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Demonstrating Stream Health Improvement from Healthy Watershed Actions in Maryland

Authors: Mark Southerland, Carlos Lozano, and Andrea Fortman
AKRF, 7250 Parkway Drive, Hanover, MD 21076

1. Background

Healthy watersheds are essential to the goals of the Clean Water Act to protect, restore, and maintain the chemical, physical, and biological integrity of our nation's waters. This study aims to advance the science of healthy watersheds conservation using the entire State of Maryland as a case study. We hope this case study report will enhance the U.S. Environmental Protection Agency (EPA) Healthy Watersheds Program by providing a critical link between statewide assessments and management actions. Specifically, the report provides scientific basis for justifying the use of specific management actions, both in Maryland and other states. Hopefully, the findings of this study will lead to greater funding of healthy watersheds initiatives nationwide.

Initiated in 1995, the Maryland Department of Natural Resources (DNR)' Maryland Biological Stream Survey (MBSS) has sampled more than 5,000 stream sites statewide using a targeted and probability-based statistical design; it currently produces regular assessments of stream health using fish and benthic macroinvertebrate Indices of Biotic Integrity (IBIs). Statewide, the health of streams varies from very poor to good, including many watersheds that are least disturbed and exemplars of healthy watersheds. Assessments are made at the Maryland 8-digit (MDE8) watershed scale (comparable to the USGS 12-digit HUC) comprising 84 primary sampling units. Program references and detailed characterizations of watershed condition can be found on the MBSS website:

http://dnr.maryland.gov/streams/Pages/mbss.aspx

The State of Maryland also has an extensive inventory of protected lands that is georeferenced and assignable to MBSS sites and their upstream catchments. The following protected land types are included in our analysis:

- Coastal and Estuarine Land Conservation Program
- DNR Owned Properties and Conservation Easements
- Forest Conservation Act Easements
- Protected Federal Lands
- Local Protected Lands
- Private Conservation Lands
- Maryland Environmental Trust Easements
- Maryland Agricultural Land Preservation Foundation Easements
- Rural Legacy Properties
- Transfer Development and Purchase Development Rights

This study attempts to demonstrate the benefits of stream health improvements from healthy watershed actions in Maryland. Specifically, the study provides estimates of stream condition in protected and unprotected watersheds of comparable size and geography over a 20-year period. The results of the study have been disseminated at (1) workshop for the Healthy Watersheds Consortium grantees; (2) seminar at Maryland Department of Natural Resources for DNR Maryland Department of the Environment (MDE), county governments, and Maryland Water Monitoring Council, and (3) seminar at Center for Urban Environmental Research and Education (CUERE) at University of Maryland Baltimore County (UMBC) for academia, city government, and federal agencies.

2. Research Question

General question:

What is the effect of healthy watershed actions on stream condition?

Specific question:

What is the condition of Maryland streams in protected vs. non-protected areas from 1995-2016?

3. Methods

This study compares the stream condition of MBSS sites sampled during the years from 1995 to 2016, using both the fish and benthic macroinvertebrate IBIs. Each MBSS site was categorized by the status of its upstream catchment in terms of site type (reason for sampling), ecoregion, land use, size of catchment, and type of protection. All sites sampled by the MBSS were included in statistical analyses, where all available factors were included and evaluated in the same mixed-effects model. Site type was included in each statistical model so that the results would not be biased by site types that targeted higher quality streams (e.g., sentinel sites). Ecoregion was found to be not significant in any analysis; therefore it was removed from the final analyses.

3.1 Geographic Information System (GIS) Methods

The MBSS stream survey data were received from Maryland DNR, in the form of a Microsoft Access Database, and converted to the Excel file format (.xlsx) and .csv, as needed, for use in other programs. We extracted fish IBI (FIBI), benthic macroinvertebrate IBI (BIBI), site coordinates (to plot the sites in ArcMap for geospatial analysis), ecoregion stratum, year sampled, and land use. Latitude and longitude coordinates for each site were imported into ArcMAP, projected to State Plane (“NAD_1983_2011_StatePlane_Maryland_FIPS_1900_Ft_US”) for subsequent analysis. The MBSS program samples multiple site types to achieve a variety of monitoring goals. These site types include Tier II, MDE 319, coldwater, EPA, national park, random, sentinel, target, and special project sites. Sampling methods, effort levels, and the distribution of site types sampled varied from 1995-2016, as the sampling program evolved (Table 3-1). MBSS sites with their upstream catchments totally within a protected land boundary are show in Figure 3-1.

Table 3-1. Sampling program types (site type) in the MBSS data

Code	Sampling Program	Years
A	Tier II	2007, 2009-2012
B	MDE 319	2007-2010,2012
C	Coldwater	2000,2001,2012-2014
E	EPA	2004
N	National Park	2004
R	Random	1995-1997,2000-2004,2007-2009,2014-2016
S	Sentinel	2000-2004,2007-2009,2010-2016
T	Target	2000
X	Special Project	2006,2009,2010-2016

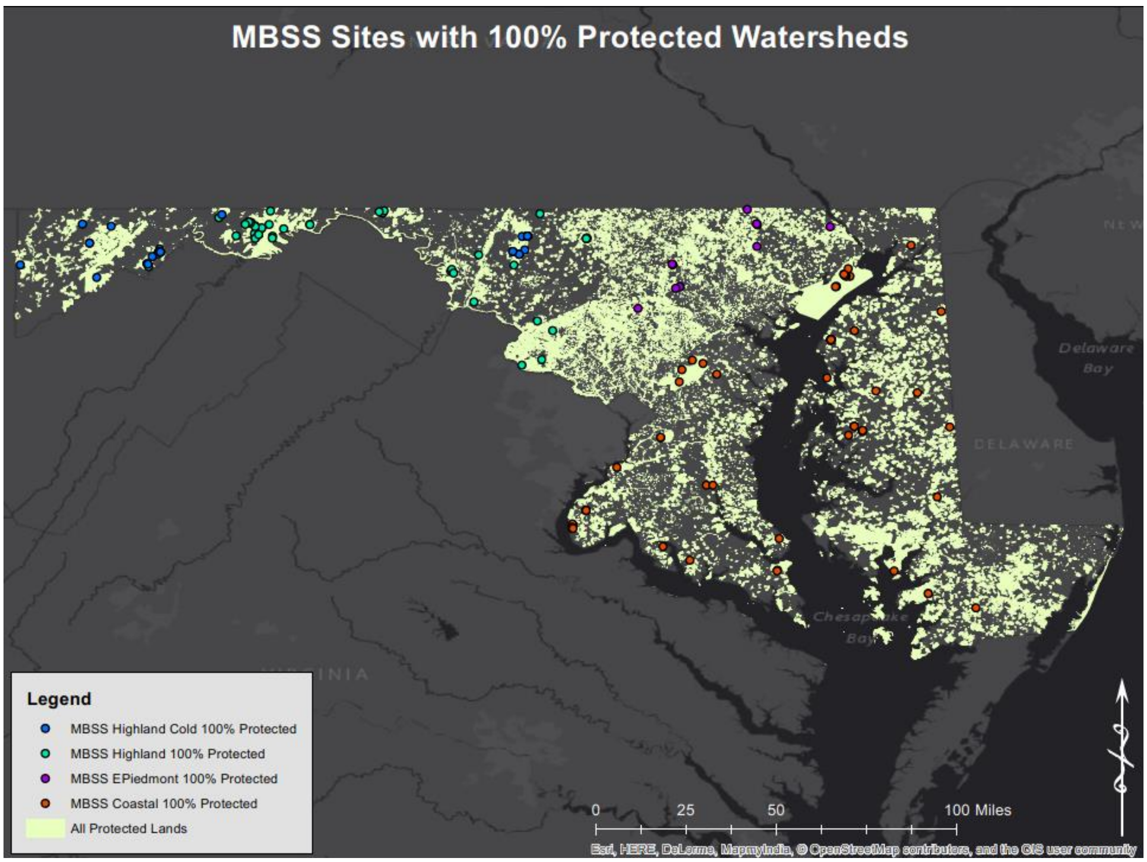

Figure 3-1. MBSS sites with their upstream catchments totally within a protected land boundary, shown by Maryland ecoregion.

