Remotely-sensed Natural Habitat Integrity Indices for Assessing the General Ecological Condition of Watersheds

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Abstract

Using geographic information system technology, the U.S. Fish and Wildlife Service has developed a set of indices to help describe the condition of natural habitats in watersheds. Indices are derived primarily from data collected through remote sensing to allow for large geographic area coverage and periodic updating. Eleven remotely-sensed natural habitat indices have been created to evaluate and report on the status of wetlands, streams, and other natural habitats. Seven habitat extent indices address the current distribution of natural habitat within the watershed, along stream and river corridors, and around wetlands, ponds, and lakes. Three disturbance indices relate to streams and wetlands. The habitat extent and disturbance indices can be aggregated to generate a composite index for the watershed. The data collected in this type of analysis allow for calculating numeric indices as well as for producing maps showing the distribution of natural habitat and vegetation throughout the watershed. These indices are useful for reporting on the current status of natural habitat in the watershed, for monitoring trends in these resources, and for informing the public on the status and fate of natural resources in watersheds. They are one of several indicators of ecological condition that can be evaluated for these purposes.

Introduction

Traditionally, natural resource management in the United States has emphasized individual species or guilds (e.g., waterfowl, furbearers, and endangered species), particular habitats (e.g., forests, waterfowl habitat, farmland, and wetlands), or "protected" lands (e.g., national and state forests, parks, and wildlife refuges or wildlife management areas and private wildlife sanctuaries). More recently, there has been growing interest in pursuing a watershed-based approach to environmental planning, management, and restoration (e.g., Naiman 1992; Williams et al. 1997). Wetlands are often the vital link between land and water resources, while rivers and streams connect many different ecological communities.

The widespread availability and use of geographic information system (GIS) technology and the existence of digital geospatial datasets have made it possible to analyze the status and trends of natural habitat and other resources for large geographic areas, including major watersheds. For more than 20 years, the U.S. Fish and Wildlife Service through its National Wetlands Inventory (NWI) Project, has been a leader in producing geospatial data on wetlands and waterbodies, while other agencies, especially state natural resource agencies, have generated digital geospatial information on land use and land cover on a periodic basis.

The NWI's experience with geospatial databases and remote sensing techniques and interest in fish and wildlife habitat conservation led to the development of GIS tools to aid resource managers and planners in developing strategies to improve the status of natural ecosystems. Since 1995, the NWI Program has been seeking ways to use geospatial data to analyze and represent wetland functions at the watershed-scale. In particular, a new product - the watershed-based wetland characterization report - has been developed and prepared for several watersheds (see Tiner 2002). This type of report includes descriptions of major wetland types and a preliminary assessment of wetland functions (identifying wetlands potentially significant for performing varied functions) for a given watershed. While this information is useful by itself, activities occurring beyond the wetland edge often have a tremendous impact on the quality or health of the wetland. The significance of outside influences on wetlands and aquatic habitats induced a desire to examine and describe the condition of natural habitat beyond wetlands. Given the availability of other geospatial data (especially for land use and land cover), we felt that it might be relatively simple to gather and assimilate geospatial information on other landscape-level properties sufficient to allow for periodic reporting on the overall condition of natural habitats for watersheds or other large geographic regions. This would be valuable information to resource managers and for informing the public on the changing status of natural landscape. It might also serve as a measure that could be frequently reported in state-of-the-environment reports published by various state agencies and possibly for a national report of this kind.

At the watershed-scale, there are many important features determining the overall health of the natural ecosystems. Out of the rather long list of features, several that could be evaluated through remote sensing were identified: 1) extent of natural habitat, 2) condition of stream corridors, 3) extent of wetlands, 4) condition of wetland and other waterbody buffers, 5) extent of waterbodies, 6) extent of altered wetlands, 7) dammed stream length, and 8) channelized stream length. A series of "natural habitat integrity indices" were created to develop a simple numeric index reflecting the condition of these key watershed features. Other photointerpretable features that may be of interest include inventories of potential wetland restoration sites and the extent of ditching. These features are not expressed as indices, but instead may be depicted on maps and conveyed in acreage summaries.

The purpose of this paper is to describe these indices and provide an example of their application for a watershed. The sample watershed is Nanticoke River watershed on the Atlantic coastal plain in eastern Maryland.

Remotely-sensed Natural Habitat Integrity Indices

There are many ways to assess land cover changes and habitat disturbances. The health and ecological condition of a watershed may be assessed by considering such features as the integrity of the lotic (streamside) wetlands and riparian forests (upland forests along streams), the percent of land uses that may adversely affect water quality in the watershed (% urban, % agriculture, % mining, etc.), the actual water quality, the percent of forest in the watershed, and the number of dams on streams, for example. Recent work on assessing the condition of watersheds has been done in the Pacific Northwest to address concerns for salmon (Wissmar et al. 1994; Naiman et al. 1992). A Wisconsin study by Wang et al. (1997) found that instream habitat quality declined significantly when agricultural land use in a watershed exceeded 50 percent, whereas when 10-20 percent of the watershed was urbanized, severe degradation occurred.

