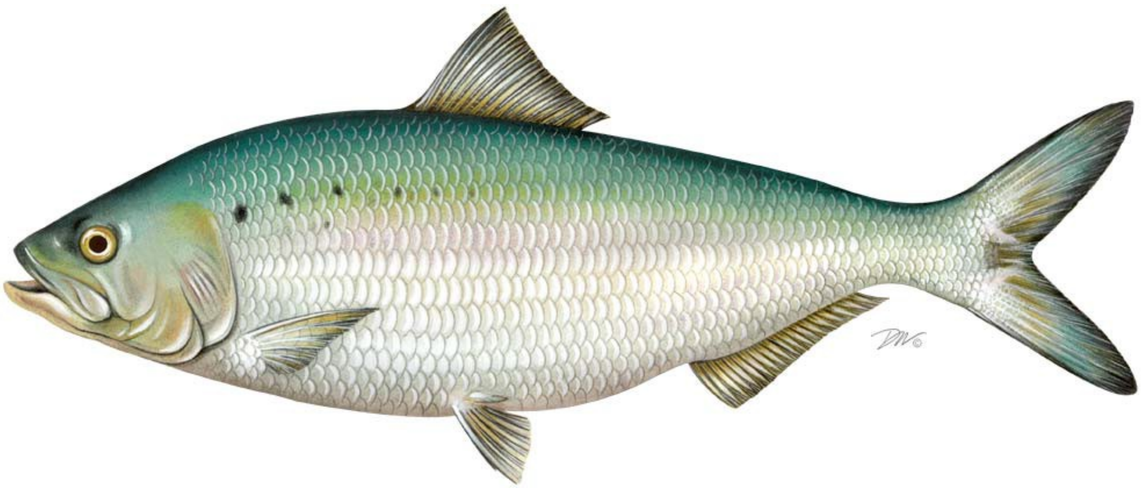
American Shad Habitat Plan for Maryland



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Habitat Assessment

Spawning and rearing habitat was determined for most major river systems under Maryland jurisdiction with a known history of American shad (*Alosa sapidissima*) spawning (Tables 1 & 2). Spawning habitat was delineated using a combination of empirical observations during scientific surveys, spring salinity regimes (MDNR, 2020), historical fishery reports, and the Chesapeake Fish Passage Prioritization tool (Martin, 2019) (Figures 1-9). Rearing habitat was delineated using a combination of empirical observations during scientific surveys and juvenile American shad distribution estimates formulated by the MDNR Fisheries Habitat and Ecosystem Program (FHEP) (Figure 10; Uphoff et al., 2017). Rearing habitat was further categorized according to average bottom salinity (1998-2003) into preferred (0-4 ppt), acceptable (4-7 ppt), and marginal (7-13 ppt) habitat (Uphoff et al., 2017). Salinity preferences were determined using frequency distributions of young-of-year American shad captured during the MDNR Estuarine Juvenile Finfish Survey by salinity (Uphoff et al., 2017).

Most rivers were assessed individually, with the only exception being the complex of waterways that feed into the upper Chesapeake Bay, which was combined into single estimates of spawning and rearing habitat. This was done in accordance with the 2020 benchmark stock assessment which identified this collection of rivers as a single stock unit (ASMFC, 2020). These rivers include Chesapeake Bay tributaries such as the Susquehanna, North East, Elk, Bohemia, and Sassafras Rivers. While spawning can occur in any of these locations, the Susquehanna River, Susquehanna Flats, and North East River are host to the majority of American shad spawning activity in the Upper Bay. While this may be partially a function of the currently depressed stock status, historical fishery landings suggest that even in times of greater abundance, spawning runs of American shad were minimal in the Elk and Sassafras Rivers relative to the Susquehanna River and Flats (Stevenson, 1899; Mansueti and Kolb, 1953; Walburg and Nichols, 1967). Stevenson (1899) even suggested that American shad often bypassed small rivers such as the Sassafras due to their attraction to the strong freshwater flow coming from the Susquehanna River.

Habitat statistics as presented in this document should be interpreted as accessible habitat rather than suitable habitat; some historically productive and accessible rivers have been significantly degraded by urban and agricultural development, leading to less than favorable environmental conditions for American shad spawning. Such rivers include the Patapsco, Patuxent, and Wicomico. The impacts of these issues on habitat quantity are variable from year to year and difficult to assess. Thus, they are addressed in the 'Threats' section of this habitat plan. Nevertheless, most dams or other anthropogenic barriers in Maryland are located far enough upstream so as not to impact American shad use of habitat. Habitat upstream of dams with fish passage facilities was considered accessible if American shad have been documented successfully using the fish ladder/lift.

Threats Assessment

Threat: Barriers to Migration

An inventory of dams that may be encountered by American shad are included in Table 3. As stated previously, most of the dams in Maryland are located far enough up the watershed so as to not impact American shad habitat use. The primary exception to this is Conowingo Dam on the Susquehanna River, which restricts access to a substantial amount of upriver spawning and rearing habitat. Only 4.38% of historical American shad habitat in the Susquehanna River drainage remains unobstructed (ASMFC, 2020). Further complicating habitat use in the Susquehanna River basin are three other major hydropower dams (Holtwood, Safe Harbor, and York Haven Dams) upstream of Conowingo, all located in Pennsylvania. The majority of suitable spawning habitat lies beyond York Haven, the most upstream of these dams. While fish passage facilities exist at all of these hydropower projects, upstream passage efficiency is poor. Mean combined upstream passage efficiency of adult American shad from all four main steam dams from 1997-2010 was estimated as 2% (Normandeau and Gomez & Sullivan, 2012a). Upstream passage efficiency of adult American shad at Conowingo Dam alone is estimated as 25.8% (Normandeau and Gomez & Sullivan, 2012b).

Despite the presence of volitional fish passage at Conowingo Dam, significant upstream passage delays are likely. Increased residence time in the dam tailrace results in greater energy expenditure during an already metabolically-costly migration. Consequences of upstream passage delays, in conjunction with poor upstream passage efficiency and downstream migration mortality, include reduced fecundity, spatial extent of spawning, spawning success, spawner abundance, and percentage of repeat spawners (Stich et al., 2018; Castro-Santos and Letcher, 2010).

As a result significantly reduced habitat accessibility, the abundance of American shad spawning in the Susquehanna River is likely near historic lows (Bourdon and Jarzynski, 2019). However, the pending relicensing of Conowingo Dam, along with ongoing upstream and downstream fish passage improvements at dams in the Pennsylvania portion of the Susquehanna, should improve riverine migratory conditions for American shad and other diadromous species.

Updating upstream and downstream passage requirements to ecologically-informed levels at major hydropower dams is essential for the restoration of American shad. In times past, losses due to poor adult downstream survival through the Susquehanna River dams essentially replaced losses due to fisheries (Sadzinski and Uphoff, pers. comm). Substantial work to improve downstream adult survival is ongoing and includes solutions such as installation of Kaplan turbines (more fish-friendly than traditional Francis turbines), seasonal alterations to turbine and spillway operations, and creation of alternative routes of downstream passage. At smaller dams throughout the state, the MDNR Fish Passage Program (FPP) prioritizes dam removal over fish passage facility installation.

The failure of fish passage facilities to restore alosine fish populations is not unique to the Susquehanna and is a ubiquitous problem throughout the range of the American shad (Brown et al., 2012). The 2020 ASMFC American shad stock assessment report highlights issues with lack of evaluation and performance standards at fish passage facilities (ASMFC, 2020). Many of these structures are decades old and their designs and operations are largely ineffective; they cannot reasonably be expected to achieve management and restoration goals without significant changes. The assessment report also provides a quantitative modeling approach examining shad habitat and passage barriers, and the need to address status quo fish passage performance. The impacts of these barriers and status quo passage are described and also modeled as effects on spawner population size under three scenarios: 1) no barriers, 2) first barrier with no passage, and 3) realistic fish passage performance measures applied to barriers (e.g., upstream passage efficiency of 50%).

The assessment report used standardized data and modelling approaches that quantified the impacts of barriers and fish passage as significant in all three management areas examined based on American shad life history and habitat (New England, Mid-Atlantic, and South Atlantic). Overall, dams completely or partly block nearly 40% of the total habitat once used by American Shad. The model results of the "no barriers" scenario yielded an estimated spawner production potential 1.7 times greater than that yielded by the scenario assuming no passage at the first barrier: 72.8 million versus 42.8 million fish. The results of the third model scenario, which applies "realistic" (i.e., current) fish passage efficiencies, resulted in a gain of less than 3 million fish. Losses in spawner production potential were significant in each state and region. The assessment report provides a strong justification for the need and benefits of requiring improved fish passage performance measures. Additionally, meeting such improved passage performance standards is now an achievable goal given the current state of knowledge on fish behavior, swimming performance, and fish passage engineering expertise.

Recommended Action 1 (See Task A1 in SRAFRC Restoration Plan): Develop and implement upstream passage plans and performance measures at the Conowingo hydroelectric dam to ensure that the facility passes at least 85 percent of the adult American shad reaching the tailrace. Incorporate upstream passage plans and evaluation requirements in FERC licenses. Recommend or conduct evaluation studies as necessary. Require additional fish passage capacity, as needed, to meet fish passage targets. Report fish passage results annually.

Agencies with Regulatory Authority: SRAFRC (made up of MDNR, PFBC, PADEP, SRBC, NYDEC, and USFWS members), MDE, and FERC.
Goal/Target: Goals listed in the recommended action are to be met in conjunction with FERC relicensing and compliance.
Progress: In April 2016, Exelon Generation LLC entered a settlement agreement with the USFWS regarding the fish passage prescription for Conowingo dam. This fish passage settlement agreement outlines the steps that will be taken to achieve the required upstream passage efficiency. The MDE and Exelon Generation LLC reached a settlement agreement in Fall 2019 regarding the water quality certification issued in 2018 by

Maryland under Section 401 of the Clean Water Act. Relicensure of Conowingo dam, and thus the implementation of upstream passage requirements, is still pending FERC approval of both the fish passage and water quality settlement agreements.
Cost: SRAFRC member agencies are responsible for overhead. The dam owner's cost is dependent on the level of fishway improvement required to meet target levels.
Timeline: Action goals are to be accomplished upon completion of FERC relicensing.

