Identifying and defining levels of meaningful change in ecosystem services of the Chesapeake Bay and its watershed

Collaboration between CBPO, Region 3 & CEMM (Gulf Breeze lab)

Presenters: Ryann Rossi (ORISE Postdoc, U.S EPA ORD)

Contact: Rossi.Ryann@epa.gov

Chesapeake Bay Program
Science. Restoration. Partnership.

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Project background:

Project objectives:

- develop a methodology CBP can use to identify the priority ecosystem services associated with the restoration and revitalization of the watershed

- quantify how management actions or BMPs may affect ecosystem services

- communicate potential co-benefits and tradeoffs to stakeholders.

What does this project lay the foundation for?:

- Benefits assessment

Goal: Describe how ecosystem services (that are important to stakeholders) may change as Best Management Practices to restore ecosystem condition are implemented

Scoped list of BMPs:

- Agricultural forest buffers
- Agricultural grass buffers
- Agricultural tree planting
- Agricultural cover crops
- Urban forest buffers
- Urban forest planting
- Urban tree planting
- Forest conservation
- Wetland creation & restoration
- Impervious surface reduction

Scoped list of Ecosystem Services:

- Air quality
- Habitat quality (for birds & brook trout)
- Temperature Reduction
- High quality soil
- Risk of flooding
- Water clarity
- Water quality- nutrients in groundwater
- Water quality- pathogens in water sources
- Water quantity
- Open space /Green Space
- Pollinator fauna
- Pest predator/depredator fauna
- Edible flora

Note: These ecosystem services were scoped with several beneficiaries in mind (e.g., residents, wildlife viewers, farmers)

We need to identify metrics to quantify ecosystem services

Note: These metrics need to resonate with beneficiaries AND have suitable data or models. Our project is focused on quantifying ecosystem services, not valuation

Ecosystem Service	Short list of metrics	Source
Air quality	concentration of CO, NO2, O3, PM 10, PM 2.5, SO2	iTree (Nowak 2020)
Edible flora	plant diversity, cover of edible species	EnviroAtlas (Pickard et al. 2015)
Habitat quality	habitat suitability for species of interest, species richness	inVEST; Smith et al 2017 (Smith et al. 2017, Sharp et al. 2020)
Heat risk	daytime and nighttime temperature reduction	EnviroAtlas (Pickard et al. 2015)
High quality soil	soil C content, N fixation, pH, salinity, type, percent sand, bulk density, organic matter	NESP; Smith et al, 2017 (Russell et al. 2013, Olander et al. 2017, Smith et al. 2017)
Open space	open space access index; distance to open space	EnviroAtlas; NESP (Russell et al. 2013, Pickard et al. 2015, Olander et al. 2017)
Pest predator/depredator fauna	density of certain pest predators (e.g., ladybugs)	ESML (US EPA 2020)
Pollinator fauna	area of wild pollinator habitat; ratio of pollinator habitat to pollinator dependent crops	EnviroAtlas; inVEST (Pickard et al. 2015, Sharp et al. 2020, Warnell et al. 2020)
Risk of flooding	flood depth, duration, extent and frequency; maximum retained rainwater; soil precipitation retention; surface water runoff; wave attenuation	EnviroAtlas; inVEST; EPA H2O; ESML (Russell et al. 2013, Pickard et al. 2015, Sharp et al. 2020)
Water clarity	mean sediment retention; secchi depth; turbidity	Angradi et al. (2018)
Water quality- nutrients	concentration of nitrates in groundwater	Terziotti et al. (2018)
Water quality- pathogens	concentration of harmful bacteria (e.g., fecal coliform)	Yee et al. (2021)
Water quantity	water availability	inVEST (Sharp et al. 2020)