To help assess the overall ecological condition of watersheds, the Northeast Region of the U.S. Fish and Wildlife Service developed a set of "remotely-sensed natural habitat integrity indices." The variables for these indices are derived through air photointerpretation and/or satellite image processing coupled with knowledge of the historical extent of wetlands and open waterbodies. They are coarse-filter variables for assessing the overall ecological condition of watersheds. The "natural habitat integrity indices" do not supplant the need for other environmental assessments. They do, however, provide a GIS-based assessment tool that can be used for developing a broad perspective of the extent and condition of natural habitat for a watershed. For fine-filter assessments, site-specific techniques for determining the ecological integrity of aquatic habitats such as indices of biological integrity (IBI) for stream macroinvertebrates and fishes (Karr et al. 1986; Karr 1991; Angermeier and Karr 1994; Lyons et al. 1996) and procedures for evaluating wetland functions by establishing and examining reference wetlands (see Brooks et al. 2002) may be employed. The natural habitat integrity indices can be used to develop "habitat condition profiles" for individual watersheds at varying scales (i.e., subbasins to major watersheds). Indices can be used for comparative analysis of subbasins within watersheds and to compare one watershed with another. They may also serve as one set of statistics for reporting on the state-of-the-environment by government agencies and environmental organizations.

The indices are cost-effective, rapid-assessment measures that allow for frequent updating (e.g., every 5-10 years). They may be used to assess and monitor the amount of "natural habitat" compared to the amount of disturbed aquatic habitat (e.g., channelized streams, partly drained wetlands, and impounded wetlands) or developed habitat (e.g., cropland, pasture, mined land, suburban development, and urbanized land). The index variables include features important to natural resource managers attempting to lessen the impact of human development on the environment. The indices may also be compared with other environmental quality metrics such as indices of biological integrity for fish and/or macroinvertebrates or water quality parameters. If significant correlations can be found, they may aid in projecting a "carrying capacity" or threshold for development for individual subbasins.

To date, a total of 11 indices have been developed. Each of them, in one way or another, represents habitat condition in a watershed. Seven indices - habitat extent indices - address natural habitat extent (i.e., the amount of natural habitat occurring in the watershed and along wetlands and waterbodies): natural cover, stream corridor integrity, river corridor integrity, wetland buffer integrity, pond and lake buffer integrity, wetland extent, and standing waterbody extent. Three indices emphasize human-induced alterations to streams and wetlands. These stream and wetland disturbance indices deal with damming and channelization of streams and wetland alteration. The 10 specific indices may be combined into a single index called the composite natural habitat integrity index for the watershed. All indices have a maximum value of 1.0 and a minimum value of zero. For the habitat extent indices, the higher the value, the more habitat available. For the disturbance indices, the higher the value, the more disturbance. For the composite natural habitat integrity index, all indices are weighted, with the disturbance indices subtracted from the habitat extent indices to yield an overall "natural habitat integrity" score for the watershed.

Presently, the indices do not include certain qualitative information on the condition of the existing habitats (habitat quality) as reflected by the presence, absence, or abundance of invasive species or by fragmentation of forests, for example. It may be possible to add such data in the future. Another consideration would be establishment of minimum size thresholds to determine what constitutes a viable "natural habitat" for analysis (e.g., 0.04 hectare/0.1 acre patch of forest or 0.4 hectare/1 acre minimum?). Other indices may also need to be developed to aid in water quality assessments (e.g., index of ditching density for agricultural and silvicultural lands).

"Natural Habitat" Defined

Use of terms like "natural habitat" and "natural vegetation" have stirred much debate, yet despite this, we feel that they are useful for discussing some of the effects of human activities on the environment. We use these terms loosely and not in the sense of native or endemic species. Instead, we view them as expressions of areas that support wildlife of forests, vegetated wetlands, shrub thickets, old fields, and sand dunes, for example.

For purposes of this analysis, natural habitats are defined as areas where significant human activity is limited to activities like nature observation, hunting, fishing, and forestry and where vegetation is allowed to grow for many years without irrigation, annual introduction of chemicals (e.g., herbicides and pesticides), or annual mowing or annual harvesting of vegetation or fruits and berries for commercial purposes. Natural habitats may be managed habitats, but they are places where wetland and terrestrial wildlife find food, shelter, and water. They are not developed sites (e.g., impervious surfaces, lawns, turf farms, cropland, pastures, nurseries, orchards, vineyards, mowed hayfields, or mined lands). Commercial forests are included as natural habitat, whereas orchards and vineyards are not. "Natural habitat" therefore includes habitats ranging from pristine woodlands and wetlands to commercial forests planted with loblolly pine and wetlands now colonized by invasive species (e.g., Phragmites australis or Lythrum salicaria). We recognize that there are differences in habitat quality among areas classified as natural habitat, but these differences are not accounted for. The focus of this coarse-filter analysis is quantitative (i.e., to identify how much wildlife habitat remains - presence or absence) and not to do a qualitative assessment of such habitats. The latter analysis typically requires field investigations (consistent with a fine-filter evaluation). Readers should also note that identifying an area as having "natural vegetation" does not imply that substantial groundcover must be present, but simply means that the area reflects the vegetation that is capable of growth and reproduction in accordance with site characteristics (e.g., coastal sand dunes).

