Development of a decision support tool to inform black duck habitat delivery goals considering current and future landscape conditions

Malcolm “Tim” Jones, Atlantic Coast Joint Venture, US Fish & Wildlife Service, Division of Migratory Bird Management, 11410 American Holly Drive, Laurel, MD 20708. 301–497–5674; Tim_Jones@fws.gov
Kirsten Luke, Atlantic Coast Joint Venture, US Fish and Wildlife Service, Division of Migratory Bird Management, 1601 Balboa Avenue, Panama City, FL 32405. 850–769–0552; Kirsten_Luke@fws.gov
John Coluccy, Ducks Unlimited, Great Lakes Atlantic Region, 1220 Eisenhower Place, Ann Arbor, MI 48108. 734–623–2010; jcoluccy@ducks.og
Patrick Devers, Black Duck Joint Venture, US Fish and Wildlife Service, Division of Migratory Bird Management, 11510 American Holly Drive, Laurel, MD 20708. 301–497–5549; Patrick_Devers@fws.gov

Final Performance Report Submitted to Chesapeake Bay Trust

15 December 2016

Introduction

The overall goal of this project was to develop a decision support tool to estimate black duck habitat needs under current and future landscape conditions to guide strategic habitat conservation (SHC) by the Atlantic Coast Joint Venture (ACJV) and other partners in the Chesapeake Bay watershed, which is a critical wintering area in the Atlantic Flyway. Approximately 90% of the non-breeding black duck population occurs within the boundaries of the ACJV (Mid-Winter Survey data; https://migbirdapps.fws.gov, accessed 29 August 2014) with the highest densities occurring in the mid-Atlantic region. The loss and degradation of wintering habitat has been hypothesized as a primary cause of the decline, >50%, of the black duck between 1955 and the 1990s (Conroy et al. 2002).

The primary causes of habitat loss and degradation during the period of rapid decline included agriculture (e.g., salt hay farming), timber operations, environmental contaminants (e.g., acid rain, DDE and DDT; phosphorus and nitrogen; Longcore 2002), introduced predators (Costanzo 2002), and urban growth (Longcore et al. 2000). Between 1953 and 1972 approximately 25,200 ha (21%) of the tidal wetlands in the northeastern states were lost to filling and diking (Longcore 2002). Conroy (2002) estimated that 8% (21,900 ha) of estuarine emergent wetlands were lost between 1961 and the 1996, peaking in 1960 and declining after the passage of federal and state wetland protection laws. The erosion of shorelines and nesting islands contributed to the decline of breeding black ducks in the Chesapeake Bay (Costanzo and Hindman 2007). Between 1970 and the early 2000s, the Maryland counties surrounding the Chesapeake Bay experienced a 38% increase in the human population (Longcore 2002). Increased human population may cause increased disturbance to wintering black ducks, which can reduce food intake and increase energy expenditure (Morton 2002).

Looking to the future, urbanization (Kelly 2001) and sea-level rise due to global climate change probably pose the greatest risk to black duck habitat in the ACJV region. Between 2004 and 2009, the U.S. lost >44,600 acres of estuarine emergent wetlands, which constituted a faster rate of loss than observed between 1998 and 2004 (Dahl 2011). The nests of breeding black ducks on the Chesapeake Bay Islands are susceptible to loss due to flooding from extreme tides and storm events (Costanzo and Hindman 2007), both of which are expected to increase with sea-level and global temperatures. By 2100, sea-level rise along the Atlantic Coast is estimated to average 4mm/year, but the accretion rate is estimated at 2 mm/year, which will result in a large scale alteration of the amount, distribution and structure of coastal marshof coastal marsh systems including the high marsh, low marsh and mud flats. These areas are critically important to non-breeding black ducks because they provide important food resources (Cramer et al. 2012) and refugia from human disturbance.

Urbanization is the leading cause of habitat loss in the eastern U.S., particularly the northeastern states. Between 1973 and 2002, the eastern U.S. experienced a 9.4% net increase in urban areas (Loveland and Acevedo 2014) and 2.3% net loss of forested lands, including forested wetlands (Drummond and Loveland 2010). Between 2004 and 2009 urban and rural development accounted for the conversion of

41,460 ha of forested wetlands to uplands (Dahl 2011). In addition to direct loss, urbanization can result in a decrease in habitat quality.

Since the early 2000's, the Black Duck Joint Venture (BDJV) has partnered with the ACJV to implement the SHC process for black ducks. Together the BDJV, ACJV and their partners at state wildlife management agencies, Ducks Unlimited and several universities have conducted a series of replicated field studies, laboratory studies, and modeling efforts to estimate habitat carrying capacity for non-breeding black ducks using a bio-energetics approach (Cramer 2009, Lewis et al. 2010, Plattner et al. 2010, Jones 2012, Coluccy et al. 2014, Ringelman et al. 2015). Work to develop a Decision Support Tool (DST), funded through this grant, has built on this previous research in an effort to help habitat planners quantify how much habitat is needed and where.

OBJECTIVES:

1. Extend prototype analysis of coastal energetic carrying capacity and demand to the entire Chesapeake Bay watershed and accounting for competition for food resources from other dabbling duck species.
2. Incorporate estimates of urban growth and sea-level rise to predict energetic carrying capacity into the future.
3. Develop decision analysis routine to prioritize land acquisition based on current and future landscape conditions (i.e., energetic supply) out to 2100.
4. Develop targeted metrics of how many hectares of black duck habitat partners need to protect, restore or enhance annually to meet established population goals.

Methods

The decision support tool we are developing is based on bioenergetics theory and assumes non-breeding black ducks are limited, primarily, by the availability of energy in the form of food. The goal of the tool is to estimate how much protection, enhancement and/or restoration is needed to supply sufficient food resources to support non-breeding black duck population goals at multiple spatial scales (e.g., sufficient energy to support 100,000 non-breeding black ducks in the Chesapeake Bay Watershed). The state variable is energetic balance (*B)* at time *t* which is a function of energy supply (*S*) at time *t* and total energetic demand needed to support the stepped down population at goal (*D*). The basic form of the model is:

$$B_t = (S_t - D)$$

This modeling project built on preliminary work already completed; particularly established methods for estimating total energetic demand and current energetic supply at multiple spatial scales. The only remaining effort on this part of the model was to incorporate other waterfowl species that compete for food in the same habitats.

$$B_t = (S_t - D^c - D^{BD})$$

Where, B_t is the energetic balance of the landscape in year t, S_t is the energy supply of the landscape in year t, D^c is the energetic demand for all other dab bling duck species (Table 3), and D^{BD} is the energetic demand for American black ducks.

Spatial Resolution

In order to target habitat conservation at a spatial scale relevant to our partners while balancing the inherent accuracy issues in some of our input GIS data we chose to use the 12-digit hydrologic unit code (HUC) sub-watersheds (http://nhd.usgs.gov/data.html). HUCs represent a hierarchical representation of watersheds across the United States. HUC12 sub-watersheds are local scale units that capture tributary systems representing about 90,000 tributary systems for the conterminous U.S. This spatial scale is being used by other planning efforts in the Chesapeake Bay watershed and avoids the uncertainties in trying to spatially represent individual project scale data that might prove to be inaccurate in the field.

Calculating Energy Supply

We used the the U.S. Fish and Wildlife's National Wetland Inventory (NWI) data which is a national, hierarchical system of mapping wetlands (https://www.fws.gov/wetlands/index.html, accessed October 2015) to map the amount and spatial distribution of wetlands used by black ducks. We used the Wetlands and Deepwater Habitats Classification Hierarchy (https://www.fws.gov/wetlands/documents/NWI_Wetlands_and_Deepwater_Map_Code_Diagram.pdf) that defines the relationship of wetland systems (e.g., estuarine), subsystems (e.g., intertidal), classes (e.g., emergent wetland) and subclasses (e.g., persistent) to develop an *a priori* reclassification into wetland types relevant to black ducks (Table 1). For each black duck wetland type we used Kcal estimates derived from a series of research studies supported by the BDJV, Ducks Unlimited, and other partners (Cramer 2009, Plattner et al. 2010, Cramer et al. 2012, Lewis 2016). After reclassification, wetland polygons were rasterized and each pixel was assigned a Kcal value (Table 2, Fig. 1, Lewis 2016). While the NWI is known to have accuracy issues, much of the data for this region has been updated in recent years. Further discussion of how we used the per pixel Kcal values can be found in Appendix A.

Though our basic approach to modeling black duck habitat carrying capacity is based on bio-energetic theory, we recognized that food availability provides an estimate of habitat quantity but does no t account for factors that may affect habitat quality and thus use. We used a Habitat Capability (HC) Index model developed by the University of Massachusetts to scale wetland quality relative to a set of factors that influence black duck use of a particular wetland. The HC index considers six factors representing: (1) terrestrial, wetland and intertidal ecosystems as defined by ecological systems, (2) Aquatic ecosystems as defined by ecological systems, bathymetry, lotic systems and proximity to undisturbed uplands; indices 1 and 2 identify foraging, roosting and resting habitat, (3) suitable habitat extent, representing the amount of suitable nonbreeding habitat in the surrounding landscape (~2km extent), (4) small extent development, representing the likelihood of anthropogenic disturbance that occur on a scale of tens to a few hundred meters from a developed edge, (5) large extent development, representing the effects of human-mediated landscape changes that accumulate over a larger geographical area, and (6) proximity of potential habitat to the coastline such that locations within 16km are most suitable and gradually declining with increasing distance. The HC index represents the relative capacity of a site to provide the habitat needed by the species during the non-breeding season based on current scientific knowledge. The HC index for black ducks values the landscape on a 0 (low value) to 1 (high value) scale. We used the HC index value to discount the energy supply (Kilocalories [Kcals] provided by wetlands) by simply multiplying the kcal value by the HC index value. We assumed all wetlands had a HC index value of 1 for all other dabbling duck species.

Table 1. Reclassification of National Wetland Inventory wetlands to wetland types relevant to American Black Duck (in bold).

