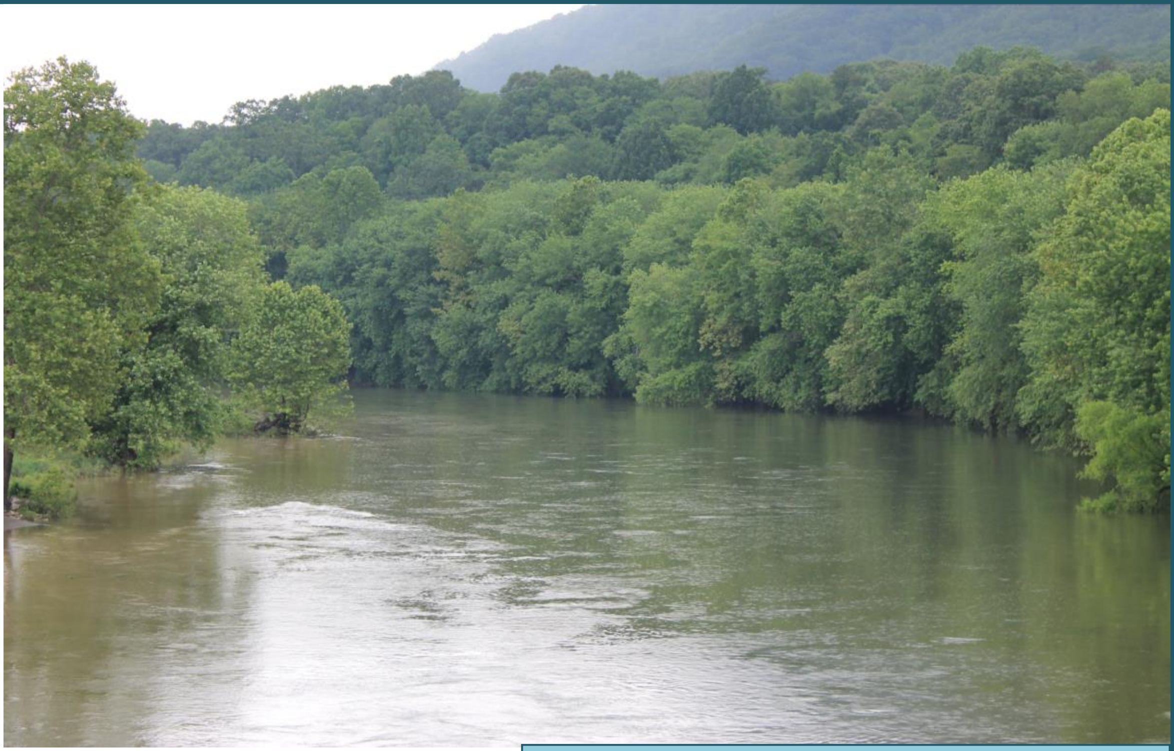
River Corridor Wildlife Habitat Metrics



Recommendations of landscape-scale indicators and metrics to track the status of wildlife habitat throughout the James River watershed.

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The Chesapeake Conservancy's mission is to strengthen the connection between people and the watershed, conserve the landscapes and special places that sustain the Chesapeake's unique natural and cultural resources, and encourage the exploration and celebration of the Chesapeake as a national treasure.

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Executive Summary

The Chesapeake Conservancy has developed a suite of landscape-scale indicators and metrics to track the status of wildlife habitat throughout the James River watershed. By designing the metrics to be GIS-detectable, Conservancy staff may monitor them, as well as conduct detailed assessments in priority areas to help understand emerging trends, threats, and opportunities.

To develop the indicators and metrics, we conducted interviews and a thorough review of metrics used by organizations at a variety of scales. It quickly became clear that there is a paucity of wildlife habitat-related metrics currently being tracked in the Chesapeake watershed; therefore, we looked at broader regional monitoring frameworks to inform our work.

Due to time and resource constraints, we chose to concentrate our reporting efforts on major systems - forests, wetlands, and rivers and streams - specifically in terms of their importance to wildlife. Metrics are organized by tiers, reflecting current data availability and ease of analysis. The 'tier' method allows us to concentrate limited resources on higher level indicators and then drill down into more fine scale indicators as time, resources, and data allow. The initial set of proposed indicators mostly fall within Tier 1, in order to limit the scope and scale of this exercise given current time and resource constraints. The following three indicators have been proposed for each system, drawn from work being done within the Chesapeake watershed, as well as peer-reviewed scientific literature linking changes in the indicator to changes in wildlife abundance and/or diversity:

1. Forest
    - Percent forest cover
    - Core habitat
    - Corridors
2. Wetlands
    - Wetland size
    - Impacts in the buffer zone
    - Road density
3. Rivers and streams
    - Buffer condition
    - Headwater stream condition
    - Impervious surfaces

We also propose actions for a pilot study to assess the feasibility of and develop baselines for these indicators. At a minimum, we will use Landsat 8 imagery (or higher resolution land use/land cover data if available for the complete watershed) to do initial, coarse analyses; then, in those areas that show notable changes, National Agriculture Imagery Program (NAIP) imagery (1m resolution) will be used to explore causality. This analysis would be repeated every two years.

In the future, we hope to engage universities throughout the James River watershed to increase analytical capacity. Ultimately, we would like to have universities 'adopt' one or more HUC12 watersheds across the larger James watershed in order to have a continuous, long-term data series for those sub-watersheds. We hope that the analyses required to monitor the above indicators can be incorporated into lesson plans and labs in GIS and remote sensing courses at these universities.

The Conservancy hopes that these landscape-scale GIS-detectable metrics will allow us to monitor wildlife habitat across the James River watershed, as well as to conduct detailed assessments in high priority areas. The proposed actions in this study significantly simplify and scale down the potential indicator analyses in order to keep the project reasonable given time, money, and staff capabilities. However, there is great potential for growth, given new data sources and increased capacity. If these indicators prove to be reasonable and feasible, they may be applied to other watersheds across the Chesapeake.

Introduction

Developing and monitoring suites of ecological indicators have become a common best practice in the field of conservation. This allows practitioners to assess the state of a resource and then track progress toward its improvement. Such indicators have been developed for various geographic areas, ranging from individual watersheds, to regions, to entire countries. Particular metrics are chosen based on their ability to accurately track an ecological system through time and their ease of monitoring.

The Chesapeake Bay restoration effort has seen the development of several suites of indicators and metrics to monitor overall progress, including pollution loads, habitat, fisheries, and particular ecological systems (forests, wetlands, streams etc.). In general, the indicators are used to set target benchmarks and track progress through yearly 'report cards.' These report cards show the overall 'grade' for each indicator, with specific metric information for each indicator. This allows for an understanding of which metrics are, or are not, showing improvement over time.