Quantifying ecosystem services involves testing several metrics and methods

Ecosystem Services	Status	Source
Air quality	Complete and checking with CAST/modeling WG	Removal multipliers based on iTree work (used in iTree Canopy)
Habitat quality for wildlife viewing- bird species richness	Complete and checking with CAST/modeling WG	Values based on 1m LULC and USGS GAP species richness data
Carbon storage/sequestration	In progress-testing methods	Values from literature including Novak #s; getting info from James Martin on NRCS values previously used
Habitat quality for brook trout- stream temperature	In progress-testing methods	CB water quality data for non-tidal streams, LULC for 1m or 30m datasets; or simple equation from literature (used in riparian buffer planning tool)
Heat risk- Air temperature reduction	In progress-testing methods	Mean LST values from NASA; LULC for 30m is less complicated but do have 1m as well. Or use Novak #s
Open space /Green Space	In progress-testing methods	Using 1m LULC and SVI data, looking into NESP methods
Water clarity	In progress-testing methods	CB water quality data and 1m or 30m LULC (no strong relationships for non-tidal streams)
Water quality- pathogen reduction	In progress-testing methods	1m LULC and previous work from Lisa Wainger
Water quantity	In progress-testing methods	Have results for 30m LULC and 1m LULC, just need to compare and look at
Pollinator fauna	In progress-testing methods	1m LULC, inVEST, literature values
High quality soil	In progress-early stage	Meeting with Olivia et al to settle on metric to use
Risk of flooding	In progress-early stage	Working with another Ches Bay ecosystem services project to get this moving
Pest predator/depredator fauna	Not started	
Edible flora	Not started	
Water quality- nutrients in groundwater	Not started	

How can we integrate ecosystem service quantification with CAST?

Goals of this broader project are complementary to CAST so we are working to:

- Develop methods that can be used to determine a per acre estimate of an ecosystem service with the goal of users receiving info such as:

  If you implement X acres of a BMP, you may get…
    - X number of bird species
    - X lb/acre of pollutants removed
    - X lb/acre/yr of C stored or sequestered

- **END GOAL: 1 multiplier/equation per BMP for the land use that the BMP converts to (e.g., forest buffers convert to forest)**

Other notes:

- For many of the services, we are using land use to quantify, in these instances, we match a BMP with the land use it will become (e.g., Forest buffer = tree canopy)

- We are using the 1m LULC for watershed wherever possible. When not, we use NLCD 30m LULC

How can we integrate ecosystem service quantification with CAST?

END GOAL: 1 multiplier/equation per BMP for the land use that the BMP converts to (e.g., forest buffers convert to forest)

BMP	**Ecosystem Service Metric**	**Multiplier or Equation (per acre)**
Cover Crop	Soil Carbon Sequestration (mass/area/yr)	261.2025
Forest Buffers, Tree planting	Soil Carbon Sequestration (mass/area/yr)	1071.6
Forest Buffers, Tree planting	CO REMOVAL (lb acre-1 yr-1)	0.893
Urban Forest Buffers, Forest Planting, Tree Planting	CO REMOVAL (lb acre-1 yr-1)	1.13411
Forest Buffers, Tree planting	NO2 REMOVAL (lb acre-1 yr-1)	4.86685
Urban Forest Buffers, Forest Planting, Tree planting	NO2 REMOVAL (lb acre-1 yr-1)	6.251
Forest Buffers	Bird Species Richness per acre	S=68.97505379*A^0.0382277
Grass Buffers	Bird Species Richness per acre	S=67.089448*A^0.04234895
Impervious Surface Reduction	Bird Species Richness per acre	S=67.089448*A^0.04234895
Wetland BMPs	Bird Species Richness per acre	S=84.59380187*A^0.0293969

Note: This is not exhaustive, just to show a variety!

Diving Deeper:

Detailed methods descriptions for:

- **Air pollutant removal- important for residents, businesses, many other beneficiaries**

- **Habitat quality- bird species richness- important for wildlife viewers, hunters**

Brief methods for:

- Carbon Storage and Sequestration
- Habitat quality for brook trout-Stream temperature
- Air/Land temperature-Heat risk
- Open space /Green Space
- Water clarity
- Water quality- pathogens
- Water quantity
- Pollinator fauna

Air pollutant removal: Using iTree Methods

1. Use values from iTree tools
   - iTree is a set of tools that quantify benefits of trees (https://www.itreetools.org/)
   - **Air pollutant removal = annual flux value (mg m^2 yr^1) x total tree cover (m^2)**

2. We can use provided multiplier to estimate air pollutant removal

Ex: Air pollutant removal= Removal Multiplier x BMP final land use acres

Caveats- this method can only be used for land uses with trees.