Recommended Action 2 (See Task A2 in SRAFRC Restoration Plan): Develop and implement downstream passage plans and measures for adult alosine species at the Conowingo hydroelectric dam to ensure at least 80 percent survival. Incorporate adult downstream passage plan and evaluation requirements in FERC licenses.

Agencies with Regulatory Authority: SRAFRC (made up of MDNR, PFBC, PADEP, SRBC, NYDEC, and USFWS members), and FERC.
Goal/Target: Goals listed in the recommended action are to be met in conjunction with FERC relicensing and compliance.
Progress: In April 2016, Exelon Generation LLC entered a settlement agreement with the USFWS regarding the fish passage prescription for Conowingo dam. This fish passage settlement agreement outlines the steps that will be taken to achieve the required downstream passage efficiency. The MDE and Exelon Generation LLC reached a settlement agreement in Fall 2019 regarding the water quality certification issued in 2018 by Maryland under Section 401 of the Clean Water Act. Relicensure of Conowingo dam, and thus the implementation of downstream passage requirements, is still pending FERC approval of both the fish passage and water quality settlement agreements.
Cost: SRAFRC member agencies are responsible for overhead. The dam owner's cost is dependent on the level of modification required to meet target levels.
Timeline: Action goals are to be accomplished upon completion of FERC relicensing.

Recommended Action 3 (See Task A3 in SRAFRC Restoration Plan): Develop and implement juvenile downstream passage plan and performance measures at the Conowingo hydroelectric dam to ensure 95 percent survival of juvenile alosine species at this facility. Incorporate juvenile downstream passage plan and evaluation requirements in FERC licenses. Include operational measures at the hydroelectric dam as needed to enhance downstream passage survival of juvenile alosine species.

Agencies with Regulatory Authority: SRAFRC (made up of MDNR, PFBC, PADEP, SRBC, NYDEC, and USFWS members), and FERC.
Goal/Target: Goals listed in the recommended action are to be met in conjunction with FERC relicensing and compliance.
Progress: In April 2016, Exelon Generation LLC entered a settlement agreement with the USFWS regarding the fish passage prescription for Conowingo dam. This fish passage settlement agreement outlines the steps that will be taken to achieve the required downstream passage efficiency. The MDE and Exelon Generation LLC reached a settlement agreement in Fall 2019 regarding the water quality certification issued in 2018 by Maryland under Section 401 of the Clean Water Act. Relicensure of Conowingo dam,

and thus the implementation of downstream passage requirements, is still pending FERC approval of both the fish passage and water quality settlement agreements.
Cost: SRAFRC member agencies are responsible for overhead. The dam owner's cost is dependent on the level of modification required to meet target levels.
Timeline: Action goals are to be accomplished upon completion of FERC relicensing.

Recommended Action 4 (See Task A9 in SRAFRC Restoration Plan): Minimize delays at the Conowingo hydroelectric dam to foster adult spawning fish migration to the upper limits of historical spawning habitat in the watershed.

Agencies with Regulatory Authority: SRAFRC (made up of MDNR, PFBC, PADEP, SRBC, NYDEC, and USFWS members), and FERC.
Goal/Target: Goals listed in the recommended action are to be met in conjunction with FERC relicensing and compliance.
Progress: In April 2016, Exelon Generation LLC entered a settlement agreement with the USFWS regarding the fish passage prescription for Conowingo dam. This fish passage settlement agreement outlines the steps that will be taken to ensure the timely upstream passage of American shad. The MDE and Exelon Generation LLC reached a settlement agreement in Fall 2019 regarding the water quality certification issued in 2018 by Maryland under Section 401 of the Clean Water Act. Relicensure of Conowingo dam, and thus the implementation of upstream passage requirements, is still pending FERC approval of both the fish passage and water quality settlement agreements.
Cost: SRAFRC member agencies are responsible for overhead. The dam owner's cost is dependent on the level of fishway improvement required to meet target levels.
Timeline: Action goals are to be accomplished upon completion of FERC relicensing.

Recommended Action 5: To continue to provide for fish passage at dams, and remove stream blockages wherever necessary to restore passage for migratory fishes to historical spawning grounds.

Agencies with Regulatory Authority: MDNR, in cooperation with the Chesapeake Bay Program, Pennsylvania, Virginia, and the District of Columbia.
Goal/Target: MDNR has been part of the Chesapeake Bay Agreement (to provide fish passage at dams and remove stream blockages) since 1987. After exceeding the initial goal by restoring access to 1,838 miles of aquatic habitat by 2005, the states decided to expand the goal to 3,500 miles by 2025. As of 2017, this goal was surpassed with a cumulative restoration total of 3,746 miles. The Chesapeake Bay Agreement prioritizes dam removals over the installation of fish ladders.
Progress: To date, the MDNR FPP has completed 78 projects, reopening a total 454.2 miles of upstream aquatic habitat (in Maryland). The FPP is currently involved in planning for the removal of three dams that American shad may encounter including Van Bibber Dam (Bush River), Atkisson Dam (Bush River), and Ft. Meade Dam (Patuxent River). Additionally, there are plans to improve natural bypass conditions around the Elkton Dam (Elk River).
Cost: Total cost and responsible agencies depend on the project. In Maryland, participants include but are not limited to MDNR, American Rivers, NFWF, NOAA, CBP, EBTJV, and the USFWS.

Timeline: Between 1989 and 2011, 2,510 miles of aquatic habitat were re-opened to migratory fish in the Chesapeake Bay watershed. In accordance with the Chesapeake Bay Watershed Agreement, the CBP adopted a goal of re-opening an additional 1,000 miles from the 2011 baseline. As of 2017, this goal was exceeded with access to 1,236 miles of aquatic habitat being restored.

<u>Threat: Water Withdrawals</u>

Power plant cooling water intakes currently account for over 91% of permitted surface water withdrawals by volume in Maryland. Cooling water intakes in excess of two-million gallons per day are regulated by the EPA National Pollutant Discharge Elimination System (NPDES). An inventory of power plants that currently withdraw water from Maryland's portion Chesapeake basin within American shad habitat are provided in Table 4. No American shad have been documented in either entrainment or impingement studies conducted at these facilities. However, other alosids such alewife and blueback herring have been infrequently documented, which would suggest that juvenile American shad could be subject to entrainment or impingement in small numbers.

The Maryland Department of the Environment (MDE) regulates surface water intake requirements for power plants drawing under two-million gallons per day as well as intakes for most other purposes. Any operation withdrawing in excess of 10,000 gallons of surface water must obtain a water appropriation and use permit from MDE. Consultation with the MDNR environmental review team is conducted for all new surface water withdrawals. Concurrent with MDNR recommendations, MDE requires a 0.5 ft/second intake velocity and one millimeter screening on most surface water intakes. While alosine fish habitat is considered during the permitting process, most water intakes do not require monitoring for impingement or entrainment of aquatic organisms.

Recommended Action: Reduce impingement and entrainment of American shad within the Maryland portion of the Chesapeake basin.

Agencies with Regulatory Authority: EPA, FERC, MDE, MDNR

Goal/Target: NA

Progress: All power plants drawing in excess of two-million gallons of surface water per day within the range of American shad have conducted impingement monitoring, and all but one (Wheelabrator) have conducted entrainment monitoring. No American shad were identified by these studies. MDE requires a 0.5 ft/second intake velocity and one millimeter screening to reduce entrainment and impingement of aquatic organisms. Additionally, the MDNR Power Plant Research Program initiated the Smart Siting Project in 1996 to provide guidance to power plant developers regarding environmental concerns and to identify areas most favorable for power plant development.

Cost: NA

Timeline: NA

Recommended Action: Maintain surface water flow velocity and volume sufficient for American shad spawning and rearing.

Agencies with Regulatory Authority: EPA, FERC, MDE, MDNR
Goal/Target: NA
Progress: The MDNR Environmental Review Team and MDE consider the impacts of proposed surface water withdrawals on flow regimes to maintain appropriate conditions for aquatic life.
Cost: NA
Timeline: NA

<u>Threat: Channelization and dredging</u>

There is no information available regarding the impacts of dredging projects on American shad in Maryland, though fish habitat may be given consideration during the permitting process. Alteration of substrate characteristics could influence spawning behavior, though American shad may not be as substrate specific as some other alosine species (Krauthamer and Richkus, 1987; Bilkovic et al., 2002). Disturbance of the benthos may also temporarily decrease water quality and suspend contaminants in the water column, especially in urban or industrial areas.

The largest dredging projects in Maryland are managed by the Maryland Department of Transportation's Maryland Port Authority (MPA) and are operated to maintain shipping channels connecting the main stem of the Chesapeake Bay and the Patapsco River (location of the Port of Baltimore). An average of 4.7 million cubic yards of sediment is dredged every year to maintain approximately 150 nautical miles of shipping channels. Most of the MPA authorized dredging occurs outside of the preferred spawning or rearing habitat for American shad, with the exception being the Upper Bay area where a 35-40' channel system is maintained to connect the Port of Baltimore to the Chesapeake and Delaware canal. Smaller dredging projects are permitted through MDE.

The MPA also manages the Dredged Material Management Program to find environmentally responsible solutions for the usage of dredged material. Much of this material is used for habitat restoration on eroding Chesapeake Bay islands and marshes. Active dredged material placements sites include Poplar Island, Masonville, and Cox Creek. The MDE oversees the proper use of dredged material, including the enforcement of sediment characterization requirements that ensure that contaminated dredged material does not negatively impact aquatic communities.

Recommended Action: Consider American shad habitat during the permitting process for dredging and dredged material placement projects.

