been prioritized by wildlife resource agencies for removal or for other construction activities by fish passage facilities to support regional diadromous fish restoration goals. Approximately 10 percent of these structures are identified as high priority (Tier 1 & 2) for removal in the near future. In most circumstances, removal of a dam will significantly increase the ecological health of a river by restoring its hydrologic connectivity to the watershed (Holmquist et al. 1998).

However, some have argued that the benefits gained from successful fish passage projects may be offset by opening corridors to invasive species that had previously been blocked from upstream reaches (Freeman 2002). For example, the Bosher's Dam fishway on the James River allowed passage of at least 8,000 blue catfish between 2002 and 2005 (Fisher 2007) and the species is now well-established upstream as far as Columbia, Virginia. Similar information may be available for flathead catfish on the Susquehanna River at the Conowingo Dam in Maryland.

We recommend an evaluation of the effectiveness of existing barriers to invasive catfish spread (i.e. dams) and suggest that the benefits of barrier removal be weighed against the risk of damage to areas of significant ecological value by invasive catfish range expansion. We suggest formal coordination between invasive catfish experts and the Fish Passage Workgroup of the Chesapeake Bay Program Habitat Goal Implementation Team to identify barriers and develop ecosystem-based recommendations that address the risk of additional invasions following dam or other barrier removal efforts. This may include requiring an assessment of the unintended consequences as part of the fish passage prioritization process, including creation of expansion corridors for invasive species, before removing or modifying Tier 1 & 2 dams. This requirement may be especially needed for Tier 1 or 2 dams within high-risk catfish watersheds, as identified by VCU's spatial model (Figure 4).

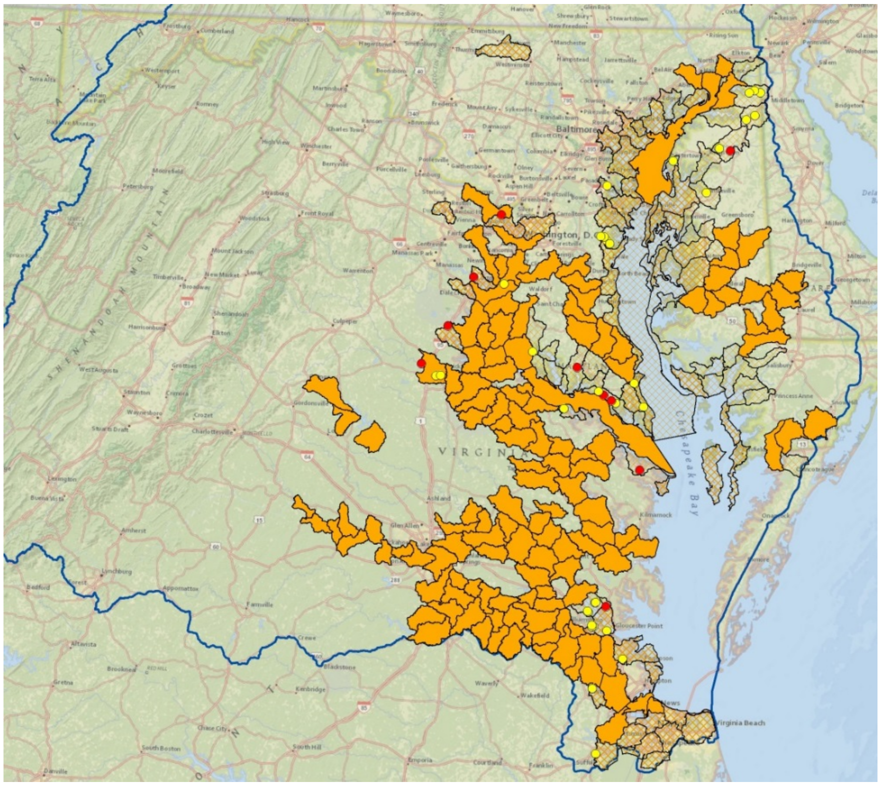

Figure 4. Tier 1 (red) and tier 2 (yellow) dams prioritized for fish passage in watersheds that currently support blue catfish (solid polygons) or at risk to support blue catfish (cross-hatched polygons). This analysis is limited to Chesapeake Bay waters below Conowingo Dam. Geospatial units are 12-digit watersheds (HUCs). Data are compiled from several sources, including VCU, TNC, VIMS, VDGIF, and MDDNR; data and current as of 1 April, 2013.