Table 1 Multipliers derived from the United States' total values

Pollutant	Removal Multiplier (g m^{-2} yr^{-1})			Value Multiplier (\$ m^{-2} yr^{-1})		
	Rural	Urban	County	Rural	Urban	County
CO	0.100	0.127	0.101	0.00000268	0.000186	0.00000948
NO_2	0.545	0.700	0.551	0.00000398	0.000337	0.0000163
O3	5.493	5.404	5.490	0.000287	0.0155	0.000850
PM_{10*}	1.851	1.534	1.839	0.000233	0.0106	0.000617
$PM_{2.5}$	0.266	0.276	0.267	0.000578	0.0324	0.00176
SO_2	0.347	0.344	0.347	0.00000101	0.0000507	0.00000285

From Hirabayashi, 2014 (iTree Canopy Air Pollutant Removal Descriptions)

Air pollutant removal: Using iTree Methods

Air pollutant removal= Removal Multiplier x BMP final land use acres

- We propose using the rural and urban multipliers rather than county since we have BMPs that would only be applied in urban areas (e.g., urban forest buffer).
  - We can certainly switch to using the county multiplier as well

Table 1 Multipliers derived from the United States' total values

Pollutant	Removal Multiplier (g m^{-2} yr^{-1})			Value Multiplier (\$ m^{-2} yr^{-1})		
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From Hirabayashi, 2014 (iTree Canopy Air Pollutant Removal Descriptions)

Air pollutant removal: iTree air pollutant removal method details

Air pollutant removal = annual flux value (mg m^2 yr^1) x total tree cover (m^2)

- Total tree cover, evergreen percentage, LAI were calculated from NLCD landuse and level-4 MODIS/Terra global LAI product
- Hourly air pollutant removal : $\mathbf{F= V_d \times C}$ where V_d = deposition velocity of pollutant to leaf surface (m h^{-1}); C= pollutant concentration (µg m^{-3})
- Surface weather, upper air, and air pollutant concentration data was taken from monitoring station closest to the area's geographic center
    - Used 979 weather stations from the National Climatic Data Center (NCDC 2013), 74 radiosonde stations from the National Oceanic and Atmospheric Administration (NOAA 2013), and 4,116 air pollutant monitoring stations from the U.S. EPA's Air Quality System (US EPA 2013)

From Hirabayashi, 2014 (iTree Canopy Air Pollutant Removal Descriptions)

Air pollutant removal: Values that CAST could use

Note: The final land use (what the BMP converts to) is what these multipliers apply to