Mudflat salt "ATTRIBUTE" LIKE 'M2US3%' OR "ATTRIBUTE" LIKE 'M2US4%' OR "ATTRIBUTE" LIKE 'E1UB4%' OR "ATTRIBUTE" LIKE 'E1UB3%' OR "ATTRIBUTE" LIKE 'E2SB5%' OR "ATTRIBUTE" LIKE 'E2SB6%' OR "ATTRIBUTE" LIKE 'E2US3%' OR "ATTRIBUTE" LIKE 'E2US4%' OR "ATTRIBUTE" LIKE 'M2US3%' OR "ATTRIBUTE" LIKE 'M2US4%' OR **Mudflat Fresh** "ATTRIBUTE" LIKE 'R1UB3%' "ATTRIBUTE" LIKE 'R1UB4%' "ATTRIBUTE" LIKE 'R2UB3%' "ATTRIBUTE" LIKE 'R2UB4%' **Subtidal Salt** "ATTRIBUTE" LIKE 'E1AB%' OR "ATTRIBUTE" LIKE 'E2AB%' OR	**Freshwater Marsh** "ATTRIBUTE" LIKE 'R1EM%N%' OR "ATTRIBUTE" LIKE 'R1EM%P%' OR "ATTRIBUTE" LIKE 'R2EM%' OR "ATTRIBUTE" LIKE 'L2EM%H%' AND "ATTRIBUTE" NOT LIKE 'L2EM%h' OR "ATTRIBUTE" LIKE 'L2AB%' AND "ATTRIBUTE" NOT LIKE 'L2AB%h%' OR "ATTRIBUTE" LIKE 'PEM1%/PFO%' AND "ATTRIBUTE" NOT LIKE 'PEM1%h%' OR "ATTRIBUTE" LIKE 'PSS%H%' AND "ATTRIBUTE" NOT LIKE 'PSS%h%' OR "ATTRIBUTE" LIKE 'PFO%H%' AND "ATTRIBUTE" NOT LIKE 'PFO%h%' OR "ATTRIBUTE" LIKE 'PAB3%H%' AND "ATTRIBUTE" NOT LIKE 'PAB3%h%' OR	**Estuarine Low Marsh Salt** "ATTRIBUTE" LIKE 'E2EM1N%' **Estuarine High Marsh Salt** "ATTRIBUTE" LIKE 'E2EM1P%‘ **Managed Freshwater Wetlands** "ATTRIBUTE" LIKE 'PAB4%h%' OR "ATTRIBUTE" LIKE 'PAB3%h%' OR "ATTRIBUTE" LIKE 'PFO%h%' OR "ATTRIBUTE" LIKE 'PSS%h%' OR "ATTRIBUTE" LIKE 'L2AB%h%' OR "ATTRIBUTE" LIKE 'PEM1%h%' OR "ATTRIBUTE" LIKE 'L2EM%h' **Saltmarsh** "ATTRIBUTE" LIKE 'E2EM1%' OR "ATTRIBUTE" LIKE 'E2SS%P%' OR "ATTRIBUTE" LIKE 'E2FO5%‘

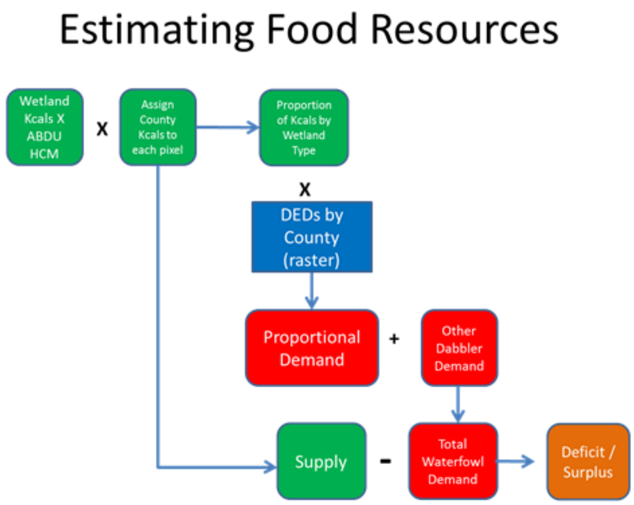
"ATTRIBUTE" LIKE 'M2AB3' OR "ATTRIBUTE" LIKE 'R1AB%N%' OR "ATTRIBUTE" LIKE 'M2AB%‘ **Subtidal Fresh** "ATTRIBUTE" LIKE 'R2AB%' OR "ATTRIBUTE" LIKE 'R1AB%V%' OR "ATTRIBUTE" LIKE 'R1AB%Q%' OR "ATTRIBUTE" LIKE 'R1AB%T%'	"ATTRIBUTE" LIKE 'PAB4%H%' AND "ATTRIBUTE" NOT LIKE 'PAB4%h%' OR ("ATTRIBUTE" LIKE 'PEM1%H%' OR "ATTRIBUTE" LIKE 'PEM1%K%') AND NOT ("ATTRIBUTE" LIKE 'PEM1%h%' OR "ATTRIBUTE" LIKE 'PEM1%5%') OR ("ATTRIBUTE" LIKE 'PEM1%H%' OR "ATTRIBUTE" LIKE 'PEM1%K%' OR "ATTRIBUTE" LIKE 'PEM1%/SS%' OR "ATTRIBUTE" LIKE 'PEM1%/PFO%') AND "ATTRIBUTE" NOT LIKE 'PEM1%h%' OR ATTRIBUTE LIKE 'PFO%J%' OR ATTRIBUTE LIKE 'PFO%K%' OR ATTRIBUTE = 'PFO' AND ATTRIBUTE NOT LIKE '%h%'	**Extra subtidal salt:** Using 0 to -1m bathymetry from the Coastal Relief Model, clip out E1UBL% and add to subtidal salt.

Table 2. Kcal value for each black duck wetland type.

ABDU_Wetland Type	**Kcal per pixel (900 m^2)**
Freshwater Wetland	22,124
High Marsh salt	32,763
Low Marsh salt	84,673
mudflat salt	6,520
Subtidal fresh	5,896

Subtidal salt	5,896
mudflat salt	6,520
High Marsh salt	32,763
Freshwater Wetland	22,124
Managed Freshwater Wetland	133,380
Saltmarsh	45,680

Figure 1. Estimating food (Kcal) supply for dabbling ducks.



Calculating County Level Population Objectives

The first step in this process was stepping North American Waterfowl Management Plan (NAWMP; NAWMP 2014) population goals down to counties within each ACJV state. We used R code and data to calculate the stepped-down goals for the Atlantic Flyway as reported in Fleming et al. 2016. For American black ducks (ABDU), we used the 2012 long-term average (LTA) goal which stipulates a breeding population objective of 956,624. The following steps were then taken using county level harvest data to arrive at state specific black duck goals.

1) County level harvest data for 1999–2013 were acquired from U.S. Fish and Wildlife Service Division of Migratory Bird Management Harvest Survey Branch in Laurel, MD. These data contained adjusted weights representing total harvest for each day in a given year.
2) Adjusted weights were added together for the entire non-breeding season to provide an estimate of total harvest for black ducks for each year in the data set.

3) The total US harvest was estimated by summing across all counties where black ducks were harvested in for each year in the data set. This total became the denominator for the following step (#4).
4) The sums from step #2 (county level estimates) were divided by the total US harvest to provide an estimate of the proportional harvest occurring in any county in a given year.
5) We assumed an 85% survival rate between the mid-winter period and the following breeding season.
6) County level estimates of proportional black duck harvest were multiplied by 956,624 and divided by 0.85 (survival estimate from step #5) to arrive at the population goal for any given county.

We distributed the population goal derived for each county to wetlands based on their proportional extent within each county. This was done so we could aggregate population objectives to each HUC12 in the watershed. We assumed that the birds distribute themselves in an Ideal Free Distribution (Fretwell and Lucas 1970, Fretwell 1972). We computed population objectives for black ducks and other dabbling ducks that use the same habitats (Table 3).

Table 3. Mean body mass (kg), mass proportionality coefficient and average exponent used to calculate mean daily energy requirement for 14 species of ducks wintering in the mid-Atlantic region.

Species	Mean body mass (*W*)[a]	Mass proportionality coefficient (*a*)	Exponent (*b*)	Mean daily energy requirement (kcal/bird/day)[b]
American black duck	1.112	457	0.77	373
American wigeon	0.767	457	0.77	274
Blue-winged teal	0.377	457	0.77	168
Canvasback	1.157	446	0.98	384
Gadwall	0.835	457	0.77	302
Greater scaup	0.976	446	0.98	324
Green-winged teal	0.309	457	0.77	135
Lesser scaup	0.749	446	0.98	253
Mallard	1.108	457	0.77	372
Mottled duck	1.049	457	0.77	350
Northern pintail	0.867	457	0.77	314
Northern shoveler	0.635	457	0.77	237
Redhead	0.971	446	0.98	332
Ring-necked duck	0.672	446	0.98	228
Wood duck	0.672	457	0.77	242

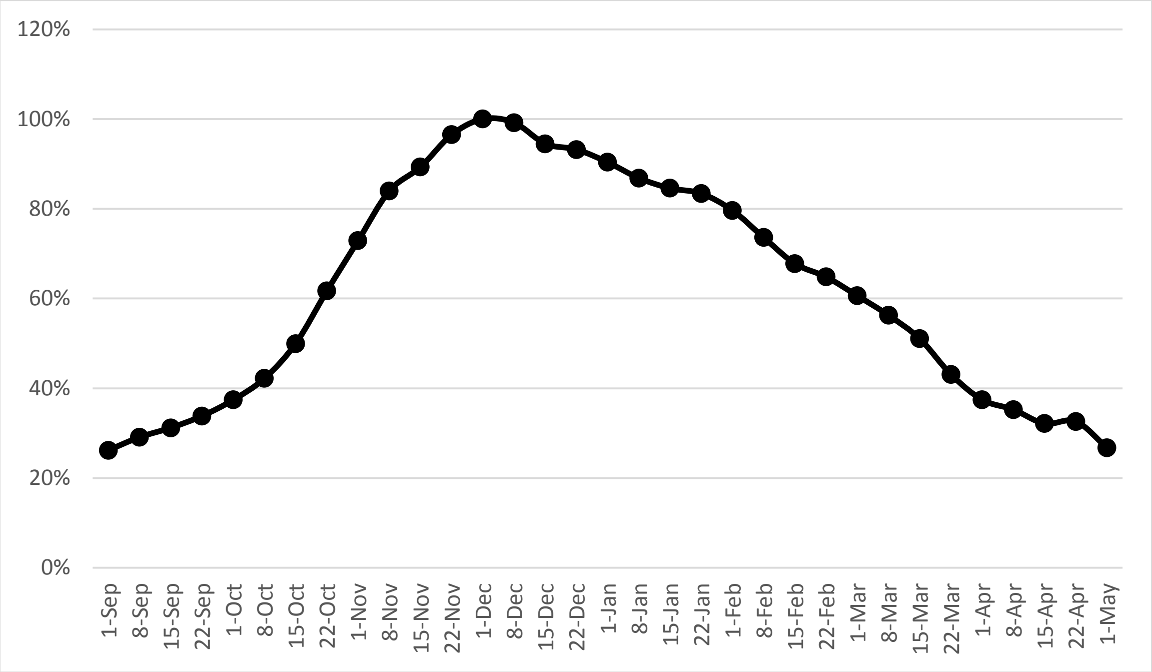
Calculating Energy Demand

Calculating demand over the non-breeding season is a multiple step process. Each step of that process is detailed in separate sections below. The ultimate goal is to determine how many duck energy days (DEDs) need to be provided to support NAWMP goal. To determine DEDs we need information on the temporal and spatial distribution of individuals throughout the non-breeding period. This is done through creating migration chronology curves. We then use that information combined with our population objectives for each HUC12 polygon to determine the total number of duck use days (DUDs) that we need to support via habitat. Finally we can calculate DEDs by multiplying the number of DUDs by the daily energy requirement (DER) for each species (Table 3).