Pro: Formal consultation in regards to the risks of invasive catfish expansion as a result of dam removal could help limit the spread of invasive catfish and foster collaboration between fishery managers and habitat restoration specialists.

Con: The benefits of providing access to habitat for species like American shad, river herring, and American eel may outweigh costs of invasive catfish range expansion. Studying invasive catfish expansion risk could increase cost, extend timelines, and potentially prevent some dam removals. Dams that are left in place to prevent upstream expansion by invasive species are still subject to the possibility of illegal transport upstream by anglers.

Recommendation 6: Review Fishing Policies and Regulations

We recommend a cross-jurisdictional review of current fishing policies and regulations to identify and address current regulations that may facilitate the persistence and expansion of invasive catfish populations. This review should also evaluate the efficacy of communications and enforcement of the current regulations regarding the illegal transport of live fish.

Managers should discuss the risks associated with maintenance of trophy fisheries. The perpetuation of these fisheries may permit these invasive species to persist in the environment for long periods of time, continue to reproduce, and potentially impact areas where control measures have been implemented. Neither Maryland nor Virginia appear to favor removal of the trophy fisheries from the James or Potomac rivers, so it is likely that other management actions will be ineffective in these two rivers. It would be difficult to support a trophy fishery in one or two systems while supporting control in others; a consistent management approach may be more credible and effective. Chesapeake Bay jurisdictions have regulations in places intended to limit human-assisted dispersal of nonindigenous species by anglers, the aquarium trade, or other pathways. Evaluation of existing rules and laws will be necessary to assess whether they are clear and comprehensive enough to effectively limit the unintentional and intentional spread of invasive catfish in the region.

Pro: Review of policies across the jurisdictions could promote dialogue on the trade-offs associated with existing policies and help jurisdictions develop shared management objectives.

Con: None.

Recommendation 7: Develop Communication Strategies

We recommend jurisdictions make information on invasive catfishes more accessible, consistent, and clearer to anglers and the general public. Information on invasive catfishes is difficult to find and not well coordinated across jurisdictions. We suggest an immediate effort be made to convene communication experts from the Chesapeake Bay region to identify inconsistences in messaging and develop an aggressive communication campaign to increase public awareness. This campaign should be paired with the development of a web portal that provides the public, researchers, and resource managers access to current information on invasive catfishes.

Information available on invasive catfishes is not consistent across jurisdictions and regulations are not easily found. Further, there is no sense of urgency in the messaging to the public or anglers about the risks posed by invasive catfishes. Jurisdictions working with the Chesapeake Bay Program should develop messaging that educates the public and anglers to relate these risks. This messaging should be applied as comprehensively as possible to posters, signs, and other educational materials at boat ramps, websites, social media, anglers' logs, bait and tackle shops, and press releases. Several invasive species in the area have awareness campaigns already developed that could serve as a model, such as the northern snakehead. The media campaign can be initiated by taking journalists and other interested parties out to sites for demonstrations of electrofishing and other control or prevention tasks, thus informing this audience about the latest invasive catfish research and risks.

There also should be a single information source (website and database) that serves as a home to the most up-to-date scientific information on invasive catfishes. A possible host for this portal may be the Chesapeake Bay Program with links to jurisdictional information. VCU developed a comprehensive database that should be incorporated into this site and improved as jurisdictional monitoring programs share additional data.

Pro: Easily accessible information informs researchers and the interested public with consistent messaging, aids decision making by management entities, and promotes research and analysis by scientists. A consistent messaging campaign supported by all jurisdictions is important for success of any control or mitigation program.

Con: Cost of development and maintenance for message development, websites, and database.

Alternative approaches to engage the public and remove invasive catfishes

For each of the above recommendations, consensus was reached by the ICTF. Several other options were also considered by the Task Force, including those that have been utilized in other regions and with other invasive species to reduce population abundance and raise public awareness; however unanimity was not reached and, therefore, these option were not included in this report as formal recommendations. These alternative options included removal efforts such as fishing derbies in which jurisdictions may work with local conservation and fishing organizations to hold invasive catfish derbies to remove fish at selected locations (i.e. smaller tributaries, places of high ecological value, and where colonization is recent) and raise public awareness. Such events have been successful in other instances (e.g. silver carp, lionfish). In the James River and other systems where invasive catfish are well established, a measurable effect on populations may not result, but the primary purpose would be to educate resource users and grow public awareness for the need to stop the spread of invasive species.