Many of these indicators are heavily focused on water quality; however, there are efforts at various scales to track terrestrial watershed quality. Some of these include the large-scale Chesapeake Bay Program, which sets goals for wetland and riparian forest restoration, and *State of Chesapeake Forests* (Sprague et al. 2006), which analyzes forest condition across the Chesapeake watershed for a variety of ecosystem services. At a more local scale, several groups issue report cards that address terrestrial and aquatic wildlife habitat needs (these will be discussed further in the next section). However, each of these efforts has defined its own indicators and methodology, making it difficult to compare watersheds against one another. At this time, the only tracking metrics that seem to be applied river by river are UMCES EcoCheck metrics, but those are heavily geared toward monitoring water quality and aquatic habitat health.

The Chesapeake Conservancy, a regional non-profit organization, approaches conservation in the Chesapeake by using the Bay's great rivers as its framework for conservation. This has resulted in a series of river corridor conservation initiatives that capitalize on the unique character and history of each river to find opportunities for conservation, education, and increased public access. The Conservancy is now seeking its own set of science-based metrics to track progress along each river corridor.

This study is a first step toward developing wildlife habitat-related indicators and metrics that are transferrable and comparable between watersheds. These metrics will be used for the first time along the James River in Virginia as a component of the *Envision the James* initiative (ETJ).

Envision the James

Launched in 2011, by the Conservancy, the James River Association, National Geographic Maps and U.S. Fish & Wildlife Service, *Envision the James* (ETJ) seeks to achieve a shared vision and on-going commitments from communities and partners throughout the James River Basin to value, sustain, and enhance the region's natural and cultural heritage, local economies, wildlife abundance, and outdoor recreation assets for present and future generations. Based on feedback from the public and practitioners throughout the watershed, a geographically-specific vision identifying the most significant enhancement actions to be undertaken along the river corridor and throughout the watershed has been crafted. Partners have released Envision the James: A Vision for the James River Watershed, introducing the two new core initiatives that emerged based on feedback: 1) James River Heritage and Recreation Corridor Initiative 2) James River Wildlife and Landscape Conservation Initiative.

The Conservancy will lead the James River Wildlife and Landscape Conservation Initiative (WLCI). The public has made it clear that they are concerned about wildlife habitat loss and population decline and believe that more wildlife habitat conservation is needed in the James River watershed, both on public and private lands. The WLCI seeks to accomplish these things, in consultation with partners and landowners.

As the WLCI is in the beginning stages, the Conservancy seeks to develop this set of wildlife habitat indicators and metrics to track wildlife habitat protection and restoration progress. This will be challenged by data limitations, as well as the desire not to be duplicative of other organizations' monitoring schemes that geographically overlap. These outcomes will be important for demonstrating how wildlife habitat is changing in the James River watershed. They may also ultimately be applied to other Conservancy river corridor initiatives across the Chesapeake.

Methods

In order to develop useful wildlife habitat indicators for the James River watershed, we went through an extensive information gathering process. We then used this information and peer-reviewed literature to create a series of system-level indicators (to be discussed further below), as well as to identify potential methods for tracking the indicators. Here we briefly discuss the process we followed.

Informal Interviews:

With numerous Important Bird Areas (IBAs), Natural Heritage Areas, and a Virginia Wildlife Action Plan, it is clear that the Commonwealth of Virginia has a commitment to wildlife conservation. Therefore, we began our process by trying to gain an understanding of the wildlife-related priorities and plans already occurring in the watershed. This included informal interviews with Mary Elfner, Director of the Virginia Audubon Council; Jason Bullock, Information Manager at the Virginia Department of Conservation and Recreation; and Chris Burkett, Wildlife Action Plan Coordinator at the Virginia Department of Game and Inland Fisheries. These interviews helped lend insight into how the Commonwealth prioritizes wildlife habitat and how IBAs have been spatially defined along the James River. This information, while not explicitly stated in this report, provided important background in developing indicators for use in the ETJ initiative.

Inventory of Indicators:

In order to develop our own indicators and metrics, we then conducted a selected inventory of indicators already being monitored along individual watersheds, across the entire Chesapeake Bay watershed, across the entire northeast, and internationally.

Across the Chesapeake Watershed, the following rivers have issued 'scorecards' or reports within the last three years (this list may not comprehensive):

- James River
- Reedy Creek
- Nanticoke River
- Sassafras River
- Wicomico Creek
- Severn River
- Anacostia River
- Magothy River
- Lynnhaven River
- Hazel Run
- Chester River
- Eastern Bay, Choptank, Miles, and Wye Rivers
- Potomac River
- West and Rhode Rivers
- South River

Bay-wide reports are also issued by the Chesapeake Bay Foundation, the University of Maryland Center for Environmental Science Integration and Application Network (IAN), and the Chesapeake Bay Program via ChesapeakeStat.

Overall, these report cards are heavily concerned with water quality health metrics. This is consistent with the emphasis put on water quality monitoring and regulation across the Bay watershed; however, metrics associated with Bay water quality are not designed to gauge landscape-level terrestrial wildlife habitat conditions. Of the above mentioned reports, only those issued by the Chesapeake Bay Foundation, Chesapeake Bay Program, James River Association, Lynnhaven River NOW, Potomac Conservancy, and University of Maryland Center for Environmental Science IAN currently include metrics that track some specific fish and wildlife species or aquatic habitat (Table 1).

Table 1. Wildlife and habitat metrics tracked by the Chesapeake Bay Foundation, Chesapeake Bay Program, James River Association, Lynnhaven River NOW, Potomac Conservancy, and UMD Center for Environmental Science IAN.

Organization	Indicator	Metrics
Chesapeake Bay Foundation	Habitat	Forested Buffers Wetlands Underwater Grasses Resource Lands
	Fisheries	Rockfish Blue Crabs Oysters Shad
Chesapeake Bay Program	Habitats and lower food web	Bay Grasses Phytoplankton Bottom Habitat Tidal Wetlands
	Fish and Shellfish	Blue Crabs Oysters Striped Bass American Shad Atlantic Menhaden
	Forest	Forest Cover
	Restoring Habitats	Planting Bay Grasses Restoring Wetlands Reopening Fish Passage Restoring Oyster Reefs
	Managing Fisheries	Blue Crab Fishery Management
	Protecting Watersheds	Developing Watershed Management Plans
	Protecting Watersheds	Protected Land

James River Association	Wildlife	Bald Eagle Breeding Pairs Rockfish Spawning Stock Number of Oysters Smallmouth Bass American Shad Brook Trout
	Habitat	Acres of Underwater grasses Percent of Streambanks Forested Stream Condition Index Tidal Water Quality
Lynnhaven River NOW	Habitat	Oysters Open Space & Public Access Wetlands Underwater Grass Beds
Potomac Conservancy	Fish	American Shad Striped Bass White Perch
	Habitat	Underwater Grasses Forested Buffers Tidal Water Quality Stream (non-tidal) Water Quality
University of Maryland Center for Environmental Science IAN	Habitat	Aquatic Grasses
	Fish	Bay Anchovy Blue Crab Striped Bass

In the absence of widely used/accepted terrestrial and freshwater wildlife and habitat indicators in the Chesapeake, we drew inspiration from other regional monitoring frameworks. In 2008, the Northeast Association of Fish and Wildlife Agencies (NEAFWA), along with members, partners, stakeholders, and scientific experts, established a regional *Monitoring and Performance Reporting Framework* focused on terrestrial and freshwater targets: forests; freshwater streams and river systems; freshwater wetlands; highly migratory species; lakes and ponds; managed grasslands and shrublands; regionally significant species of greatest conservation need; and unique habitats in the Northeast. A suite of monitoring indicators was developed to track the health of the targets and indicate “the general health of fish and wildlife and their habitats in the Northeast” (Tomajer et al. 2008).