BMP	Pollutant	Multiplier	Units
Forest Buffers	CO REMOVAL (lb acre-1 yr-1)	0.893	lb acre-1 yr-1
Tree Planting	CO REMOVAL (lb acre-1 yr-1)	0.893	lb acre-1 yr-1
Urban Forest Buffers	CO REMOVAL (lb acre-1 yr-1)	1.13411	lb acre-1 yr-1
Urban Forest Planting	CO REMOVAL (lb acre-1 yr-1)	1.13411	lb acre-1 yr-1
Urban Tree Planting	CO REMOVAL (lb acre-1 yr-1)	1.13411	lb acre-1 yr-1
Forest Buffers	NO2 REMOVAL (lb acre-1 yr-1)	4.86685	lb acre-1 yr-1
Tree Planting	NO2 REMOVAL (lb acre-1 yr-1)	4.86685	lb acre-1 yr-1
Urban Forest Buffers	NO2 REMOVAL (lb acre-1 yr-1)	6.251	lb acre-1 yr-1
Urban Forest Planting	NO2 REMOVAL (lb acre-1 yr-1)	6.251	lb acre-1 yr-1
Urban Tree Planting	NO2 REMOVAL (lb acre-1 yr-1)	6.251	lb acre-1 yr-1
Forest Buffers	O3 REMOVAL (lb acre-1 yr-1)	49.05249	lb acre-1 yr-1
Tree Planting	O3 REMOVAL (lb acre-1 yr-1)	49.05249	lb acre-1 yr-1
Urban Forest Buffers	O3 REMOVAL (lb acre-1 yr-1)	48.25772	lb acre-1 yr-1
Urban Forest Planting	O3 REMOVAL (lb acre-1 yr-1)	48.25772	lb acre-1 yr-1
Urban Tree Planting	O3 REMOVAL (lb acre-1 yr-1)	48.25772	lb acre-1 yr-1
Forest Buffers	PM10 REMOVAL (lb acre-1 yr-1)	16.52943	lb acre-1 yr-1
Tree Planting	PM10 REMOVAL (lb acre-1 yr-1)	16.52943	lb acre-1 yr-1
Urban Forest Buffers	PM10 REMOVAL (lb acre-1 yr-1)	13.69862	lb acre-1 yr-1
Urban Forest Planting	PM10 REMOVAL (lb acre-1 yr-1)	13.69862	lb acre-1 yr-1
Urban Tree Planting	PM10 REMOVAL (lb acre-1 yr-1)	13.69862	lb acre-1 yr-1
Forest Buffers	PM2.5 REMOVAL (lb acre-1 yr-1)	2.37538	lb acre-1 yr-1
Tree Planting	PM2.5 REMOVAL (lb acre-1 yr-1)	2.37538	lb acre-1 yr-1
Urban Forest Buffers	PM2.5 REMOVAL (lb acre-1 yr-1)	2.46468	lb acre-1 yr-1
Urban Forest Planting	PM2.5 REMOVAL (lb acre-1 yr-1)	2.46468	lb acre-1 yr-1
Urban Tree Planting	PM2.5 REMOVAL (lb acre-1 yr-1)	2.46468	lb acre-1 yr-1
Forest Buffers	SO2 REMOVAL (lb acre-1 yr-1)	3.09871	lb acre-1 yr-1
Tree Planting	SO2 REMOVAL (lb acre-1 yr-1)	3.09871	lb acre-1 yr-1
Urban Forest Buffers	SO2 REMOVAL (lb acre-1 yr-1)	3.07192	lb acre-1 yr-1
Urban Forest Planting	SO2 REMOVAL (lb acre-1 yr-1)	3.07192	lb acre-1 yr-1
Urban Tree Planting	SO2 REMOVAL (lb acre-1 yr-1)	3.07192	lb acre-1 yr-1

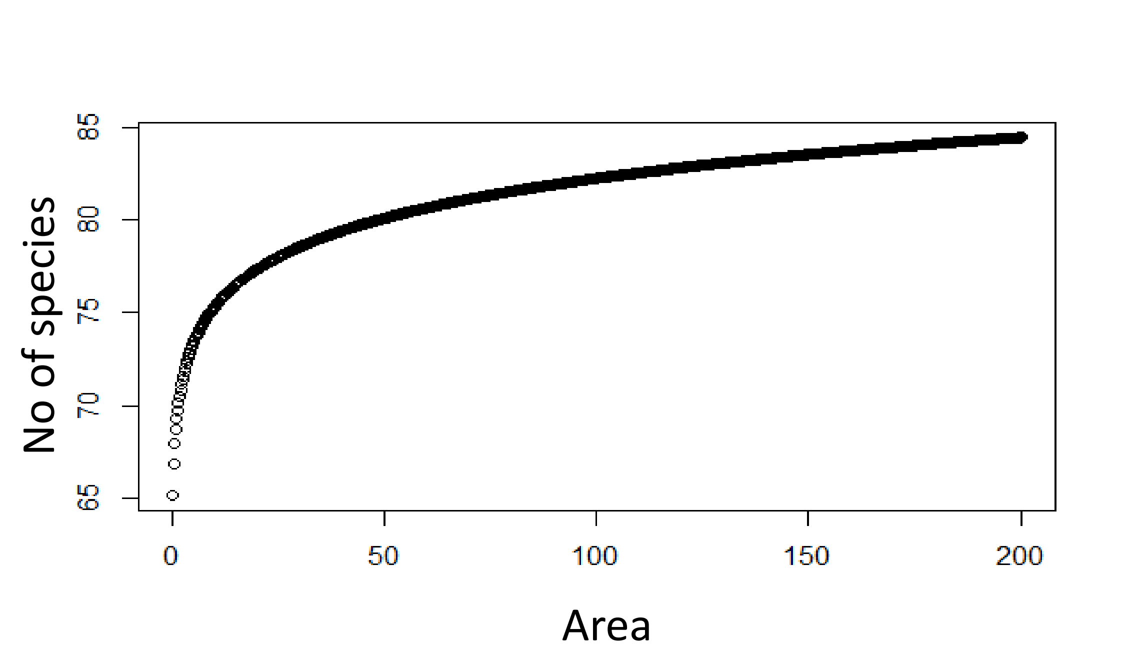
Habitat quality- bird species richness

Approach:

- Use Species Area Curve for different land uses to estimate species richness per acre
  In theory no. of species (S) will change with area (A) depending on constants c and z: $S=cA^z$
- Apply the corresponding species are curve to the final land use associated with each BMP.