Conclusion

We believe that these recommendations in this report, implemented individually or collectively, may form a foundation to address the many challenges associated with the catfish invasion of the Chesapeake Bay. Furthermore, lessons learned during implementation will allow for adaptation and improvements. Refer to the Appendix B which lays out a draft logic model outlining how the recommendations in this report can meet the stated objectives over the near and long term. We suggest that the Fisheries GIT Executive Committee prioritize these recommendations and determine the most effective way for to implement the actions that result. We also note that knowledge of invasive catfishes is still limited; consequently there is uncertainty that the recommendations above will have the desired result of reducing impacts on native species, increasing public awareness, and slowing the spread of invasive catfishes. We can envision that as these recommendations are implemented a more comprehensive management strategy will begin to emerge, a process that is playing out with other invasive fish species such as lionfish in the South Atlantic, Gulf and Caribbean water and Asian carp in the Great Lakes.

Appendix A. Summary of Current Research and Findings

In summer 2011, NOAA funded five research projects to address scientific knowledge gaps and management concerns about the blue catfish in Chesapeake Bay tributaries (principal investigators and their home institution are provided in parentheses). Each topic is summarized in the sections below:

- Risks of expanding the blue catfish fishery as a population control strategy: influence of ecological factors on fish contaminant burdens (R. Hale, VIMS)
- Trophic dynamics of blue catfish in Maryland (A. Hines, SERC)
- Predation by introduced blue catfish as a potentially important and novel source of mortality for selected fishery resources in Chesapeake Bay waters (G. Garman, VCU)
- Characterizing the growth dynamics of blue catfish in the Chesapeake Bay watershed (R. Latour, VIMS)
- Estimating population size and survival rates of blue catfish in Chesapeake Bay tributaries (M. Fabrizio, VIMS)

Risks of expanding the Blue Catfish fishery as a population control strategy: influence of ecological factors on fish contaminant burdens -- As contaminants in edible fish tissues may present toxicological risks to human consumers, VIMS determined concentrations of several toxins known to pose human health concerns (i.e., mercury, chlorinated and brominated organic micropollutants). This study examined contaminates in fillets from blue catfish (>300 mm) from three Chesapeake Bay tributaries: the James, Rappahannock and Potomac rivers. Fish from these locales were exposed to differing levels of point- and non-point sources of pollutants. Blue catfish from the upper Potomac and upper James exhibited greater fillet burdens of most contaminants than conspecifics from the lower James or Rappahannock rivers. However, despite high human population densities in the area, mercury levels were lower in Potomac blue catfish fillets. Fish sex and $\delta^{15}N$ values (as a surrogate for trophic position) had minimal influences on contaminant fillet burdens in blue catfish of the sizes examined in this study. Potomac catfish exhibited distinctly greater $\delta^{15}N$ values, suggestive of feeding at a higher trophic level or ingestion of prey items with higher $\delta^{15}N$ signatures. For most contaminants, pollutant burdens increased with fish size. Fillet % lipid was positively related to lipophilic organic pollutant concentrations, but not to total mercury. Our contaminant burden results support existing Virginia and Maryland advisories regarding regional fish consumption, i.e. concentrations of PCBs and Hg in blue catfish fillets from some locales pose risks to human health, and this risk varies with fish consumption rate. Based on the Hg and PCBs concentrations we observed, the majority of blue catfish sampled surpassed existing EPA recommended limits for unrestricted human consumption. Furthermore, river-segment specific consumption advisories are necessary as contaminant types and concentrations varied within rivers. Within river segments, fish length and weight were useful predictors of concentrations of most contaminants. Consideration of % lipid content improved predictions of fat-soluble organic pollutants, but not Hg. However, % lipid is not a measure that is readily usable by anglers or consumers to inform or limit their contaminant exposure.

A 1998 report by Garman and Hale evaluated contaminant concentrations in tissues from 48 blue catfish (mean TL = 65 cm) collected from the James River near Hopewell, Virginia. They found elevated levels for several contaminants, including TBT (up to 29 µg/kg, wet mass) and total PCBs (up to 5,309 µg/kg, dry mass; equivalent to approximately 1060 ug/kg on a wet weight basis). Concentrations were positively and significantly correlated with catfish size (mass, kg).