Agencies with Regulatory Authority: MDOT, MPA, MDE
Goal/Target: NA
Progress: MDE may consult the MDNR Environmental Review Team during the permitting process for dredging projects. MPA and MDE are both involved in site selection for the reuse of dredged material. MDE considers toxicity thresholds for aquatic communities during sediment characterization studies required before the placement of

dredged material. To offset the impacts of dredging, the MPA funded shad and river herring restoration in the Patapsco River through fish production, stocking, and assessment.
Cost: NA
Timeline: NA

<u>Threat: Land Use</u>

Land use has a profound impact on water quality and fisheries health within Maryland. Many fish stocks, including American shad, have experienced significant declines due to uninformed land use decisions among other factors. One of the earliest realized effects of poorly regulated land use on fisheries in Maryland was the siltation of anadromous fish spawning grounds (Mansueti and Kolb, 1953). While American shad spawning may not be as substrate dependent as some other alosines (Krauthamer and Richkus, 1987; Bilkovic et al., 2002), siltation of spawning grounds contributed to American shad declines in Maryland in the early 20^{th} century (Mansueti and Kolb, 1953; Klauda et al., 1991a). The topography of watersheds on the western shore of the Chesapeake Bay may promote rapid runoff of surface water into rivers and streams, especially when natural land cover has been disturbed. The American shad spawning grounds of one such watershed, the Patuxent, suffered under heavy siltation associated with gravel mining and tobacco farming in the early to mid-1900's (Mansueti and Kolb, 1953). The degree of siltation in most eastern shore rivers during that time was likely not as severe, despite the prevalence of agriculture; the flat land does not promote rapid runoff of surface water into rivers (Mansueti and Kolb, 1953). Siltation from flood stages at Conowingo Dam likely restricted spawning habitat on the Susquehanna Flats in the Upper Bay soon after dam construction in 1928. Fishermen in the region reported that they could no longer operate drift nets over the Susquehanna Flats due to the degree of siltation and sunken logs deposited from upstream (Mansueti and Kolb, 1953).

Modern best management practices currently prevent siltation from occurring on such large scales, but localized siltation events still occur. Streambank erosion in headwater streams and the discharge of legacy sediments stored in stream valleys continue to impact aquatic ecosystem health (Noe et al., 2020). Furthermore, sediment retention in Conowingo Reservoir is at maximum capacity; the discharge of water from the dam, particularly at flood stages, is now associated with the release of sediment and associated nutrients, heavy metals, and other pollutants that have accumulated behind the dam over the last century (Palinkas et al., 2019).

Few sampling programs have successfully monitored the impact of watershed development on American shad specifically. However, the MDNR Fisheries Habitat and Ecosystem Program (FHEP) assesses alosine fish habitat use across a gradient of development to explore the effects of urbanization on spawning habitat (Uphoff et al., 2019). The critical egg and larvae life stages are targeted by this survey. While no American have been detected to date, they are expected to demonstrate similar responses to development as the positively detected alosine species (river herring and hickory shad); American shad eggs and larvae have similar tolerances as other Maryland alosines for salinity, temperature, turbidity, pH, dissolved oxygen, and suspended solids (Klauda et al., 1991a; Klauda et al., 1991b).

The level of development in a watershed is often measured using a metric of impervious surface coverage (Topolski, 2015; Uphoff et al., 2019). Increases in impervious surfaces are associated with greater surface water runoff into surrounding waterways and declining water quality. This runoff acts as a vector for excess nitrogen, phosphorus, and contaminants such as heavy metals, dissolved minerals, and PAHs. The FHEP demonstrated that the presence of alosine eggs and larvae is negatively correlated with both the level of development and conductivity, a commonly used measure of water quality associated with development (Uphoff et al., 2019). These findings suggest that increases in urban and suburban development are causative factors of the deterioration of alosine spawning habitat and overall spawning success. Rivers impaired by high levels of development are unlikely to produce notable quantities of juvenile American shad, even if the abundance of spawners is sufficient (Uphoff et al., 2018).

Excess nutrient loading due to land development also has a significant influence on dissolved oxygen (DO) availability. Bottom water hypoxia significantly reduces available habitat for most aquatic species and is an annually observed phenomenon throughout most of the Chesapeake basin during the summer (Rabalais and Turner, 2001; Breitburg et al., 2003; D’Elia et al., 2003). Nutrient runoff from agricultural lands has often been implicated as a primary driver of seasonal hypoxic events in the Chesapeake Bay (Kemp et al., 2005; Brush, 2009). However, other types of human-altered land coverage negatively influence DO availability as well. Uphoff et al. (2011) demonstrated significant relationships between various modes of watershed land use, summer DO, and presence of finfish and shellfish indicator species in various Maryland sub-estuaries. Percent impervious surface coverage was used as an indicator of urban development intensity. Bottom DO was negatively influenced by impervious surface coverage while surface DO exhibited no relationship to impervious surface coverage. Surprisingly, mean bottom DO was positively correlated with the percentage of agricultural land cover. No matter the cause, summer hypoxia influences the amount and quality of rearing habitat available to American shad. However, the extent of summer hypoxia usually does not impact freshwater and oligohaline waters that compose the preferred rearing habitat identified by the FHEP (Figure 10; Uphoff et al., 2017). The mesohaline waters characteristic of acceptable and marginal rearing habitat are much more susceptible to hypoxic conditions (Figure 10; Uphoff et al., 2017). Exposure to hypoxic waters may cause direct mortality of finfish, or increase mortality indirectly through density-dependent interactions with predators, impaired growth, or suppressed immune responses among other factors (Breitburg, 2002; Breitburg et al., 2003, 2009).

Fisheries managers do not have authority to manage land use and are limited to managing the harvest of fishes that may be threatened. The FHEP works to tie land use and fisheries management together; this program’s research supports a 10% impervious surface threshold as the ‘tipping point’ beyond which little success is expected in maintaining sustainable fisheries. A characterization of estimated impervious surface coverage, along with select other watershed characteristics, is provided for spawning and rearing rivers in Table 5. American shad fisheries are closed in Maryland, but an explanation of Maryland’s watershed fishery management priorities are as follows (Figure 11):

- Conserve - areas with less than 5% impervious surface; recommend harvest restrictions and stocking for effective fisheries management and watershed conservation for sound land management.
- Revitalize – areas with 5-10% impervious surface; recommend options to decrease harvest and increase stocking to compensate for effective fishery management, and conserve and revitalize watershed for sound land management.
- Re-engineer – areas with 10-15% impervious surface; fisheries are highly variable; traditional fishery management tools are not reliable. Recommend conserving and reconstructing degraded watershed for land management – typically re-engineering will address nutrient reductions for larger scale TMDL, but this is not expected to have local biological lift.
- 15% impervious – from a fishery management point of view, investments to enhance large scale fisheries are not expected to be effective; local re-engineering can address localized habitat stability needs, but are not expected to provide additional ecological lift.

Recommended Action: To continue to promote the conservation and revitalization of watersheds, especially in areas vulnerable to growth. Conserving watersheds at a target level of development is ideal [0.27 structures per hectare (C/ha) or 5% impervious surface cover; Uphoff et al. 2018]. Once above this level of development, revitalization and reconstruction could consist of measures such as road salt management, stemming leaks in sewage pipes, improving septic systems, stormwater retrofits, stream rehabilitation, replenishment of riparian buffers, creation of wetlands, planting upland forests, and "daylighting" of buried streams (Uphoff et al. 2018). Other effects that may exacerbate development related habitat stressors (i.e., climate change) should also be considered.

Agencies with Regulatory Authority: The planning authority for each county is typically the local government, with the Maryland Department of Planning serving in an advisory capacity.
Goal/Target: Maryland does not have measureable goals for protecting American shad from land use impacts; fisheries managers can only influence land use in an advisory capacity. If the fishery reopens, management strategies may be adapted to the level of watershed development, as advised by the FHEP.
Progress: Maryland instituted a moratorium on American shad fisheries in 1980 to reduce stress on the depleted American shad stock. Many state and grassroots organizations work to preserve as much of the remaining natural land in Maryland as possible. The FHEP acts in an advisory capacity to local governments to promote natural land conservation and more responsible development practices.
Cost: NA
Timeline: NA

<u>Threat: Climate Change Assessment</u>

Diadromous fish, including American shad, are among the most vulnerable aquatic species to the effects of climate change (Hare et al., 2016). Of 36 Northeast U.S. continental shelf fish species analyzed in a spatial distribution study, American shad exhibited one of the greatest poleward shifts in distribution during their marine residence from 1968-2007 (Nye et al., 2009). However, given the natal homing behavior exhibited by American shad, a northward shift of the same magnitude is unlikely for the spawning range, though there is greater uncertainty surrounding this prediction (Hare et al., 2016). Changes in stock structure due to climate change should be given greater consideration during future diadromous fish stock assessments (Nye et al., 2009).

American shad migration and spawning are heavily influenced by water temperature. Models focusing on American shad in the Hudson River, New York predict that by the 2090's, the onset of spawning will begin 15 days earlier and the duration of spawning will be truncated by 4 days (Nack et al., 2019). In Maryland, peak spawning time is mid-April through early June, with temperatures ranging from 55°F to 68°F. In addition to anticipated changes in spawning time and duration, spring temperature increases may lead to a mismatch between larval rearing phases and phytoplankton blooms required to support them (Boesch, 2008). The migration of juvenile alosine fish, including American shad, to the ocean in the fall is triggered by decreasing water temperature, and may be delayed due to warmer fall temperatures (Kane, 2013).

Maryland lies in the middle of the coastwide range of American shad, which minimizes the potential for distributional shifts of this species in the state. However, the impacts of climate change on American shad may manifest themselves in more indirect ways. The combined effects of temperature change, sea level rise, and changes to precipitation patterns will likely exacerbate the impacts of other threats described in this document including development and poor water quality (Boesch, 2008). Notably, temperature, freshwater flow, and sea level rise predictions specific to the Chesapeake Bay are expected to decrease dissolved oxygen availability in the basin despite substantial efforts to reduce nutrient inputs throughout the watershed (Irby et al., 2018). American shad, especially larvae and juveniles, may also experience stress due to changes in the abundance and distribution of food resources (Boesch, 2008); distributional shifts of other species in response to climate change may also increase competition for these resources and expose American shad to novel predatory interactions.