Data sources:

- USGS GAP Species Richness Raster: Richness based on summing binary (habitat/non-habitat) versions of habitat distribution models
  - There are 621 bird species + 28 subspecies included in the dataset.
  - Gergely, K.J, Boykin, K.G, McKerrow, A.J., Rubino, M.J., Williams, S.G. 2019. Gap Analysis Project (GAP) terrestrial vertebrate species richness maps for the conterminous U.S.: U.S. Geological Survey Scientific Investigations report 2019-5034, 99 p., https://doi.org/10.3133/sir2019503
- 1m LULC for Chesapeake Bay Watershed



$S=cA^z$

S= No of species

A= area

C=fitted constant

Z= fitted constant

Habitat quality- bird species richness

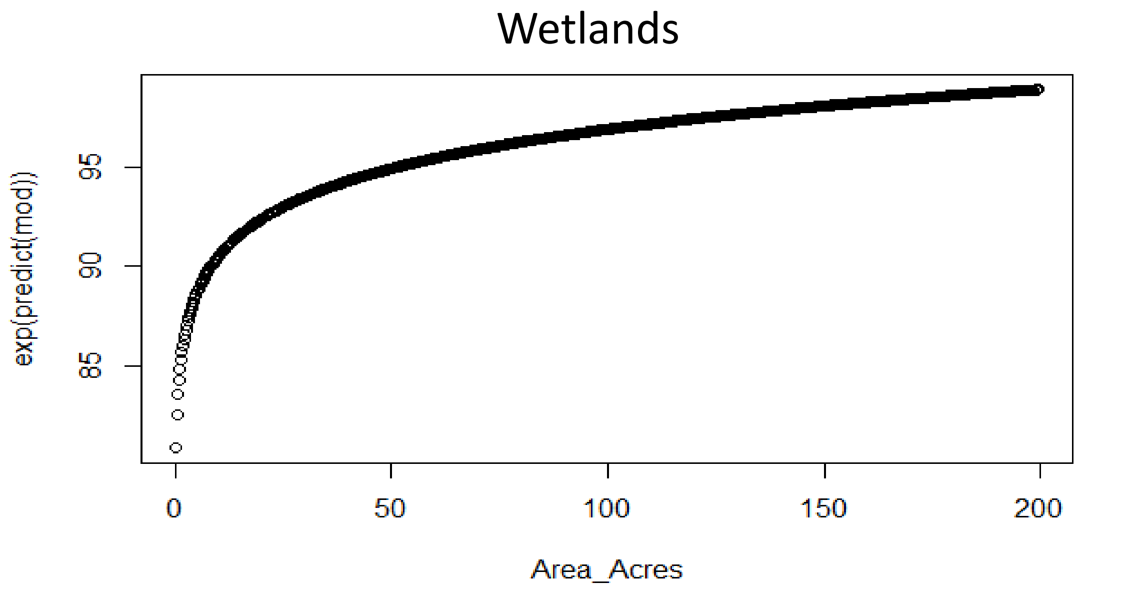
__Approach:__

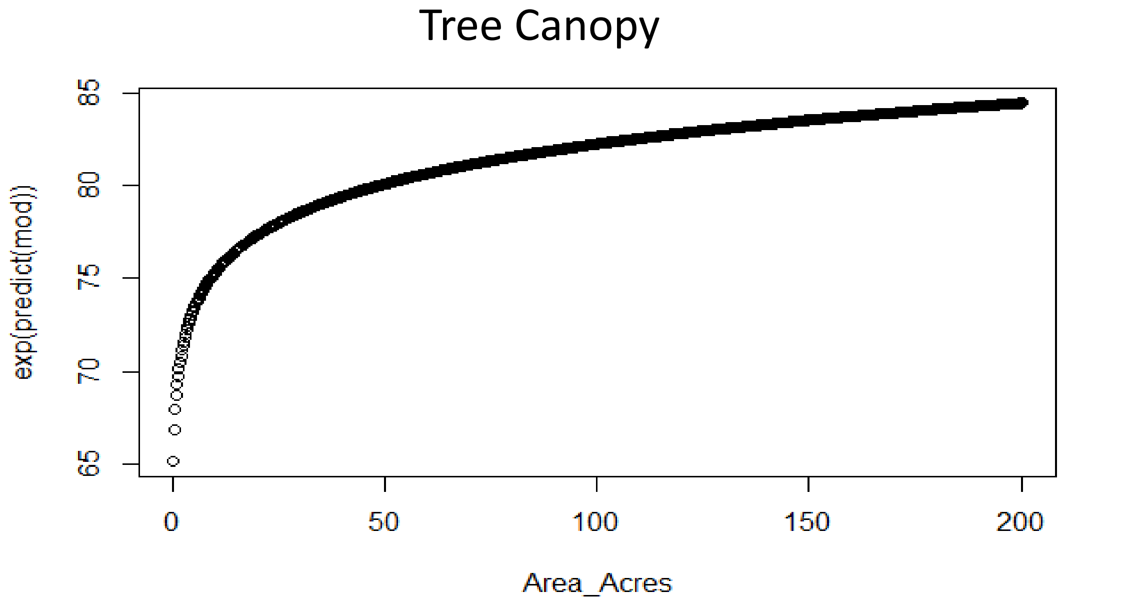