A study funded by Virginia Sea Grant in 2010 (Newman and Fabrizio, VIMS) included analysis of total mercury and methyl mercury concentrations in blue catfish (standard fillets) from Virginia tidal tributaries. The 35 blue catfish analyzed in that study ranged between 386 and 428mm total length (mean=407 mm TL) and had total mercury concentrations between 42.5 and 55.3 µg/kg wet weight (mean=48.4 µg/kg wet weight), which are below the EPA human health screening value of 300 µg/kg wet weight (Xu, X, M. C. Newman, M. C. Fabrizio, and L. Liang. 2013; US EPA 2009). On average, about 61.3% of the total mercury present in blue catfish muscle tissue was methyl mercury (Xu, X, M. C. Newman, M. C. Fabrizio, and L. Liang. 2013).

For blue catfish, methyl mercury concentrations measured on a dry weight basis increased significantly with increasing $\delta^{15}N$, indicating that blue catfish that occupied higher trophic positions in the food web (i.e., those that consumed more fish) also accumulated more methyl mercury (MHg).

Trophic dynamics of blue catfish in Maryland -- Four river systems in Maryland (Patuxent, Nanticoke, Sassafras, and Northeast/Susquehanna Flats) were sampled for catfish species by SERC in 2012 and 2013 via low-frequency electrofishing. In 2012, 172 blue catfish were collected along with 236 channel catfish and 118 white catfish. Stomach contents are currently being analyzed using traditional microscopic/visual approaches, in combination with DNA barcoding that enables species-specific identification of partially digested fish prey to determine the diet of blue catfish and make comparisons with other catfish species, in particular the native white catfish. The composition of prey fish in the same areas in these four rivers were also sampled via high-frequency electrofishing to determine whether blue catfish are generalist predators or whether they are targeting specific prey species. Muscle tissue samples from blue catfish were analyzed for stable isotopes (C^{13}, N^{15} and S^{34}) and total mercury concentration; tissues were also collected for genetic analysis and otoliths removed for age and growth rate determination.

SERC is also studying the movement, migration, and spread of blue catfish in Chesapeake Bay using an acoustic telemetry study (funded by the Smithsonian Institution Competitive Grants for Science Program) and the smartphone app Project Noah that allows recreational and commercial fishers to upload photos and locations of captured blue catfish. For the acoustic telemetry study, SERC has deployed an array of eight VEMCO VR2 acoustic receivers along the length of the Patuxent River (to be expanded to 12 receivers in 2014). To date, 13 blue catfish have been tagged with V-13 transmitters in the upper Patuxent River and we anticipate that at least 50 fish will be tagged by the end of 2014. The goal of this study is to document daily movements, seasonal migrations, and habitat use. The study utilizes the citizen science smartphone app Project Noah, to collect catfish distribution information from commercial and recreational fishermen. The app, backed by National Geographic, is free to download and can be viewed at http://www.projectnoah.org/missions/38272048.

Predation by introduced blue catfish as a potentially important and novel source of mortality for selected fishery resources in Chesapeake Bay waters -- This project seeks to determine the likely effects of predation from invasive catfishes on selected fishery resources and investigates the use of an experimental barrier aimed at controlling catfish predator access to streams that are essential habitat for anadromous clupeids (*Alosa* spp.). More than 3,000 blue catfish and flathead catfish (> 300 mm TL) have been sampled by VCU for stomach content analysis at 17 locations in Virginia and Maryland. A diel consumption model that permits estimation of the overall catfish predation mortality on key resources (e.g. blueback herring) in the tidal James and Rappahannock rivers has been completed. GIS models to forecast future distributions and potential threats (predation and other interactions) from invasive catfishes in the Chesapeake Bay basin have been completed. Results indicate that although diets of blue catfish are highly variable over space and time, predation impacts on key fishery resources may be locally significant. For example, blue catfish consumption of juvenile Atlantic menhaden in the lower James River (near Newport News) averaged 41% (as frequency of occurrence) and ranged up to 71% during a five-week period in spring 2012. Using a spatially-explicit consumption model, approximately 1 million juvenile Atlantic menhaden and 0.6 million blue crabs were estimated to be consumed by large blue catfish in Burwell Bay (lower James River, Virginia) during April and May 2012. A similar model was used to estimate that flathead catfish consumed between 7,680 and 10,002 spawning blueback herring (*A. aestivalis*) during April 2012 at the James River Fall Zone. Tests in a tidal tributary of the James River (Kimages Creek, Virginia) with exclusion nets indicated that non-rigid nets were ineffective barriers for mitigating predation effects of invasive catfishes in tidal creeks.

