Designing Sustainable Landscapes: Northeast Aquatic Core Areas

A project of the University of Massachusetts Landscape Ecology Lab

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General description

Northeast aquatic cores is one of the principal Designing Sustainable Landscapes (DSL) landscape conservation design (LCD) products for aquatic ecosystems and species, and it is best understood in the context of the full LCD process described in detail in the technical document on landscape design (McGarigal et al 2017). This particular set of products was developed for the entire Northeast region as part of the Nature's Network project (www.naturesnetwork.org) — a collaborative partnership under the auspices of the North Atlantic Landscape Conservation Cooperative (NALCC).

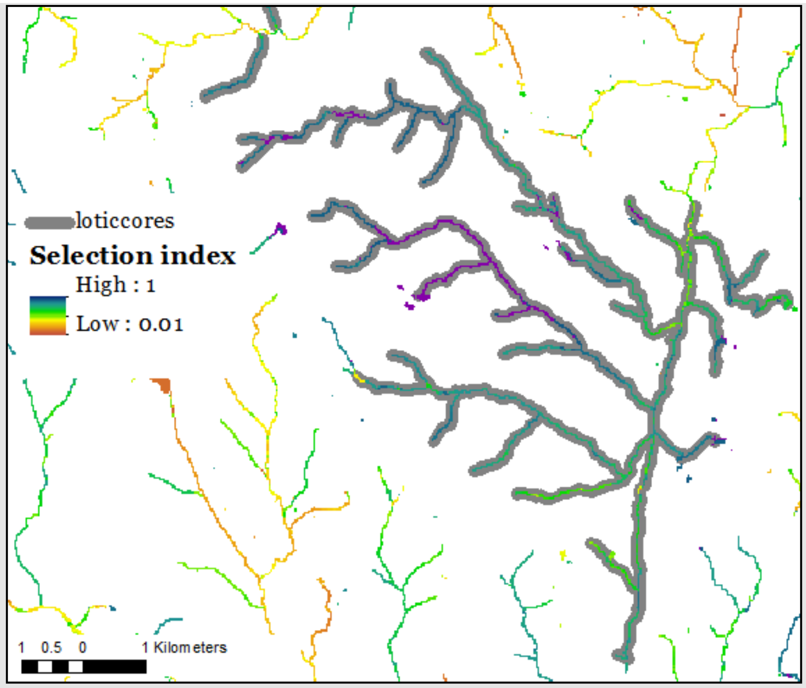

Figure 1. Lotic (riverine) core area showing the initial "seeds" (purple) and the final grown out core (gray), and the underlying aquatic ecosystem-based corea area selection index (depicted as a gradient) on the basis of which this core was derived.

Northeast aquatic cores represent a combination of **lotic core areas** (rivers and streams) and **lentic core areas** (lakes and ponds) selected at the Northeast regional scale to complement the lotic and lentic cores selected at the HUC6 scale (see aquatic cores document, McGarigal et al 2017) (**Fig. 1**).The HUC6 aquatic cores represent the primary LCD product for aquatic ecosystems; they were built to capture the best of each aquatic ecosystem in each HUC6 watershed in order to ensure a well-distributed network of aquatic cores across the region. However, the HUC6 scaling of the ecological integrity index (see IEI document, McGarigal et al 2017) from which the HUC6 cores were derived (see below) trades off some of the best areas of each aquatic ecosystem in the region for lower-valued areas in each HUC6 to achieve a more even distribution across the region for same total conserved area. The Northeast scaling of IEI forces the best areas of each ecosystem in the region to be included in the cores regardless of the final distribution.

Core areas serve as the foundation of the LCD. They reflect decisions by the LCD planning team about the highest priority areas for sustaining the long-term ecological values of the landscape, based on currently available, regional-scale information. In this product, aquatic core areas represent the following:

1) areas of relatively high **ecological integrity** across all aquatic ecosystem types, including both lotic and lentic systems, emphasizing areas that are relatively intact (i.e., free from human modifications and disturbance within the aquatic environment

as well as the surrounding area and contributing watershed) and resilient to environmental changes (e.g., climate change). Integrity has the potential to remain high in these areas, at least in the short-term due to their size and connectivity to similar natural environments; and

2) areas of relatively high current **landscape capability** for the following focal aquatic species, emphasizing areas that provide the best habitat and climate conditions today:

   - Brook trout in headwater creeks, based on a model developed by B. Letcher and associates, USGS Conte Anadromous Fish Lab. Specifically, this index represents the species' current probability of occurrence within headwater creeks at the catchment scale;
   - Atlantic salmon rearing habitat in the rivers and streams of Maine, based on a model developed by J. Wright and associates, USFWS Gulf of Maine; and
   - Atlantic sturgeon, short-nosed sturgeon and sea-run (salter) brook trout in the coastal rivers and streams of the Northeast, based on known occurrence compiled by D.C. Dauwalter and associates, Trout Unlimited;
   - Alewife, blueback herring, and American shad in the major coastal rivers and streams of the Northeast, based on a prioritization developed by The Nature Conservancy; and
   - Loons in lakes, based on the corresponding DSL landscape capability model.