Ecoregion Layer: The Level III Ecoregions of the Conterminous United States shape file (.shp polygons) published by the U.S. EPA was used to illustrate the extents of the ecoregion strata assigned to the MBSS data. The ecoregion layer attribute “US_L3Name” was used to create a new layer showing the outlines of the three major classifications used by the MBSS to describe physiographic regions in Maryland: Highlands (comprised of the L3 categories of “Blue Ridge”, “Ridge and Valley”, and “Central Appalachians”), Piedmont (L3 Name of “Northern

Piedmont"), and Coastal Plains (L3 Name categories "Southeastern Plains" and "Middle Atlantic Coastal Plains").

Land Use layer: 2002 Land Use/Land Cover for Maryland data set shape files (.shp polygons) were downloaded from the Maryland Department of Planning. Other land use data sets that are available from the same source show land use during 1973 and 2010. The 2002 dataset was selected as a mid-point in the sampling time period (1995–2016). The dataset, initially developed using high altitude aerial photography and satellite imagery, uses the Anderson Level 2 Classification System to display land use/land cover throughout the state. Land use classifications are shown in Table 3-2.

Table 3-2. Land use designations

Urban Land Uses	Low Density Residential
	Medium Density Residential
	High Density Residential
	Commercial
	Industrial
	Institutional
	Extractive
	Open Urban Land
Agricultural	Cropland
	Pasture
	Orchards/Vineyards/Horticulture
	Feeding Operations
	Agricultural Building Breeding and Training Facilities
	Row and Garden Crops
Forest	Deciduous Forest
	Evergreen Forest
	Mixed Forest
	Brush
Water	Rivers, waterways, reservoirs, ponds, bays, estuaries, and ocean
Wetlands	Forested or non-forested wetlands
Barren Land	Beaches
	Bare Exposed Rock
	Bare Ground
Transportation	Miscellaneous Transportation features not elsewhere classified

MDE8 Digit Watersheds: Shapefiles (.shp polygons) showing the 8-Digit watersheds used for management purposes by the MDE were received from Don Dorsey of the Frederick County Office of Sustainability and Environmental Resources.

Protected Lands Layers: Shapefiles (.shp polygons) were downloaded from the Maryland iMAP GIS Data Catalog. The Chesapeake Bay Protected Land Layer, created by the US EPA Chesapeake Bay Program Office, was also utilized, as it contains some land protections not included under the other land layers. Each layer has different attributes describing the data, and some are available in a projected coordinate system; those that were not already projected were converted to the Maryland State Plane coordinate system so that the area of protected land could be calculated. The protected lands programs vary in management styles, goals, and land uses, amongst other attributes, and are described in Table 3-3 and shown in Figure 3-2.

Table 3-3. Protected Lands Programs

Data Layers	**Description**
The Chesapeake Bay Protected Land Layer	The Chesapeake Bay Program defines protected lands as lands that are permanently protected from development, whether by purchase, donation, a perpetual conservation or open space easement, or fee ownership for their cultural, historical, ecological or agricultural value. This definition includes non-traditional conservation mechanisms like transfer or purchase of development rights programs. Lands protected through easements and purchase of development rights typically remain in private ownership. Protected lands include: county, town, city, state and federal parks; designated open space and recreational land; publicly owned forests and wetlands; privately owned working farms or forests with conservation easements; historically important lands, such as protected battlefields, colonial towns and farms; military-owned parks and recreational areas.
Coastal and Estuarine Land Conservation Program	A nationally-competitive land conservation program through NOAA started in MD in 2008. Properties must be located in the coastal zone. Goal: protect important coastal and estuarine areas with significant conservation, recreation, ecological, historical, or aesthetic values that may be vulnerable to conversion. Method: Maryland's Chesapeake & Coastal Program can submit up to three project proposals each with a requested funding of $3,000,000 per project and 1:1 match. Project proposals support coastal land conservation goals outlined in the state's CELCP plan.
DNR Owned Properties and Conservation Easements	Public land and protected open space owned or managed by the Maryland Department of Natural Resources. Land Units: State Parks, Natural Resources Management Areas, Natural Environmental Areas, State Battlefields, Rail Trails, State Forests, Demonstration Forests, the John S. Ayton Tree Nursery, Chesapeake Forest Lands, Forest Fire Tower sites, Wildlife Management Areas, Fishery Management Propagation Areas, Fishery Management Public Fishing Areas, State Wildlands, Heritage Conservation Sites, Marine/Communication Facilitates, and Undesignated lands
Forest Conservation Act Easements	The Forest Conservation Act of 1991 requires units of local government with planning and zoning authority to establish and implement local forest conservation programs. Goal: to minimize the loss of Maryland's forest resources during land development by making the identification and protection of forests and other sensitive areas an integral part of the site planning process Method: Identification of priority areas prior to development makes their retention possible. Of primary interest are areas adjacent to streams or wetlands, those on steep or erodible soils or those within or adjacent to large contiguous blocks of forest or wildlife corridors.

Protected Federal Lands	Land areas that are run and maintained by United States Governmental authorities and are considered protected. Owned by US NPS, US FWS, US BLM, US DOD. US NPS lands include monuments, historic sites, and historic trails. US BLM lands include 2,632 acres under lease by private mining companies for soil and natural gas exploration.
Local Protected Lands	Parcels subject to some type of preservation easement as well as properties owned by federal, state, and local governments. In addition, properties owned by local land trusts and private conservation organizations such as The Nature Conservancy are included. Conversation easements include easements from the Maryland Agricultural Land Preservation Foundation (MALPF), Rural Legacy, Forest Legacy, Maryland Environmental Trust (MET), county and state purchases of development rights, transfers of development rights, open space from home owners associations, local open space requirements, and private conservation easements. These data are compiled from settlement data directly from conservation program administrators, county GIS updates on preservation activities, and public available data from the Maryland Department of Natural Resources
Private Conservation Lands	Properties that are protected from development by a Private Conservation group or society either through ownership or conservation easement. Owners include: Accokeek Foundation, American Chestnut Land Trust, Blackwater-Saulsbury LLC, Chesapeake Bay Foundation, Chesapeake Wildlife Heritage, Civil War Preservation Trust, Hammond, Izaak Walton League, Lefebvre & Micucio, MD Ornithological Society, MD University BD of Regents, Potomac Conservancy Inc., Private Land Owner - TNC Easement), Somerset, Sporting Goods Properties, Stonebraker, Stronghold Inc., The Aspen Institute, The Nature Conservancy (TNC), Twelve Points LLC, and Wildlife Trust of America Inc.
Maryland Environmental Trust Easements	A statewide land trust, governed by a citizen Board of Trustees; program created in 1967. Goal: preservation of open land, including farmland, forest land, and significant natural resources. Method: conservation easements - agreements between landowner and MET
Maryland Agricultural Land Preservation Foundation Easements	Administered by a designated person in each county; program created in 1977. Goal: preserve productive agricultural land and woodland to provide for the continued production of food and fiber. Method: (1) short-term protection with an agricultural district, or (2) permanent protection with an agricultural easement.
Rural Legacy Properties	Easement acres determined by the Board of Public Works approval; program created in 1997. Goal: enhance natural resource, agricultural, forestry, and environmental protection while maintaining the viability of resource-based land uses such as farm production and timber harvest. Method: provides funds to local governments and land trusts to conserve land through the purchase of conservation easements, stressing partnerships among local, state, and federal governments and non-profit land trusts.

Transfer Development and Purchase Development Rights	"Transfer of Development Rights (TDR) is a voluntary, incentive-based program that allows landowners to sell development rights from their land to a developer or other interested party who then can use these rights to increase the density of development at another designated location. While the seller of development rights still owns the land and can continue using it, an easement is placed on the property that prevents further development. A TDR program protects land resources at the same time providing additional income to both the landowner and the holder of the development rights." The Purchase of Development Rights (PDR) is a voluntary program in which a land trust or a local, county or state agency buys the development rights on a parcel of land, primarily agricultural. PDRs "permanently extinguish all preexisting development potential of a particular property and are not used to offset development elsewhere in the county. Other than very limited rights reserved to the original grantor and their immediate family, no further commercial or residential subdivision is allowed. The grantor of the easement and all subsequent owners of the property retain full fee simple ownership of the land, but are bound by the terms of the Deed of Easement" in perpetuity.