Recommended Action: Incorporate the effects of climate change on American shad migration, spawning, distribution, habitat, and trophic interactions into decisions impacting the management of anadromous fish stocks and habitat.

Agencies with Regulatory Authority: ASMFC, MAFMC, NMFS, MDNR
Goal/Target: NA
Progress: The Maryland Climate Change Commission advises the Governor and General Assembly "on ways to mitigate the causes of, prepare for, and adapt to the consequences of climate change." While this effort does not directly address the effects of climate change on American shad, it does promote ecosystem resiliency efforts which indirectly work to conserve anadromous fish habitat.
Cost: NA
Timeline: NA

Threat: Competition and Predation

American shad, particularly juveniles and sub-adults, are forage for a wide variety of species. Given their great historic abundance, young-of-year American shad were likely a common prey item for most piscivorous or generalist fish during the summer and fall in tidal Maryland waters. Presently, few, if any, predators have a stronger influence on American shad population dynamics than the striped bass (*Morone saxatilis*). Predation by striped bass has been identified as a driver of American shad population density in the Albemarle Sound (Tuomikoski et al., 2008). In the Connecticut River, predation by an increasing abundance of striped bass was implicated in the drastic decline of American shad in the 1990's (Savoy and Crecco, 2004). Being the primary spawning and nursery area for the coastal migratory stock, the Chesapeake Bay is home to an abundance of striped bass; annual fluctuations in the abundance of resident, pre-migratory striped bass likely exert a strong effect on successful recruitment of juvenile American shad to the offshore migratory stock.

The proliferation of invasive predators in Maryland waters is of particular concern to all alosine species. Blue catfish (*Ictalurus furcatus*), flathead catfish (*Pylodictis olivaris*), and Northern snakehead (*Channa argus*) are all recently introduced predators with the potential to impact American shad restoration efforts. Schmitt et al. (2017) analyzed prey selectivity of both flathead and blue catfish in the James River, a Virginia tributary of the Chesapeake Bay, during March-May of 2014 and 2015. They found that flathead catfish were highly piscivorous and selectively preyed on adult American shad relative to other available forage. Blue catfish had broad, omnivorous diets but became more piscivorous with age; predation upon adult American shad was documented, but there was no evidence for selectivity of American shad over other available forage. The impacts of Northern snakehead upon American shad are not well understood, but predation, especially upon juveniles, is likely (Fofonoff et al., 2003).

Migration obstacles such as dams that facilitate dense aggregations of American shad are likely to increase their susceptibility to predation by these species (Schmitt et al., 2017). In Maryland, this is mainly a concern at Conowingo dam, where high numbers of American shad congregate near the entrances of fish lifts. Flathead catfish, blue catfish, and Northern snakehead are also abundant in the Conowingo dam tailrace, so predation upon American shad is expected.

Flathead catfish are almost entirely restricted to freshwater habitats. Within Maryland, their most dense populations are located in the Susquehanna River and the non-tidal Potomac River, though they have also been documented in the Upper Chesapeake Bay, the Elk River, and the Sassafras River. Northern snakehead and especially blue catfish have proven themselves more adaptable to the primarily brackish waters of the Chesapeake basin and are now found in almost all Maryland tributaries. Therefore, the potential for the interaction of these species with both adult and juvenile American shad is high. Despite this, American shad population declines in response the proliferation of invasive predators has not been documented in Maryland. In the Potomac River, the epicenter of both the blue catfish and Northern snakehead invasions in the state, relative abundance of both juvenile and adult American shad continues to increase (Bourdon and Jarzynski, 2019). Further work is needed to fully understand the impacts that this suite of invasive predators may have on the recovery of American shad in Maryland waters.

Long established non-native predators such as the channel catfish (*Ictalurus punctatus*), smallmouth bass (*Micropterus dolomieu*), and largemouth bass (*Micropterus salmoides*) may also impede the recovery of alosine fish populations. Given the long history of these species in the Chesapeake basin, their impacts on American shad populations are unknown. However, all have been documented consuming American shad (Fofonoff et al., 2003). Most notably, juvenile smallmouth bass were the dominant predator of recently stocked larval American shad in the Susquehanna River (Johnson and Dropkin, 1992).

While many native species compete for food resources with American shad, the gizzard shad (*Dorosoma cepedianum*) presents particularly strong challenges for American shad recovery via non-predatory, density-dependent effects. Stocks of many native fish species declined throughout the 20th century due to a myriad of factors including deteriorating water quality and overfishing. However, gizzard shad thrived in this changing environment. There is substantial diet overlap between juvenile gizzard shad and young-of-year American shad, and gizzard shad have been implicated in the lack of recovery of American shad stocks in the Susquehanna River (Klauda et al., 1991a). High abundances of gizzard shad may also interfere with the ability of American shad to effectively utilize fish passage facilities, as has been observed at Conowingo Dam (SRAFRC, 2010). From 2010-2019, the East Fish Lift at Conowingo passed 1,090 gizzard shad per lift on average; the average passage of gizzard shad outnumbered American shad by a ratio of 80:1 during the same time period (Normandeau, 2019).

Recommended Action: Promote the commercial and recreational harvest of flathead catfish, blue catfish, and northern snakehead as means of population control.

Agencies with Regulatory Authority: MDNR, MDA, FDA, USDA

Goal/Target: Maryland has no specific goals or targets for population control of invasive finfish predators. Population reduction and stabilization will be promoted through commercial and recreational fisheries.

Progress: There are no creel limits or size restrictions on the recreational fisheries for the aforementioned species. Likewise, the commercial fishery operates under no size restrictions with an unlimited quota. MDNR has conducted extensive public outreach to encourage recreational harvest of these species. In 2018, the state of Maryland announced the Blue Catfish Purchasing Initiative, which promotes the sale of blue catfish to state institutions with food services. MDNR is currently supporting the Maryland General Assembly in an effort to overturn USDA inspection rules for catfish species which significantly hinder the harvest and sale of blue catfish. MDNR is currently drafting the Invasive Catfish Fishery Management Plan which will further outline goals to control invasive catfish in Maryland waters.

Cost: NA

Timeline: NA

Recommended Action: Control the further spread of flathead catfish, blue catfish, and northern snakehead in waters under Maryland jurisdiction.

Agencies with Regulatory Authority: MDNR, USFWS, SRAFRC (made up of MDNR, PFBC, PADEP, SRBC, NYDEC, and USFWS members), FERC

Goal/Target: Northern snakehead and blue catfish are already present in most rivers systems in the Chesapeake basin. Flathead catfish populations are more localized and restricted by salinity. Intentional spread of these species is prohibited.
Progress: While Northern snakehead and blue catfish are now present in most suitable waters in the Chesapeake basin, they are mostly absent upstream of Conowingo Dam. For the 2021 fish passage season, volitional passage to Conowingo Pond via the East Fish Lift (EFL) will not be conducted. Alternatively, the West Fish Lift (WFL) will pass anadromous fish upstream via a trap and truck transport program. Every effort will be made to sort the entire catch and remove invasive species captured in the WFL. Volitional upstream passage via the EFL will likely not resume until adequate procedures to control invasive species passage are implemented. Intentional release of invasive catfish or northern snakehead into a different waterbody from where it was caught is illegal in Maryland. Furthermore, it is illegal to possess, import, or transport a live northern snakehead.
Cost: NA
Timeline: NA

Habitat Restoration Programs

MDNR Fish Passage Program (FPP):

The FPP was established in the Chesapeake Bay Agreement in 1987. To date, the FPP has completed 78 projects, reopening a total 454.2 miles of anadromous fish habitat. The program favors dam removals over fish passage facility construction and priority is given to projects which open large stretches of the highest quality habitat. Additionally, priority is given to projects which enhance passage of migratory fish and where shad or river herring stocking programs operate.

MDNR Fish Hatcheries Division:

The MDNR Fish Hatcheries Division sources American shad broodstock from the Potomac River, operating under a collection permit from the Potomac River Fisheries Commission. Stocking of American shad began in 1994 in the Patuxent River. Since that time, stocking has been conducted in various tributaries including the Nanticoke River, Marshyhope Creek, the Choptank River, and the Patapsco River. Currently, American shad stocking occurs on the Choptank and Patapsco Rivers. From 1994-2019, the Fish Hatcheries Division stocked over 55-million American shad in Maryland waters.

Water Quality Improvement Program (Water withdrawals and thermal/toxic discharge):

No specific program exists to address the impacts of water withdrawals, thermal discharge, or toxic discharge on spawning success or juvenile recruitment of American shad. However, all power plants drawing in excess of two-million gallons of surface water per day within the range of American shad have conducted impingement monitoring, and all but one (Wheelabrator) have conducted entrainment monitoring. No American shad were identified by these studies. Consistent with MDNR recommendations, MDE requires a 0.5 ft/second intake velocity and one millimeter screening on all surface water withdrawals to reduce entrainment or impingement of aquatic organisms. Additionally, the MDNR Power Plant Research Program (PPRP) initiated the

Smart Siting Project in 1996 to provide guidance to power plant developers regarding environmental concerns and to identify areas most favorable for power plant development.

Habitat Improvement Programs:

Numerous state programs are involved with land acquisition and habitat improvement including Program Open Space, the Rural Legacy Program, the Maryland Environmental Trust, the Forest Legacy Program, and the Conservation Reserve Enhancement Program. To date, these programs have protected approximately 657,690 acres of state land. Various other county organizations and non-profits also work to conserve natural land throughout the state. While these land conservation efforts do not focus directly on anadromous fish habitat protection or restoration, American shad will benefit indirectly through the preservation of natural land cover. The MDNR FHEP has identified watershed management priorities throughout the Chesapeake basin (Figure 11); the FHEP advises state and county planners on land management decisions and how they relate to fish habitat and fisheries health.

Permit Review Process:

The MDE is the primary permitting agency in the state of Maryland for water withdrawals, channelization and dredging, and land use/development. The MDNR Environmental Review Team reviews most proposed projects; anadromous fish spawning areas identified by O'Dell et al. (1975, 1980) are considered during the review process. Other MDNR programs including the FHEP may periodically act as advisors to the environmental review process.