Developing Migration Chronology Curves

We developed migration chronology curves using eBird data for 14 duck species that winter in the ACJV region including American black duck, American wigeon, blue-winged teal, gadwall, green-winged teal, mallard, northern pintail, northern shoveler, wood duck, canvasback, greater scaup, lesser scaup redhead, and ring-necked duck. Species-specific curves were developed for three regions including New England (Maine – New York), Mid-Atlantic (New Jersey – Virginia) and Southeast (North Carolina – Florida). We compiled weekly average count data for the period 2006–2015 to represent contemporary conditions and capture variation in chronologies over the past decade. Weekly average counts were calculated starting with the commencement of fall arrival (September 1) through the spring departure (April 30). A three week moving average was calculated to assist in smoothing curves and the percent of peak was calculated by dividing each weekly average count by the peak average count for the period (September 1 April 30) and plotted (Fig. 2).

Figure 2. Migration chronology curve for American black ducks in the mid-Atlantic region based on eBird data, 2006–2015.



Calculating Duck Use Days

Duck use days (DUDs) for each species and county were calculated using the following equation

$$DUDs = \sum_{i=1}^{n\,weeks} \%\,of\,peak\; \times Population\;objective\; \times 7\;days$$

DUDs are the product of the species specific population objective and the weekly % of peak and 7 days summed across the nonbreeding period. In other words, DUDs are the sum of the area under the migration curve (Fig. 2).

Calculating Daily Energy Demand

Species specific daily energy requirement (DER; kcal/bird/day) was calculated using the following equation (Miller and Eadie 2006)

$$DER_i = 3\; \times aW^b$$

Where DER_i is the daily energy requirement of species *i*, *a* is the mass proportionality coefficient, *W* is body mass (kg), *b* is the average exponent derived by Miller and Eadie (2006), and 3 is a multiplier to account for the energetic costs of daily activities during the non-breeding period (King 1974, Prince 1979). Mean body mass for the 14 species were gathered from Bellrose (1980) and are presented in Table 3 along with mass proportionality coefficients, average exponents and DER.

Calculating Total Energy Demand

Total energy demand (TED) was calculated for each county using the following equation

$$TED = \sum_{i=1}^{n} DER_i \times DUDs_i$$

Where *TED* is total energy demand (kcal), DER_i is daily energy requirement for species *i* and $DUDs_i$ is the total duck use days for species *i* during the non-breeding period.

Calculating Surplus/Deficit

Finally, we calculate the energetic balance for each HUC12 by subtracting demand from supply. For each HUC12 polygon this gives us whether it is in a deficit situation (demand > supply) or in surplus (supply > demand). We can then convert the deficits into the amount of habitat we need to add to the landscape by dividing the deficit by the mean Kcal/ha value of all black duck wetland types.

Future Change

We estimated future wetland loss by incorporating output from Sea-level Affecting Marsh Model (SLAMM) data for the Chesapeake Bay area (Glick et al. 2008) using a 1.5m by 2100 estimated rise and data from Virginia's Eastern Shore SLAMM outputs using the HIGH scenario (Clough et al. 2015).

SLAMM wetland codes were cross-walked to black duck wetland types so we could assign Kcal values to the predicted wetland change areas. We also incorporated future urban growth based on a model developed by the University of Massachusetts (http://www.umass.edu/landeco/research/dsl/documents/dsl_documents.html). By modifying our current landscape with the changes at 2030 and 2080 we can calculate how food resources change over time in response to the two major drivers of change in Chesapeake Bay watershed (Fig. 3). In order to include shallow water subtidal wetlands identified by the SLAMM data, we incorporated the output of a new U.S. Geological Survey (USGS) model that predicts the maximum elevation while accounting for isostatic rebound (Lentz et. al. 2015). We identified subtidal as SLAMM classes Riverine Tidal Open Water and Estuarine Open Water within the predicted 0 to -1m depth contour at 2030 and 2080. To prevent over estimating wetland loss and change we only used the SLAMM tidal or salt water classes. After updating the land cover data to account for future change, the University of Massachusetts re-ran their HC model so we have updated values to discount wetland Kcals appropriately (Fig. 4). Further discussion of how we developed the future supply and HC input can be found in Appendix A and B.

Figure 3. Updating land cover data with future change.

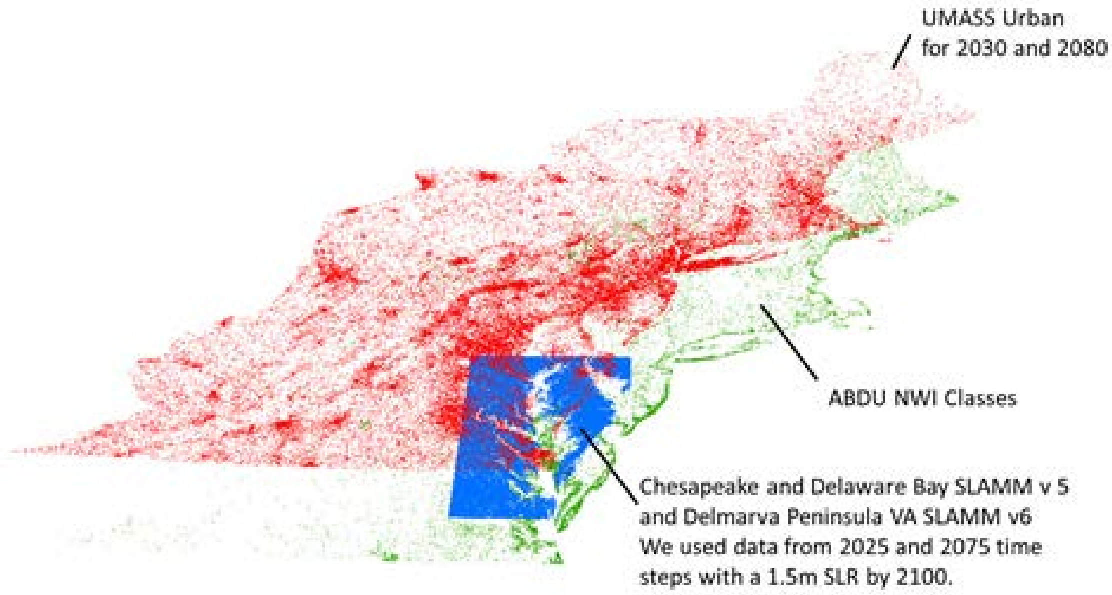
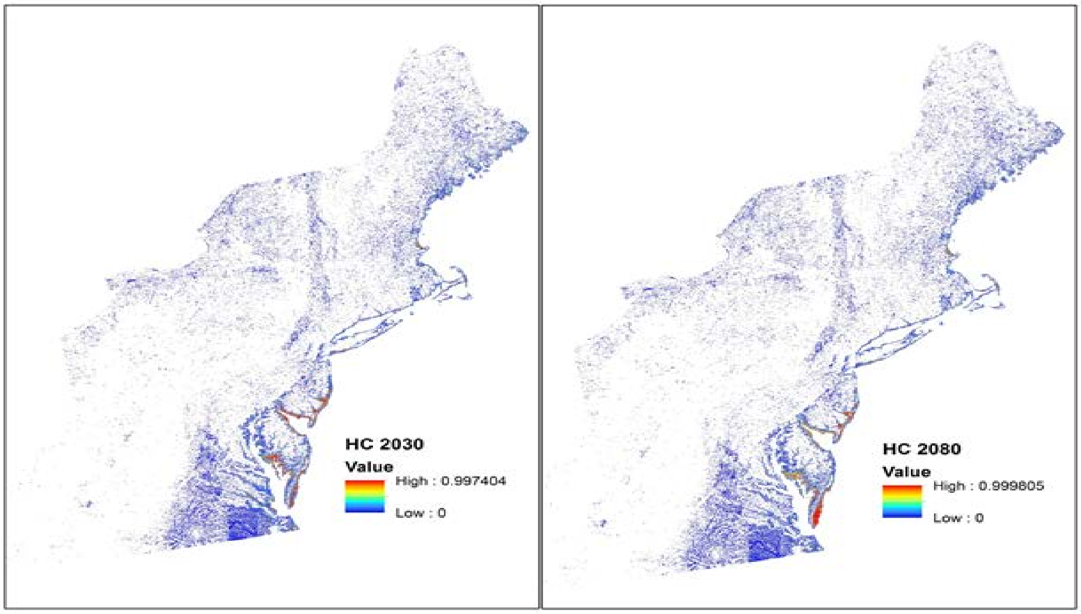


Figure 4. Updated HC models derived from future land cover change incorporating sea-level rise and urban growth.



<u>GIS Models</u>

All models were built in ArcGIS Pro (version 1.3.1) Model Builder and are available upon request. We assumed, based on expert opinion, that other dabbling duck species (Table 3) obtained 10% of their daily energetic requirement from salt marsh food resources and 90% from freshwater wetlands. This 10/90 allocation was derived from expert opinion of waterfowl biologists in the Atlantic Flyway. Further detail on each step of the GIS processing can be found in Appendix A.

Results

To support dabbling duck species at the 2012 NAWMP population objectives requires enough habitat to provide over 45 billion Kcals throughout the non-breeding season (Table 3). The requirements for black ducks comprise just over 30% of that total. As expected, most food energy is concentrated in the lower CBWS (Fig.5). After accounting for competition from other dabbling duck species, our model indicates that the Chesapeake Bay watershed does not currently provide the necessary forage to support black ducks at 2012 NAWMP population goals. Based on the deficit in Kcals we estimate, on average, that partners need to restore or enhance and additional 61,244 ha (151,272 ac) of black duck wetlands (Table 4). Moreover, our model provides insights which watersheds are currently or will be deficient in food resources and are thus in need of securement and restoration efforts Fig. 6). Future conditions at 2030 and 2080 indicate that black duck habitat increases in the short-term, but decreases back to current conditions in the absence of conservation action (Table 4). The spatial allocation of habitat goals for 2030 and 2080 are shown in Figures 7 and 8, respectively. Note, areas shaded in orange and red not only need to be restored or enhanced but in many cases also will need to be protected.