Northeast aquatic cores were built separately for lotic and lentic systems from focal areas in the Northeast that have high ecological integrity. These "seeds" were expanded to encompass surrounding aquatic areas (e.g., upstream and downstream, or the entire water body) that provide additional ecological value and resilience to both short- and long-term change. These initial ecosystem-based cores were supplemented with areas of high landscape capability for one or more of the focal aquatic wildlife species. Finally, these initial cores were supplemented with additional areas to better balance the representation of aquatic ecosystems. Collectively, the final lotic core areas identified in this product encompass ~33 (by stream length) of all rivers and streams in the Northeast, as decided by the LCD planning team, including a total of 5,752 core areas encompassing a total of 218,834 km in stream length and ranging in size from 5 to 3,172 km in stream length, with an average size of 38 km. Similarly, the final lentic core areas identified in this product encompass ~13% (by area) of all lakes and ponds in the Northeast and ~19% excluding lakes >8,094 ha/20,000 acres, as decided by the LCD planning team, including a total of 7,054 core areas encompassing a total of 189,977 ha and ranging in size from 0.1 to 7,553 ha, with an average size of 27 ha.

Use and interpretation of these layers

The Northeast aquatic cores are intended to complement the HUC6 aquatic cores, or as an alternative, that can be used in combination with other sources of information to direct and prioritize conservation action within the region. The use of these layers should be guided by the following considerations:

- It is important to acknowledge that these products were derived from a model, and thus subject to the limitations of any model due to incomplete and imperfect data, and a limited understanding of the phenomenon being represented. In particular, the GIS data upon which these products were built are imperfect; they contain errors of both omission and commission. Consequently, there will be places where the model gets it wrong, not necessarily because the model itself is wrong, but rather because the input data are wrong. Thus, these products should be used and interpreted with caution and an appreciation for the limits of the available data and models. However, getting it wrong in some places should not undermine the utility of these products as a whole. As long as the model gets it right most of the time, it still should have great utility. Moreover, the model should lead to new insights that might at first seem counter-intuitive or inconsistent with limited observations. This is so because the model is able to integrate a large amount of data over broad spatial scales in a consistent manner and thus provide a perspective not easily obtained via direct observation.

- It must be acknowledged that lotic systems are inherently continuous networks; water and materials move from their point of entry into the riverine system continuously downstream to the ocean, and many diadromous organisms do the same (and in both directions). No one segment of a stream or river can be conceived of as an independent entity, and thus the integrity of any segment ultimately depends on the integrity of the entire riverine network. From this perspective, the entire riverine network could be considered a single aquatic core, and while this may be the ecological reality of riverine systems, it does not provide much in the way of practical guidance for conservation. Consequently, we define and delineate individual sections of rivers and streams and small to large riverine networks as aquatic core areas to focus attention on places that meet certain criteria (e.g., relatively good local conditions, high probability of supporting local brook trout populations, etc.), but acknowledge that the entire riverine system is critically important to conserve in order to maintain the integrity of any local section of the river.

- The Northeast aquatic cores are in large part derived from the index of ecological integrity (see IEI document, McGarigal et al 2017), which is scaled from relatively low to high separately for each ecological system within the Northeast region. Consequently, the best areas of each ecological system within the Northeast are captured by these aquatic cores. However, while this ensures that these cores always include high-valued areas for one or more ecosystems, it does not guarantee a well-distributed network of cores across the region. For example, all of the cool, medium-sized rivers in relatively good condition may be located in a single part of the region. The HUC6 aquatic cores, in contrast, capture the best examples of each ecosystem within each HUC6 watershed and thus ensure a more well-distributed network of cores. Thus, depending on your objective, it may be wise to consider the complementary use of both the Northeast and HUC6 aquatic cores.