In order to use the Species Area Curve, we need data on bird species richness for different areas of each land use type so in GIS we:

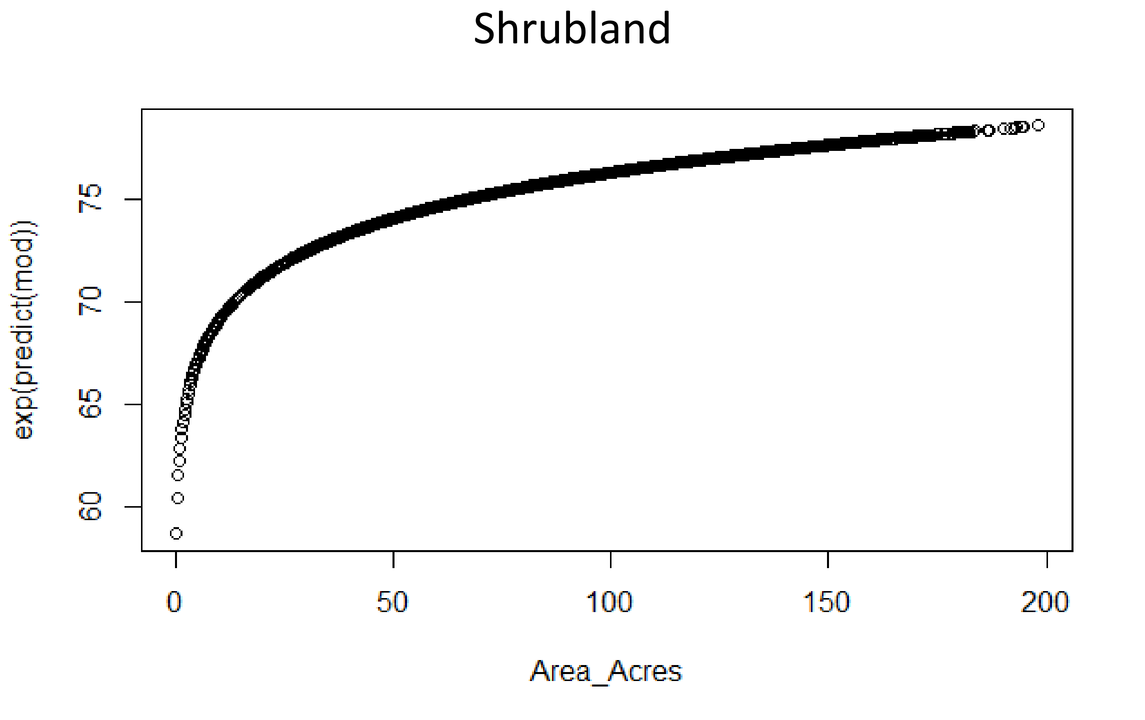
- Resampled the rasters for different size areas and extracted max bird species richness for each LU class at different areas.
  - Ex: We extracted the max species richness associated with 1, 10, 25, 50 acres for tree canopy, wetland, low vegetation.
- Plotted the log of the max species richness by log of the area (produce a linear line):
  - Log Species= z*logArea + logc
    - Where c =y-intercept and z= slope are constants and are determined from model output
    - Transform logc to c, then can use c and z in the power function equation to predict species richness based on area.
- **End goal:** unique species area curves for each land use which can be applied to the final land use a BMP converts to.