Data Sources

Data for these indices are drawn from several sources. Wetland and deepwater habitat data are derived from existing or enhanced NWI digital database. Stream data come mainly from the U.S. Geological Survey's digital hydro layer based on 1:24,000 mapping, while in some areas, more detailed digital stream data may be available from state or other government agencies. Land use and land cover data may be obtained from several sources: U.S. Geological Survey or state agencies, county or local governments, or be derived by processing current satellite imagery or interpreting recent aerial photography.

Habitat Extent Indices

These indices have been developed to provide some perspective on the amount of natural vegetation remaining in a watershed. The following areas are emphasized: the entire watershed, stream and river corridors, vegetated wetlands and their buffers, and pond and lake buffers. The extent of standing waterbodies is also included to provide information on the amount of open water habitat in the watershed. Each index is briefly described below.

The Natural Cover Index (I_{NC}) represents the percentage of a watershed that is wooded (e.g., upland forests or shrub thickets and forested or scrub-shrub wetlands) and "natural" open land (e.g., emergent wetlands or "old fields;" but not cropland, hayfields, lawns, turf, or pastures). These areas are lands supporting "natural vegetation;" they exclude open water of ponds, rivers, lakes, streams, and coastal bays.

> $\mathbf{I_{NC} = A_{NV}/A_W}$, where A_{NV} (area in natural vegetation) equals the area of the watershed's land surface in "natural" vegetation and A_W is the area of "watershed" excluding open water.

The Stream Corridor Integrity Index (I_{SCI}) reflects the condition of the stream corridors:

> $\mathbf{I_{SCI} = A_{VC}/A_{TC}}$, where A_{VC} (vegetated stream corridor area) is the area of the stream corridor that is colonized by "natural vegetation" and A_{TC} (total stream corridor area) is the total area of the stream corridor.

The width of the stream corridor may be varied to suit project goals, but for this index, a 100-meter corridor (50m on each side of the stream) will be evaluated at a minimum, due to its well-recognized role in water quality maintenance and contributions to aquatic habitat quality. If wildlife travel corridors are a primary concern, a larger corridor (e.g., 200m to 1000m) may be examined. The stream corridor may be restricted to "streams" (linear tributaries on a 1:24,000 map) or expanded to include "rivers" (polygonal features at this scale). When rivers are included in the stream corridor integrity index, the index should be called River/Stream Corridor Integrity Index (I_{RSCI}). When the river corridor is analyzed separately, then the index should be called River Corridor Integrity Index (I_{RCI} ; use equation $I_{RCI} = A_{VC}/A_{TC}$ to calculate).

A 100m-wide buffer has been reported to be important for neotropical migrant bird species in the Mid-Atlantic region (Keller et al. 1993) and streamside vegetation providing canopy coverage over streams is important for lowering stream temperatures and moderating daily fluctuations that are vital to providing suitable habitat for certain fish species (e.g., trout). Review of the literature on buffers suggests wider buffers, such as 500m or more for certain species of wildlife (e.g., Kilgo et al. 1998 for southern bottomland hardwood stream corridors). The condition of stream buffers is also significant for locating possible sources of water quality degradation. Wooded corridors should provide the best protection, while developed corridors (e.g., urban or agriculture) should contribute to substantial water quality and aquatic habitat deterioration. For literature reviews of wetland and stream buffers, see Castelle et al. (1994) and Desbonnet et al. (1994).

The Wetland Buffer Index (I_{WB}) is a measure of the condition of wetland buffers within a specified distance (e.g., 100m) of mapped wetlands for the entire watershed:

> $\mathbf{I_{WB} = A_{VB}/A_{TB}}$, where A_{VB} (area of vegetated buffer) is the area of the buffer zone that is in natural vegetation cover and A_{TB} is the total area of the buffer zone (excluding open water).

This buffer is drawn around existing vegetated wetlands. While the buffer zone may include open water, the buffer index will focus on vegetated areas. Note that the buffers of this index were included with the pond and lake buffers in an index called Wetland and Waterbody Buffer Index (I_{WWB}) in earlier analyses; such as the example for the Nanticoke watershed given later in this paper. As mentioned previously, buffer width can be varied according to regional needs and conditions. For our work, the buffer examined will be at least 100m wide.

Semlitsch and Jensen (2001) emphasize that "wetland buffers" should be better described as "core habitat" for semiaquatic species and they urge that such areas be protected and managed as vital habitats. They found that 95 percent of the breeding population of mole salamanders lived in the adjacent forest within 164m of their vernal pool wetland. An interesting article by Finlay and Houlahan (1996) indicates that land use practices around wetlands may be as important to wildlife as the size of the wetland itself. They reported that removing 20 percent of the forest within 1000m of a wetland may have the same effect on species as destroying 50 percent of the wetland.
The Pond and Lake Buffer Index (I_{PLB}) addresses the status of buffers of a specified width around these standing waterbodies:

> $\mathbf{I_{PLB} = A_{VB}/A_{TB}}$, where A_{VB} (area of vegetated buffer) is the area of the buffer zone that

is in natural vegetation cover and A_{TB} is the total area of the buffer zone (excluding open water).