Table 3. Total Duck Use Days (DUDs) and Duck Energy Days (DEDs) by species for the Chesapeake Bay Watershed.

Species	DUDs	DEDs (Kcals)
American Black Duck	36,467,304	13,602,304,433
Green-winged Teal	3,951,462	533,447,310
American Wigeon	3,556,722	974,541,883
Blue-winged Teal	74,238	12,471,971
Gadwall	2,983,541	901,029,442
Mallard	69,784,295	25,959,757,687
Northern Pintail	4,326,714	1,358,588,129
Northern Shoveler	862,972	204,524,425
Wood Duck	6,877,407	1,664,332,554
Total	128,884,655	45,210,997,834

Figure 5. Distribution of food energy (Kcals) suitable for black ducks.

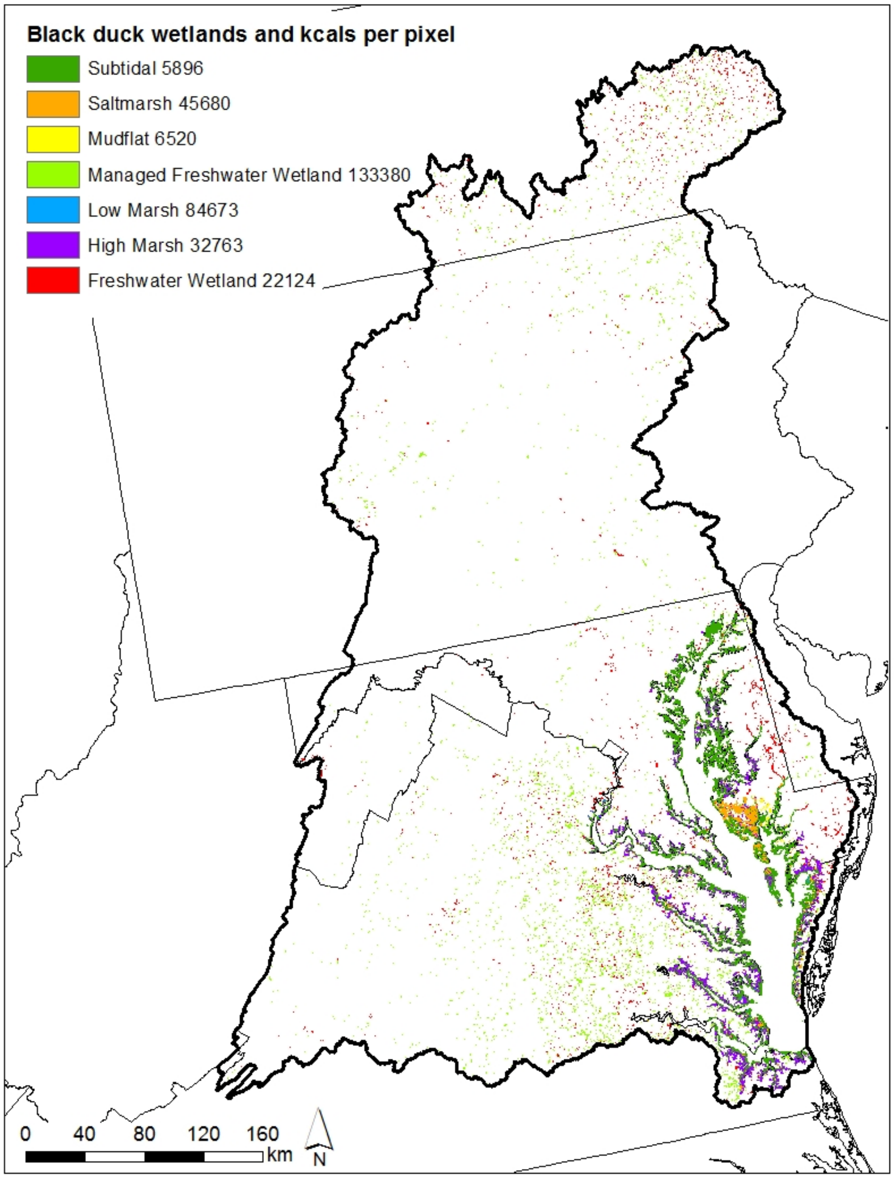


Figure 6. Habitat goals to meet 2012 NAWMP population objective for black ducks based on current habitat conditions (ca. 2010). Areas shaded in blue are areas to target acquisition while areas in orange and red may need protection as well as restoration and enhancement.

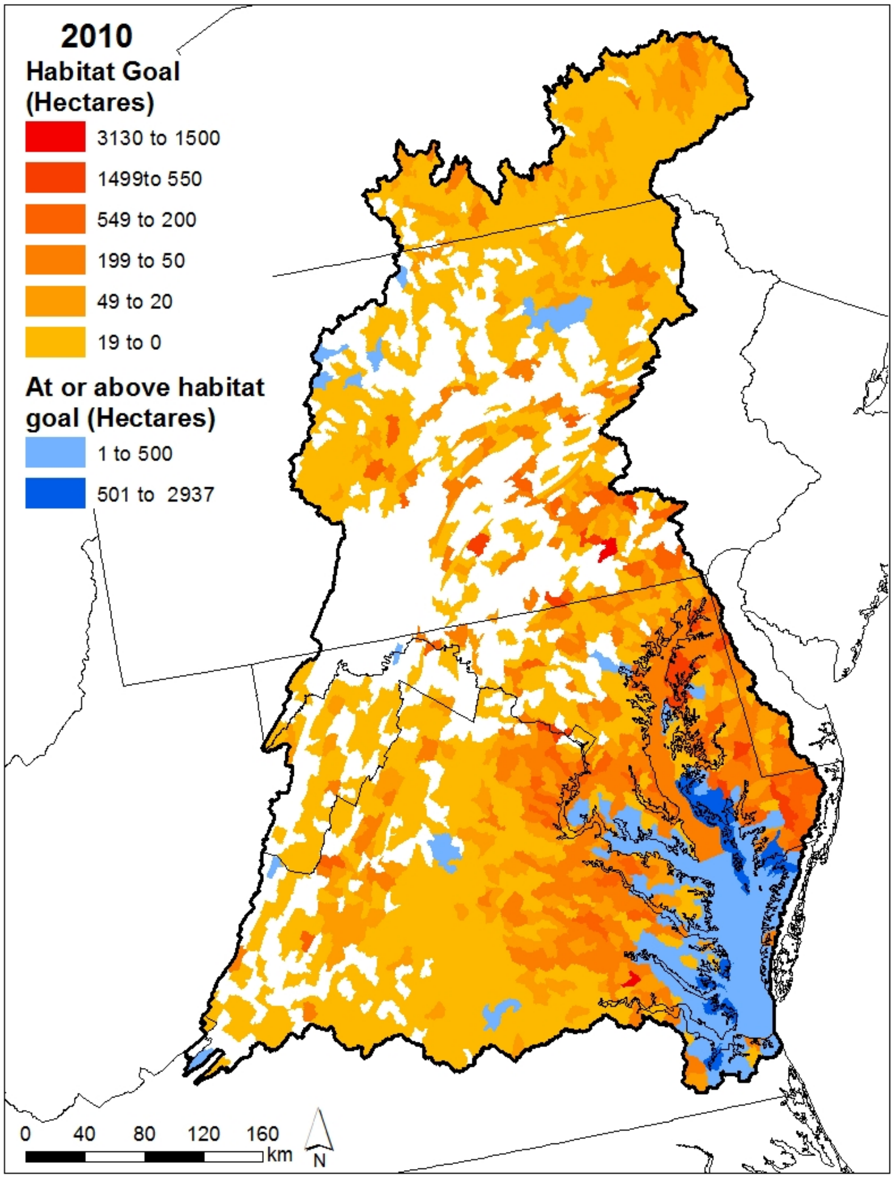


Table 4. Habitat goals to meet 2012 NAWMP population objectives for the Chesapeake Bay Watershed. Goals are presented in hectares and acres in parentheses.

Year	Low CL	Habitat Goal	High CL
2010	35,400 (87,439)	61,244 (151,272)	226,860 (560,344)
2030	32,426 (80,092)	56,098 (138,562)	207,799 (513,263)
2080	35,364 (87350)	61,182 (151,118)	226,630 (559,775)

Figure 7. Habitat goals to meet 2012 NAWMP population objective for black ducks based on future habitat conditions in 2030. Areas shaded in blue are areas to target acquisition while areas in orange and red may need protection as well as restoration and enhancement.