In 2011, these indicators were put to the test as The Nature Conservancy and partners tried to implement the recommendations in the monitoring framework. The final product was a slight revision of the original framework, and provides insight for the development of our wildlife and habitat monitoring indicators (see Table 2 for a simplified indicators highlighted in Anderson and Sheldon 2011).

Table 2. Targets and indicators used by The Nature Conservancy across the Northeast (adapted from Anderson & Sheldon 2011).

Target	Sub-Target	Indicator
Secured Land	Distribution of Secured Lands in the Northeast and Mid-Atlantic	Patterns of Securement
		Conversion versus Securement
Forests	Distribution, Loss, and Protection Status	Patterns of Securement
	Forest Condition	Fragmentation
		Connectivity
		Age and Size Structure
		Forest Disturbance

	Trends in Forest Bird abundance	*by forest type*
Wetland	Distribution, Loss, and Protection	Wetland Conversion
		Conversion versus Securement
		Conservation and Wetland Size
	Ecological Condition	Impacts in the Buffer Zone
		Road Density
		Changes in Wetland Acreage over Time
	Trends in Wetland Bird abundance	By wetland type
Unique Habitats in the Northeast	Distribution, Loss, and Protection	Conversion per habitat type
	Ecological Condition	Fragmentation
		Connectivity
Streams & Rivers	Conversion and Securement of the Riparian Zone	Secured Land in the Riparian Buffer
		Condition of the Riparian Buffer
		Conversion vs. Securement
	Fragmentation and Flow	Impervious Surfaces
		Stream Barriers - dam density and road crossing density
		Connected Stream Networks
		Flow Alteration
	Biotic Patterns and Trends	Distribution and Population Status of Native Eastern Brook Trout
		Index of Biotic Integrity
		Non-Indigenous Aquatic Species
		Reduction in Native Fish Diversity
Lakes & Ponds	Distribution, Loss, and Protection	Securement Status
		Conversion in the Shoreline Buffer Zone
		Conversion Versus Securement
	Ecological Condition	Impervious Surface
		Isolation from Roads
		Road Density
		Presence of Dams
	Biological Integrity	Index of Taxa Loss
		Trends in Loon Abundance
Regionally Significant Species of Greatest Conservation Need	Distribution, Rarity, and Protection Status	Conservation Status and Distribution of Species of High Regional Responsibility
		Conservation Status and Distribution of Species of Widespread High Concern

This report by The Nature Conservancy reveals several techniques that seem particularly applicable to our work on the James. First, they use a **systems** approach, which allows them to target appropriate indicators for a range of species, spanning various habitat and systems types. Also illustrated by the report is the practice of **hierarchical nesting** of indicators. For example, to indicate forest condition, five different metrics are used. This sort of nesting serves as a good model for what can be done in the ETJ initiative because displaying information in this way shows people how they can improve the resource relative to the metrics selected. This allows for the metrics to be used both to report on the success of conservation efforts and also to inform where more effort needs to be dedicated in the future.

Finally, we looked at biodiversity indicators used internationally. According to the United Nations Environment Programme (UNEP), the most common biodiversity indicators used internationally are coverage of protected areas, extent of forest and forest type, invasive alien species, and water quality; however, they are not always measured quantitatively, as availability of data and technical and institutional capacity are challenges for many countries (Bubb et al. 2011).

UNEP also shares criteria for developing and using indicators, created by the 2010 Biodiversity Indicators Partnership. While various sources have identified criteria for developing and using indicators, we have chosen to abide by those accepted by the international community (Figure 1). These have guided our choice of metrics in this study.

Figure 1. Criteria in developing and using indicators (adapted from Bubb et al. 2011).

A 'successful' indicator should be:

- Scientifically valid - a) there is an accepted theory of the relationship between the indicator and its purpose, with agreement that change in the indicator does indicate change in the issue of concern; b) the data used is reliable and verifiable.
- Based on available data – so that the indicator can be produced over time.
- Responsive to change in the issue of interest.
- Easily understandable – a) conceptually, how the measure relates to the purpose, b) in its presentation, and c) the interpretation of the data.
- Relevant to user's needs.
- It is used! - for measuring progress, early-warning of problems, understanding an issue, reporting, awareness-raising, etc.

Monitoring in the James:

After reviewing the report card models being used across the Chesapeake's major river corridors, it is clear that none is sufficient for capturing progress made in terrestrial and aquatic wildlife habitat conservation and restoration. The report card issued by the James River Association (JRA), *The State of the James River*, seems to be the broadest of the river-specific report cards, including indicators for wildlife, habitat, and restoration efforts, in addition to water pollution (Appendix, Table 1). The JRA has also created benchmarks, or referenced other benchmarks, that they grade their progress against, as well as have partnerships with state agencies and universities necessary to acquire the data needed for their report card. There is no need for the ETJ Initiative to duplicate efforts by the JRA. Rather, our report card will build on the indicators being monitored by the JRA by taking a systems-level approach and filling in gaps.

For ETJ, due to time and resource constraints, we chose to concentrate our reporting efforts on major systems, specifically in terms of their importance to wildlife. These systems are forests, wetlands, and rivers and streams. In the future, we hope to add an aquatic system, as well.

For our purposes, we have derived three 'tiers' of metrics, based on their relative complexity and the effort required to gather and to analyze the data. As we expect that the majority of the reporting will be carried out by Chesapeake Conservancy staff and university partners, the 'tier' method allows us to concentrate limited resources on higher level indicators and then drill down into more fine scale indicators as time, resources, and data allow. This sort of breakdown is consistent with the work of others, such as Brooke et al. (2004) who advocate for tiered indicators for wetland monitoring based on available resources (Figure 2).

	INVENTORY	ASSESSMENT	RESTORATION
Level 1	Use existing map resources (NWI) of wetlands	Map land uses in watershed; compute landscape metrics	Produce synoptic watershed map of restoration potential
Level 2	Enhance inventory using landscape-based decision rules	Rapid site visit and stressor checklist; preliminary condition assessment	Select sites for restoration; examine levels of threat from surroundings
Level 3	Map wetland zones abundance using verified inventory	Apply HGM and IBI models to selected sites for condition based on reference	Map specific sites for restoration; design projects with reference data sets

Figure 2. Integrated tasks for wetland monitoring by watershed at three levels of effort (from Brooks et al. 2004).

For the purposes of this study, we have defined our indicator tiers as the following:

- Tier 1 – analysis and reporting possible based on currently existing data sets
- Tier 2 – analysis and reporting would require the creation of new data sets or analytical techniques
- Tier 3 – analysis and reporting would require field collection and verification of new data

The initial set of proposed indicators mostly fall within Tier 1, in order to limit the scope and scale of this exercise to reporting that would be reasonable given current time and resources. Several Tier 2 indicators that we believe could be assessed with the current resources have also been included. For those indicators that are currently infeasible due to limited data or analytical capacity, we made note of them in the tables below and hope to, one day, have the resources or other willing partners to measure them using a distributive model of workload with defined analysis protocols.