In the Rappahannock basin and, to a lesser extent, in the James River, electrofishing survey results indicate a decline in the percent of large (>300 mm TL; i.e., piscivorous) blue catfish. For example, larger blue catfish (> 450 mm TL) in the upper tidal James River comprised 40.5 percent of the population in 2007, but only 11.5 percent of blue catfish in 2012 (using similar sampling gear and in the same location). Changes in the size frequency distribution of a population may reflect recruitment pulses or differential movement of size classes. For instance, large catfish may be moving out of tidal freshwater reaches and into mesohaline habitats further downstream. Overall densities remained high in these systems, but size distributions in long-established populations may have shifted. If these changes in size distribution reflect a permanent redistribution of size classes in the river, then it may be difficult to support upriver trophy fisheries. However, without additional data on year-class composition of the population, it cannot be known for certain which hypothesis may account for the observed shift in size frequency.

Characterizing the growth dynamics of blue catfish in the Chesapeake Bay watershed – This VIMS study aimed to develop a 'master' database of existing and newly collected data on the growth of blue catfish in the James, York, Rappahannock, and Potomac Rivers and to formally describe the growth patterns and dynamics of blue catfish in tributaries of Chesapeake Bay. The master database includes 'historic' data on age , size, and total weight of blue catfish collected in the James, York, and Rappahannock Rivers from 1998-2000 (n=613 individuals; Connelly 2001). The database also includes 'current' data on size and weights for blue catfish collected in the same primary Virginia tributaries from 2010-present (n=560, otoliths not yet processed) and fish from the Potomac River from 2008-present (n=330, ages have been assigned to 97 specimens). Modeling results indicate that the mean weight of blue catfish at a given length is generally less for the current time period compared with the historic time period; this was true for the all rivers examined (James, York, and Rappahannock rivers). For the James and Rappahannock rivers, changes in the weight-at-length relationship were most likely due to time period rather than sexual dimorphism in growth. This result suggests that weight accumulation at length is currently slower than in the late 1990s. Because blue catfish abundances are believed to be considerably higher now than they were 10+ years ago (Schloesser et al. 2011), these observed changes in growth may be related to fish density. Interestingly, modeling results for the York River suggest that sexual dimorphic growth may be present in this population. It should be noted that the historic data from the Rappahannock River does not encompass a wide length range, so detecting density related impacts on growth is difficult for blue catfish in this river system. In terms of future sampling, there continues to be a need to collect specimens of larger lengths (> 600 mm FL) in the James and Rappahannock rivers and a need to discern sex and determine the degree of sexual dimorphism in growth for blue catfish populations in Chesapeake Bay tributaries.

Estimating population size and survival rates of blue catfish in Chesapeake Bay tributaries -- Experiments in early 2012 at VIMS (n=93 blue catfish held in captivity) indicated that coded-wire tags could be readily inserted in the dorsal musculature and that tag retention rates were sufficiently high to pursue a field-based tagging study in the James River. The lab-based tagging study also revealed that tag retention rates improved with increasing tagger experience. Blue catfish (≥ 250 mm FL) were sampled from the James River and 15,721 fish (> 250 mm FL) were tagged with coded-wire tags between 9 July 2012 and 3 August 2012. All fish were trapped, tagged, and released in the 10-km area between the Chickahominy River confluence and Brandon Point (near the mouth of Upper Chippokes Creek); traps were set and tended by a cooperating waterman. During the tagging period, 930 fish were recaptured, representing a 5.9% recapture rate. Based on the pattern of catches and recaptures within the study site, tagged fish were more likely to move upriver after release. In 2013, coded wire tags were used to tag 18,531 blue catfish (≥ 250 mm FL) in the James River; about 1.2% of these fish were recaptured (n=216). Harvests from the commercial watermen operating in the James River were inspected for tags and this information will be used to adjust the population model to account for these removals.