Protected Lands Acquisitions data were downloaded as a .kmz file from geodata.md.gov. The dataset contain point feature data with the date of acquisition for properties within the Rural Legacy Properties, Maryland Environmental Trust Easements, and Maryland Agricultural Land Preservation Foundation Easements layers. The .kmz file was converted to an ArcGIS .shp file using ArcMap tools. Acquisition date tracking for these protection types began in 2007, so protected lands and the MBSS sample sites located on them were classified as either being protected before 2007, protected between 2007 and 2016, or as having an unknown protection date (if they did not belong to one of the above listed land protection program types).

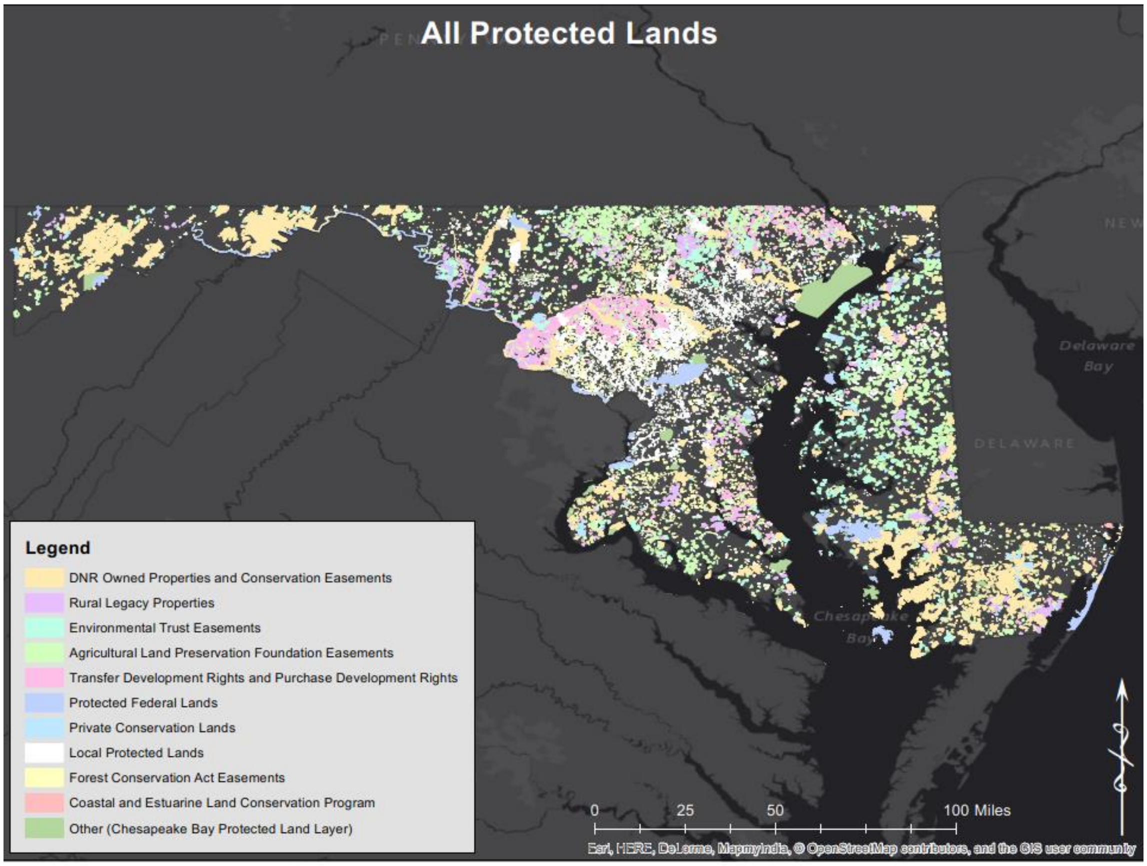

Figure 3-2. Protected lands by type throughout Maryland.

GIS Data Limitations:

- There is not comprehensive information about when each land area was protected, so a detailed title search would be required to determine when many of the lands (those not shown in the Protected Lands Acquisitions layer) were protected. This would be a time-consuming task for the more than 34,000 individual parcels within the state.
- Land use data is a snapshot of the land use in 2002, at the time that the dataset was produced and does not necessarily reflect the land use at the time that the protection was established, the time(s) when the site was sampled, or the current land use.
- There are different management objectives for different land management designations. Level of protection varies among land protection types, and sometimes within types (e.g., DNR has multiple management styles based on land use designation). However, our analysis only considered DNR lands managed for conservation (i.e., they did not include lands managed by Fisheries Service or Natural Resources Police, nor lands designated as fire towers and state park battlefields).
- The large number of MBSS sites precluded delineation of each watershed through the use of ArcMap toolsets (delineation of each individual site using the typical series of ArcMap Spatial Analyst tools was too time consuming and batch processing the sites produced inaccurate results). Therefore, drainage areas used for our analysis were determined by

visual examination of the topography of the land draining to each site, with the protected areas overlain on the contour lines to determine if the drainage area was 100% protected or less than 100% protected. If a polygon could be created to represent each MBSS site's drainage area, the percentage of the drainage area that is protected could be determined, which would help refine the analysis.

3.1.1 Geospatial analysis

ArcMAP version 10.3.1 was used for the geospatial analysis of the MBSS sites as follows:

- The Spatial Join tool was to assign land use/land cover values to each MBSS site point.
- The Union and Dissolve tools were used with the MDE8 Watersheds and protected lands layers to determine the percentage of each MDE8 Watershed that is protected.
- The Select by Location and Select by Attribute tools were used to create subsets of the MBSS sites for analysis. The sites were stratified by:
  - Ecoregion, which was subdivided into Coastal Plains, Piedmont, and Highlands, as shown
  - Sites located within protected lands versus sites located within unprotected lands
  - Sites located on protected lands that have a drainage area that is 100% within protected lands versus a drainage area that is partially protected (protection exists at the site and typically within some other portion of the drainage area, but not within the entire drainage area), or sites that are unprotected and have a 100% unprotected watershed
  - Acquisition date: as described above, MBSS sample sites were classified as being protected before 2007, protected between 2007 and 2016, or as having an unknown protection date
  - Sites located within DNR conservation areas (defined by DNR personnel as those area that are managed for conservation purposes, which excludes those managed by the Fisheries Service and the National Resources Police, as well as those designated as fire towers and state park battlefields)
  - Sites located within a protected area that is 100 acres or larger (MBSS site watershed size is variable within this category and the watershed is not necessarily 100% protected if the site is within this category)
  - Sites located within DNR conservation areas that are greater than 100 acres in size (MBSS site watershed size is variable within this category and the watershed is not necessarily 100% protected if the site is within this category).
- The intention of examining sample sites located within large protected areas is to show the effect of large, contiguous areas of protection on stream biology, as opposed to protecting only the entire upstream watershed, since organisms in a stream move both upstream and downstream, and impacts can cross ridge lines.

3.2 Statistical Analysis

The fish and benthic macroinvertebrate IBIs were the response variables indicating stream condition (comparable to a healthy watershed) (Southerland et al. 2007). One form of response was the probability of the IBI being 3 or greater (i.e., not degraded or unimpaired waters); the second form of response was the actual IBI score on the 1 to 5 scale (estimated IBI). Two kinds of statistical analysis were undertaken: (1) logistic and linear regression of the IBIs against the percentage of the MDE8 watershed that is protected and (2) logistic and Gaussian generalized linear mixed model of the IBIs against the factors of protected status, in combination with year sampled, site types, land use, and the interaction of year and protected status. Ecoregion was not significant in any analyses and was eliminated from the model. For each of the mixed model analyses, protected status was redefined as (1) all protected lands, (2) DNR protected lands, (3) 100-acre-minimum protected lands, and (4) 100-acre-minimum DNR protected lands.