Indicators

Below are the indicators identified for each of the three systems – forests, wetlands, and rivers/streams – proposed for monitoring within the James River watershed. We were sensitive in choosing indicators that relate directly to wildlife, rather than those tied primarily to water quality or other topics. Each indicator discussed below has been drawn from work being done within the Chesapeake watershed, as well as peer-reviewed scientific literature linking changes in the indicator to changes in wildlife abundance and/or diversity.

Forests[1]:

The Chesapeake Bay ecosystem evolved in a landscape dominated by trees; however, today, only about 60% of the Chesapeake watershed remains forested (Sprague et al. 2006). Forests play a critical role in landscape ecology, performing ecosystem services such as protecting water quality, preventing erosion, improving air quality, filtering pollutants from water, providing habitat for wildlife, and moderating climate, as well as providing unique habitats, such as vernal pools. However, in the Chesapeake watershed, forest health is threatened by a suite of factors, including sprawling development and the parcelization of large forest blocks into smaller ones. 60% of Chesapeake forests are fragmented by development, farms, or other human uses (Sprague et al. 2006).

The importance of forests as landscape-level regulators is being increasingly recognized and monetized. It has become clear that dropping below certain thresholds can cause the ecosystem services that forests provide to begin to deteriorate. Many species, such as interior dwelling birds and top predators, also require large, contiguous forest patches to breed and thrive. The tipping points associated with consequences like reduced water quality and unsuitable habitat for rare species points are critical to understanding how forests regulate biological and ecological processes. A significant body of research suggests that wildlife populations are affected by changes in mature forest composition, configuration, and condition (ex. Trzcinscki et al. 1999; Rempel et al. 2007), and it is against tipping points in these categories that progress in restoring forests can be measured.

Over 60% of the Commonwealth of Virginia is forested (VA DGIF 2005). As of 2000, the James River watershed, with its relatively undeveloped headwaters, contained the largest percentage of intact (unfragmented) forest in the Chesapeake Bay watershed (Sprague et al. 2006). However, the Hampton Roads and Richmond regions are two of the most rapidly growing in Virginia (Weldon Cooper Center for Public Service 2012), and with that development will come additional forest fragmentation, degradation, and destruction.

With these impending changes, it will be important to track the state of the James' forests into the future. The table below (Table 3) presents three Tier 1 indicators that may be used to track forest health, as it pertains to wildlife.

[1] This system also includes forested wetlands.

Table 3. Proposed forest system indicators, their justification for wildlife, accepted thresholds, potential methods for tracking, and potential related Tier 2 and 3 indicators to pursue in the future.

Indicator	Justification for Wildlife	Thresholds	Potential Methods for Tracking Indicators	Potential related 2nd and 3rd tier indicators
Percent Forest Cover	- Trzcinscki et al. (1999) – forest cover has a positive effect on the distribution of forest breeding birds, and suggests that a conservationist's primary focus should be preventing decrease in forest cover, as that appears to have a greater effect on forest breeding birds than fragmentation at a landscape scale. - Fahrig (2002) – Studies suggest that the effects of habitat amount far outweigh the effects of habitat fragmentation.	- Fahrig (2001) – There is not necessarily a common threshold value across species; percent habitat required for persistence of all species in an area range widely from 20-75%. - Brooks et al. (2004) - Impairment occurs when less than 60% of the watershed is forested. - Chesapeake Bay Program has set a target of 70% forest cover. - Turner et al. (2001) – Simulation studies suggest a critical threshold value of at least 59% of the total landscape area be maintained in forest to maintain many ecological functions and services. - Lookingbill et al. (2013) – For monitoring at Petersburg National Battlefield, suggest thresholds of forest land cover: >59% good condition, 59-30% moderate, <30% significant concern (based on studies by Turner et al. 2001; Fahrig 2003).	Using updated land cover data, derived from satellite imagery, determine the percent forest cover in sub-watersheds, with a goal of having each sub-watershed at least 70% forested.	- Forest Disturbance - Age and Size Structure (FIA data) - Forest type
Core Habitat	Not all forest is equal. Forest edges are drier, more exposed to wind, the elements, and predators, and more likely to be colonized by invasive species. In contrast, interior forests (called core habitat in this analysis) provide sheltered habitat for sensitive species that may require low disturbance, are more sensitive to predators or invasive species, or rely on a food source that requires a moister environment.	- Jones et al. (2000) - The Chesapeake Bay Critical Area Program suggests that forest interior dwelling birds require forest of at least 100 acres, which has been furthered refined by the Maryland Department of Natural Resources to "Forests at least 50 acres in size with 10 or more acres of 'forest interior' habitat (i.e., forest greater than 300 feet from the nearest forest edge)." - McIntyre (1995) – Contiguous forest areas larger than 10 ha are needed to maintain high levels of avian diversity.	Using updated land cover data, derived from satellite imagery, forest patches, bounded by major roads, may be identified (Anderson and Sheldon 2011). Road bounded blocks have been identified by the North Atlantic Landscape Conservation Cooperative and that data has been made available. The blocks may be overlaid with the high resolution land cover and the forest patches within each block may be calculated. Core habitat is commonly defined as beginning 100m from the patch edge (Jones et al. 2000; VaNLA 2007; Anderson and Sheldon 2011). Therefore, core habitat can be calculated from the patches by doing a reverse buffer of 100m and calculating the area inside each. This will reveal	- edge to area ratio - degree of human disturbance - adjacent land uses - land use in the buffer zone (100m)

	- Jones et al. (2000) - Forest interior dwelling birds provide an important point of reference for core habitat because they require large interior forest area as high quality breeding habitat. These birds are rapidly declining across the Chesapeake, largely due to fragmentation of forests needed for breeding. - McIntyre (1995) – Study found a significantly greater number of interior species in contiguous forests than in fragmented landscapes, and significantly more interior species in larger fragments (10-13.25 ha) than small ones (less than 3.25 ha).	These areas are also particularly important for species that rely on interior forests for breeding, some of which have specific area thresholds (*for example, see* Stauffer and Best 1980).	the amount of core habitat area within each road bounded block, which can then be tracked each year for changes.	
Corridors	- Tewksbury et al. (2002) - Across a fragmented landscape, corridors are known to facilitate animal movement, pollination, and seed dispersal between patches at both ends. This allows for the re-colonization of species to patches where they have been lost (metapopulations), as well as genetic exchange to maintain healthy populations. - Lindenmayer and Franklin (2002) - Shorter, wider corridors are correlated with abundance and species richness of birds, mammals, and invertebrates.	Unable to find literature that suggests an optimal level of connectedness across a landscape (percent of patches connected by corridors)	1) The Virginia Natural Landscape Assessment (VaNLA 2007) has identified corridors between their ecological cores (which should correlate to our calculation of core habitat). Using updated land cover data, derived from satellite imagery, the amount of natural land cover in the corridors may be calculated and tracked yearly with a goal of maintaining or increasing the amount of natural land cover within the identified corridors. 2) Using updated land cover data, derived from satellite imagery, the percent of habitat cores connected with natural land cover may be calculated and tracked yearly with a goal of maintaining or increasing the number of cores connected. 3) Least cost paths may be calculated between habitat cores or the large patches, identified in the VaNLA (VaNLA 2007). These would then be thresholds to show only those 300m in width (100 meters of core with 100 meters of buffer on each side). This information may then be reported in a number of ways: 1. a metric representing the percent of patches connected to others 2. the average length of corridors Alternatively, circuit theory may be employed to assess resistance across a landscape (McRae et al. 2008). This may be done using the open source python GUI Circuitscape or Matlab (Shah and McRae 2008).	- Analysis of surrounding matrix