To date, recaptured tagged fish have not been recovered in several electrofishing surveys conducted by VDGIF and VCU. These sampling efforts have occurred within, downstream, and upstream of the tagging area in 2012 and 2013. These results suggest the population in the James River may be extremely large or that fish vulnerable to traps are not vulnerable to low-frequency electrofishing. Additionally, monthly sampling by the VIMS Trawl Survey has failed to encounter a single tagged fish (the survey area extends downstream from the mouth of the Chickahominy River, but overlaps somewhat with the tagging study site), suggesting that the population in the James River is extremely large or that fish movements are somewhat restricted within the river. An additional explanation may be that only a small proportion of blue catfish are vulnerable to the trawl and most fish remain within relatively complex habitats that are not well sampled by bottom trawls.

A study of blue catfish movement was undertaken in the Potomac River in summer 2012 by the Maryland DNR (M. Groves). For this study, two dart tags were inserted in 739 large (>300 mm FL) catfish captured by low-frequency electrofishing in the tidal freshwater region of the Potomac River. By the end of 2012, 16 fish had been recaptured by anglers (2.2% recapture rate); of these, 15 retained both tags (93.8% tag retention rate). Fish recaptured by anglers tended to be larger (on average) than the average size tagged and released, indicating that anglers targeted the larger fish (> 480 mm). In addition, these fish moved between 0 and 64 km, but due to the type of tagging study, the time of year when the movement occurred could not be discerned. During the summer, however, most fish moved less than 10 km.

Additional Research Efforts

In addition to the five studies above, NOAA Chesapeake Bay Office modeling team developed a modified version of the Chesapeake Bay Fisheries Ecosystem Model (CBFEM) to describe trophic interactions for fish communities of Chesapeake Bay tributaries with an emphasis on the role of blue catfish (Turner et al, *in prep*). The main purpose of this effort was to organize the sparse information available on blue catfish and help highlight the research and monitoring needs to better understand the blue catfish population and its potential impacts on the food web. This research emphasized a significant impact on key species of particular interest to recreational and commercial fisheries. Results from the model suggested that in a status quo scenario, i.e., no direct action taken to curb the blue catfish population, invasive catfish populations would increase to a point where predation impacts would negatively impact striped bass, white perch, Alosines, native catfish, and blue crab populations. Furthermore, simulations of nutrient reductions seemed to be the most effective control measure for blue catfish as they thrive in eutrophic systems. However, a recent review of the CBFEM's ability to model nutrient and eutrophication impacts on fisheries indicates that the model produces variable results. In alternative model scenarios, where fishing mortality on blue catfish was increased tenfold to reduce the population;

there was little evidence of any measurable impacts on populations of blue catfish biomass over the 20 year progression. However, the model runs were based on limited data on population biomass, landings, and diet composition. These initial model results demonstrate that blue catfish are likely going to have appreciable impacts on other important fisheries species and that efforts to control the population through direct fishing mortality are not as effective as controlling indirectly through environmental factors. Further study on the implications of environmental factors affecting the population is warranted.

The model has served its original purpose in highlighting needs for research and monitoring. The model and the ICTF have developed recommendations for blue catfish research and monitoring. Several agencies and academic institutions are moving to fill these information gaps. NCBO and VDGIF have funded research that will help us understand the basic ecology of blue catfish in the Chesapeake (e.g., tagging studies, diet studies, geospatial databases). MD DNR, VMRC, and PRFC have improved blue catfish monitoring and landings data. The NCBO modeling team completed a Fisheries Ecosystem Model to investigate predation impacts. The Taskforce is working to synthesize the new research and apply it to blue catfish management.

With the new information available from these monitoring and research programs and Task Force synthesis, the NCBO Modeling Team has planned and ongoing model improvements that include: 1) Incorporating new initial parameter inputs, 2) making a spatial model of the Chesapeake that incorporates spatial and temporal changes in environmental variables (e.g., salinity, temperature), 3) improving the way the model incorporates eutrophication.

With an improved model, the NCBO modeling team plans to explore additional combinations of environmental (e.g., temperature and salinity) and fishing pressure as means to control the populations. Using this spatial model with environmental forcing functions, the team will be able to explore the extent to which the blue catfish population can be controlled in certain regions of the Chesapeake given environmental variability and focused fisheries efforts.