3.2.1 Percentage of watershed protected

We tested the IBIs against the percent of MDE8 watershed that was protected using linear regression. In this analysis, the IBI was the response and the percent of watershed protected was used as the independent variable. We used both logistic and linear regression to test the effect of percent of watershed protected. The logistic model is:

$$(3)\ \log\left[\frac{Pr(Y_{pp}=1)}{1-\Pr(Y_{pp}=1)}\right]=\beta_0+\beta_1 x_{pp}+\varepsilon_{pp}$$

where:

$\log\left[\frac{Pr(Y_{pp}=1)}{1-\Pr(Y_{pp}=1)}\right]$ is the logit link of the probability of the and IBI being 3 or greater, $\Pr(Y_{pp}=1)$,
β_0 is the intercept or the log odds value when x=0;
$\beta_1 x_{pp}$ is the parametric estimate of the effect from the percent of watershed protected (*pp*; possible range from 0 to 100%);
and ε_{pp} is the error associated with the logistic function link (logit) given pp, the percent of watershed protected.

The linear model is:

$$(4)\ Y_{pp}=\beta_0+\beta_1 x_{pp}+\varepsilon_{pp}$$

where:

Y_{pp} is the calculated IBIs from the MBSS survey,
β_0 is the intercept;
$\beta_1 x_{pp}$ is the parametric estimate of the effect from the percent of watershed protected (*pp*; possible range from 0 to 100%);
and ε_{pp} is the error.

3.2.2 Logistic generalized linear mixed model

The MBSS program classifies an IBI of 3 or greater to be a "healthy" watershed. The probability of an IBI being 3 or greater was modeled using a logistic regression Generalized Linear Mixed Model ("GLMM") with a logit link. A mixed model approach was used for more than one reason: (1) some of the sampling effort in the MBSS survey relied on fixed sample sites that were sampled multiple years, (2) more than one sampling strategy was used in the MBSS survey, and (3) the number of sites within levels of our tested factors (described below in this section) were unbalanced. Year was used in the model as a continuous variable, though 1998 and 1999 were not sampled, and the independent factors were (1) protected versus unprotected, 2) site types (i.e., sample design in program), (3) land use categories, and (4) the interaction between years and protected versus unprotected. Site type was included in the analyses to account for the expected effect of the sentinel site sampling program. Sentinel sites are high quality sites that made up a greater proportion of sampled sites in later years. If a significant difference between random and sentinel sites is detected then the overall model is adjusted accounting for this difference. The random unit in the mixed model was MDE8 watershed. Sampling within each MDE8 watershed was done randomly for the randomly sampling effort of the MBSS. The model used in this portion of the analyses is:

$$(1)\ \log\left[\frac{Pr\left(Y_{i,y,p,s,l,y*p}=1\right)}{1-\Pr\left(Y_{i,y,p,s,l,y*p}=1\right)}\right] = (\alpha+u_i)+\beta_1 x_y+\beta_2 x_p+\beta_3 x_s+\beta_4 x_l+\beta_5 x_{y*p}+\varepsilon_{i,y,p,s,l,y*p}$$

where:

$\log\left[\frac{Pr\left(Y_{i,y,p,s,l,y*p}=1\right)}{1-\Pr\left(Y_{i,y,p,s,l,y*p}=1\right)}\right]$ is the logit link of the probability of and IBI being 3 or greater, $Pr\left(Y_{i,y,p,s,l,y*p}=1\right)$, given MDE8 watershed, *i*, year, *y*, protected versus unprotected, *p*, station type, *s*, land use, *l*, and the interaction between year and the protected versus unprotected factor, *y*p*;
α is the intercept or the log odds value when x=0;
u_i is in matrix notation representing the combination of random intercepts for each subject (MDE8 watershed);
$\beta_1 x_y$ is the parametric estimate of the year effect (1995-2016);
$\beta_2 x_p$ is the parametric estimate for the protected versus unprotected factor;
$\beta_3 x_s$ is the parametric estimate for site type factor (see Table);
$\beta_4 x_l$ is the parametric estimate of the land use factor (see Table);
$\beta_5 x_{y*p}$ is the parametric estimate of the interaction between year and the protected versus unprotected factor,
and $\varepsilon_{i,y,p,s,l,y*p}$ is the error associated with the logistic function link (logit) given station, *i*, year, *y*, protected versus unprotected, *p*, site type, *s*, land use, *l*, and the interaction between year and the protected versus unprotected, *y*p*.

Differences among levels within the factors in the model were compared using pairwise least squares contrasts. We set up contrasts for protected versus unprotected, the interaction between year and protected versus unprotected, and site type. The only two levels we compared in the site type factor were the random versus sentinel sites. Random and sentinel sites accounted for most of the samples in the data. We also wished to know the effect of including the sentinel sites in the analysis since they were specifically selected because they had high IBI scores.

3.2.3 Generalized linear mixed model

A separate analysis was done to evaluate the IBIs with respect to our suite of independent variable and factors. In this analysis we used the actual IBI values as the response assuming a Gaussian distribution. The statistical model used in this analysis was a GLMM with a Gaussian distribution. The model was structure was set up identically to the logistic GLMM. Under this assumption an identity link is used in the response and is equivalent to that of that of the general linear model. The model is:

$$(2)\ \mathrm{E}\left(Y_{i,y,p,s,l,y*p}\right) = (\alpha+u_i)+\beta_1 x_y+\beta_2 x_p+\beta_3 x_s+\beta_4 x_l+\beta_5 x_{y*p}+\varepsilon_{i,y,p,s,l,y*p}$$

Where the units of the response with the identity link, $E(Y_{i,y,p,s,l,y*p})$, has the exact same units as the IBI. The parameters and random unit are the same as in the logistic GLMM explained above.

4. Results

The study results address the following questions:

- Does the percentage of protected land in a watershed affect stream condition?
- Does protected status, in combination with year sampled, site types, land use, and the interaction of year and protected status, affect stream condition?
- Do the following types of protected status affect stream condition differently:
  - all protected lands
  - DNR protected lands
  - 100-acre-minimum protected lands
  - 100-acre-minimum DNR protected lands.

Results are presented separately for fish IBI and benthic IBI. Results are also presented for the probability of the IBI being 3 or greater and estimated IBI score. The effect of land use that is accounted for in the model is also described. The sample sizes available for the analyses are shown in Table 4-1.

	Fully Protected	Partially Protected	Fully + Partially
All Protected	117	1343	1460
DNR Protected	51	515	566
All Protected 100+ Acres	54	142	196
DNR Protected 100+ Acres	37	125	162

	Fully Protected	Partially Protected	Fully + Partially
All Protected	143	1497	1460
DNR Protected	66	566	632
All Protected 100+ Acres	64	150	214
DNR Protected 100+ Acres	47	132	179

Table 4-1. Sample sizes for MBSS sites with upstream catchments that are fully and partially located within protected lands boundaries (Left: Fish IBI sites; Right: Benthic IBI sites).

4.1 Percentage of Protected Land in a Watershed

The probability of a fish IBI being 3 or greater from logistic regression and estimated fish IBI from linear regression significantly increased with respect to the percent of a watershed that is protected ($p < 0.05$; Figure 4-1). This analysis was conducted using random sites only to meet the assumptions of the analysis.

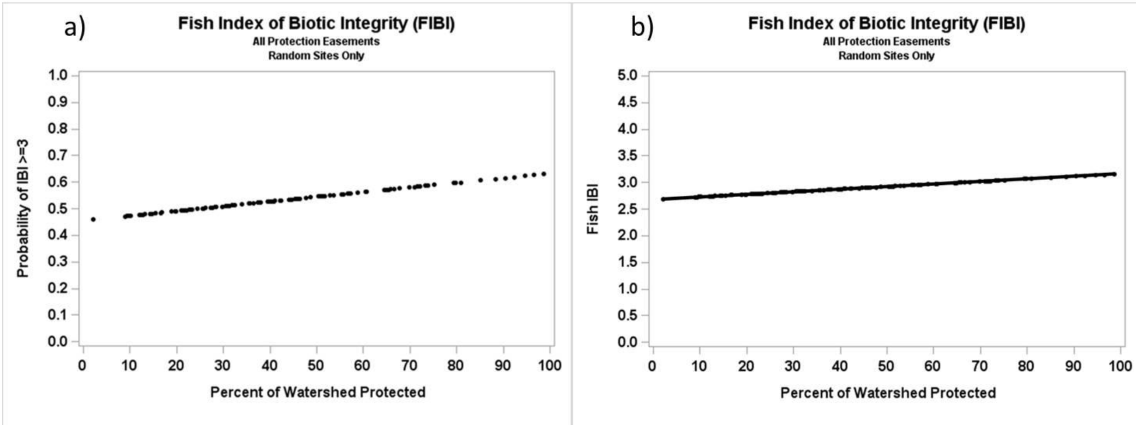

Figure 4-1. The (a) probability of a fish IBI being 3 or greater from a logistic regression and (b) estimated fish IBI from a linear regression with respect to the percentage of a MDE8 watershed that is protected.