See comments under the wetland buffer index above. Ponds are mapped as palustrine unconsolidated bottoms and unconsolidated shores by NWI. Vegetated ponds are mapped as a vegetated wetland type and their buffers are not included in this analysis, but instead are evaluated as wetland buffers.

The Wetland Extent Index (I_{WE}) compares the current extent of vegetated wetlands (excluding open-water wetlands) to the estimated historic extent.

> $\mathbf{I_{WE} = A_{CW}/A_{HW}}$, where A_{CW} is the current area of vegetated wetland in the watershed and A_{HW} is the historic vegetated wetland area in the watershed.

The I_{WE} is an approximation of the extent of the original wetland acreage remaining in the watershed. For example, a watershed with a current coverage of 10 percent wetland would have an I_{WE} of 1.00 where the estimated original extent of wetlands was 10 percent (i.e., no wetlands were lost) or it would have an I_{WE} of 0.50 where 20 percent of the watershed once contained wetlands (i.e., half of the wetlands were lost). When data on historical wetland area are not available, it may be possible to predict this extent. It may be calculated by either evaluating a relatively undisturbed subwatershed in the watershed (i.e., one with similar properties of landscape, soils, and surficial geology) or using the area of hydric soils (and possibly the "made-land" area) as the historic extent of vegetated wetlands. Although not the typical case, one should recognize that areal extent of historic hydric soils may be less than the current wetland extent due to level of mapping detail (e.g., scalar issues) or to wetland-creation activities, especially due to beaver influence and shallow pond construction. When this happens, for purposes of this landscape-level assessment, it is assumed that wetland change has not been significant and the I_{WE} is recorded as 1.0.

The Standing Waterbody Extent Index (I_{SWE}) addresses the current extent of standing fresh waterbodies (e.g., lakes, reservoirs, and open-water wetlands - ponds) in a watershed relative to the historic area of such features.

> $\mathbf{I_{SWE} = A_{CSW}/A_{HSW}}$, where A_{CSW} is the current standing waterbody area and A_{HSW} is the historic standing waterbody area in the watershed.

In most cases, watersheds have experienced an increase in standing water due to reservoir, artificial lake, impoundment, and pond construction. Where this is true, the I_{SWE} value is 1.0+ which indicates a gain in this aquatic resource. For this situation, one should use a value of 1.0 when applying this index to determine the composite natural habitat integrity index for the watershed. If one suspects a loss of waterbody habitat, additional calculations are necessary. The historic and present acreages may be created by consulting older USGS topographic maps, comparing them against newer topographic maps (or NWI maps and statistics), and generating numbers showing acreage differences. Readers should note, however, that every wetland trends study that we have conducted over the past 20 years has shown a net increase in open freshwater habitat due to pond construction.

Stream and Wetland Disturbance Indices

A set of three indices have been developed to address alterations to streams and wetlands. For these indices, a value of 1.0 is assigned when all of the streams or existing wetlands have been modified.

The Dammed Stream Flowage Index (I_{DSF}) highlights the direct impact of damming on rivers and streams in a watershed.

> $\mathbf{I_{DSF} = L_{DS}/L_{TS}}$, where L_{DS} is the length of perennial rivers and streams impounded by dams (combined pool length) and L_{TS} is the total length of perennial rivers and streams in the watershed.

It does not attempt to predict the magnitude of downstream effects from such dams. The stream length of the dammed section is determined by drawing a centerline through the impounded polygon. It is, therefore, likely to be a conservative estimate of original stream length which often contains meanders or bends. The total stream length used for this index will be greater than that used in the channelized stream length index, since the latter emphasizes existing streams and excludes dammed segments.

The Channelized Stream Length Index (I_{CSL}) is a measure of the extent of channelization of streams within a watershed.

> $\mathbf{I_{CSL} = L_{CS}/L_{TS}}$, where L_{CS} is the channelized stream length and L_{TS} is the total stream length for the watershed.

Since this index addresses channelization of existing streams, the total stream length does not include the length of artificial ditches excavated in farmfields and forests or the length of dammed sections of streams. It will usually emphasize perennial streams, but could include intermittent streams, if desirable.

The Wetland Disturbance Index (I_{WD}) focuses on alterations of existing wetlands. As such, it is a measure of the extent of existing wetlands that are diked/impounded, ditched, or excavated:

> $\mathbf{I_{WD} = A_{DW}/A_{TW}}$, where A_{DW} is the area of disturbed or altered wetlands and A_{TW} is the total wetland area in the watershed.

Wetlands are represented by vegetated and nonvegetated (e.g., shallow ponds) types and include natural and created wetlands. Since the focus of our analysis is on "natural habitat," diked or excavated wetlands (or portions thereof) are viewed as an adverse action. We recognize, however, that many such wetlands may serve as valuable wildlife habitats (e.g., waterfowl impoundments), despite such alteration.