Maryland Climate Change Commission (MCCC):

The MCCC advises the Governor and General Assembly "on ways to mitigate the causes of, prepare for, and adapt to the consequences of climate change." While this effort does not directly address the effects of climate change on American shad, it does promote ecosystem resiliency efforts which indirectly work to conserve anadromous fish habitat.

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Table 1. Historical and currently accessible spawning habitat for American shad in waters regulated by the state of Maryland. River kilometer (rkm) habitat estimates incorporate both tidal and non-tidal spawning reaches. Habitat area estimates were only available for tidal sections of spawning reaches and are thus not a complete representation of spawning habitat.

System	Historical Habitat (rkm)	Current Habitat (rkm)	Percent Available	Historical Tidal Habitat Area (ha)	Current Tidal Habitat Area (ha)	Percent Available	Limited By
Chester	32.3	32.3	100.0	1,139	1,139	100.0	Habitat
Choptank	75.4	75.4	100.0	1,360	1,360	100.0	Habitat
Nanticoke	44.9	44.9	100.0	1,018	1,018	100.0	Habitat
Patapsco	45.9	34.4	75.0	76	76	100.0	Dam
Patuxent	71.9	71.9	100.0	869	869	100.0	Habitat
Pocomoke	62.9	62.9	100.0	761	761	100.0	Habitat
Upper Bay*	213.5	213.5	100.0	46,274	46,274	100.0	Habitat
Wicomico	26.1	21.0	80.3	400	348	86.9	Dams
TOTAL	**580.4**	**556.3**	**97.1**	**51,897**	**51,844**	**99.9**	

* The estimates presented in this table represent river km and habitat area estimates for all areas in the Upper Chesapeake Bay where spawning could theoretically occur. In reality, the bulk of American shad spawning activity in the Upper Chesapeake Bay occurs in the Susquehanna River, Susquehanna Flats, and North East River. This 'preferred' spawning area is composed of 53.1 rkm and 14,071 ha of habitat.

Table 2. Historical and currently accessible rearing habitat for American shad in waters regulated by the state of Maryland. Current habitat is only shown if it differs from historically available habitat. River kilometer (rkm) habitat estimates incorporate both tidal and non-tidal rearing areas. Habitat area estimates were only available for tidal sections of rearing areas and are thus not a complete representation of rearing habitat.

System	Historical Preferred Habitat (rkm)	Current Preferred Habitat (rkm)	Historical Acceptable Habitat (rkm)*	Historical Marginal Habitat (rkm)*	Historical Preferred Tidal Habitat (ha)*	Historical Acceptable Tidal Habitat (ha)*	Historical Marginal Tidal Habitat (ha)	Current Marginal Tidal Habitat (ha)	Limited By
Chester	31.0	31.0	14.9	61.1	1,028	945	9,966	9,966	Habitat
Choptank	85.5	85.5	16.3	123.9	1,445	1,118	29,479	29,479	Habitat
Nanticoke	49.4	49.4	2.6	15.9	2,086	341	4,299	4,299	Habitat
Patapsco	35.6	25.3		64.7			9,601	9,601	Dam
Patuxent	87.3	87.3	8.1	55.3	1,132	1,243	11,898	11,898	Habitat
Pocomoke	55.8	55.8	8.9	7.8	599	107	706	706	Habitat
Upper Bay	169.2	169.2			35,461				Habitat
Wicomico	7.1	0.0		56.7			2,037	1,985	Dams
TOTAL	**520.7**	**503.3**	**50.8**	**385.3**	**41,752**	**3,754**	**67,986**	**67,934**	

* 100% of historical habitat of this type is currently available.

Table 3. Inventory of riverine barriers that American shad can potentially encounter in waters regulated by the state of Maryland. Data on dam dimensions, storage, and drainage area were queried from the Maryland Department of the Environment's dam inventory unless otherwise noted.

Barrier Name	**System**	**Passage Type**	**Latitude**	**Longitude**	**Dam Height (m)**	**Dam Length (m)**	**Normal Dam Storage (m^3)**	**Upstream Drainage Area (km^2)**
Van Bibber Dam	Bush	Steeppass	39.4686252	-76.3347629	4.3	182.9	16,035	142
Jones Lake Dam	Chester	Steeppass	39.2469732	-75.8179534	4.0	359.7	40,705	112
Williston Mill Dam	Choptank	Denil	38.8277559	-75.8468516	5.5	192.0	481,057	20
Tuckahoe Dam	Choptank	Denil	38.9675226	-75.9425857	4.3	518.2	32,070	258
Rewastico Pond Dam	Nanticoke	None	38.4107288	-75.7536718	3.0	140.2	49,709	26
Galestown Mill Pond Dam	Nanticoke	Steeppass	38.5675008	-75.7133338	2.7	152.4	141,850	21
Mill Creek Dam	Nanticoke	None	38.5948363	-75.8267003	3.4	91.4	33,304	9
Lake Chambers Dam	Nanticoke	None	38.6963525	-75.7646134	3.4	118.9	27,137	14
Daniel's Dam	Patapsco	Denil	39.3147660	-76.8164480	8.2	137.2	634,009	688
Ft. Meade Dam	Patuxent	Denil	39.0927176	-76.7683366	2.7	21.3	4,934	313
Higgins Mill Pond Dam	Transquaking	None	38.5189625	-75.9646440	2.7	275.8	310,837	30
Elkton Dam	Upper Bay	Denil	39.6123677	-75.8172330	1.5	33.5	6,167	194
Wilson's Mill Dam	Upper Bay	Denil	39.6145948	-76.2060399	2.7	51.8	6,167	466
Conowingo Dam	Upper Bay	Lift	39.6612120	-76.1731769	32.0	1,415.5	382,378,800	69,930
Allen Town Pond Dam	Wicomico	None	38.2832350	-75.6889157	2.4	121.9	118,414	33
Camden Avenue Dam	Wicomico	None	38.3361100	-75.6133320	3.7	106.7	123,348	30
Anderson Mill Pond Dam	Wicomico	None	38.3557130	-75.6738657	3.4	73.2	48,106	15
Isabella Street Weir	Wicomico	None	38.3718872	-75.6027689	NA	NA	NA	100*

* Upstream drainage area for Isabella Street Weir was calculated using the USGS StreamStats Application

Table 4. Mean daily 2018 water withdrawal and entrainment and impingement of American shad by power plants in the Maryland portion of the Chesapeake basin.

Power Plant	System	Mean Daily 2018 Water Withdrawal (million gallons/day)	Entrainment	Impingement	Source
Calvert Cliffs	Chesapeake Bay	3350	0 (2006)	0 (1975-1995)	EA, 2008a; Ringger, 2000
Vienna	Nanticoke	0.0188	no data	no data	
Wagner	Patapsco	239	0 (2006-2007)	0 (2006-2007)	EA, 2008b
Wheelabrator	Patapsco	37.8	no data	0 (1985-1986)	EA, 2017
Chalk Point	Patuxent	268	0 (1977-1979)	0 (1976-1985)	EPRI, 2010
Morgantown	Potomac	819	0 (2007)	0 (2006-2007)	EPRI, 2009

Table 5. Watershed characteristics for American shad spawning rivers, queried from the USGS StreamStats application. Percent forest and impervious land surface coverage was estimated by the Maryland Department of Planning in 2010 unless otherwise noted. Percent developed land was estimated by the National Land Cover Database, combining land use classes 21-24.

System	Tributary	% Forest	% Impervious	% Developed	Drainage Area (km^2)
Upper Bay	Susquehanna	65.7*	1.7**	8.3	71,225
	North East	36.1	7.8	17.2	201
	Elk Bohemia C&D Canal	27.1	6.1	17.4	679
	Sassafras	22.3	2.2	5.3	248
Chester	Chester	21.5	2.5	6.8	1,230
Choptank	Choptank	21.4	3.6	7.6	2,049
Nanticoke	Nanticoke	27	3.5	7.3	2,142
Wicomico	Wicomico	36	10.6	19.4	482
Pocomoke	Pocomoke	54.4	2.2	5.8	1,261
Patuxent	Patuxent	40.1	13.5	25.3	2,401
Patapsco	Patapsco	25.9	23.7	44.2	1,567

* Maryland Department of Planning forest coverage data was not available for the entire Susquehanna watershed. The provided estimate is sourced from the enhanced 1992 National Land Cover Database.
** Maryland Department of Planning impervious surface coverage data was not available for the entire Susquehanna watershed. The provided estimate is sourced from the 2011 National Land Cover Database.

Figure 1. Chester River American shad spawning reach. The spawning pathway represents the path used for river km habitat estimates. All historical spawning habitat is currently accessible.

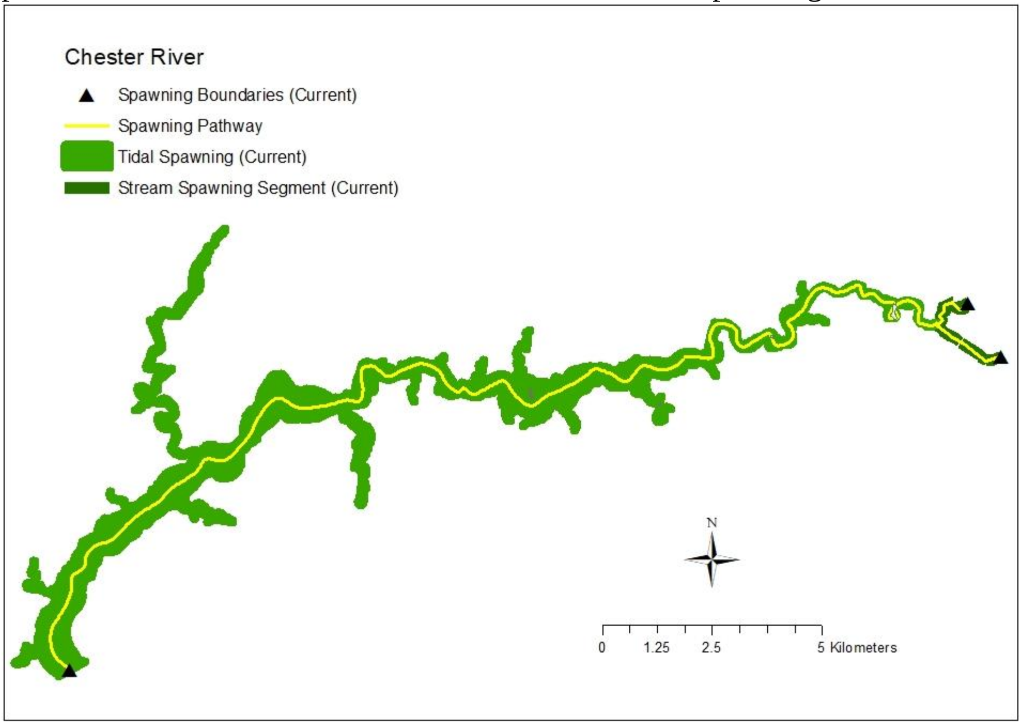


Figure 2. Choptank River American shad spawning reach. The spawning pathway represents the path used for river km habitat estimates. All historical spawning habitat is currently accessible.