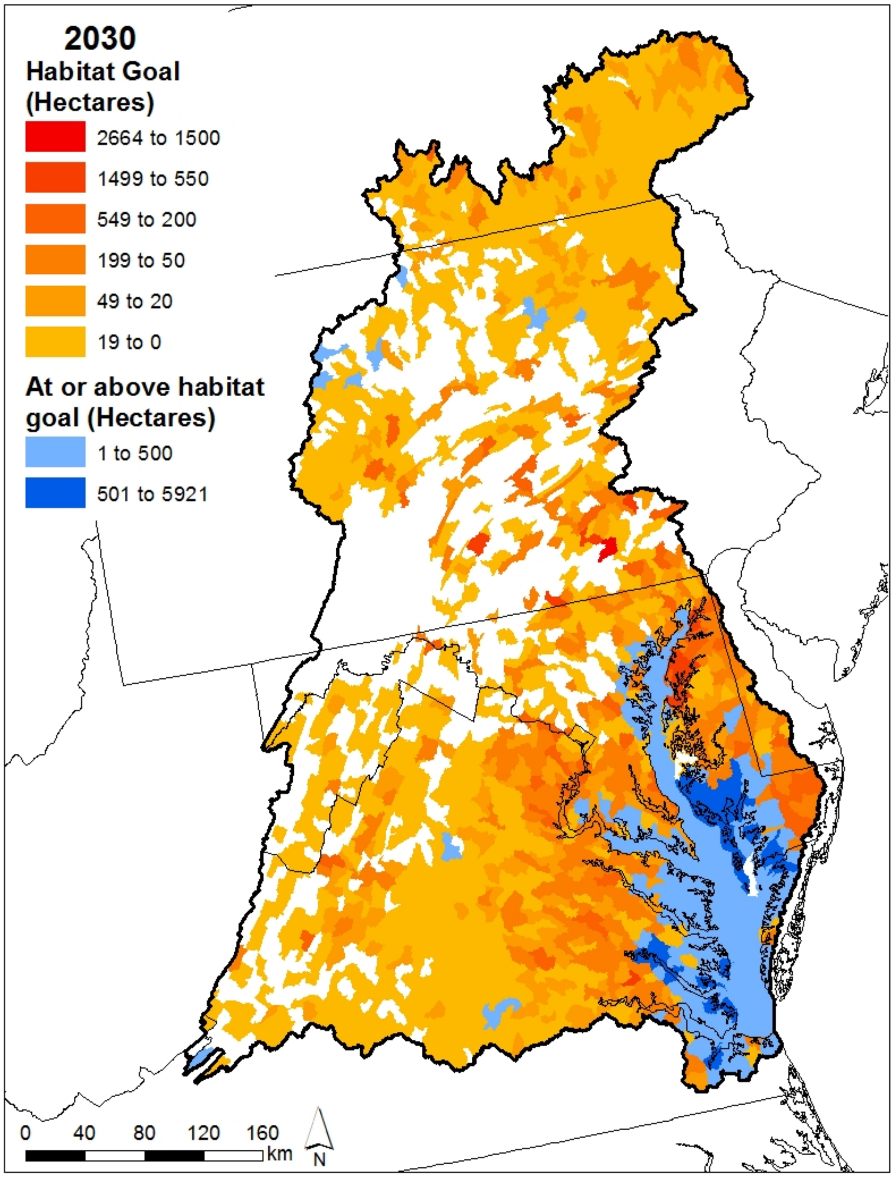
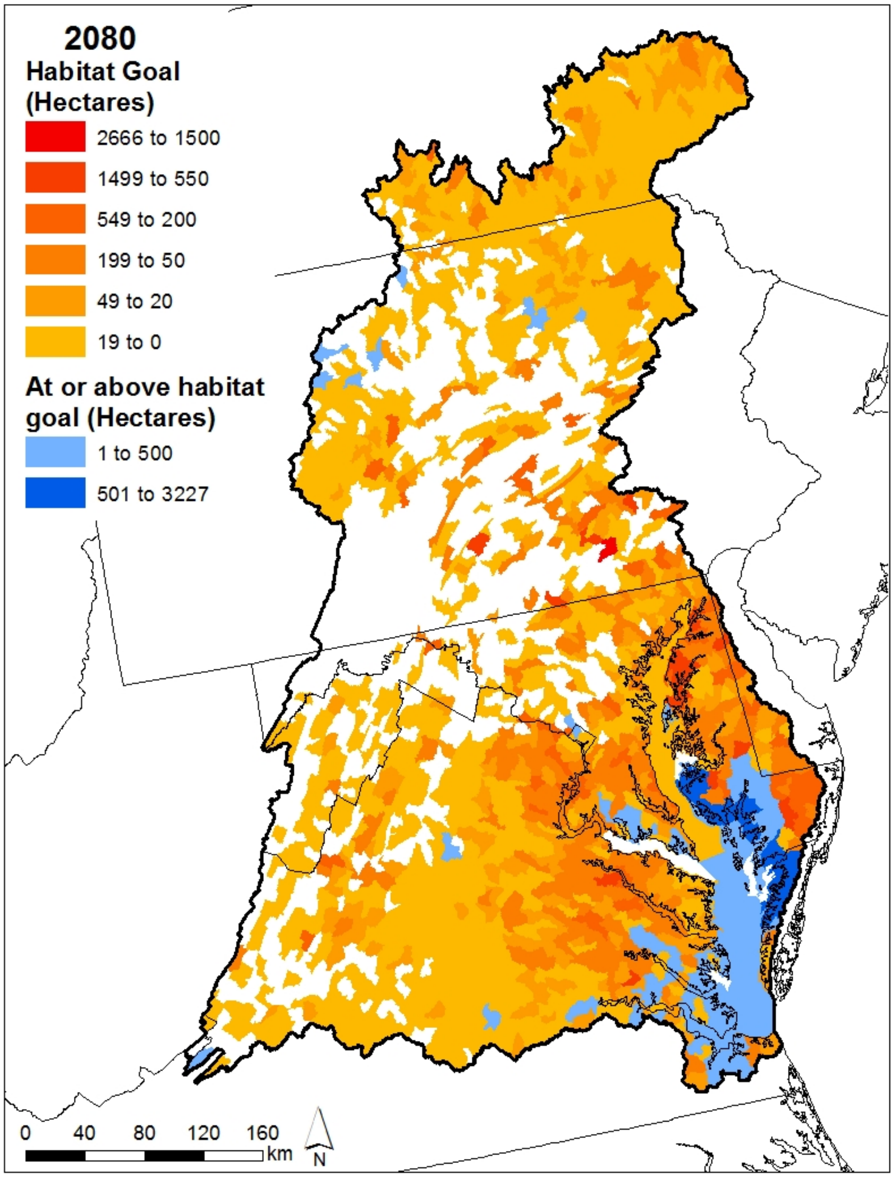


Figure8. Habitat goals to meet 2012 NAWMP population objective for black ducks based on future habitat conditions in 2080. Areas shaded in blue are areas to target acquisition while areas in orange and red may need protection as well as restoration and enhancement.



Discussion

Changes predicted by our energetics model are driven by changes in wetland types from future urban growth and sea-level rise (Table 5). It is also important to recognize that the estimation of acreage needed to support black duck populations at NAWMP goals depend upon the type of wetland habitat being protected, restored or enhanced. The habitat goals we provide used a mean Kcal/ha across all wetland types used in our analyses. For example, if one excludes freshwater wetlands and only focuses on saltmarsh habitat, then the number of acres needed increases. If we examine one specific HUC and target restoration goals by providing the additional Kcals required in the following mix of habitats: subtidal – 13%, mudflat – 4%, saltmarsh – 80% and managed freshwater wetlands – 3%, then the habitat goal increases by 770 ha (1,903 ac) due to requiring more area in habitat with lower Kcal values. The spatial allocation of those habitats also would change.

There are a variety of assumptions throughout this modeling exercise which were reviewed by waterfowl specialists that belong to the Atlantic Coast Joint Venture Technical Committee. These include:

1. The Habitat Capability Index model reflects actual use of wetlands by black ducks;
2. For other dabblers we assume all wetlands are of equal quality since we do not have a habitat capability model for those species;
3. We can distribute population objectives based on proportional distribution of wetland energy (Kcals) assuming an Ideal Free Distribution (more food = more ducks);
4. Distributed 10% of the other dabbler demand to saltmarsh habitats and the remaining 90% to freshwater wetlands;
5. National Wetland Inventory accurately reflects actual wetland occurrence on the landscape;
6. Energetic values for each habitat type (Kcal) are accurately reflected by the studies conducted under the auspices of the BDJV;
7. DEDs can be distributed based on proportional energy on the landscape (see #3);
8. All other dabbler species are lumped into one estimate of DEDs;
9. DERs are estimated accurately.
10. All new habitats created by sea-level rise are good for black ducks.

The ACJV Technical Committee has recommended that we conduct sensitivity analyses to understand the impact of these assumptions. Other assumptions (e.g., 5 and 6) will be tested as new data becomes available and we re-run our analyses. We will work with partners to determine the quality of new habitats being created by sea-level rise to black ducks.

Table 5. Percent change from current conditions (ca. 2010) in wetland types from future urban growth and sea-level rise.

Year	Subtidal	Mudflat	Freshwater Wetland	High Marsh	Saltmarsh	Low Marsh	Managed Freshwater Wetland
2030	111%	215%	127%	103%	65%	2801%	92%
2080	109%	1232%	104%	87%	6%	4237%	88%

The information contained in the black duck bio-energetics model can be used in multiple ways to engage partners and facilitate on the ground habitat conservation to benefit black ducks. The application of the bio-energetics model can only be determined by the specific conservation context. We can envision two types of applications that may be informed by the bio-energetics model, 1) habitat conservation planning and 2) allocation of financial resources to specific projects.

We anticipate the most common application of the bio-energetics model will be related to conservation planning by state resource agencies, federal resource agencies, and non-government organizations involved in habitat conservation and land planning. In this context, users commonly identify priority areas to focus on-the-ground conservation efforts. Planning is commonly used as a coordination and communication tool among partners and to support application for competitive grant funds, but does not involve the allocation of resources (e.g., money, equipment, personnel time) to individual conservation projects. In this context, we recommend using the bio-energetics model to identify areas for securement (i.e., fee simple acquisition or conservation easement) or restoration projects (which may include securing a parcel of land and conducting restoration, Fig. 9). Areas that currently have and are predicted to have sufficient or excessive food resources in the future should be targeted for securement. Since these areas have and are predicted to have sufficient food resources, limited resources (e.g., funds, equipment, or personnel time) should not be used for restoration. In contrast, areas that are currently deficient or are predicted to become deficient in food resources due to habitat degradation or loss should be secured and restored. This process should ensure limited funds are not used to restore areas that currently provide and are anticipated to provide high quality habitat.

The information contained in the black duck bio-energetics model can also be used to support more formal decision analyses, particularly single objective and multi-objective resource allocation decisions. These decisions are characterized by the allocation of limited financial resources to a subset of potential securement (fee simple or conservation easement) and or restoration activities. Given insufficient funds to complete all possible activities, resource managers must decide how to allocate the funds to maximize the desired benefits. In this case of a single objective decision, where the only objective of the funding program is to maximize black duck habitat, managers can use linear programming to identify the suite of projects that maximize habitat on the ground given specific budget and other constraints (e.g., jurisdictional boundaries, Table 5). In this situation, we can use the black duck bio-energetics model to predict the energetic capacity of all proposed projects in 2016, 2030, and 2080 and calculate the net change in energy assuming no conservation action. We can then estimate the net change in energy over time for each project or combination of projects. Using this information it is possible to identify the suite of projects that maximize energetic carrying capacity today and in the future given the available funds. In other words, the bio-energetics model can be used, in combination with a suite of proposed actions, to estimate and identify the net effect of the potential action(s) on habitat carrying capacity. In most situations, habitat conservation programs seek to secure and restore habitat to achieve multiple objectives such as protecting wildlife habitat and increasing water quality. These decisions are referred to as multi-criteria decisions and can be developed by extending the single-objective analysis to account for additional objectives (Table 6 and 7).

The black duck bio-energetics model provides information, based on the best available science, to estimate the biological value of individual land parcels today and in the future for American black ducks. This information can be used to guide allocation decisions related to habitat conservation. However, at least 2 policy issues must be addressed prior to using the bio-energetics model to conduct a formal decision analysis; 1) discounting predicted future landscape conditions, and 2) establishing agreed upon importance or weights for competing objectives (e.g., wildlife habitat versus clean water). In both cases, decisions-makers will have to agree, *a-priori*, on discounting estimates of future energetic capacity versus contemporary estimates. There are no commonly accepted scientific recommendations for discounting future conditions, but it must be recognized that in absence of explicit discounting, decisions-makers implicitly weight estimates of current conditions equal to predicted future conditions. In the case of a multi-objective funding program, decision-makers must also agree, *a-priori*, on the relative importance (or weight) of each objective (Table 6). In absence of agreed upon objective, the decision-maker(s) assume equal importance of the objectives. Importantly, the weights ascribed to the competing objectives does influence the allocation of limited funds across proposed projects (Table 7).