Summary of Research Findings to Date -- Together the above studies indicate predation effects of blue catfish may be substantial depending on time of year (e.g., during blueback herring spawning) and location. Findings also suggest that blue catfish may forage in mesohaline habitats (up to 14 ppt) and prey upon commercially important fishery resources. Additional studies in newly or recently colonized Maryland tributaries should prove useful in understanding the relationship between blue catfish diets and available prey. Geographically explicit information can be used to identify areas within the Chesapeake Bay basin that are vulnerable to colonization by blue catfish.

In recent years, the size-class composition of the population has shifted in favor of smaller individuals; although the cause of this shift remains unknown. Such shifts could indicate that fewer trophy-size fish may be available to the sport fishery. Furthermore, biomass accumulation at length is slower now than it was in the late 1990s, indicating a potential density-dependent response.

Preliminary observations from fish tagged and recaptured in the James River indicate that population size in the James River may be extremely high; explanations include relatively restricted movements of fish within the river (a hypothesis that is not supported by observations from the Potomac River) or differential vulnerability of fish to the gear. Fish tagged with dart tags in the Potomac River exhibit high tag-retention rates, higher than those typically reported for this species with similar tags (t-bar anchor tags); thus, dart tags are recommended for future studies where external tags are desired. Fish in the Potomac River can make long distance movements, up to 64 km, but their movements during summer appear to be more restricted (< 10 km).

The Blue Ocean Institute has listed blue catfish from the Chesapeake Bay region as a sustainable seafood source (http://Blueocean.org/seafoods/), Analyses of the suite of contaminants found in blue catfish from this region should be useful in providing consumption advice to consumers; though, current data on mercury and methyl mercury concentration in fish ranging between 386 and 428 mm TL indicate these fish have levels below the EPA human health screening level. However, other contaminants in blue catfish may be present at levels that warrant consumption advisories.

Appendix B. Logic Model

The ICTF organized their thoughts on management recommendations and actions in the following logical model chart. This logic model clearly shows the management objectives for addressing invasive catfish in the Bay, the required inputs and activities to achieve these objectives, and the short- and long-term outcomes associated with those activities.

Objective	Current Situation	Inputs	Activities/Outputs	Short-term Outcomes	Long-term Outcomes
To minimize the ecological impacts of invasive catfishes on native species	Blue Catfish make up a significant proportion of the biomass in several bay tributaries. Recent studies suggest Blue Catfish are having ecological impacts on native species via predation. There are also economic impacts as catfish co-occur with commercially important species. Further, predation of commercially important species can have economic impacts on fisheries. Eutrophication is likely supporting productive conditions advantageous to invasive catfish.	• ICTF • Science-VIMS, VCU, SERC, MD DNR, VDGIF (VT) • Jurisdiction Management-VMRC, VDGIF, MD DNR, PRFC, DENREC, DDOE, PA Fish and Boat, ASMFC • Federal-NOAA, FWS • CBP • Mid Atlantic Panel on Aquatic Invasive Species • Anglers • Funding	• Complete catfish population estimates for key tributaries • Apply the catfish portal mapping tool to identify candidate tributaries for targeted removals • Design removal methods and initiate pilot removal project /protection projects for the Dragon Run in Virginia and 1-2 to two Maryland tributaries • Use findings from removals projects to determine the extent to which populations can be reduced and develop population "control targets" • Complete a synthesis of current research quantifying ecological impacts on native species • Engage recreational and commercial fishing organizations in dialogue on known risks of invasive catfish	• Criteria are established to target tributaries for pilot removals and target tributaries are selected • Removal methods developed and tested • Pilot removals in targeted tributaries planned and initiated. • Population "control targets" are established for tributaries to achieve reasonable population reductions Extent to which populations can be reduced by targeted removals quantified • Synthesis of research projects complete and its applications communicated to managers • Anglers understand the impacts and help identify solutions	• Documented changes of lower catfish abundance and decreased ecological impact in targeted tributaries using comparative study of tributaries with and without removal efforts • Targeted citizen groups understand risks and support management efforts to reduce populations and mitigate spread • Improved and tested further testing of removal methods of removal in targeted tributaries • Pilot removal study completed and evaluated • Tributary- specific catfish management strategies developed • Develop scientifically based tributary specific control targets
To slow and reduce the spread of and invasive catfishes populations into currently	Blue catfish have been documented in all major tributaries of the Bay. Recent studies suggest impacts on native	• ICTF • Science-VIMS, VCU, SERC, MD DNR, VDGIF (VT) • Jurisdiction Management-VMRC, VDGIF,	• Develop targeting criteria to identify tributaries to protect from invasion (places where catfish not yet established, with high ecological value, already protected, etc.)	• Tributaries are identified that should be targeted for invasive catfish early detection and monitoring • Identify conservation partners to collaborate with and integrate invasive	• Develop tributary-specific public outreach plans in targeted areas to educate the public and watermen of the water about catfish and their impacts