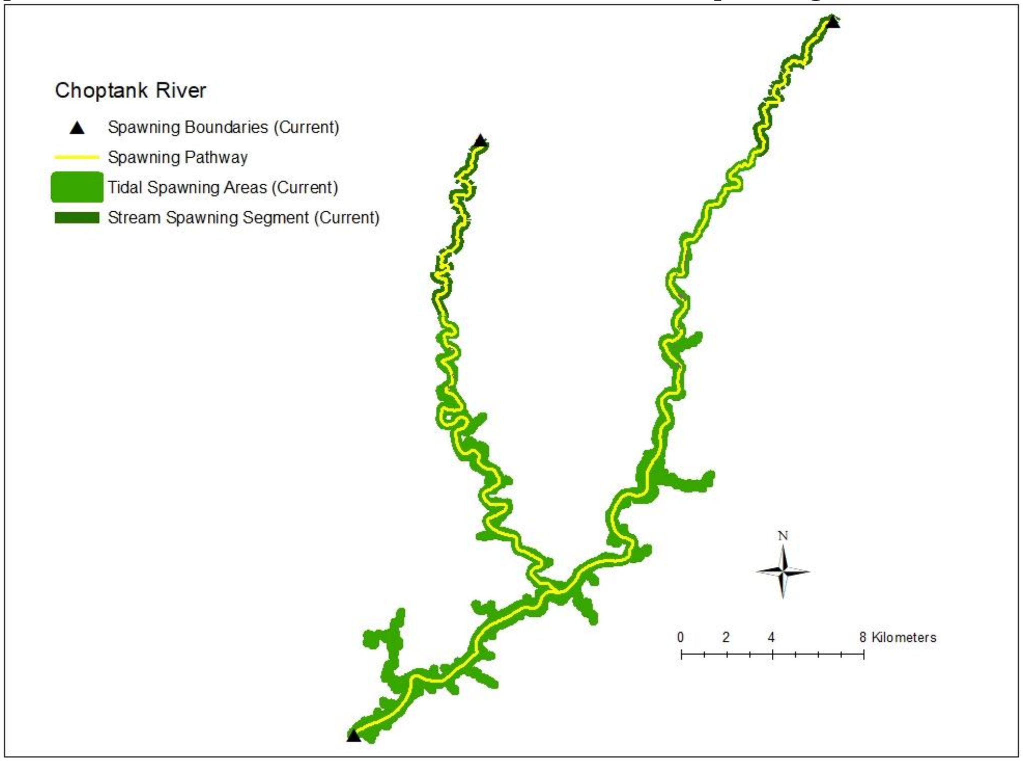


Figure 3. Nanticoke River American shad spawning reach. The spawning pathway represents the path used for river km habitat estimates. All historical spawning habitat is currently accessible.

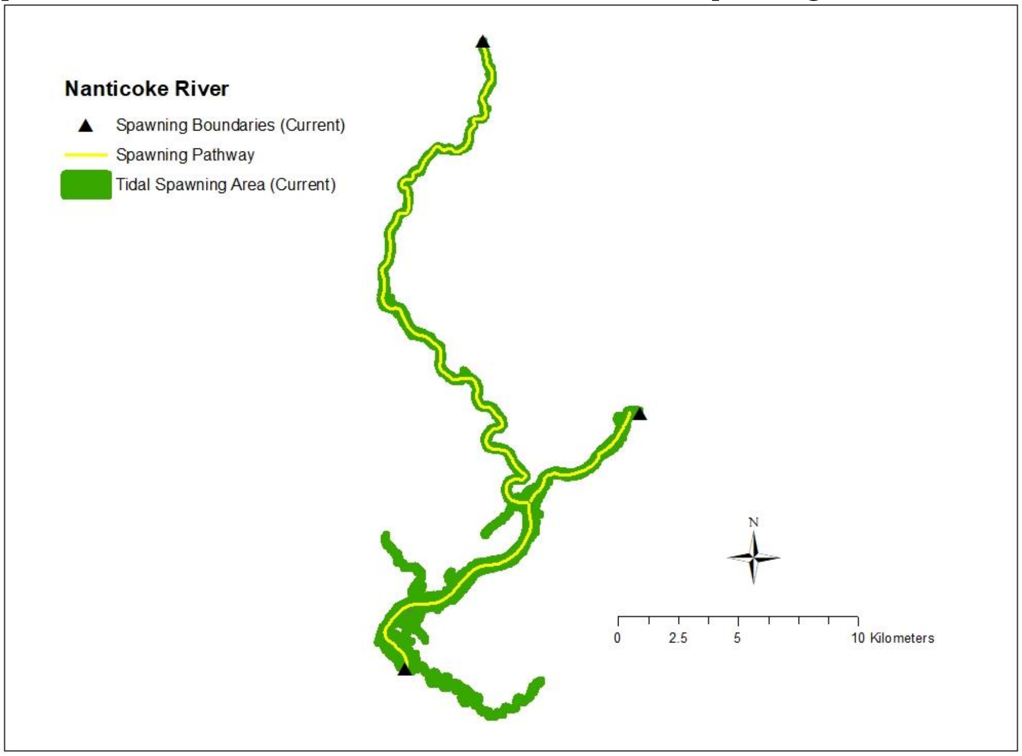


Figure 4. Current and historical Patapsco River American shad spawning reaches. The spawning pathway represents the path used for river km habitat estimates.

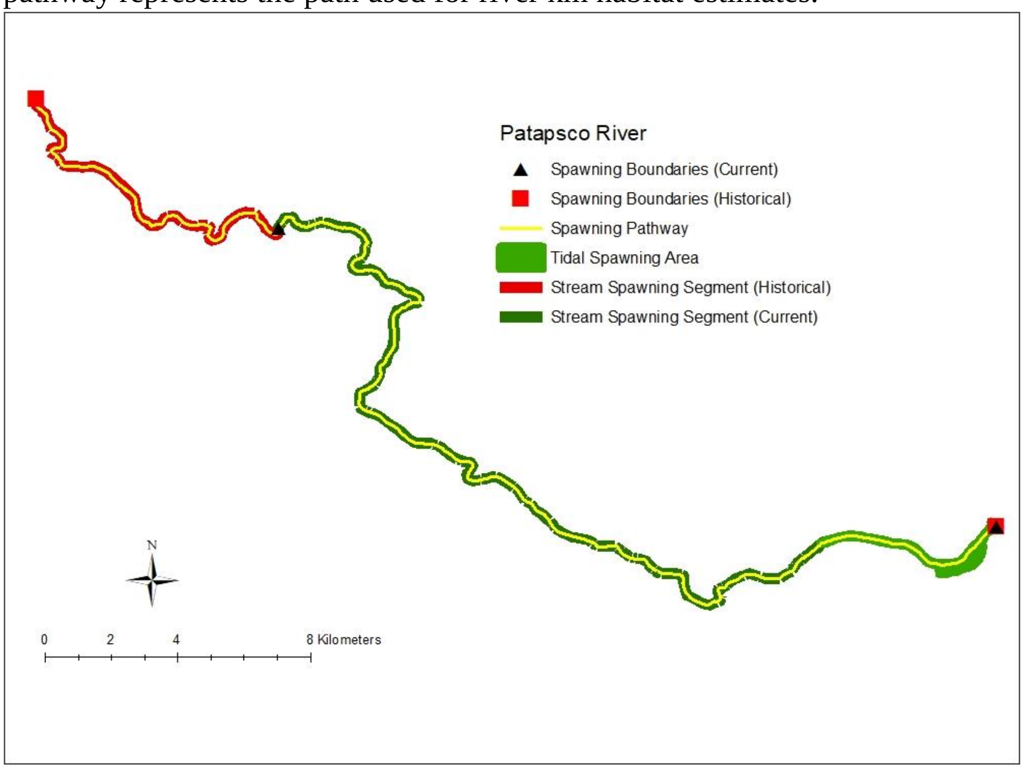


Figure 5. Patuxent River American shad spawning reach. The spawning pathway represents the path used for river km habitat estimates. All historical spawning habitat is currently accessible.