Composite Habitat Index for the Watershed

The Composite Natural Habitat Integrity Index (I_{CNHI}) is a combination of the preceding indices. It seeks to express the overall condition of a watershed in terms of its potential ecological integrity or the relative intactness of "natural" plant communities and waterbodies, without reference to specific qualitative differences among these communities and waters. Variations of I_{CNHI} may be derived by considering buffer zones of different widths around wetlands and streams (e.g., $I_{CNHI\ 100}$ or $I_{CNHI\ 200}$) and by applying different weights to individual indices or by separating or aggregating various indices (e.g., stream corridor integrity index, river corridor integrity index, or river/stream corridor integrity index).

An example of this composite index is given below emphasizing a 100-meter buffer:

$$I_{CNHI\ 100} = (0.5 \times I_{NC}) + (0.1 \times I_{SCI200}) + (0.1 \times I_{WB100}) + (0.1 \times I_{PLB100}) + (0.1 \times I_{WE}), + (0.1 \times I_{SWE}) - (0.1 \times I_{DSF}) - (0.1 \times I_{CSL}) - (0.1 \times I_{WD})$$

where the condition of the 100m buffer is used throughout. (Note: With this size buffer, the stream corridor width becomes 200m.)

A second example shows how weighting may be changed when a river corridor integrity index is added to the equation:

$$I_{CNHI\ 100} = (0.5 \times I_{NC}) + (0.05 \times I_{SCI200}) + (0.05 \times I_{RCI200}) + (0.1 \times I_{WB100}) + (0.1 \times I_{PLB100}) + (0.1 \times I_{WE}), + (0.1 \times I_{SWE}) - (0.1 \times I_{DSF}) - (0.1 \times I_{CSL}) - (0.1 \times I_{WD})$$

The weighting of the indices is debateable, but as long as a standard weighting scheme is applied, the results of this analysis would be comparable between subbasins and watersheds. The same weighting scheme must be used whenever comparisons of this index are made from one watershed to another, for example.

An Application of the Natural Habitat Integrity Indices for a Watershed

In 2000, we conducted a watershed study of two watersheds (Nanticoke and Coastal Bays) in eastern Maryland for the Maryland Department of Natural Resources. The study included the following for each watershed: a wetland characterization, preliminary assessment of wetland functions, an inventory of potential wetland restoration sites, an inventory of wetland and waterbody buffers (100m), an evaluation of the extent of ditching, and calculation of natural habitat integrity indices. This was the first time we applied these indices to a large watershed. The complete results are available for viewing and downloading at the NWI homepage (wetlands.fws.gov). The findings for natural habitat integrity indices will be given for the Nanticoke watershed to illustrate their application for watershed evaluation.

Study Area

The study area is the Maryland portion of the Nanticoke River watershed, a 323-square mile drainage area in eastern Maryland. Major tributaries of this portion of the watershed are Marshyhope, Rewastico, Quantico, and Wetipquin Creeks. It is composed of 61 percent upland, 8 percent deepwater habitat, and 31 percent wetland. Forty-two percent of the watershed is in agricultural usage and 6 percent is developed, while the rest remains in "natural vegetation" (e.g., wetlands, forests, thickets, and old fields). The watershed extends into Delaware, but that portion was not evaluated at that time. The Maryland portion includes parts of Dorchester, Wicomico, and Caroline Counties.

Almost 1,400 wetlands were mapped by the NWI in this watershed (Tiner et al. 2000). Roughly 64,000 acres of wetlands occurred in this watershed. Palustrine wetlands were most abundant, covering nearly 47,000 acres (73% of the wetlands), with forested wetlands predominating (80% of the palustrine wetlands). The bulk of the remaining wetlands (or 26%) is represented by estuarine wetlands, mostly emergent types (salt and brackish marshes). From the hydrogeomorphic (HGM) perspective, about two-thirds of the wetlands were terrene (52% of the wetlands, excluding ponds). Interfluve and fringe wetlands were the main types (37% and 35%, respectively) and outflow was the major water flow path descriptor (about 50% of the wetland acreage).

Methods Overview

The foundation of this project was construction of a fairly comprehensive, geospatial wetland database. The existing wetland digital data for Maryland included the NWI data (based on 1:24,000 maps derived from mostly early 1980s-1:58K color infrared photography) and the State's wetland data (based on digital orthophoto quarter-quads produced from 1989-1:40K color infrared photographs). The State data were used as collateral data to improve the delineation of wetlands in the NWI database. A 100m buffer was positioned around wetlands, waterbodies, and ditches. To evaluate the condition of the upland buffer, we created a land use/land cover data layer by combining existing digital data with new photointerpretation. The state's digital data on land use and land cover were used as the baseline data and were updated by interpreting 1998 aerial photography (1:40,000 black and white) using a digital transfer scope. The Anderson et al. (1976) land use and land cover classification system was used to classify upland habitats to level two. The following categories were among those identified: developed land (residential, commercial, industrial, transportation/communication, utilities, other, institutional/government, and recreational, farmsteads/farm-related buildings), agricultural land (cropland/pasture, orchards/nurseries/horticulture, and feedlots/holding areas), forests (deciduous, evergreen, mixed, and clear-cut), wetlands (from NWI data), and transitional land (moving toward some type of development or agricultural use, but future status unknown). Data layers were constructed for the entire "land" area of each watershed so that information could also be used for assessing their overall ecological condition.