The probability of a benthic IBI being 3 or greater from logistic regression and estimated benthic IBI from linear regression significantly increased with respect to the percentage of a watershed that is protected ($p < 0.05$; Figure 4-2).

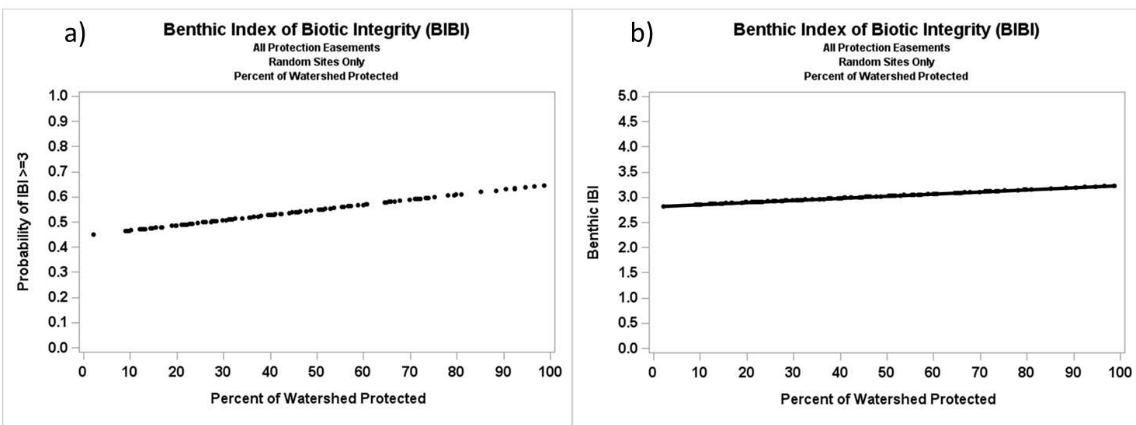

Figure 4-2. The (a) probability of a benthic IBI being 3 or greater from a logistic regression and (b) estimated benthic IBI from a linear regression with respect to the percent of a MDE8 watershed that is protected.

4.2 Effect of Protected Status on Stream Condition

Results are presented separately for fish IBI and benthic IBI. Results are also presented for the probability of the IBI being 3 or greater and IBI score (estimated IBI).

Protected status is evaluated for (1) all protected sites, (2) DNR protected lands, (3) 100-acre-minimum protected lands, and (4) 100-acre-minimum DNR protected lands, in each analysis.

4.2.1 Fish IBI

Probability of a fish IBI being 3 or greater

All Protected Sites. Overall the probability of a fish IBI being 3 or greater using all types of protected lands is higher at unprotected sites (0.17) compared to protected sites (0.06). This difference was significant ($p < 0.05$). The interaction between year and protected versus unprotected sites was significant, however, indicating a difference in the linear relationship between the two site categories. The estimated slope in the log odds linear relationship of the logistic model for unprotected sites with respect to year was 0.021 compared to the significantly higher ($p < 0.05$) slope for protected sites (0.045). The estimated probability of fish IBI being 3 or greater for protected sites surpassed the estimated probability for unprotected sites in the most recent years (Figure 4-3a).

DNR Sites. When comparing only DNR protected sites with unprotected sites the difference in probability between the two is slightly smaller but still significant ($p < 0.05$). In this case the overall probability of fish IBI being 3 or greater for DNR protected is 0.06 while the probability for unprotected sites is 0.15. The estimated log odds slope of the unprotected sites with respect to year is 0.012 compared to 0.023 of the DNR protected sites and this difference is significant ($p < 0.05$). The estimated probability of fish IBI being 3 or greater for protected sites surpassed the estimated probability for unprotected sites in the most recent years (Figure 4-3b).

100-acre Sites. Comparing the sites considering all protected sites but only those that were in 100 acres or greater, the protected sites had significantly ($p < 0.05$) higher overall probability of fish IBI being 3 or greater (0.50) compared to unprotected sites (0.14). The difference in the log odds slopes between protected (-0.01) and unprotected (0.014) was significant ($p < 0.05$). The estimated probabilities did not demonstrate a large difference in the trends between protected and unprotected sites (Figure 4-3c).

100-acre DNR Sites. Using only DNR sites that were in 100 acres or greater protected lands the overall difference in probability of fish IBI being 3 or greater between protected and unprotected was bigger. In this analysis the probability was 0.56 for protected sites versus 0.14 for unprotected sites and the difference is significant ($p < 0.05$). The slope of the protected sites with respect to year (-0.026) was significantly different than the slope of the unprotected sites (0.015). The estimated probabilities did not demonstrate a large difference in the trends between protected and unprotected sites (Figure 4-3d).

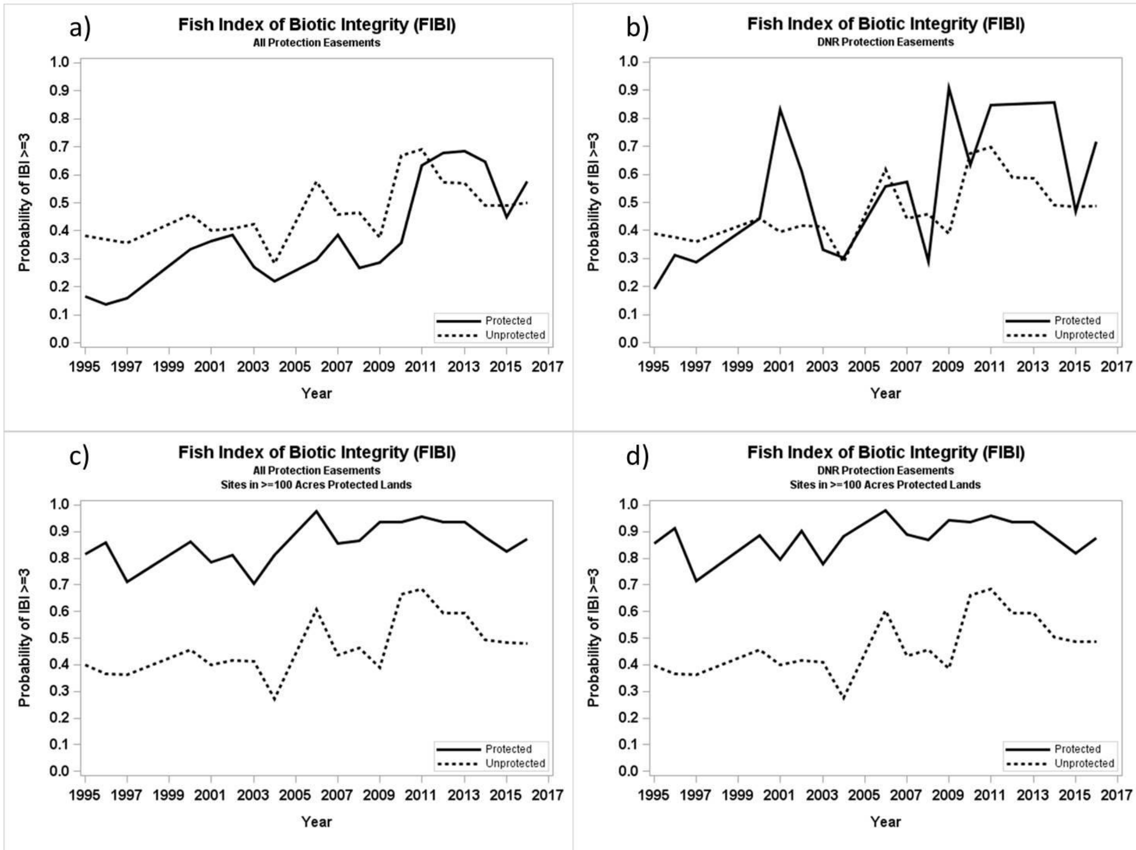

Figure 4-3. The probability of a fish index of biotic integrity being 3 or greater modeled from logistic generalized linear mixed models for a comparison of sample sites in (a) all types of protected lands, (b) DNR sites only, (c) all types of protected lands that have 100 acres or greater protected lands, and d) DNR sites that have 100 acres or greater.