Wetlands[2]:

Wetlands, in their many forms, are some of the world's most productive and diverse ecosystems (Anderson and Sheldon 2011). They serve a wide array of functions, from flood protection and water quality maintenance to providing nursery habitat for some of the nation's most lucrative commercial and recreational fisheries (Tiner and Burke 1995). Location and size are leading factors in determining which functions wetlands perform, and how well. Much like forests, wetlands are largely dependent on size for maintaining their ecosystem functions and supporting a diversity of species (Houlahan et al. 2006).

However, one cannot only be concerned about the size and condition of each wetland – a wetland's ability to maintain a high diversity of plant and animal species is also affected by the surrounding land uses (Houlahan et al. 2006). Human activities around wetlands can impact both water and habitat quality (Tiner 2004), and land-use patterns are usually highly correlated with wetland condition (Brooks et al. 2004). With impending sea level rise, the importance of land use in the buffer zone increases, as wetlands will need land on which to retreat inland as the coastline changes.

About 4% of Virginia's land is wetland, of which 1.1 million acres is palustrine and 0.19 million acres is estuarine, lacustrine, and riverine (VA DGIF 2005). Virginia's wetlands are threatened by conversion to other land cover, conversion to other uses, hydrologic alterations, invasive species, and fragmentation (VA DEQ 2011). Conversion to uplands and open water most greatly affect palustrine and estuarine wetlands, respectively (Tiner et al. 2005).

Despite a national 'no net loss' policy, conversion, wetland health, and surrounding land cover remain concerns that we hope to track through the ETJ initiative. The table below (Table 4) presents three Tier 1 indicators that may be used to track wetland condition, as it pertains to wildlife.

[2] This system includes hydrologically connected estuarine, lacustrine, and palustrine wetlands (forested wetlands are within the *Forest* system and riparian wetlands are within the *Rivers and Streams* system).

Table 4. Proposed wetland system indicators, their justification for wildlife, accepted thresholds, potential methods for tracking, and potential related Tier 2 and 3 indicators to pursue in the future.

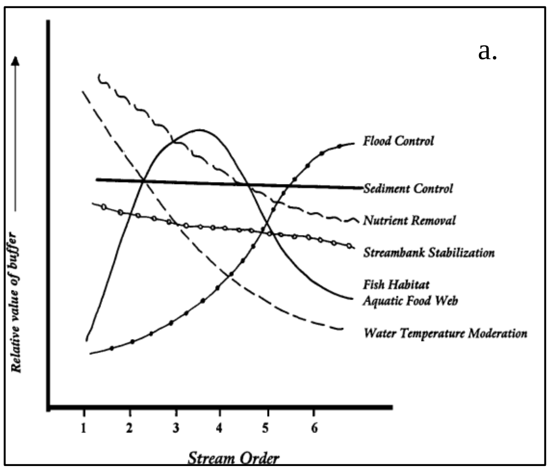
Indicator	Justification for Wildlife	Thresholds	Potential Methods for Tracking Indicators	Potential related 2nd and 3rd tier indicators
Wetland Size	- Anderson and Sheldon (2011) - The number of species supported by a wetland is correlated with its size. - Houlahan et al. (2006) - Wetland size is the most important predictor of total plant species richness and richness within other functional groups.	- Findlay and Houlahan (1997) – Study found a significant species-area relationship for birds, mammals, herptiles and plants. Based on their species-area model, a reduction in wetland area of 50% would result in a loss of 10-16% of the species in any taxonomic group.	Using the National Wetlands Inventory (or using updated land cover data, derived from satellite imagery), wetlands can be identified and the size of each can be calculated. Then, the average wetland size across the largest 20% of wetlands may be calculated and tracked yearly.	- changes in functionality when NWI+ is released - average size and change over time of each wetland type
Impacts in the Buffer Zone	- Anderson and Sheldon (2011) - The buffer zone around a wetland influences the quality and diversity of the wetland. - Houlahan et al. (2006) - Land use within 250–400 m of the wetland edge was most strongly correlated with species richness.	- Brooks et al. (2004) - Impairment occurs above a disturbance score of 60 or higher.	1) Anderson and Sheldon (2011) assessed the condition of the buffer zone by defining a 100 m zone [though Houlahan et al. (2006) found the 'critical' distance for which forest cover was most important to be 250–300m; in other words, loss of forest cover within this zone affects plant diversity] around each individual wetland greater than 2 acres in size and calculated the amount of development, agriculture, and natural vegetation within it. This was then summarized in an index of disturbance, in which development was weighted higher than agriculture and score ranged from 100 for a wetland with its buffer zone totally developed, to 0 where the buffer was completely within natural cover types: *Disturbance Score = 1.0 times the percent high intensity development + 0.75 times the percent low intensity development, + 0.50 times the percent agriculture* The mean buffer condition score (across all wetlands or the largest 20%) can then be calculated and classified as low, moderate, or severe disturbance, or tracked over time. 2) Alternatively, Brooks at al. (2004) defined a 1 km^2 circle around the center point of a selection of wetlands (identified through the NWI) in a HUC14 watershed (these may also be aggregated into HUC11 watersheds). They then determined the percentage of each land cover type around each wetland and gave that a disturbance score (100 minus percent forest, so that a score of 0 is most degraded and a score of 100 is most ecologically	- disturbance by wetland type or function - Brooks et al. (2004) - Hydrogeomorphic (HGM) Functional Models and Indices of Biological Integrity (IBIs) can be used to identify specific stressors in the system