Results for the Nanticoke River Watershed

The values for eight indices for the Nanticoke watershed are calculated and presented in Table 1. The composite natural habitat integrity index had a value of 0.53 using the formula: $I_{CNHI\,100} = (0.6 \times I_{NC}) + (0.1 \times I_{SC1200}) + (0.1 \times I_{WWB100}) + (0.1 \times I_{WE}), + (0.1 \times I_{SWE}) - (0.1 \times I_{DSF}) - (0.1 \times I_{CSL}) - (0.1 \times I_{WD})$. These indices provide evidence of a stressed system. A pristine watershed has an index value of 1.0 for natural habitat integrity. The value of 0.53 for the Nanticoke watershed signifies significant human modification. While stream corridors seem to be in reasonable shape with natural vegetation encompassing 66 percent of the 200m corridor and 73 percent of the 100m corridor, about half of the wetland and waterbody buffer has been developed (Figure 1). Overall, the Nanticoke watershed has lost about half of its natural habitat and almost 40 percent of its streams have been channelized. While slightly more than half (52%) of the land in the watershed is covered with "natural vegetation," about 42 percent is in agriculture and only 6 percent is developed (Figure 2). Application of these indices to individual subbasins within the watershed could aid in targeting areas for preservation and restoration.

Table 1. Index values for the Maryland portion of the Nanticoke River watershed (Tiner et al. 2000).

Index	Calculation	Value	Comment
Natural Cover	98,544/188,410	0.52	52% of the watershed contains "natural vegetation"
Stream Corridor Integrity (200m)	13,581/20,552	0.66	66% of the stream corridors are vegetated with "natural vegetation"
Wetland and Other Waterbody Buffer (100m)	23,181/46,978	0.49	49% of these buffers are colonized by "natural vegetation"
Wetland Extent	25,387/31,761	0.79	Based on Dorchester Co. portion only which is the least altered section of the watershed; the actual wetland extent is much less than this index suggests
Standing Waterbody Extent	No calculation	1.0+	There has been a net increase in standing open water in the watershed over time, due to the construction of impoundments and ponds.
Dammed Stream Flowage	6.5 miles/259.3	0.03	Only 3% of the perennial stream length has been dammed.
Channelized Stream Length	101.3/259.3	0.39	39% of the perennial stream length has been channelized.
Wetland Disturbance	22,767/64,139	0.35	35% of the wetlands have been partly drained (through ditching), excavated, and impounded (diked)

Figure 1. Condition of wetland and waterbody buffer (100m) in the Maryland portion of the Nanticoke watershed.