Fish IBI scores

All Protected Sites. The estimated fish IBIs (fish IBI scores) were not significantly different between protected (1.69) and unprotected sites (2.19) in the analysis assuming a Gaussian distribution ($p > 0.05$). The estimated slopes in the log odds linear relationship were not different between protected (0.037) and unprotected (0.002) sites ($p > 0.05$). The trends in fish IBIs with respect to year exhibited a similar pattern as with the first analysis, i.e., estimated probabilities of being 3 or greater. The estimated fish IBI for protected sites were less than the unprotected in the earlier years but over time the estimates for protected sites surpassed those for unprotected sites in the most recent years (Figure 4-4a).

DNR Sites. Using only the DNR sites, estimated fish IBIs were not significantly different between protected (1.78) and unprotected sites (2.23) in the analysis assuming a Gaussian distribution ($p > 0.05$). The estimated slopes in the log odds linear relationship were not different between protected (0.035) and unprotected (-0.002) sites ($p > 0.05$). The estimated fish IBI for protected sites being less than the unprotected in the earlier years but the inverse is true in the most recent years (Figure 4-4b).

100-acre Sites. For the sites considering all protection sites, but only those that were in 100 acres or greater, the protected sites had higher overall estimated fish IBI (3.12) compared to unprotected sites (2.13), but the difference was not significant ($p > 0.05$). The difference in the log odds slopes between protected (-0.013) and unprotected (0.001) was not significant ($p > 0.05$). The estimated fish IBIs did not demonstrate a large difference in the trends between protected and unprotected sites (Figure 4-4c).

100-acre DNR Sites. For the sites considering DNR sites, but only those that were in 100 acres or greater, the protected sites had higher overall estimated fish IBI (3.21) compared to unprotected sites (2.15), but the difference was not significant ($p > 0.05$). The difference in the log odds slopes between protected (-0.017) and unprotected (0.002) was not significant ($p > 0.05$). The estimated fish IBIs did not demonstrate a large difference in the trends between protected and unprotected sites (Figure 4-4d).

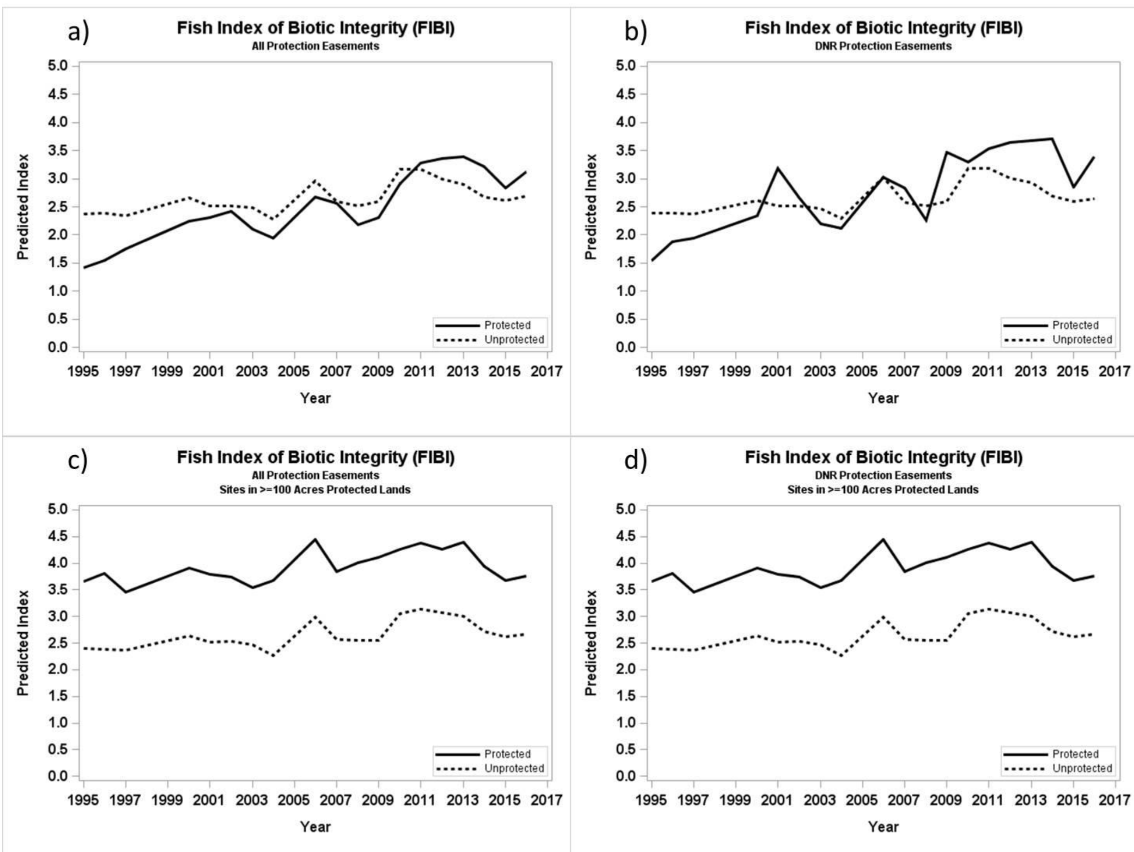

Figure 4-4. The estimated fish index of biotic integrity modeled from Gaussian generalized linear mixed models for a comparison of sample sites in (a) all types of protected lands, (b) DNR sites only, (c) all types of protected lands that have 100 acres or greater protected lands, and (d) DNR sites that have 100 acres or greater.

Effect of land use accounted for in models

The land use factor was significant in each model in our analyses ($p < 0.05$) except for the logistic GLMM using DNR sites ($p > 0.05$). In the models, the probabilities of fish IBI being 3 or greater and estimated fish IBI from the Gaussian GLMM were highest for sites in the "Other" and "Forested" land use categories (Table 4-2). Pairwise comparisons between each level combination were not made but the effect from the land use factor is accounted for in each model.

Table 4-2. Estimated probability of fish IBI being 3 or greater from logistic generalized linear mixed model ("Log"; blue) and estimates of fish IBI from Gaussian generalized linear mixed model ("Gau"; olive) for all levels within the land use factor and each analysis: using sites from all protection easements ("All"), DNR protection easements ("DNR"), all protection easements in 100 acres or greater protected lands ("All 100 Acres"), and DNR protection easements in 100 acres or greater protected lands ("DNR 100 Acres").

	All		**DNR**		**All 100 Acres**		**DNR 100 Acres**	
Land Use	**Log**	**Gau**	**Log**	**Gau**	**Log**	**Gau**	**Log**	**Gau**
Agricultural	0.17	2.09	0.17	2.13	0.45	2.82	0.48	2.86
Barren	0.02	0.93	0.02	0.99	0.06	1.67	0.07	1.69
Commercial	0.08	2.07	0.09	2.14	0.27	2.81	0.29	2.83
Forested	0.31	2.46	0.32	2.52	0.66	3.23	0.68	3.24
Industrial	0.02	1.59	0.02	1.66	0.06	2.34	0.07	2.35
Institutional	0.07	2.15	0.02	1.90	0.07	2.57	0.07	2.59
Other	0.72	2.54	0.82	3.03	0.95	3.61	0.95	3.63
Development	0.29	1.94	0.30	1.98	0.48	2.29	0.66	2.67
Residential	0.15	2.20	0.15	2.24	0.42	2.93	0.44	2.95
Wetlands	0.02	1.44	0.02	1.48	0.04	1.97	0.03	1.97

4.2.2 Benthic index of biotic integrity

Probability of a benthic IBI being 3 or greater

<u>All Protected Sites</u>. Overall the probability of a benthic IBI being 3 or greater using all types of protected lands is higher at unprotected sites (0.22) compared to protected sites (0.17). This difference was not significant however ($p > 0.05$). None of the factors or the year variable were significant in this model ($p > 0.05$). The estimated slope in the log odds linear relationship of the logistic model for unprotected sites with respect to year is between -0.001 and 0 compared to the slope for protected sites (0.044). The estimated probability of benthic IBI being 3 or greater for protected sites surpassed the estimated probability for unprotected sites in the most recent years (Figure 4-5a).