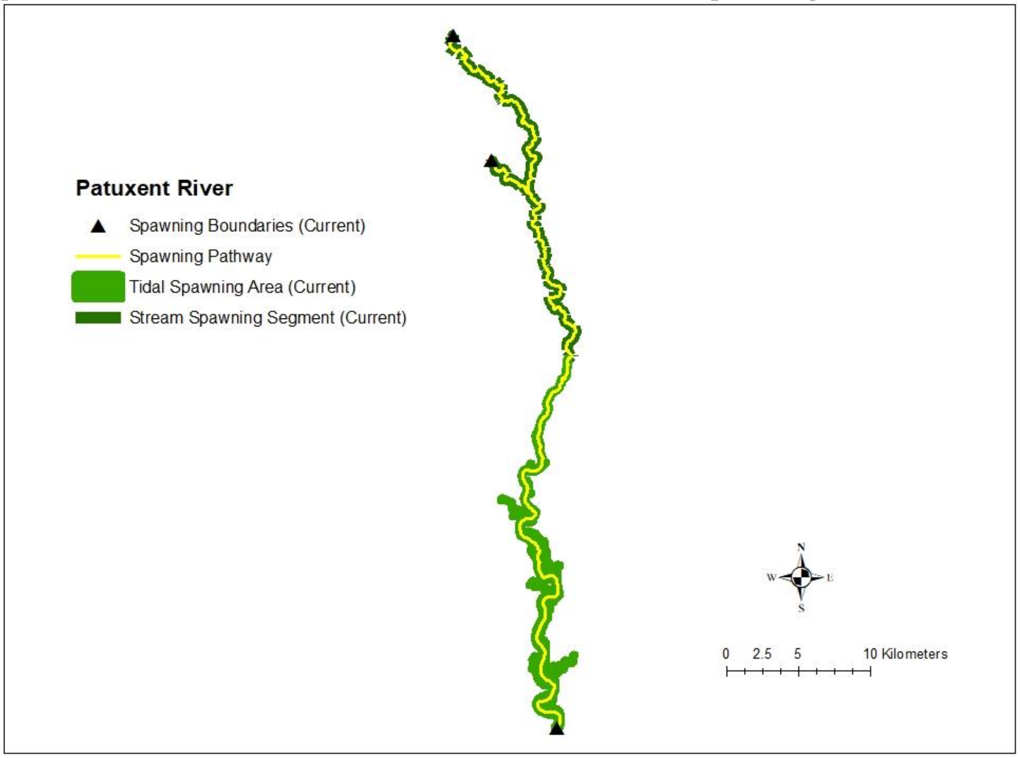


Figure 6. Pocomoke River American shad spawning reach. The spawning pathway represents the path used for river km habitat estimates. All historical spawning habitat is currently accessible.

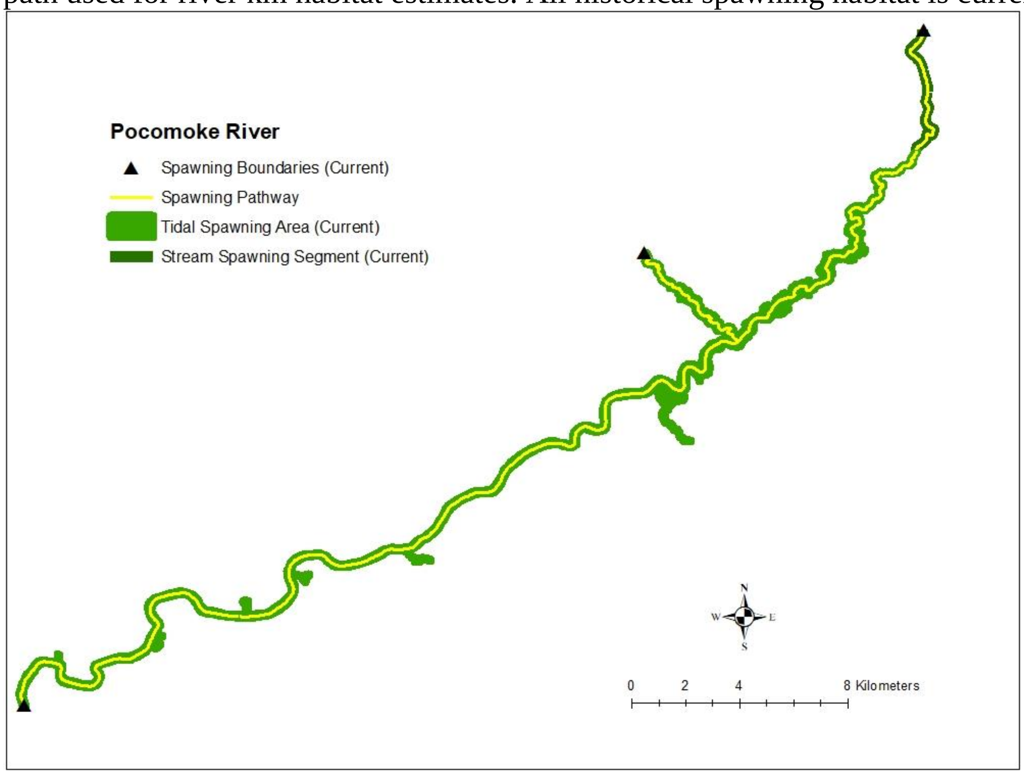


Figure 7. Upper Chesapeake Bay American shad spawning areas. The spawning pathway represents the path used for river km habitat estimates. All historical spawning habitat is currently accessible, though Conowingo Dam presents a significant barrier.

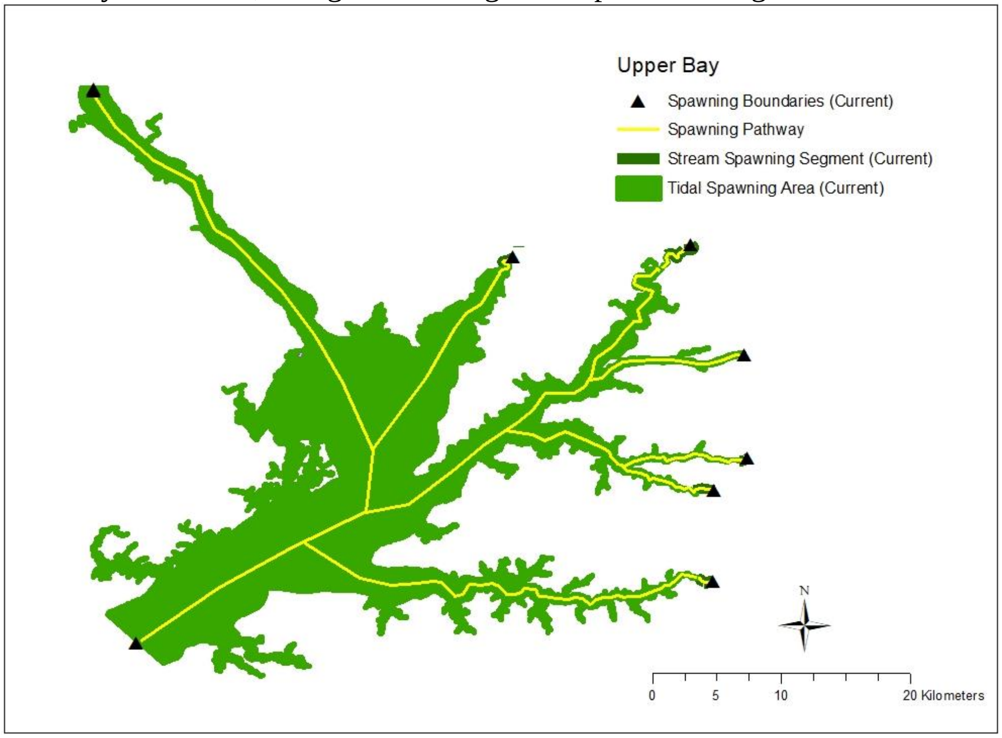


Figure 8. Preferred Upper Chesapeake Bay American shad spawning areas. The spawning pathway represents the path used for river km habitat estimates. All historical spawning habitat is currently accessible, though Conowingo dam presents a significant barrier.

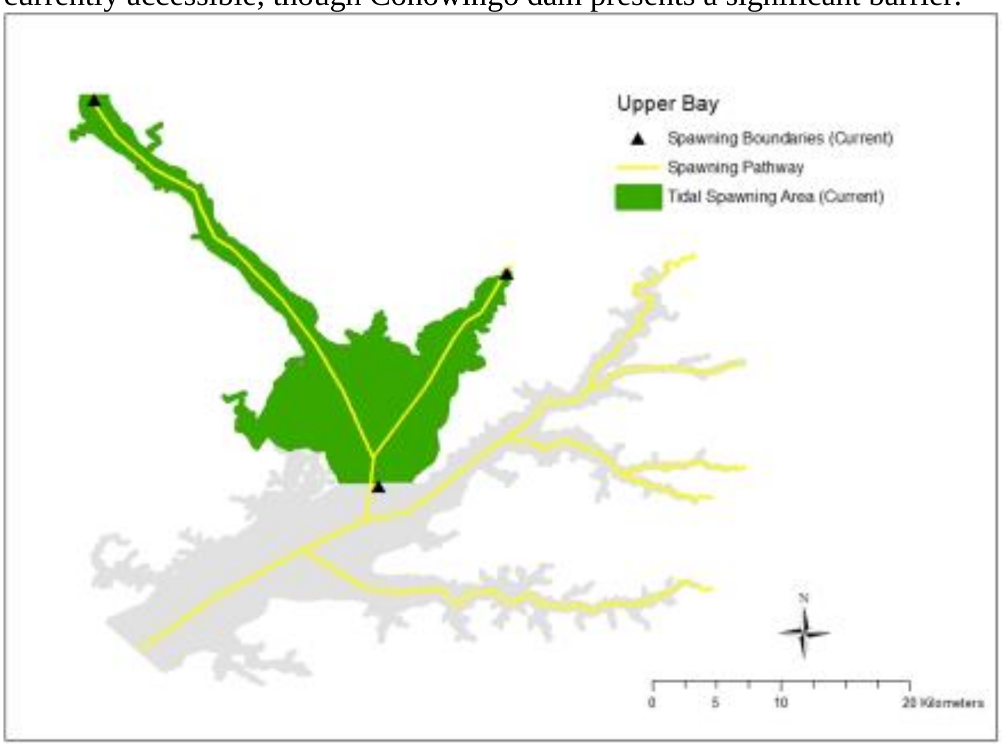


Figure 9. Current and historical Wicomico River American shad spawning reaches. The spawning pathway represents the path used for river km habitat estimates.