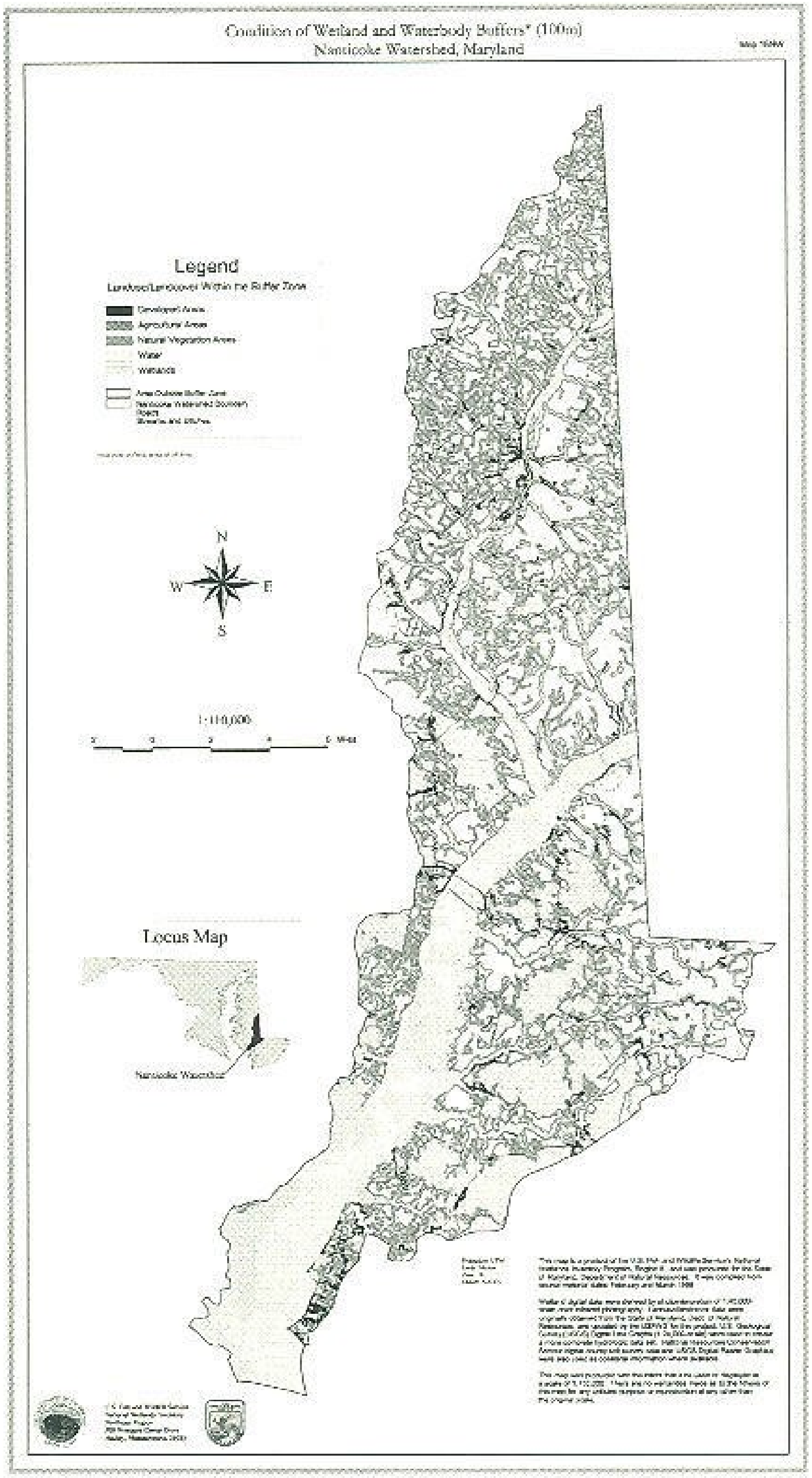
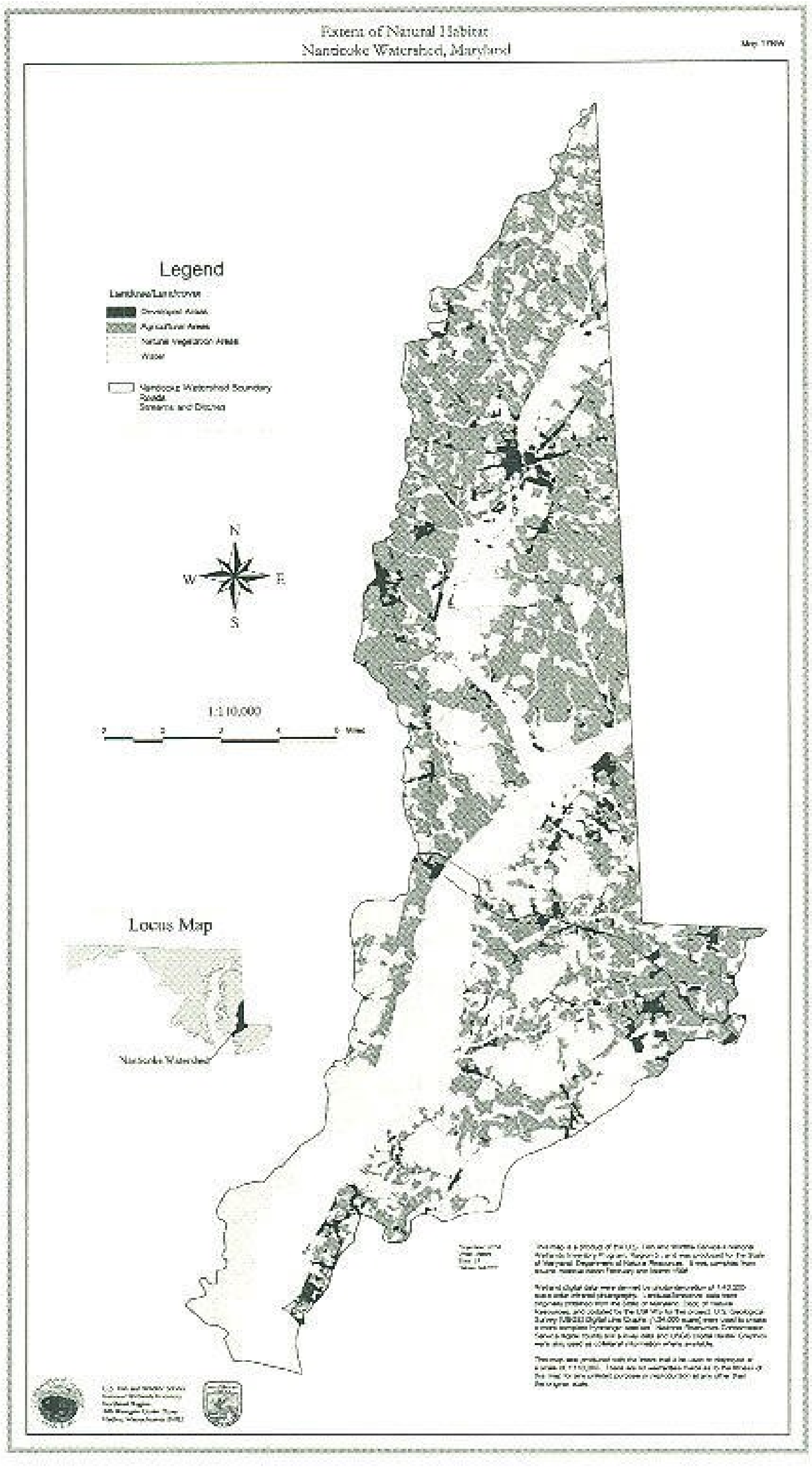


Figure 2. Extent of natural vegetation and developed lands in Maryland's Nanticoke River watershed.