Figure 9. Decision tree for identifying priority areas for habitat securement or restoration based on black duck bio-energetic modeling of current and future energetic carrying capacity.

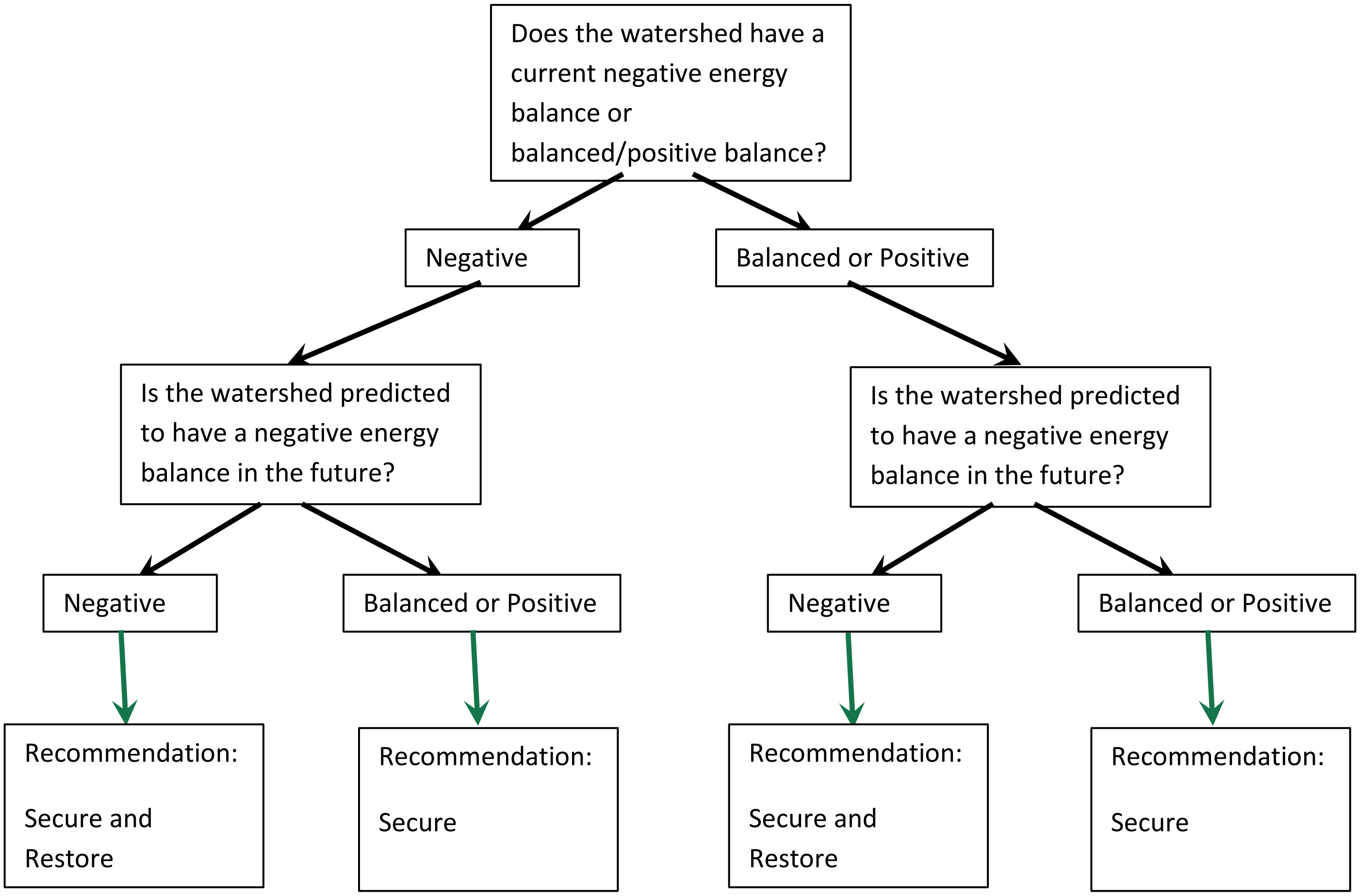


Table 5. Theoretical example of single-objective decision analysis, using linear program, to allocate limited habitat conservations funds to maximize energetic carrying capacity for American black ducks conditional on current and future habitat conditions.

Parcel	units protected	total cost	Energy (2016)	Energy (2030)	Energy (2080)	Time Discout (equal weighted)	Fund?	Energy	Cost
1	303	$9,090.00	747	742	737	735	1	735	$9,090.00
2	400	$12,000.00	747	740	732	732	0	0	$0.00
3	373	$11,190.00	747	741	733	733	0	0	$0.00
4	**313**	$9,390.00	747	740	733	733	1	733	$9,390.00
5	300	$9,000.00	747	740	732	732	1	732	$9,000.00
6	701	$21,030.00	747	739	731	732	0	0	$0.00
7	510	$15,300.00	747	742	735	734	1	734	$15,300.00
8	**420**	$12,600.00	747	739	731	732	0	0	$0.00
9	365	$10,950.00	747	740	731	732	0	0	$0.00
	Total request	$110,550.00				**2,933**		**2,933**	$42,780.00
									($2,220.00)

Table 6. Hypothetical example of a multi-criteria decision analysis to inform the allocation of limited habitat conservation funds.

		Weight	?	?	?	?
Parcel	units protected	total cost	Water Quality	Black Duck	Climate Change	Landscape
1	303	$9,090.00	0.82	1	0	0.59
2	400	$12,000.00	0.69	0.14	0	0.897
3	373	$11,190.00	0.59	0.39	0	0
4	313	$9,390.00	0.79	0.39	1	0.885
5	300	$9,000.00	0.26	0.18	0	0.423
6	701	$21,030.00	0	0.02	0	0.641
7	510	$15,300.00	0.67	0.66	0	0.449
8	420	$12,600.00	1	0	1	1
9	365	$10,950.00	0.31	0.12	0	0.526
	Total request	$110,550.00				

Table 7. Results of hypothetical example of multi-criteria decision analysis to inform the allocation of limited habitat conservation funds.

	Weights				Projects Funded	
Scenario	Water Quality	Black Duck	Climate Change	Landscape	Multiple Objectives	Black Duck Only
1	0.80	0.10	0.05	0.05	1,2,4,8	1,4,5,7
2	0.02	0.50	0.40	0.08	1,3,4,8	1,4,5,7
3	0.03	0.70	0.20	0.07	1,3,4,7	1,4,5,7
4	0.25	0.25	0.25	0.25	1,2,4,8	1,4,5,7

Literature Cited

Bellrose, F. C. 1980. Ducks, geese and swans of North America. Stackpole Books, Harrisburg, Pennsylvania, USA.

Clough, J., Polaczyk, A., and Propato, M. 2015. Enhancing Coastal Resilience on Virginia's Eastern Shore: Application of the Sea-Level Affecting Marshes Model Prepared for: The Nature Conservancy Charlottesville, VA

Coluccy, J. M., M. V. Castelli, P. M. Castelli, J. W. Simpson, and S. R. McWilliams. 2014. True metabolizable energy of American black duck foods. Journal of Wildlife Management In review.

Conroy, M. J., M. W. Miller, and J. E. Hines. 2002. Identification and synthetic modeling of factors affecting American black duck populations. Wildlife Monographs No. 150. The Wildlife Society, Bethesda, Maryland, USA.

Costanzo, G. R. 2002. Black duck nesting in the Virginia portion of Chesapeake Bay. Page 11, in M.C. Perry, editor, Black ducks and their Chesapeake Bay habitats: proceedings of a symposium. U.S. Geological Survey, Biological Resources Discipline Information and Technology Report USGS/BRD/ITR-2002-0005, Laurel, Maryland, USA.

Costanzo, G. R., and L. J. Hindman. 2007. Chesapeake Bay breeding waterfowl populations. Waterbirds 30 (Special Publication 1):17–24

Cramer, D. M. 2009. Estimating habitat carrying capacity for American black ducks wintering in southern New Jersey. Thesis, University of Delaware, Newark, USA.

Cramer, D. M., P. M. Castelli, T. Yerkes, and C. K. Williams. 2012. Food resource availability for American black ducks wintering in southern New Jersey. Journal of Wildlife Management 76:214–219.

Dahl, T. E. 2011. Status and trends of wetlands in the conterminous United States 2004 to 2009. U.S. Department of the Interior; Fish and Wildlife Service, Washington, D.C., USA.

Drummond, M.A. and T.R. Loveland (2010). Land-use Pressure and a Transition to Forest-cover Loss in the Eastern United States. BioScience vol. 60, pp. 286–298. Jones, O. E., III. 2012. Constructing a 24-hour time-energy budget for American black ducks wintering in coastal New Jersey. Thesis, University of Delaware, Wilmington, USA.

Fleming, K. K., M. G. Brasher, D. D. Humburg, M. J. Petrie, and G. J. Soulliere. 2016. Derivation of regional, non-breeding duck population abundance objectives to inform conservation planning. North American Waterfowl Management Plan Science Support Team Technical Report 2016-xx. 31pp.

Fretwell, S. D. 1972. Populations in a seasonal environment. Princeton University Press, Princeton, New Jersey, USA.

Fretwell, S. D., and H.L. Lucas. 1970. On territorial behaviour and other factors influencing habitat distribution in birds. I. Theoretical development. Acta Biotheor 19:16–36.

Glick, P., J. Clough, and B. Nunley. 2008. Sea-level rise and coastal habitats in the Chesapeake Bay region. Technical Report. 121pp.

Kelly, N. M. 2001. Changes to the landscape pattern of coastal North Carolina wetlands under the Clean Water Act, 1984–1992. Landscape Ecology 16:3–16.

King, J. R. 1974. Seasonal allocation of time and energy resources in birds. Pages 4–70 *in* R. A. Paynter, Jr., editor. Avian Energetics. Nuttall Ornithological Club Publication 15, Cambridge, Massachussetts, USA.

Lentz, E. E., S. R. Stippa, E. R. Thieler,N. G. Plant,D. B. Gesch, and R. M. Horton. 2015. Evaluating coastal landscape response to sea-level rise in the northeastern United States—Approach and methods (ver. 2.0, December 2015): U.S. Geological Survey Open-File Report 2014–1252, 26.