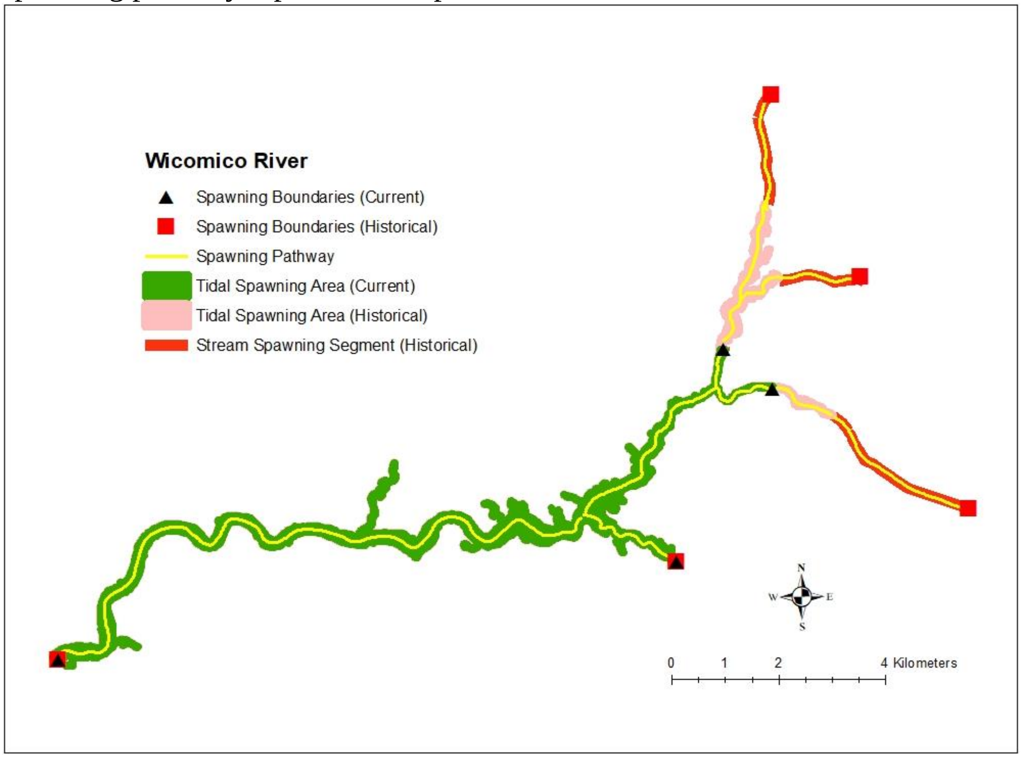


Figure 10. American shad rearing habitat in select Maryland rivers. Rearing habitat favorability was assigned according to average bottom salinity: Preferred (0-4 ppt), Acceptable (4-7 ppt), or Marginal (7-13 ppt). Rearing habitat lines represent the path used for river kilometer habitat estimates. Barriers restricting access to historic habitat are present on the Patapsco and Wicomico Rivers.

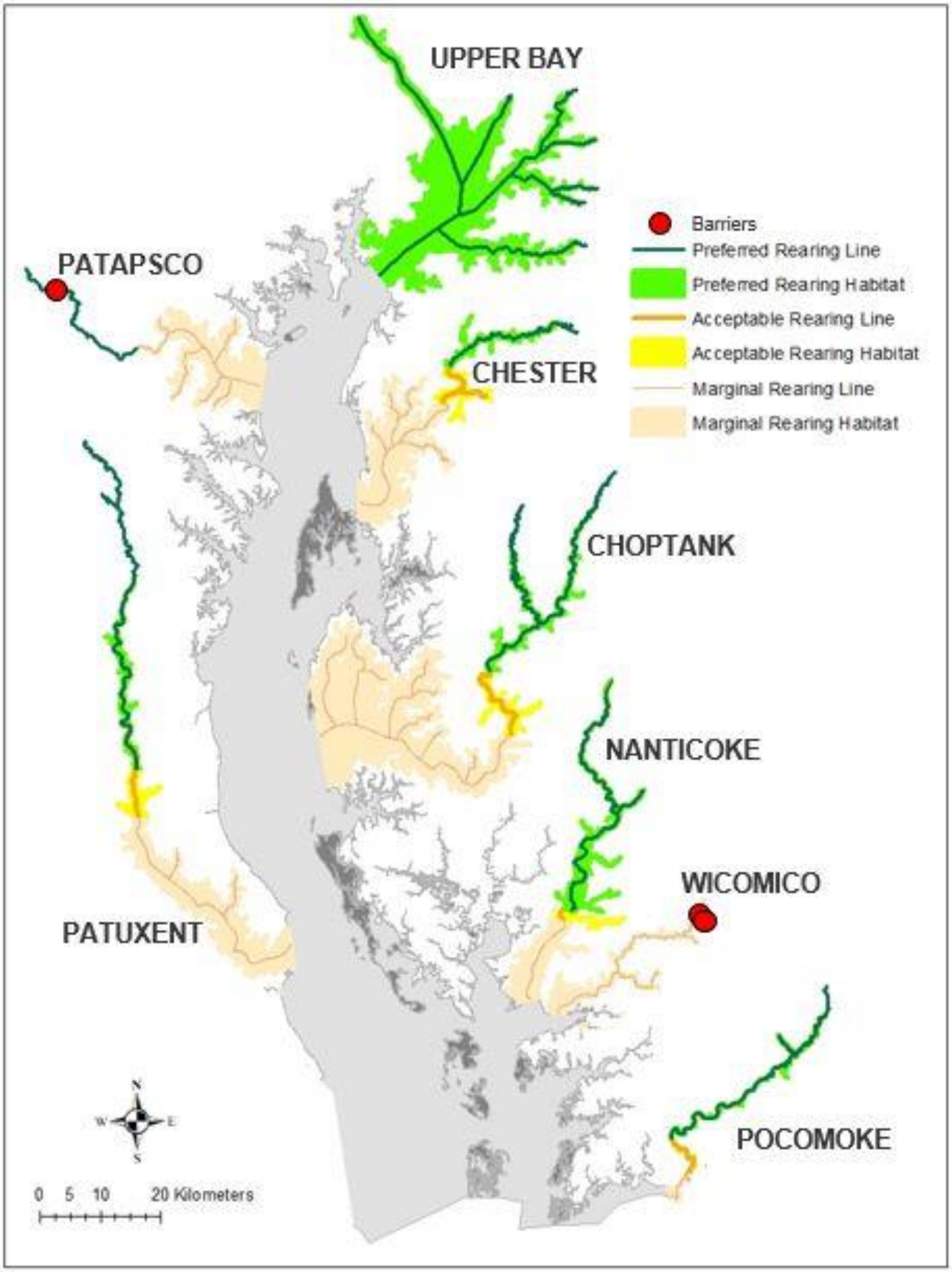
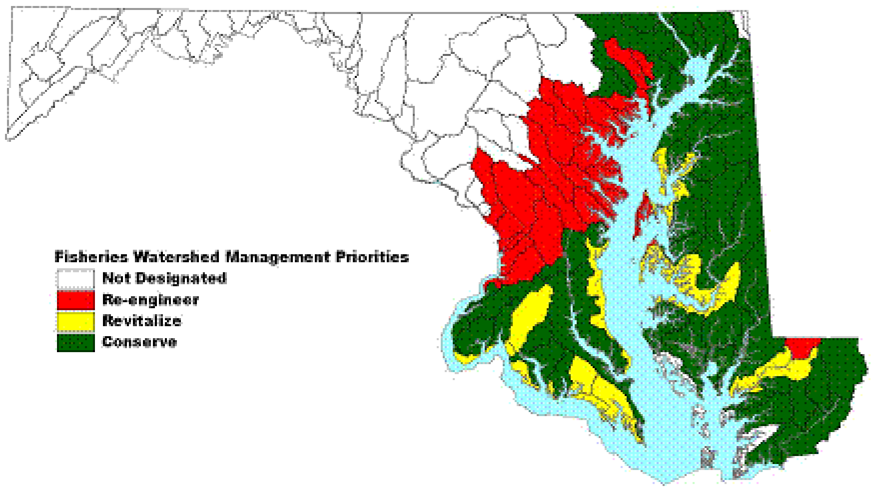


Figure 11. Fisheries watershed management priorities in Maryland. *Conserve* - areas with less than 5% impervious surface; recommend harvest restrictions and stocking for effective fisheries management and watershed conservation for sound land management. *Revitalize* – areas with 5-10% impervious surface; recommend options to decrease harvest and increase stocking to compensate for effective fishery management, and conserve and revitalize watershed for sound land management. *Re-engineer* – areas with 10-15% impervious surface; fisheries are highly variable; traditional fishery management tools not reliable. Recommend conserving and reconstructing degraded watershed for land management.



Acronyms:

- MDNR: Maryland Department of Natural Resources
- MDE: Maryland Department of the Environment
- MDOT: Maryland Department of Transportation
- MPA: Maryland Port Authority
- FHEP: MDNR Fisheries Habitat and Ecosystem Program
- PPRP: MDNR Power Plant Research Program
- FPP: MDNR Fish Passage Program
- MCCC: Maryland Commission on Climate Change
- MDA: Maryland Department of Agriculture
- USFWS: United States Fish and Wildlife Service
- FERC: Federal Energy Regulatory Committee
- SRAFRC: Susquehanna River Anadromous Fish Restoration Cooperative
- ASMFC: Atlantic States Marine Fisheries Commission
- NMFS: National Marine Fisheries Service
- MAFMC: Mid Atlantic Fisheries Management Council
- NOAA: National Oceanographic and Atmospheric Administration
- NFWF: National Fish and Wildlife Foundation
- NDPES: National Pollutant Discharge Elimination System
- EPA: Environmental Protection Agency
- FDA: Food and Drug Administration
- USDA: United States Department of Agriculture
- PFBC: Pennsylvania Fish and Boat Commission
- PADEP: Pennsylvania Department of Environmental Protection
- SRBC: Susquehanna River Basin Commission
- NYDEC: New York Department of Environmental Conservation
- CBP: Chesapeake Bay Program
- EBTJV: Eastern Brook Trout Joint Venture
- EFL: Conowingo East Fish Lift
- WFL: Conowingo West Fish Lift
- PAHs: Polycyclic Aromatic Hydrocarbons
- DO: Dissolved Oxygen
- TMDL: Total Maximum Daily Load