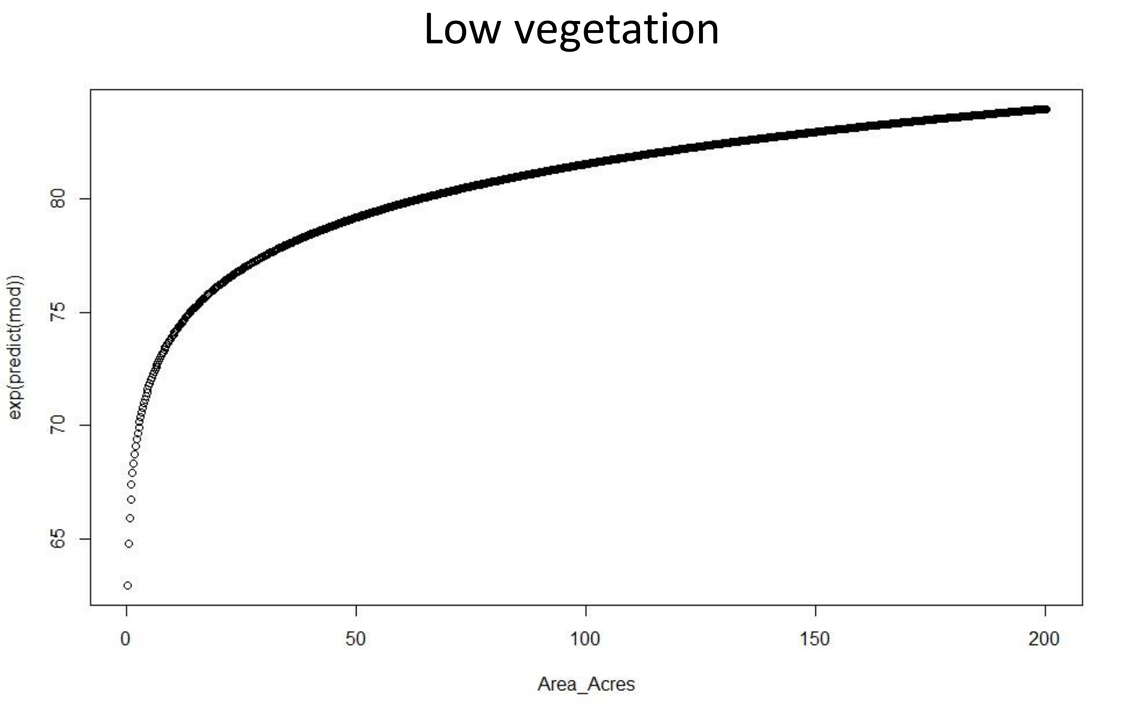
  - Caveats- 1m LULC does not break out crops vs low vegetation so hard to produce a value for cover crop BMPs (unless we want to assume cover crop=low vegetation)

Habitat quality- bird species richness: Species Area Curve Examples based on 1m LULC









Habitat quality- bird species richness: Equations that CAST could use

In theory no. of species (S) will change with area (A) depending on constants c and z: $S=cA^z$

Note: These equations would be applied to the final land use that a BMP converts to.