uninhabited waters	species are likely in these tributaries. Models suggest that Blue and Flathead catfish distribution will continue to expand throughout the Bay, which threatens the native fish species in tributaries that are not yet inhabited by invasive catfish. Eutrophication is likely supporting productive conditions advantageous to invasive catfish.	MD DNR, PRFC, DENREC, DDOE, PA Fish and Boat, ASMFC • Conservation areas and refuges (NEERS, etc.) • Watermen • Mid Atlantic Aquatic Nuisance Species Panel	• Update distribution data to determine current extent of tributary invasion • Review, communicate, and enforce catfish live transport policies • Design and early detection and monitoring methodology • Complete development of Blue Catfish Portal with fishery independent data and new fishery dependent data to track spread Create mobile device app to aid public in identifying and reporting invasive catfish	catfish monitoring into existing environmental programs • Watermen are informed of fines and regulations associated with invasive catfish • Necessary components of early detection and monitoring programs protocols are identified and accounted for • Conservation areas and groups are working with management agencies to monitor spread Develop and implement test novel, rapid, and relatively inexpensive surveillance protocols (e.g. environmental DNA tools) to monitor expansions in near real time	• Early detection and monitoring methodology is tested • Early detection and monitoring programs in targeted tributaries implemented • Begin implementation and continue development of surveillance tools and monitoring protocols
To promote a large-scale, fishery to significantly reduce abundance of invasive catfishes populations and provide economic benefits to the region	A recreational trophy fishery does exist for Blue catfish in the Bay. There is currently no significant commercial market or fishery for these catfish.	• Jurisdiction Management- VMRC, VDGIF, MD DNR, PRFC, DENREC, DDOE, PA Fish and Boat, ASMFC • Watermen	• Investigate the contaminant levels to inform any consumption advisories • Testing of different gear types • Use spatially explicit ecosystem models to determine what level of fishing is needed to have a significant impact on catfish populations in	• Watermen entry into the fishery • Tributaries are targeted for the fishery • Most efficient gear types and mechanism established	• A fishery built on a valuable market for Blue catfish provides a new source of revenue for watermen • Catfish viewed as a valuable product and is used by the consumer • Effective reduction in population sizes in places where fishery takes place

			individual tributaries or Bay wide Develop a marketing campaign to promote the commercial harvest and use of invasive catfish		
To increase outreach and education to improve public awareness that Blue and Flathead catfishes are not native and pose a risk to native species and to continue to lessen the probability of unauthorized introductions into other water bodies in the Bay watershed	Although information is available on invasive catfish, it is not consistent across jurisdictions, regulations are not easily found, and there is no sense of urgency in the messaging to public or anglers about the risk they pose.	• Jurisdiction fishing guides and web resources • Watermen • ICTF • Social media • CBP • Jurisdiction Management- VMRC, VDGIF, MD DNR, PRFC, DENREC, DDOE, PA Fish and Boat, ASMFC	• Emphasize that it is illegal to transport Blue and Flathead catfish • Complete a synthesis of current research quantifying ecological impacts on native species • Create outreach materials that inform the public and watermen about the ecological impacts of catfish on native species in the Bay • Compile the catfish research into the catfish portal to have a "one-stop shop" for information on invasive catfish in the Bay • Continue research efforts to better understand invasive catfish and their impacts • Work with conservation organizations to integrate invasive catfish information into their programs	• Increased information and messaging on jurisdiction websites on the impacts of Blue catfish and the associated no transport and other associated regulations • Conservation areas and groups are working with management agencies to inform the public	• The public and watermen better understand that Blue and Flathead catfish are invasive and are negatively impacting other species in the Bay • Public support actions to manage Blue and Flathead catfish

		• Create mobile device app to aid public in identifying and reporting invasive catfish		

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