- Northeast lotic cores can and do include sections of lower-valued rivers/streams and extend beyond road-stream crossings; however, they do not extend past dams. Similarly, Northeast lentic cores can and do include partially-developed shorelines. For lotic cores, this is the result of growing out the cores from the highest-valued seed areas in which we elected to extend the cores through small sections of degraded river/stream in order to encompass larger, contiguous stream networks. For lentic cores, this is the result of growing out the cores from the highest valued seed areas to include the entire water body, which we deemed the more logical conservation unit. The inclusion of such degraded areas in the cores should not be interpreted as indicating their intrinsic ecological value, but rather that they represent places with high influence on the target ecological values in the high-valued areas of the cores. Note, these degraded areas could be considered high priorities for restoration.

- Northeast aquatic cores were derived from regionally consistent data. As such, they may not capture all resource priorities identified at the state or local level made possible with local data. Consequently, this network of aquatic cores should not be viewed as "the" conservation network, but rather as a regional complement to state and locally identified conservation priorities.
- Northeast aquatic cores can be used in combination with the dam removal impacts and culvert upgrade impacts layers (see critical linkages document, McGarigal et al 2017) to identify places where the integrity of the aquatic cores is limited by dams and/or culverts, which may represent priorities for restoration.
- For convenience, the size of each lotic core area is expressed in terms of stream length, but note that the core actually includes the entire shore-to-shore aquatic environment, and often encompasses or extends through adjacent wetlands and water bodies, as depicted in the ecological systems map (see DSLland document, McGarigal et al 2017).
- HUC6 lentic cores exclude the 14 lakes > 8,094 ha (25,000 acres), because including these largest lakes tends to skew the results. We assume that nobody will forget that Lake Champlain or Moosehead Lake are important for conservation.

Derivation of these layers

The derivation of the Northeast aquatic cores was quite complex, as described in detail in the technical document on landscape design (McGarigal et al 2017. Here, we describe a highly abbreviated version of the process that is sufficient for the use and interpretation of these products.

1. Create the initial ecosystem-based core area selection index

The first step in building aquatic core areas was to create an initial "selection index" that integrates the different ecosystem-based values that core areas are intended to represent and reflects the landscape design criteria. The selection index can be created from any number of data layers, but for the purpose of the Northeast regional product described here, we used only the DSL index of ecological integrity (see IEI document, McGarigal et al 2017). Note, for this product IEI was quantile-scaled by ecological system across the entire Northeast region.

2. Build initial ecosystem-based cores

The next step was to build cores based on the selection index. Here, we built lotic cores separately from lentic cores owing to some fundamental differences between the treatment of contiguous stream networks and discrete ponds and lakes. However, the basic idea behind the core building algorithm in both cases was to select the very best places based on the selection index by "slicing" the surface above some threshold level, which essentially guaranteed redundant representation of all aquatic ecological systems, and then "growing" out these "seed" areas through surrounding areas of lower-value areas to create larger, contiguous cores in which the highest-value places (i.e., the seeds) were now buffered (**Fig. 1**).

Growing a core area outward from the seed was relatively straightforward for lentic cores (ponds and lakes). If the seed met a minimum size threshold (0.9 ha), then the seed was grown out to include the entire water body regardless of the selection index value for these cells. Thus, the entire water body (pond or lake) was treated as the logical unit for lentic cores. However, we excluded large lakes (>8,094 ha/20,000 acres) from consideration.

Creating a lotic core was somewhat more complicated. Briefly, if the seed met a minimum size threshold (0.9 ha), then the seed was grown out by spreading upstream and downstream (including back upstream on the downstream tributaries) along the stream centerline such that it spread further through cells with higher value (based on the selection index) and did not spread through lakes or past a dam (of any size). Moreover, it spread further with increasing stream size, so that all other things being equal it would spread further on larger rivers. The final expanded seed had to exceed a minimum total stream length threshold of 5 km) to become a lotic core. The actual process of building the lotic cores was of course considerably more complex.

It is important to recognize that through this process of spreading outward from the high-value seeds, the final lotic cores may include sections of lower-valued streams and extend beyond road-stream crossings; however, they do not extend past dams. Similarly, the lentic cores may include partially-developed shorelines. The expanded seed areas, however, typically include areas with high to moderate ecological value and often include a variety of aquatic ecosystem types that differ from those in the initial seed areas.