			intact). Finally, they computed an average disturbance score for the watershed (average of all individual wetland scores). This could then be tracked.	
Road Density	- Findlay and Houlahan (1997); Houlahan and Findlay (2003); Houlahan et al. (2006) - The species richness of birds, amphibians, reptiles, and plants within an individual wetland is negatively correlated with the density of paved roads surrounding the wetland. Critical distances vary from 200m (for rare species) to 2,000m (for herptiles).	- Findlay and Houlahan (1997) – Study found a significant negative relationship between plant species richness and paved road density, particularly between 0-1,000m from the wetland. Their model predicts that an increase of 2m/ha in the density of paved roads within 1000m will lead to a 13% decrease in plant species richness. The effects of roads in the buffer differ slightly for birds (an increase of 2m/ha in the density of paved roads within 500m will lead to a 14% decrease in bird species richness) and herptiles (an increase of 2m/ha in the density of paved roads within 2000m will lead to a 19% decrease in herptile species richness). There was not a pronounced effect on mammal species richness.	Using the road bounded block dataset mentioned above, the density of roads (meters/hectare) within a 1,000 meter buffer around each wetland greater than 2 acres may be calculated (or for the largest 20% of wetlands). Alternatively, this could be done including the wetland to find the road density for the wetland and its 1000m buffer. (See other potential methodology in Anderson and Sheldon 2011). Anderson and Sheldon (2011) created a road impact index for each wetland occurrence based on Findlay and Houlahan (1997) • No impact: 0- 2 m/ha roads of roads (estimated 80-100% of natural species richness) • Moderate impact: 2 to 6 m/ha of roads (estimated 50-80% of natural species richness) • Impacted: 6 to 18 m/ha of roads (estimated 25-50 of natural species richness) • Severe impact: >18 m/ha of roads (estimated >25% of natural species richness)	- Houlahan et al. (2006) found that the road density effect was strongest from 400-500m from the wetland (200m for rare species); therefore, this analysis could be performed at these distances.

Rivers and Streams:

Rivers and streams serve as the lifeblood of ecosystems, from carrying essential nutrients to providing micro-habitats. Unfortunately, due to a range of factors, "freshwater dependent species are among the most threatened group of species in the region and are of great conservation concern" (Anderson and Sheldon 2011).

Although their biological communities vary with stream size and flow, the ability of rivers and streams to provide habitat for a range of species is largely dictated by their buffers. Forested buffers provide organic input into stream ecosystems, as well as regulate microclimates, create complex aquatic habitats, support many rare species and communities, and serve as biological corridors (Anderson and Sheldon 2011). Ecological services in terms of water filtration and flood mitigation further highlight the importance of steam buffers to landscapes. The ability of stream buffers to serve each of these services is largely a function of stream order and buffer width (Figure 3a & b). Of all of the functions that riparian buffers serve, wildlife habitat requires the largest buffer width (Figure 3b).



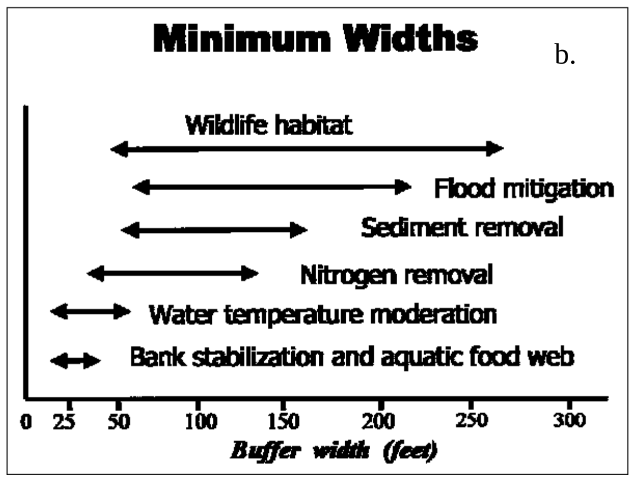


Figure 3. a. Generalized effect of stream order on variations in buffer function. b. Range of minimum widths for meeting specific buffer objectives. (Adapted from Palone and Todd 1997).

It is also important to recognize that not all rivers are equal. Headwater streams represent the majority of total stream length within a catchment (60 to 80%) and drain the majority of the catchment area (70 to 80%), making them an important source of sediment, fine and coarse organic matter, and nutrients and the primary source of streamflow (MacDonald and Coe 2006). Buffers along headwater, first order streams are particularly important for water temperature moderation and removing nutrients from runoff (Palone and Todd 1997; Figure 3a).

The ETJ team has performed a preliminary, very coarse analysis of buffer coverage along the James River. About 24%, 23%, and 34% of streams in the upper, middle, and lower James, respectively, lack a 500 foot vegetative buffer. As part of this study, we will perform more fine-scale and targeted analyses to help us understand the changing buffer dynamics across the watershed and, particularly, in headwater sub-watersheds. The table below (Table 5) presents three Tier 1 indicators that may be used to track the condition of rivers and streams, as it pertains to wildlife.

Table 5. Proposed river system indicators, their justification for wildlife, accepted thresholds, potential methods for tracking, and potential related Tier 2 and 3 indicators to pursue in the future.

Indicator	Justification for Wildlife	Thresholds	Potential Methods for Tracking Indicators	Potential related 2nd and 3rd tier indicators
Buffer Condition (100m buffer)	- Palone and Todd (1997) - Buffer width is one of the most important factors in determining buffer effectiveness. Optimal minimum buffer width varies with the desired service, and even with the desired wildlife outcome. Having trees streamside is crucial for providing aquatic food and habitat, but the width increases with wildlife outside of the stream itself. Buffers not only serve as habitat for terrestrial species, they provide corridors between habitat patches and transition zones between upland and aquatic habitat types.	- Goetz et al. (2003) – Watershed stream health was considered "excellent" with at least 77% tree cover in the riparian zone; "good" with 72% tree cover; "poor" with less than 56% tree cover in the buffer area. - Sprague et al. (2006) – A goal has been set to ensure the forests buffer more than 70% of riparian areas throughout the Chesapeake watershed. - The James River Association has identified a goal of 85% of streambanks in the James River watershed forested in their *State of the James* report.	1) Using updated land cover data, derived from satellite imagery, and the National Hydrological Dataset, the amount of forest cover within a 100m (~300 ft) buffer can be calculated (Palone and Todd (1997) suggest that larger mammals and reliable migratory songbird breeding habitat require buffers 100-300 feet wide). This can then be averaged across HUC12 watersheds to see the mean tree cover in the riparian area for each sub-watershed. 2) Alternatively, this indicator could be looked at as buffer intrusion and the amount of agriculture and developed land within each buffer zone can be calculated. Anderson and Sheldon (2011) developed a summary small watershed index for each HUC12 in which they transformed the land cover information into a numeric impact index: *Impact = 0.5 * % agriculture + 0.75* % low intensity development+ 1.0* % high intensity development*. The impact index ranged from 100 for a watershed with its buffer zone totally developed to 0 where the buffer zone was completely within natural cover types. (Anderson and Sheldon 2011) These analyses can be narrowed down by stream order size, if desired. [see Anderson and Sheldon 2011, methods on B-5 for a potential way to map rivers and streams]	- buffer continuity; contiguous buffers may be even more important than increasing width for wildlife habitat (Palone and Todd 1997) [see CWP 2003 for additional information]. - buffer vegetation; maintaining forests as a component of the buffer greatly enhances diversity and abundance of birds and other wildlife (Palone and Todd 1997).
Headwater Stream Condition	- Palone and Todd (1997) - Headwater streams are defined as first or second order streams that ultimately comprise 75 percent or more of the total stream and river miles. Buffers have the greatest potential to affect water quality in these streams. It is also possible that headwater streams may be in less developed areas, thus making buffer integrity and connectivity an important part of the hub and	- Goetz et al. (2003) – Watershed stream health was considered "excellent" with at least 51% watershed tree cover; "good" with 45% tree cover; "poor" with less than 30% tree cover. - Brooks et al. (2004) - Impairment occurs when less than 60% of the watershed is forested. Unable to find such a threshold that is	The National Hydrological Dataset will be expanded, where possible, with functional streams, determined using flow path networks. The density of streams can be used to identify the headwater sub-watersheds, as they will have the highest densities. Percent forest cover may then be calculated for the headwater sub-watersheds (this may dovetail with the "Percent Forest Cover" indictor for forest health, but with a particular emphasis on headwater streams).	