Concluding Remarks

The indices provide valuable information for resource planners and decision-makers. They present a picture of how much natural habitat is present in a watershed and the amount of stream and wetland alteration that has taken place. Moreover, the specific locations of encroachments to wetland and waterbody buffers can be shown on maps which can be prepared using GIS technology. After this type of analysis, maps can be prepared to show the following features: 1) land cover and land use in river and stream corridors and buffers around wetlands, lakes, and ponds, 2) potential sites for restoring vegetated corridors and buffers, 3) channelized streams vs. nonchannelized streams, 4) dammed stream segments vs. free-flowing segments, 5) altered wetlands vs. nonaltered wetlands, and possibly 6) former wetlands vs. current wetlands (where digital soil data are available). Other information can be added to this type of analysis to provide a more complete view of wetlands and disturbance in the watershed, such as a preliminary assessment of wetland functions, an inventory of potential wetland restoration sites, and a map showing fragmented wetlands.

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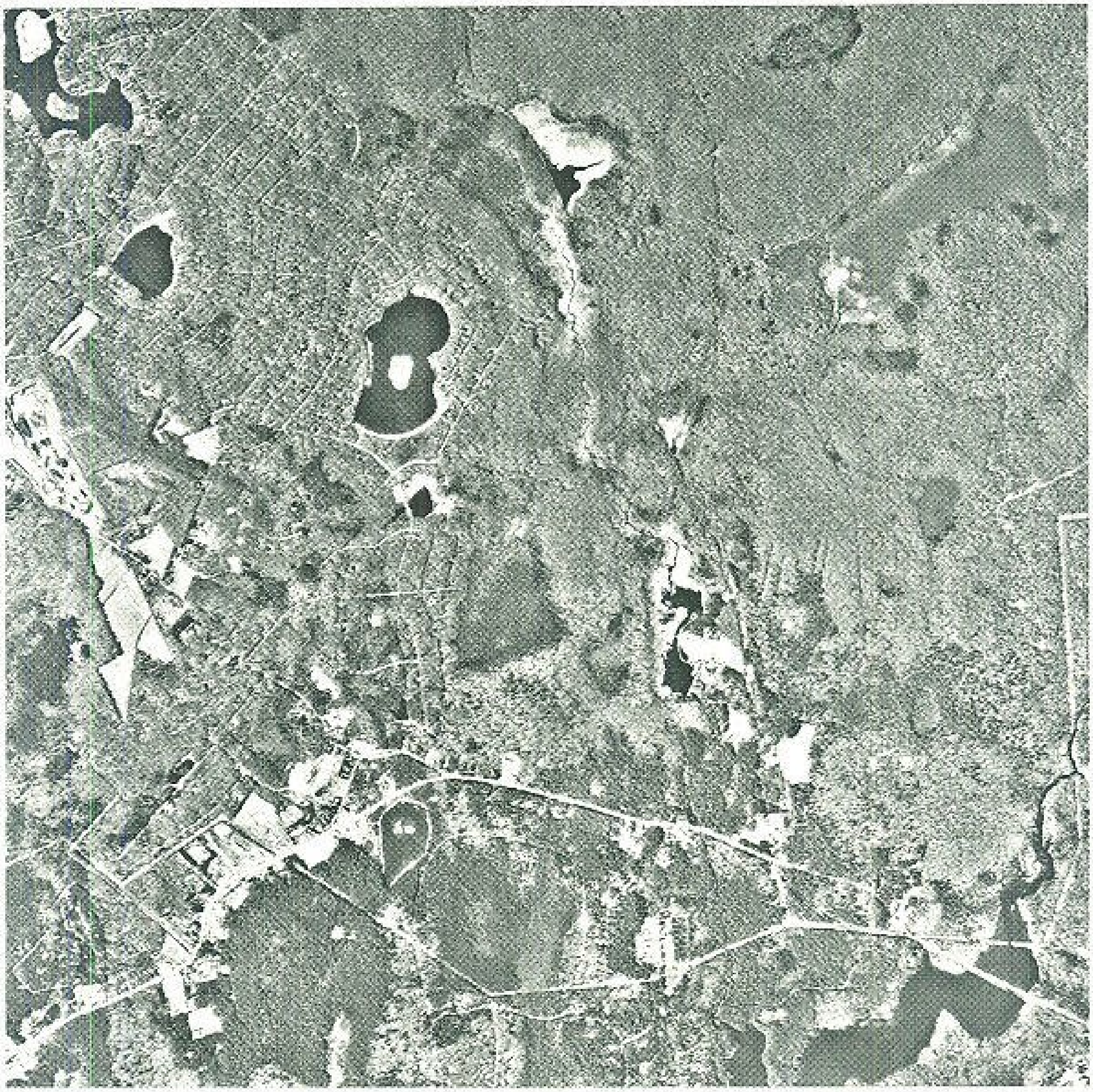

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