Lewis, Jr., B. S. 2016. Determining food resources for American black ducks wintering and spring staging on the eastern shore of Virginia. Thesis, Southern Illinois University, Carbondale, USA.

Lewis, B., Jr., M. Eichholz, and T. Yerkes. 2010. Determining food resources and estimating habitat carrying capacity for wintering and spring staging American black ducks in the Chesapeake Bay of Virginia. Final Report to the Black Duck Joint Venture, Laurel, Maryland, USA.

Longcore, J. R., D. G. McAuley, G. R. Hepp, and J. M. Rhymer. 2000. American black duck (Anas rubripes). In The Birds of North America No. 481 (A. Poole and F. Gill, editors). The Birds of North America, Incorporated, Philadelphia, Pennsylvania, USA.

Longcore, J. R. 2002. American black duck summer range versus winter range: a dichotomy of riches. Pages 7–11 in M.C. Perry, editor, Black ducks and their Chesapeake Bay habitats: proceedings of a symposium. U.S. Geological Survey, Biological Resources Discipline Information and Technology Report USGS/BRD/ITR-2002-0005, Laurel, Maryland, USA.

Loveland TR, Acevedo W. 2014. Land Cover Change in the Eastern United States. Reston, VA: US Geological Survey. Available at http://landcovertrends.usgs.gov/east/regionalSummary.html.

Morton, J. M. 2002. Effects of human disturbance on wintering black ducks. Pages 11–16 in M.C. Perry, editor. Black ducks and their Chesapeake Bay habitats: proceedings of a symposium. Information and Technology Report USGS/BRD/ITR 20022005, USGS, BRD, Reston, Virginia, USA.

Miller, M. R., and J. M. Eadie. 2006. The allometric relationship between resting metabolic rate and body mass in wild waterfowl (Anatidae) and an application to estimation of winter habitat requirements. Condor 108:166–177.

North American Waterfowl Management Plan. 2014. Revised objectives: an addendum to the 2012 North American Waterfowl Management Plan. 10pp.

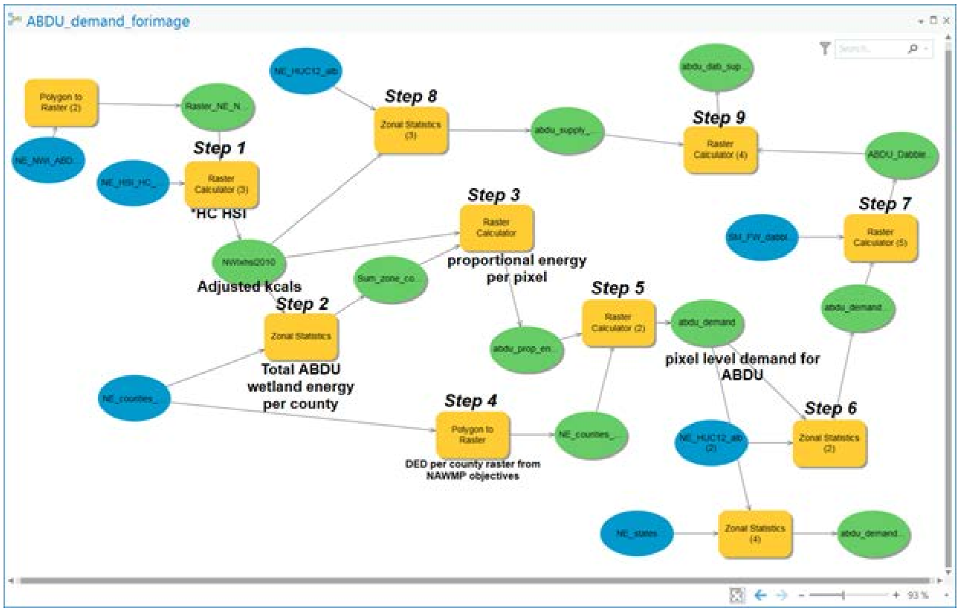
Plattner, D. M., M. W. Eichholz, and T. Yerkes. 2010. Food resources for wintering and spring staging black ducks. Journal of Wildlife Management 74:1554–1558.

Prince, H. H. 1979. Bioenergetics of postbreeding dabbling ducks. Pages 103–117 *in* T. A. Bookhout, editor. Waterfowl and wetlands – an integrated review. La Crosse, Printing Co. Inc. La Crosse, Wisconsin, USA.

Ringelman, K. M., C. K. Williams, P. K. Devers, J. Coluccy, P. Castelli, K. Anderson, J. Bowman, G. Costanzo, D. Cramer, M. Eichholz, B. Lewis, T. Yerkes, T. Jones, M. Huang, D. Plattner, and M. DiBona. 2015. A meta-analysis of American black duck winter habitat use along the Atlantic coast. Journal of Wildlife Management 79:1298–1307.

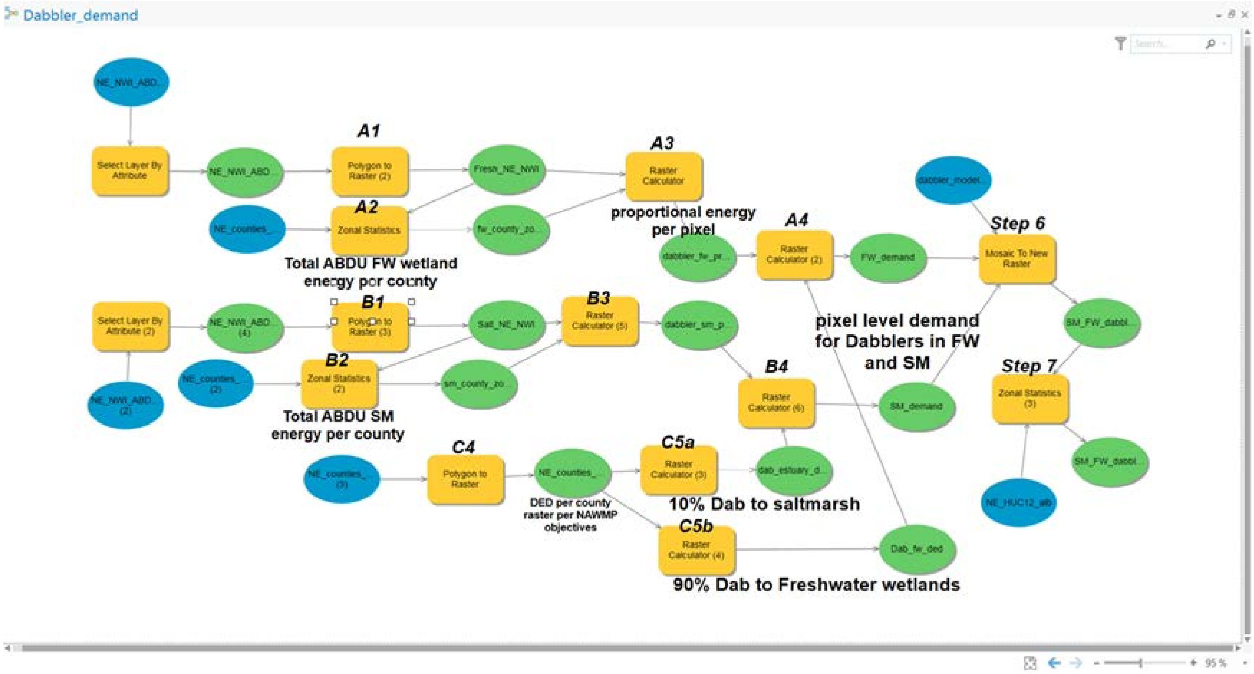
Appendices

Appendix A. Calculating Forage Surplus/Deficit at HUC12 level



1. NWI Kcals – rasterized pixels (30m) * ABDU Habitat Capability model[1] (values 0.0-1.0) = Adjusted Kcals (not all wetlands are equally valuable for ABDUs)
2. Summarize adjusted Kcals by County (Zonal Stats) – raster; each pixel = total county Kcal
3. Calculate proportion of county Kcals to each wetland pixel so we distribute objective according to an Ideal Free Distribution (Fretwell-Lucas)
    a. Step 1 x Step 2 = proportional energy within a county at pixel level
4. Convert NAWMP objectives at county to Duck Energy Days (DEDs) and convert to raster
5. Multiply DEDs * Proportional Energy = Distribution of bird use at county level (Step 3 x Step 4)
6. Zonal statistics to re-aggregate Demand from Step 5 to HUC12 boundaries
7. Add Demand of all other dabblers to Demand of ABDU (from Step 6)
    a. Input from Dabbler_demand mode + ABDU_demand = Total Waterfowl Demand
    b. Missing Habitat Capability model for other dabblers (assumption)
8. Zonal Statistics to convert Adjusted Kcals to HUC12
    a. Output = Total adjusted Kcals per HUC12
9. Supply (Step 8) – Demand (Step 7) = SURPLUS
    a. This is a measure of surplus or deficit Kcals per pixel (representing average over HUC12)

Calculating Demand for Other Dabblers



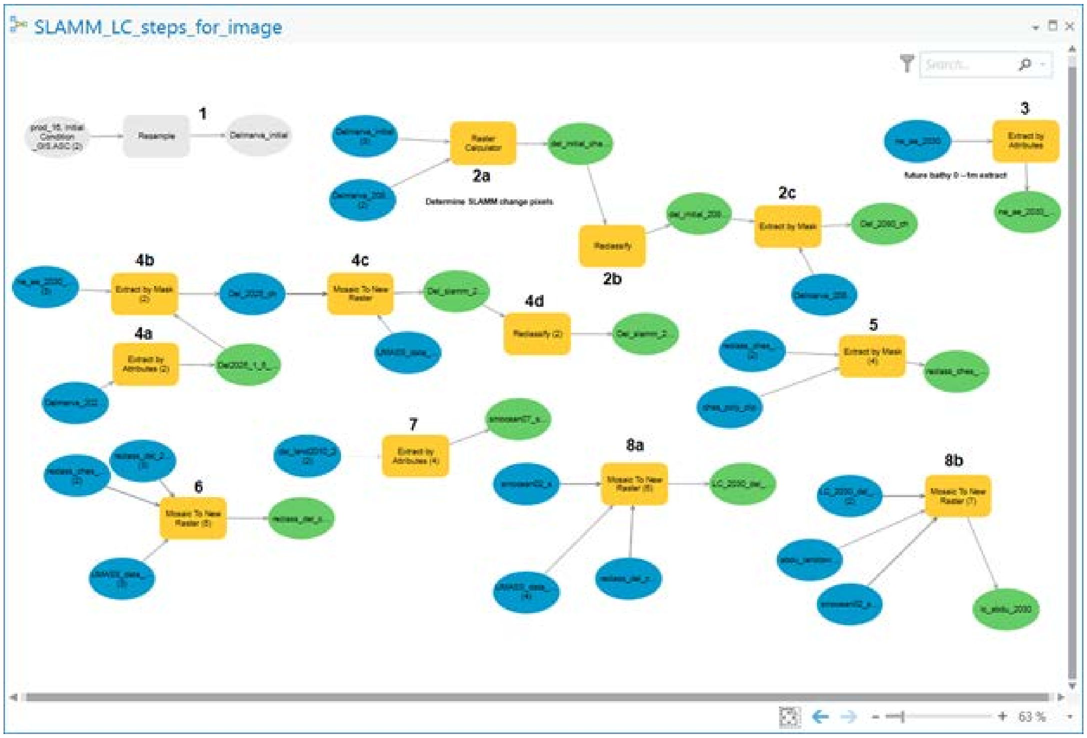
A. Freshwater Wetland Calculations
    a. Select Freshwater wetland classes from NWI and convert to raster
    b. Zonal Statistics – county level sum of total Kcals (Freshwater wetlands only)
    c. a ÷ b = proportional Kcals per pixel
B. Saltmarsh Wetland Calculations
    a. Select Saltmarsh wetland classes from NWI and convert to raster.
    b. Zonal Statistics – county level sum of total Kcals (saltmarsh wetlands only)
    c. a ÷ b = proportional Kcals per pixel
C. Rasterizing total DEDs for other dabblers to county level
D. 10% of total demand of other dabblers to Saltmarsh Wetland types
    a. DED per county * 0.1
E. 90% of total demand to FW types
F. Multiply output of E * A.c. = Demand at pixel level for Freshwater Wetland type