	corridor network.	specific to headwater streams.		
Impervious Surfaces	- CWP (2003) - Impervious surfaces can cause a range of changes in the stream network, including increased flow, increased sediment, loss of pools and riffles, loss of large woody debris, and increased turbidity, that affect the condition of habitat for aquatic species. Impervious cover is "the most commonly used index to assess the impacts of watershed urbanization on aquatic insect and fish diversity." - Uphoff et al. (2011) - Impervious surface was the landscape feature that was best associated with degraded bottom habitat in nine brackish sub-estuaries of Chesapeake Bay. - Gergel et al. (2002) - Percent impervious surface can provide a good approximation of watershed and aquatic habitat degradation, even within areas of little development.	- CWP (2003) - Impervious cover model (ICM) shows "most stream quality indicators decline when watershed impervious cover (IC) exceeds 10%, with severe degradation expected beyond 25% IC. Above 10% also shows noticeable in aquatic insect species diversity (Klein 1979 *in* CWP 2003); those above 25% IC cannot support diverse aquatic insect communities." Fish decline also noticeably occurs at about 10% IC. *Importantly, this model applies only to 1st, 2nd, 3rd order streams and was designed particularly for mid-Atlantic region.* - MNCPPC (2000) – Study suggests that IC is the best predictor of stream condition, based on a combined fish and aquatic insect IBI. Streams with less than 6% watershed IC classified as "excellent," with less than 12% IC as "good," and less than 20% IC as "fair." - Boward et al. (1999; *in* CWP 2003) - Particular species may be more sensitive. For example, brook trout were not found in sub-watersheds that had more than 4% IC in Maryland. - Goetz et al. (2003) – Watershed stream health was characterized as "excellent" with less than 4% IC; "good" with less than 5% IC' "poor" with more than 20% impervious cover. - Snyder et al. (2005) – in a study of watersheds in Montgomery County, MD, watersheds in excellent health averaged less than 8% impervious	1) Using the National Land Cover Impervious Dataset, or updated land cover data derived from satellite imagery, the percent impervious cover can be calculated for the upstream watershed of each stream reach (Anderson and Sheldon 2011, see methods on B-5). Anderson and Sheldon (2011) grouped each stream and river reach in the region into one of four impact categories guided by the thresholds found in King and Baker (2010): • Class 1: Undisturbed: 0 < 0.5 percent impervious. • Class 2: Low impacts: 0.5-2 percent impervious. • Class 3: Moderately impacted: >=2-10 percent impervious. • Class 4: Highly impacted: >=10 percent impervious. To see the spatial distribution of impervious impacts, Anderson and Sheldon (2011) combined the impact classes into an index of impervious surfaces for HUC12 watersheds: *Impact score = 1* (%Class 1) + 2* (%Class 2) + 3* (% Class 3) + 4* (%Class 4).* This resulted in scores that ranged from 400 for a watershed where all stream and river miles were in the high impact class to a low of 100 where all streams and river miles were in the undisturbed class. 2) Using the road bounded block dataset mentioned above, the density of roads (meters/hectare) within each sub-watershed may be calculated.	- stream barriers (dams and culverts) - connected stream network - index of biotic integrity

		surface area; good health averaged less than 10%; poor health exceeded 29%. - King and Baker (2010) - Disaggregated species in analysis and found that numerous taxa decline at thresholds between 0.5 and 2% imperviousness. They advocate for a community threshold at 1% impervious cover. - Uphoff et al. (2011) – Study of Chesapeake Bay brackish subestuaries found that mean bottom dissolved oxygen did not fall below the threshold of 3-mg/L DO threshold when there was 5.5% imperviousness (however, they also did not reach the target threshold of 5mg/L). Mean bottom DO did not rise above the threshold with approx. 20% imperviousness.		

Pilot Study

In keeping consistent with techniques used by others (particularly Anderson and Sheldon's 2011 assessment of northeast indicators proposed in Tomajer et al. 2008), we propose a pilot study to test the feasibility of the recommended monitoring framework. This study may result in a slight revision to our proposed indicators.

This pilot study will also be the first look into baseline conditions of these indicators across the watershed, and will help identify locations that may be targeted for fine-scale monitoring in the future by Conservancy staff or university partners.

Pilot Study Recommendations:

Using Landsat 8 imagery (30m resolution and revisited every 16 days), we will create a land cover data layer for the entire James River watershed that will be used to do a preliminary, coarse analysis for all indicators[3]. This layer will benefit from being able to be updated more often than the conventional National Land Cover Database (NLCD). In some cases, we will use the most up-to-date NLCD 2011 to set a baseline of conditions that can be compared with 2013/2014 Landsat imagery. In those areas that preliminary analysis shows large changes, NAIP imagery (1m resolution and released every two years) will be used to explore causality within sub-watersheds. This analysis would be repeated every two years (with only one Landsat classification [or high-resolution land cover analysis] being completed in that period).

Forests:

For forests, the NLCD 2011 will be used to calculate percent forest in each sub-watershed, as well as to calculate the amount of core habitat within each road bounded block. This will provide us with a baseline of forest cover and core habitat area across the watershed. NLCD 2011 data will be compared with 2013/14 Landsat imagery that has been classified into land cover types, and we will identify sub-watersheds in which there are substantial changes in the percent forest or area of core habitat. If substantial changes in are noted, NAIP imagery will be used to take a more fine-scale look at the sub-watershed in which the change is occurring in an attempt to determine causality and appropriate conservation actions.

In order to assess corridors between core habitat areas, we will use the corridors identified in the Virginia Landscape Assessment and monitor natural land cover within the corridor. We will also use Circuitscape at the James River watershed level to explore connectivity between the largest core habitat areas. In addition to exploring whether these corridors remain over time, Circuitscape will allow us to see choke points and key corridors that are necessary to preserve for wildlife movement across the landscape. We may also threshold these corridors and look at changes to their width over time.

[3] In the case that higher resolution land cover data exists, that may be used instead from the beginning of these analyses.

Table 6. Pilot study recommendations for the forest system.

		Unit of Analysis		
System	Indicator	Landsat 8	NAIP	Notes
Forests	Percent Forest Cover	X	X	Using Landsat, calculate percent forest in each watershed. Where large changes in patch size occur, explore causality with NAIP.
	Core Habitat	X	X	Using road bounded blocks overlaid with Landsat imagery, calculate forest patches and their core habitat areas. Identify where large changes in core habitat are occurring and, in those areas, explore causality using NAIP.
	Corridors	X		Using Landsat, quantify natural land cover within the corridors identified in the VaNLA. Then, Circuitscape will be used at the watershed level to explore connectivity between key core areas.