This is what we would give to CAST and all that would be needed is # of acres (A)

LULC type	SA equation	Apply to which BMP(s)?	Units
Natural Tree Canopy (lu 3)	S=68.97505379*A^0.0382277	Ag Forest buffers, Forest Conservation, Ag tree planting	Bird species per acre
Low vegetation (lu5)	S=67.089448*A^0.04234895	Grass buffers, Imp surface reduction	Bird species per acre
Wetland (lu2)	S=84.59380187*A^0.0293969	Wetland restoration, creation	Bird species per acre

Diving Deeper:

Detailed methods descriptions for:

- Air pollutant removal
- Habitat quality- birds

These are additional ecosystem services we are testing methods for:

- **Carbon storage and sequestration**
- **Habitat quality for brook trout**
- **Heat risk-temperature reduction**
- **Water quality- pathogens**
- **Water quantity**
- **Pollinator fauna**
- **Open space /Green Space**
- **Water clarity**

C storage and sequestration:

Option 1: Use iTree estimates to quantify aboveground C storage and sequestration for tree related BMPs data on BMP implementation for tree related BMPs

Option 2: Narrow to Soil C and use literature values to determine estimates for BMPs

- Could use literature values for land use classes
- Could use literature values from studies that have actually quantified soil C for some of the BMPs (e.g., riparian buffers, grass buffers, cover crops)

- We have combined options 1&2 and calculated average estimates based on all available literature values.

Other data sources/approaches we should use? Any complementary projects going on that have methods we should also use?

Habitat quality- brook trout:

Option 1: Use equation from Fink, 2008 and riparian buffer planning tool (https://ecosheds.org/geoserver/www/index.html)

- If percent shade increases from 0% to 100% the mean daily stream temperature would be 1.45 °C cooler at site X and daily maximum stream temperature would be 1.97 °C cooler at site X.

- Stream Temp = B + x1(air temp) + x2(%shade); Fink uses 80% shade for “mature” tree canopy
  - based on degree C so would need to convert

Option 2: Use regression to predict water temp per land use

- Downloaded stream temperature (C) data from CB water quality data website for non-tidal streams.
  - Chose HUC12 level for the “smallest” resolution
  - Total of 146 HUC12 catchments with data available from 2016-2020
- Extracted landcover area for each HUC12 in the watershed to determine %lulc for each LULC in each HUC12 area.
- Determine if relationships between water temp and %lulc or acres of lulc exists for any LULCs.

Other data sources/approaches we should use? Any complementary projects going on that have methods we should also use?

Heat risk-temperature reduction

Option 1: Use Novak Numbers for air temperature reduction estimates

- Use Maximum mid-day air temperature reductions estimate of 0.04C to 0.2C per percent canopy cover increase.

- Below individual and small groups of trees over grass, mid-day air temperatures are 0.7C to 1.3C cooler than in an open area
  - Source- Novak 2002, but solely focused on trees and from urban areas

Option 2: Use regression to predict mean land surface temperature (LST) per land use

- Extract the mean LST for each LULC based on 1m dataset OR 30m NLCD dataset

- Get mean LST for each county in watershed

- Use regression to predict mean LST for each LULC type in county

Other data sources/approaches we should use? Any complementary projects going on that have methods we should also use?

Water quality- pathogen reduction

Methods adapted from:

- Wainger, L., J. Richkus, AND M. Barber. ADDITIONAL BENEFICIAL OUTCOMES OF IMPLEMENTING THE CHESAPEAKE BAY TMDL: Quantification and description of ecosystem services not monetized. U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-15/052, 2015.
- Data is based on Potomac watershed

Basic steps below:

1. estimated the pathogen reductions (as percent removal) that were likely to be associated with the BMPs
2. estimated the total baseline pathogen load by multiplying an average per acre pathogen load for major land uses (derived from Vann et al. 2002) by the land use acreages of the CBP baseline scenario to generate a total baseline pathogen load at the edge of stream.
3. applied an average downstream delivery factor derived from Vann et al. (2002) to capture the attenuation of pathogens that occurs in stream prior to delivery in the main channel.
4. using the BMP reduction efficiencies and downstream delivery factors, we estimated the total reduction of pathogen loadings (*E. coli* and fecal coliform) to edge of stream and main channel due to TMDL implementation.

$$\Delta FIB_{DS} = \sum_{l}\left(\sum_{b}\frac{(BMP\ Acres)_{b,l}}{(Total\ land\ area)_{l}}(\%FIB\ reduction)_{b}\right)(EOS\ load)_{l}(\%DS\ Delivery)_{l}$$

Other data sources/approaches we should use? Any complementary projects going on that have methods we should also use?