3. Build species-complemented cores

The next step was to supplement the ecosystem-based (stage 1) cores with additional core area to meet the habitat needs of all focal aquatic species. The basic idea behind this stage of the core-building algorithm was to complement what was already captured in the stage 1 cores by expanding them or creating new cores to ensure that a specified target for each focal species was included in the final cores. Here, we expanded the stage 1 cores for the focal species as follows:

- *Brook trout in headwater creeks* — based on a model developed by B. Letcher and associates, USGS Conte Anadromous Fish Lab, that gives the species' current probability of occurrence within headwater creeks at the catchment scale. Specifically, we added headwater creeks to lotic cores sequentially starting with the highest probability of brook trout occurrence and continuing until we captured 25% (by stream length) of headwater creeks in the Northeast region within lotic cores. In this manner, we ensured that the best headwater creeks within the region for brook trout were included as lotic cores;
- *Atlantic salmon rearing habitat in the rivers and streams of Maine* — based on a model developed by the U.S. Fish and Wildlife Service and the National Oceanic and

Atmospheric Administration (NOAA). The model assesses salmon rearing habitat throughout the range of the Gulf of Maine Distinct Population Segment (DPS) of Atlantic salmon, which is federally listed as an endangered species. The model was developed using data from habitat surveys conducted in the Machias, Sheepscot, Dennys, Sandy, Piscataquis, Mattawmkeag, and Soudabscook Rivers. The model uses reach slope derived from contour and digital elevation model (DEM) datasets, cumulative drainage area, and physiographic province to predict the total amount of rearing habitat within a stream reach. The variables included in the model explain 73% of the variation in rearing habitat. More details about the model are available at: https://www.greateratlantic.fisheries.noaa.gov/prot_res/altsalmon/Appendix%20C%20-%20GIS%20Salmon%20Habitat%20Model.pdf. We transferred the line work to our high-resolution (1:24k) NHD stream line work and added stream reaches to lotic cores as needed to capture the top 10% (by stream length) of the salmon rearing habitat in Maine;

- *Atlantic sturgeon, short-nosed sturgeon and sea-run (salter) brook trout in the coastal rivers and streams of the Northeast* — based on known occurrences compiled by D.C. Dauwalter and associates, Trout Unlimited, mapped to 1:100K NHDplus stream line work. We transferred the line work to our high-resolution (1:24K) NHD stream lines and added all identified rivers and streams to lotic cores;
- *Alewife, blueback herring, and American shad in the major coastal rivers and streams of the Northeast* — based on a prioritization of HUC12 watersheds using four metrics: (1) population or run size, 2) habitat quantity based on unrestricted access to the ocean, 3) water quality based on extent of impervious surface, and 4) water quantity based on upstream dam storage potential, developed by The Nature Conservancy and mapped to 1:100K NHDplus stream line work. These metrics were weighted by importance for each species based on expert knowledge. The results of the simple weighted ranking prioritization algorithm were then binned into 5% tiers for each species; the top tier was considered to have the greatest restoration potential. The top tiers for each of the three species were combined to result in a combined Top 5% representing the highest tier for one or more of the three species. We transferred the line work for the combined Top 5% to our high-resolution (1:24K) NHD stream lines added these to lotic cores; and
- *Loons in lakes* — based on the corresponding DSL landscape capability model (see common loon document, McGarigal et al 2017). Considering only lakes <8,094 ha (20,000 acres), we rank ordered lakes based on the maximum Landscape Capability value in each lake and then added lakes to lentic cores as needed to capture the top 25% (by area) of lakes within the loon's range.

4. Build additional ecosystem-based cores to balance out ecosystem representation

The result of building the initial ecosystem-based cores (step 2 above) and then supplementing them to meet the focal species targets (step 3 above) resulted in a set of lotic and lentic cores that included representative and well-distributed areas of relatively high ecological integrity across all aquatic ecosystem types, plus additional areas representing

Table 1. Representation of lotic ecosystems in the Northeast lotic cores (i.e., % of each ecosystem in the Northeast captured in lotic cores) after the initial ecosystem and species cores (steps 2-3) and in the final cores (step 4), and the percent gain.

	Percent of Ecosystem within the Northeast		
Lotic ecosystem	**Original**	**Final**	**Gain (%)**
Freshwater Tidal Riverine	55.86	56.50	0.64
Stream (headwater/creek) cold low	28.85	31.58	2.73
Stream (headwater/creek) cold moderate	24.27	27.95	3.68
Stream (headwater/creek) cold high	28.98	31.39	2.41
Stream (headwater/creek) cool low	13.51	28.45	14.94
Stream (headwater/creek) cool moderate	16.09	32.47	16.38
Stream (headwater/creek) cool high	29.54	41.02	11.48
Stream (headwater/creek) warm low	16.87	25.72	8.85
Stream (headwater/creek) warm moderate	23.84	32.21	8.37
Stream (headwater/creek) warm high	33.17	39.41	6.24
Stream (small) cold low	36.68	37.66	0.98
Stream (small) cold moderate	45.00	45.85	0.85
Stream (small) cool low	14.08	31.77	17.69
Stream (small) cool moderate	26.25	38.50	12.25
Stream (small) warm low	30.94	36.96	6.02
Stream (small) warm moderate	33.73	39.53	5.80
Stream (medium) cold	51.12	51.12	0.00
Stream (medium) cool	22.64	32.39	9.75
Stream (medium) warm	30.67	36.68	6.01
Stream (large) cool	59.51	61.55	2.04
Stream (large) warm	31.13	32.54	1.41