Wetlands:

For wetlands, National Wetlands Inventory (NWI) data will be used to identify hydrologically connected estuarine, lacustrine, and palustrine wetlands (forest and riverine wetlands are encompassed by the *Forests* and *Rivers/Streams* system indicators) within the James River watershed (although NWI may not show all wetlands, it is the most easily accessible national wetlands data). Area will be calculated based on the NWI. NLCD 2011 will then be used to explore land use change within the buffers of all wetlands greater than 2 acres in size. The road layer created as part of the North Atlantic Landscape Conservation Cooperative will be used to similarly assess road density within the buffer of each wetland greater than 2 acres in size. If this proves too mammoth a task, a sample of wetlands can be analyzed - Brooks et al. (2004) suggests a sample size of 50 wetlands for a HUC11 or 14 watershed, particularly if we hope to follow-up with more rigorous remote sensing or ground-based assessments – or only the largest percentage of wetlands can be analyzed.

Note, Brooks et al. (2004) suggests this analysis for watersheds between 100–1,000 km^2; however, the James is significantly larger. It may be preferable to do a coarse preliminary exploration of the landscape and then choose sub-watersheds (Brooks et al. suggests their methods be applied to 11-digit HUC watersheds) to monitor.

Classified 2013/14 Landsat imagery will then be compared to the NWI wetlands and NLCD 2011 to monitor encroachment into wetlands and their buffer zones. If substantial changes in the size of the wetlands or quality of wetland buffers is noted, NAIP imagery will be used to take a more fine-scale look at the sub-watershed in which the change is occurring in an attempt to determine causality.

Table 7 Pilot study recommendations for the wetland system.

		Unit of Analysis		
System	Indicator	Landsat 8	NAIP	Notes
Wetlands	Wetland Size	X	X	Using NWI, identify wetlands and monitor size with Landsat. Where large changes in size occur, explore causality with NAIP.
	Impacts in Buffer Zone	X	X	Using Landsat, monitor land use impacts in wetland buffer zones. Where large changes in land use occur, explore causality with NAIP.
	Road density	X		Using Landsat and road layer, monitor road density within wetland buffer zones.

Rivers and Streams:

The National Hydrologic Dataset (NHD) will be used to identify rivers and streams in the James River watershed. A 100m buffer will be applied to all streams, and NLCD 2011 data will be used to determine presence or absence of vegetation within the buffers. Percent vegetated buffer will be calculated for each stream reach and then put into categories of buffer intrusion based on thresholds. We can then use NAIP imagery to take a closer look at watersheds with the highest density of impaired stream reaches (based on the threshold). This will be important, as it is possible that at the coarse resolution allowed by Landsat data that buffers up to about 50m in width may be overlooked in the preliminary analysis.

In order to address changes in headwater sub-watersheds, we will use the NHD to calculate the stream density in each sub watershed. In those with highest density, we will quantify what percentage of that sub-watershed is forested. In sub-watersheds with notable or alarming trends, we may then use NAIP imagery to explore causality. This will allow us to pay particularly close attention to these high value areas.

Classified 2013/14 Landsat imagery will be compared NLCD 2011 to monitor encroachment into buffers. If substantial changes in the buffer intrusion are noted, NAIP imagery will be used to take a more fine-scale look at the sub-watershed in which the change is occurring in an attempt to determine causality.

In those areas that NAIP imagery has been analyzed due to changes in forest cover, wetland condition, or buffer condition, impervious surfaces will also be analyzed.

Table 8. Pilot study recommendations for the rivers and streams system.

		Unit of Analysis		
System	Indicator	Landsat 8	NAIP	Notes
Rivers/ Streams	Buffer Intrusion	X	X	Preliminarily, with Landsat, determining presence or absence of vegetation within 100m buffer of streams. Then, with NAIP, explore causality in areas with loss of buffer vegetation.
	Headwater Stream Condition	X	X	Using NHD, calculate stream density in each sub watershed. In those with highest density, assess percent of forest cover. Then, select key watersheds to examine detailed forest buffer conditions using NAIP.
	Impervious Surfaces		X	Impervious surfaces will be quantified in those sub-watersheds that have the greatest changes in forest patch size, wetland size or buffer quality, or stream buffer quality, warranting deeper analysis using NAIP imagery.

Engaging students

Our proposed pilot study significantly simplifies and scales down the potential indicator analyses in order to keep the project reasonable given time, money, and staff capabilities. However, we may be able to increase analytical capacity by enlisting the help of students at universities within the James River watershed.

Ultimately, we would like to have universities 'adopt' HUC12 watersheds across the larger James watershed in order to have a continuous, long-term data series for those sub-watersheds. We hope that the analyses required to monitor the above indicators can be incorporated into lesson plans and labs in GIS and remote sensing courses at these universities. That way, every year or two, the analyses will be done for the 'adopted' watersheds – providing students an opportunity to learn new skills and to take ownership of the James River and building long term datasets for these watersheds.

Conclusion:

The Conservancy hopes that these landscape-scale GIS-detectable metrics will allow us to monitor wildlife habitat across the James River watershed, as well as to conduct detailed assessments in high priority areas. The monitoring information will help the Conservancy, their partners, and the public be better informed of the key threats affecting wildlife habitat and the species that depend upon these landscapes. Ultimately, we believe this will help mobilize public support and the resources needed to ensure that sufficient landscape areas and habitat conditions will be maintained in future years to sustain healthy reproducing populations of native wildlife in the James River watershed. If these indicators prove to be useful in tracking and sustaining wildlife habitat in the James, they may be applied to other watersheds across the Chesapeake.

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Appendix:

Table 1. Indicators and metrics used by the James River Association in the *State of the James* 2013 report[4].

Indicator	Metric
Wildlife	Bald Eagle breeding pairs
	Rockfish spawning stock
	Number of oysters (million)
	Average number of smallmouth bass caught/hour
	American Shad - catch index value
	Brook Trout population
Habitat	Underwater grasses - acres
	Riparian Forests - percent of streambanks forested
	Stream Condition Index
	Tidal Water Quality
Pollution	Sediment Pollution Reduction - tons of pollution per year
	Nitrogen Pollution Reduction - pounds per year
	Phosphorus Pollution Reduction - pounds per year
Protection and Restoration Actions	Wastewater Treatment Pollution Reduction
	Continuous No Till - acres of cropland enrolled in program for continuous no till farming
	Winter Cover Crops - acres of farmland enrolled in program for winter cover crops
	Farm Nutrient Management - acres of farmland with nutrient management plans
	Stream Protection - acres of pasture fencing installed
	Low impact development policies - % of policies recommended by the state adopted
	Urban Storm water Management - acres of urban storm water management practices documented
	Urban Nutrient Management - acres of urban lands with documented nutrient management plans in place
	Riparian Buffer Restoration - acres of restored buffers
	Land Conservation - acres

[4] Available here: http://www.jrava.org/what-we-do/Publications/StateOfTheJames2013.pdf