<u>DNR Sites</u>. When comparing only DNR sites with unprotected sites the overall probability of fish IBI being 3 or greater for DNR protected sites is 0.45 while the probability for unprotected sites is 0.33. This difference is not significant ($p > 0.05$). The estimated log odds slope of the unprotected sites with respect to year is -0.011 compared to 0.1072 of the DNR sites, but this difference is not significant ($p > 0.05$). The estimated trend in probability of fish IBI being 3 or greater for protected sites surpassed the estimated probability for unprotected sites in the most recent years (Figure 4-5b).

100-acres Sites. Comparing the sites considering all protection easements, but only those that were in 100 acres or greater, the protected sites were not significantly ($p > 0.05$) different in overall probability of fish IBI being 3 or greater (0.43) compared to unprotected sites (0.20). The difference in the log odds slopes between protected (-0.01) and unprotected (between -0.01 and 0) was not significant ($p > 0.05$). The estimated probabilities did not demonstrate a large difference in the trends between protected and unprotected sites, but after initially being equal in earlier years the estimated probabilities for protected sites surpassed those from unprotected sites (Figure 4-5c).

100-acres DNR Sites. Using only DNR sites that were in 100 acres or greater, the overall difference in probability of fish IBI being 3 or greater between protected and unprotected was greater, however still not significant ($p > 0.05$). The probability for protected sites was 0.55 versus 0.20 for unprotected sites. The slope of the unprotected sites with respect to year (-0.006) was not significantly different than the slope of the protected sites (-0.018). The estimated probabilities did not demonstrate a large difference in the trends between protected and unprotected sites (Figure 4-5d).

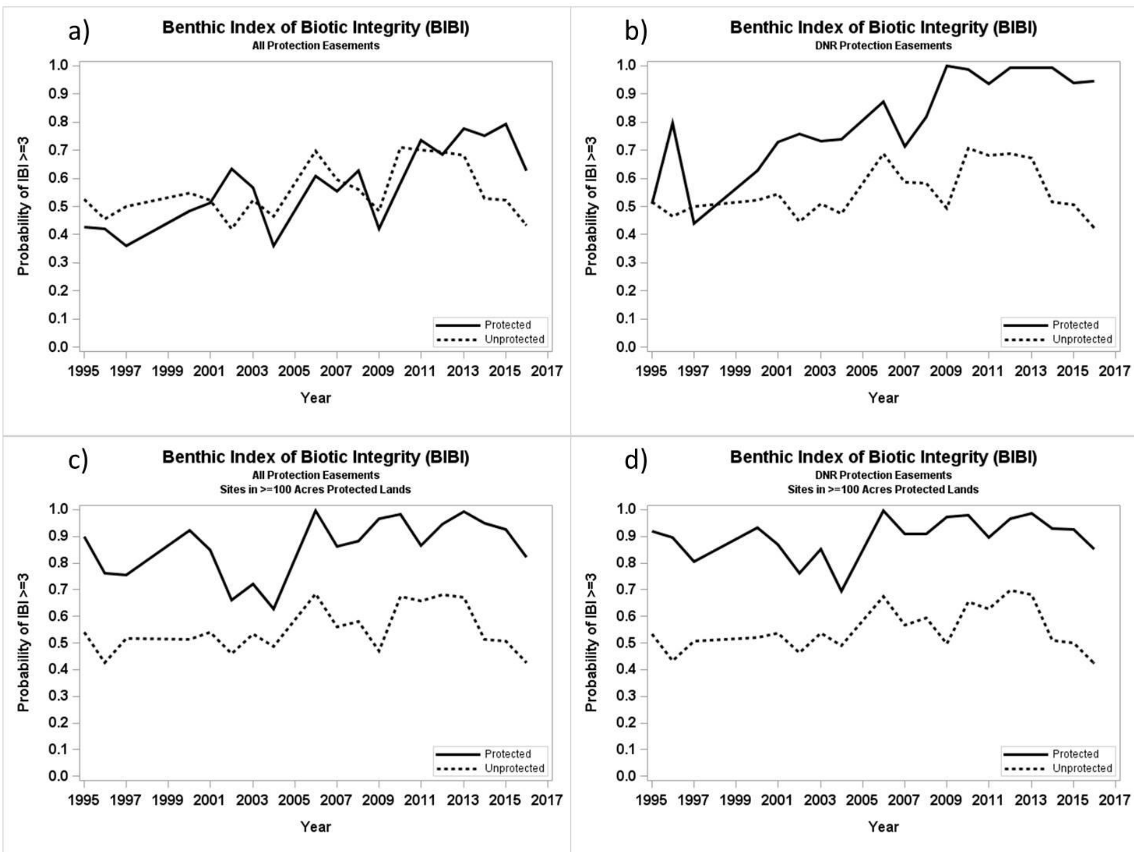

Figure 4-5. The probability of a benthic index of biotic integrity being 3 or greater modeled from logistic generalized linear mixed models for a comparison of sample sites in (a) all types of protected lands, (b) DNR sites only, (c) all types of protected lands that have 100 acres or greater protected lands, and (d) DNR sites that have 100 acres or greater.

Benthic IBI scores

All Protected Sites. The estimated benthic IBIs were not significantly different between protected (2.55) and unprotected sites (2.59) in the analysis assuming a Gaussian distribution ($p > 0.05$). The estimated slopes in the log odds linear relationship also were not different between protected (-0.001) and unprotected (0.013) sites ($p > 0.05$). The estimated benthic IBIs for protected sites were lower than the unprotected sites in the earlier years and over time the estimates for protected sites surpassed those from unprotected sites in the most recent years (Figure 4-6a).

DNR Sites. Using only the DNR sites, estimated benthic IBIs were not significantly different between protected (2.73) and unprotected sites (2.79) in the analysis assuming a Gaussian distribution ($p > 0.05$). The estimated slopes in the log odds linear relationship are not different between protected (0.028) and unprotected (-0.001) sites ($p > 0.05$). The estimated benthic IBI for protected sites were approximately equal to the unprotected in the earlier years but surpassed them in later years (Figure 4-6b).

100-acre Sites. For the sites considering all protection easements, but only those that were in 100 acres or greater, the protected sites had an overall estimated benthic IBI of 2.84 compared to 2.56 for unprotected sites, but this difference was not significant ($p > 0.05$). The difference in the log odds slopes between protected (-0.013) and unprotected (0.003) was not significant ($p > 0.05$). The estimated benthic IBIs did not demonstrate a large difference in the trends between protected and unprotected sites (Figure 4-6c).

100-acre DNR Sites. For the sites considering DNR protection easements but only those that were in 100 acres or greater, the protected sites had higher overall estimated benthic IBI (3.00) compared to unprotected sites (2.56), but the difference was not significant ($p > 0.05$). The difference in the log odds slopes between protected (-0.019) and unprotected (0.001) was not significant ($p > 0.05$). The estimated benthic IBIs did not demonstrate a large difference in the trends between protected and unprotected sites (Figure 4-6d).