Putting it all together

10. Mosaic A4 & B4 output together gives us Total Other Dabbler Demand
11. Zonal Stats to aggregate DEDs to HUC12 = Total Demand from all other dabblers assuming a 10% competition in Saltmarsh Wetland types and remainder in Freshwater Wetland types

Appendix B. Preparing the future time steps spatial data.

Extracting and burning in sea-level rise from SLAMM onto LCC/UMASS future land cover for ABDU Habitat capability model run and onto the current NWI and future urban predictions.



This Model builder routine is repeated for each time step

We decided to use SLAMM scenarios that had 1.5m sea level rise by 2100.
Extract SLAMM:

1. If necessary, resample SLAMM data to 30m resolution (needed for the newer (SLAMM v6) VA Delmarva portion of the Bay)
2. Determine pixel changes between SLAMM initial condition and SLAMM future time step (2025 & 2075):
    a. Using raster calculator subtract Initial – 2025 and then Initial – 2075. The output pixels that are not zeros are where there are changes between the initial condition and the future time step.
    b. Reclassify output from step 2a where zeros (no change) become NoData.
    c. Determine the actual pixel data that has changed: Use output from step 2b to extract SLAMM pixels from SLAMM data. Repeat for each time step (2025 and 2080) and each data set (Chesapeake Bay and Delmarva)

Extract SLAMM subtidal categories.

3. Extract value 2 Coastal landscape response to sea-level rise assessment for the northeastern United States data (value 2 represents 0 to -1m depth predictions). (http://woodshole.er.usgs.gov/project-pages/coastal_response/data/NE_region_AE.zip) Extract value 2 from NE_ae_2030 and NE_ae_2080 data
4. Extract subtidal classes from SLAMM 2025 and 2075
    a. Extract by value (16 Riverine Tidal Open Water and 17 Estuarine Open Water).
    b. Using the 0 to -1m result from step 3 extract the open water classes from step 4a that occur within 0 to -1m depth.
    c. Mosaic step 4b with 2c.
    d. Reclassify to change urban classes and freshwater classes (see table) to NoData.
5. Extract Chesapeake Bay SLAMM change data for the whole area excluding the VA Delmarva.
6. Mosaic together Chesapeake Bay SLAMM change (without Delmarva portion) with the more recent Delmarva SLAMM change.

    Steps 1 through 6 results in SLAMM tidal or salt wetland classes that have changed from initial condition to 2025 or 2075 plus subtidal from SLAMM that occurs 0 to -1m depth.

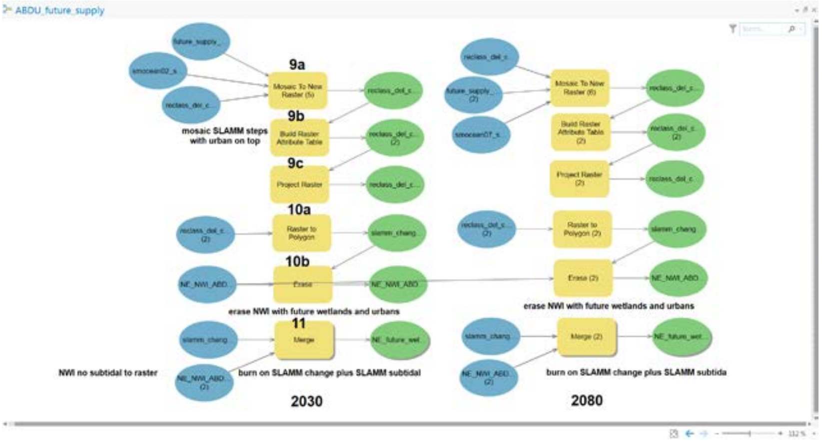
7. Extract urban classes from UMASS Land Cover layer at 2030 and 2080. Extract urban classes 1-8 and 21

Putting it all back together to include SLAMM in the UMASS land cover 2030 and 2080 for the Habitat Capability (HC) index model.

8. Mosaic the layers in order
    a. SLAMM change (from step 6) onto UMASS land cover.
    b. Urban classes (from step 7) onto result of step 8a.

The result from 8b was sent to Dr Bill DeLuca as an input into the HC index model for 2030 and 2080. The HC index data for 2030 and 2080 was then fed into the “Calculating Surplus/Deficit at HUC12 level” GIS model.

Putting it all back together to create a supply layer for 2030 and 2080.



9. Mosaic the layers in order
   a. Mosaic to new raster SLAMM change classes from step 6 above with all urban classes from step 7 above.
   b. Build raster attribute table
   c. Project raster to the same projection as NWI data.

10. Use urban and SLAMM change polygon from 1c to erase NWI data that will not exist in the future due to urbanization.
    a. Convert result from 9c (the SLAMM change with urban) to a polygon.
    b. Erase ABDU NWI using 10a

11. Select and export SLAMM (wetland codes only, not urban) from step 2a to merge with ABDU NWI wetland layer.

This future supply layer for 2030 and 2080 was then fed into the “Calculating Surplus/Deficit at HUC12 level” and “Calculating Demand for Other Dabblers” GIS model.

Appendix C: GIS Data citations.

- **National Wetlands Inventory (NWI)**
  NWI version October 2015 (https://www.fws.gov/wetlands/index.html).
  Wetland code descriptions:
  https://www.fws.gov/wetlands/documents/NWI_Wetlands_and_Deepwater_Map_Code_Diagram.pdf

- **UMASS ABDU Habitat Capability model for American Black Duck.**
  http://jamba.provost.ads.umass.edu/web/lcc/DSL_documentation_abdunb_abstract.pdf

  http://jamba.provost.ads.umass.edu/web/lcc/DSL_documentation_species.pdf

- **UMASS Land cover used in HC model with SLAMM**
  http://jamba.provost.ads.umass.edu/web/lcc/DSL_documentation_DSLland_abstract.pdf
  http://www.umass.edu/landeco/research/dsl/documents/dsl_documents.html

- **Hydrological Units**
  HUC12 – 12 digit hydrologic unit code sub watershed unit. (http://nhd.usgs.gov/data.html and https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1042207.pdf)

- **Counties**
  Counties with boundaries extending into water bodies, (http://water.usgs.gov/GIS/metadata/usgswrd/XML/county2m.xml#stdorder)

- **Sea-level Rise Affecting Marshes Model**
  SLAMM – (http://www.warrenpinnacle.com/prof/SLAMM/) **Chesapeake Bay, MD. 2007-2008**
  http://www.nwf.org/pdf/Reports/FullSeaLevelRiseandCoastalHabitats_ChesapeakeRegion.pdf
  GIS Raster files with results are available on DataBasin.
  The 1.5 m rise scenario was used in the DST model for 2025 and 2075.
  Chesapeake Bay region sea-level rise modelling - Habitat classification, 2025 (1.5 meter rise scenario)
  (che_25_1_5m)
  Chesapeake Bay region sea-level rise modelling - Habitat classification, 2075 (1.5 meter rise scenario) che_75_1_5m
  Delmarva Peninsula, SLAMM v6 data. prod_16, 2025, ESVA High _GIS and
  prod_16, 2080, ESVA High _GIS
  http://warrenpinnacle.com/prof/SLAMM/TNC_ESVA/ESVA_SLAMM_Nov_2015_Report_Final.pdf

SLAMM codes were crosswalked to the ABDU wetland codes developed for this project.

NE_LC_code	SLAMMCode	SLAMMName	ABDU_wetlands	kcalpix
2006	6	Tidal Fresh Marsh	Freshwater Wetland	22124
2007	7	Transitional Marsh / Scrub-Shrub	High Marsh salt	32763
2008	8	Regularly Flooded Marsh (Saltmarsh)	Low Marsh salt	84673
2011	11	Tidal Flat	mudflat salt	6520
2016	16	Riverine Tidal Open Water	Subtidal fresh	5896
2017	17	Estuarine Open Water	Subtidal salt	5896
2018	18	Tidal Creek	mudflat salt	6520
2020	20	Irregularly Flooded Marsh	High Marsh salt	32763
2023	23	Tidal Swamp	Freshwater Wetland	22124
		N/A	Managed Freshwater Wetland	133380
		N/A	Saltmarsh	45680

- **Coastal Relief Model Bathymetry**
  Black ducks use some subtidal habitats. Much of the subtidal area identified by NWI as Estuarine-subtidal-unconsolidated-bottom-subtidal (E1UBL) includes deeper estuaries. We used the E1UBL code only where the bathymetry was 0 to -1m in depth. We identified that depth contour using the Coastal Relief Model data (https://www.ngdc.noaa.gov/mgg/coastal/crm.html) for the present day (2010) data.

- **USGS Sea-level Rise and Coastal Change**
  As explained above, the coastal relief model was used to identify and keep subtidal NWI data within the 0 to -1m depth contour for the present day data. For the future scenarios when we expect sea-level rise, we used USGS sea-level rise predictions to identify subtidal data from SLAMM (Riverine Tidal Open Water and Estuarine Open Water) within the predicted 0 to -1m depth contour.
  http://www.nature.com/nclimate/journal/vaop/ncurrent/full/nclimate2957.html