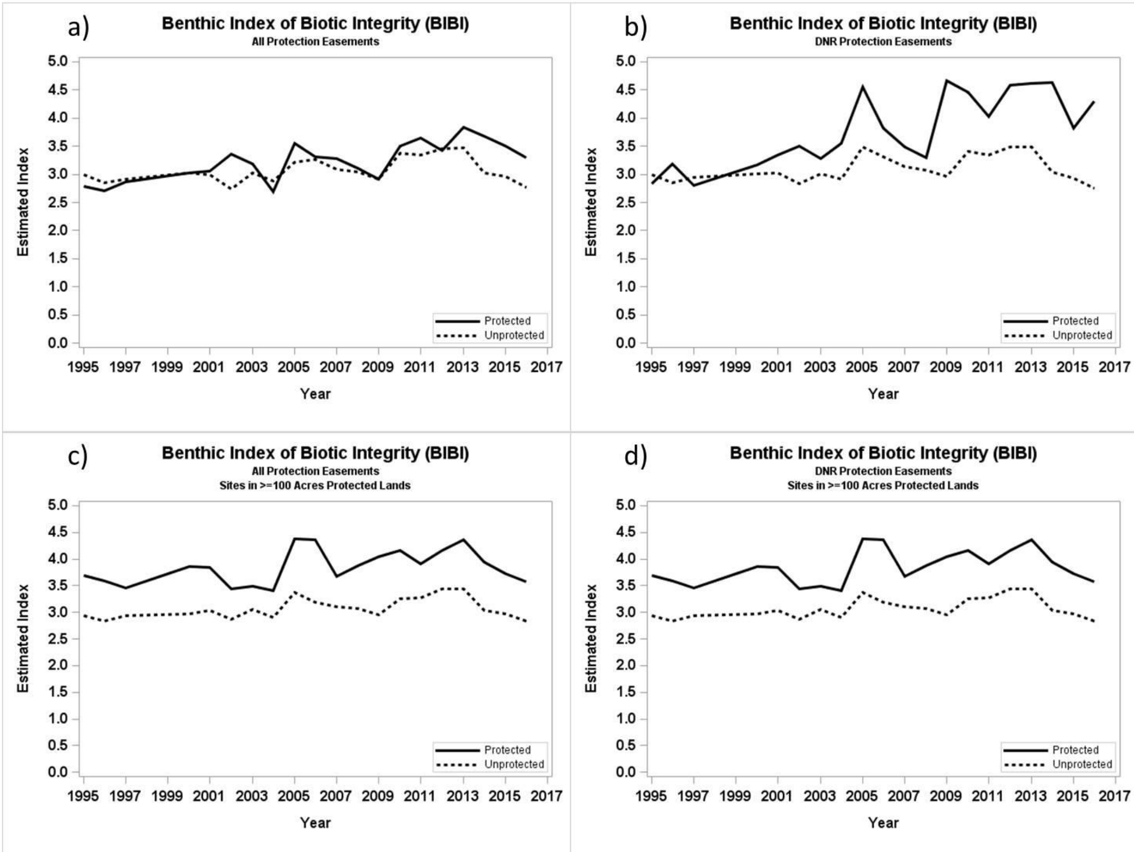

Figure 4-6. The estimated fish index of biotic integrity modeled from Gaussian generalized linear mixed models for a comparison of sample sites in (a) all types of protected lands, (b) DNR sites only, (c) all types of protected lands that have 100 acres or greater protected lands, and (d) DNR sites that have 100 acres or greater.

Effect of land use accounted for in models

The land use factor was significant in each Gaussian model in our analyses ($p < 0.05$) but not for any logistic GLMM ($p > 0.05$). In the models, the probabilities of benthic IBI being 3 or greater and estimated benthic IBI from the Gaussian GLMM were highest for sites in the “Forested”, “Water”, and “Wetlands” land use categories (Table 4-3). Pairwise comparisons between each level combination were not made but the effect from the land use factor is accounted for in each model.

Table 4-3. Estimated probability of benthic IBI being 3 or greater from logistic generalized linear mixed model ("Log"; blue) and estimates of benthic IBI from Gaussian generalized linear mixed model ("Gau"; olive) for all levels within the land use factor and each analysis: using sites from all protection easements ("All"), DNR protection easements ("DNR"), all protection easements in 100 acres or greater protected lands ("All 100 Acres"), and DNR protection easements in 100 acres or greater protected lands ("DNR 100 Acres").

	All		**DNR**		**All 100 Acres**		**DNR 100 Acres**	
Land Use	**Log**	**Gau**	**Log**	**Gau**	**Log**	**Gau**	**Log**	**Gau**
Agricultural	0.45	2.72	0.69	2.91	0.49	2.82	0.53	2.88
Barren	0.57	2.45	0.80	2.67	0.62	2.52	0.66	2.59
Commercial	0.01	2.20	0.02	2.44	0.01	2.26	0.01	2.34
Forested	0.64	3.21	0.83	3.40	0.69	3.30	0.72	3.37
Industrial	0.01	2.47	0.02	2.71	0.01	2.54	0.01	2.61
Institutional	0.36	2.43	0.58	2.63	0.37	2.46	0.41	2.53
Other	0.33	2.04	0.60	2.25	0.38	2.16	0.42	2.24
Development	< 0.01	1.69	0.01	1.96	< 0.01	1.72	0.01	1.87
Residential	0.72	2.79	0.69	3.00	0.50	2.91	0.54	2.98
Water	0.43	3.01	0.69	3.26	> 0.99	4.66	> 0.99	4.75
Wetlands	0.76	3.19	0.79	3.19	0.34	2.36	0.35	2.40

4. Conclusions

This study used the robust stream condition data of the MBSS, in combination with GIS data on the boundaries of lands with protected status, to demonstrate some significant effects of protection on watershed and stream condition. The models incorporated the additional factors of year, site type (because types include different expectations for stream quality), and land use that were expected to affect stream condition. Ecoregion was not significant in any analyses, so was removed from the final models. All results take these factors into account when evaluating the significance of protected status.

More Protected Land Means Better Watershed Condition

The probability of the fish and benthic IBIs being 3 or greater, as well as the IBI scores themselves, significantly increased with the percentage of protected land in the Maryland 8-digit watersheds. The percentage where the probability of IBIs being 3 or greater exceeded 50% was approximately 30% of the watershed being protected.

All Protected Lands are Not Created Equal

When considering lands in all types of protected status, protected sites were significantly poorer stream condition than non-protected sites. This is evidence that many types of protected status are not providing better management or were in poor condition when designated.

Land Use is a Major Determinate of Stream Condition

Land use has long been understood to be a major driver affecting watershed and stream condition. The land use factor was significant in each Gaussian and some logistic GLMM models, and the probabilities of benthic IBI being 3 or greater and estimated benthic IBI were generally highest for sites in the natural land use categories, i.e., “Forested,” “Water,” “Wetlands,” and “Other.” This effect of land use was accounted for in our statistical models, so did not affect evaluations of significant effect from protection status.

Management of Protected Lands is Likely Important

The subset of protected lands managed by DNR for conservation produced higher probabilities and IBI scores than unprotected lands, but the differences were not significant. Greater understanding of the management programs involved, as well as the time since the lands were protected and their condition when protected, could help refine this apparent effect.

Smaller Protected Lands May Improve Over Time

Some analyses show a significant improvement in stream condition over the 20 years of the MBSS data. This result is the probability of fish IBIs being 3 or greater on all protected lands and on DNR lands increasing from less than unprotected lands to greater in the last 5 years. This is not the case for protected land greater than 100 acres. It is possible that these smaller protected lands were protected more recently or were in poorer condition when protected.

Larger Protected Lands Have Better Stream Conditions

The probability of fish IBI being 3 or greater was significantly higher for 100-acre protected lands (and 100-acre DNR lands) than on unprotected lands. This was an average two-fold difference from 0.4 probability in unprotected lands to 0.8 probability in 100-acre protected lands. It is likely that 100-acre protected lands capture lands that are managed more effectively for conservation, have been protected for a longer time, and/or were in better condition when protected.

5. Next Steps

As described above, this study could be improved by obtaining more information on the following:

- Details of the management programs involved
- Year the lands were protected
- Condition of streams when the lands were protected

In addition, analyses could be expanded beyond the fish and benthic IBIs to include component metrics or individual taxa for greater sensitivity.

Analyzing for other factors, such as direct water quality measurements, might show a faster response to protection benefits or could identify other stressors to include in the model.

6. References

Southerland, M.T., G.M. Rogers, M.J. Kline, R.P. Morgan, D.M. Boward, P.F. Kazyak, R.J. Klauda, and S.A. Stranko. 2007. Improving Biological Indicators to Better Assess the Condition of Streams. *Ecological Indicators* 7:751–767.