the best habitat for several focal aquatic species. Not surprisingly, given the selection offocal species and the varying targets set for each species, the representation of each aquatic ecosystem in the aquatic cores was highly uneven (**Table 1**). For the purpose of the Northeast regional product described here, the LCD planning team decided that the representation of lentic ecosystems was adequate. For the lotic ecosystems, we created a new aquatic core area selection index that upweighted lotic ecosystems by the degree of their underrepresentation (up to 20%). For example, the most underrepresented stream class (Stream (headwater/creek) cool low), at 16.3%, got upweighted by 20%. Based on this weighted selection index, we built additional lotic cores as before (step 2 above) but using a slightly higher "slice" of the selection index to define the "seeds". Our goals was to end up with a minimum of roughly the top 25% (by stream length) of each lotic ecosystem. In general, the underrepresented ecosystems gained enough and the overrepresented ones didn't gain much (**Table 1**).

GIS metadata

There are three different GIS products associated with Northeast aquatic cores. These data products can be found at McGarigal et al (2017):

1. **Northeast lotic cores shapefile —** ESRI ArcGIS shapefile (polylines) including the attributes listed below for each polygon.
    - FID = ESRI assigned unique number (which we do not use) for each polyline.
    - Shape = ESRI assigned feature type = "polyline".
    - coreID = unique number (ID) assigned to the core.
    - lengthKm = stream length (km) of the core. The length of the lotic core is approximated by the number of 30 m centerline cells. In addition, lotic cores can include centerlines through contiguous wetlands as well as contiguous lentic cores; thus, length of the lotic core represents the approximate length of contiguous lotic (including through wetlands) and lentic cores.
    - system1, system2, system3 = list of the top three lotic ecological systems for which the core is particularly important; specifically, systems for which the cumulative ecological integrity of the system within the core is greater than expected (from a statistical perspective) given its distribution across the entire core area network. Note, the lotic systems listed here are not necessarily the most abundant systems in the core, but rather reflect the systems for which the core is especially important. A complete listing of all aquatic systems present in the core (including wetland and lentic systems), along with their relative abundance, is available separately in the Ecosystem table described below.
    - troutSum = sum of the brook trout probability of occurrence index in the core.
    - troutMean = mean of the brook trout probability of occurrence index in the core.
    - salmonSum = total number of cells in the core comprised of the top 10% of Atlantic salmon rearing habitat.
    - salmonMean = percentage of the core comprised of the top 10% of Atlantic salmon rearing habitat.
    - anadSum = total number of cells in the core comprised of the designated anadromous fish habitat, including all sturgeon and salter brook trout rivers and streams, and the top 5% HUC12 watersheds for the three Alosid species.
    - anadMean = percentage of the core comprised of the designated anadromous fish habitat.

Detailed core area composition statistics

Detailed aquatic ecosystem composition statistics are available for each lotic core and are provided as a separate table for each core (see files in the loticCoreNEStats folder). In these tables, there are four different indices computed (and their corresponding ranks) that represent different ways of understanding the relative importance of the cores to specific ecosystems. In all cases, larger values indicate greater importance.

Ecosystem table:

- coreID = unique number assigned to each core.
- systemName = name of the ecological system group as given in the ecological systems map. Note, although wetland and lentic systems are included in the composition of the core (lengthKm), the four importance indices described below apply only to the riverine systems for which the lotic cores have been developed.
- lengthKm = stream length (km) of the corresponding system in the core. Note, the length of the system in the core is approximated by the number of 30 m centerline cells of the system.
- index1 = index of importance of the core for the corresponding lotic system, based on deviation of the observed sum of the selection index for the system from its expected value, which is based on the size of the core and the system's average selection index and proportional representation across all cores. The index ranges from 0 to unbounded on the upper end; <1 indicates observed value less than expected, whereas >1 indicates the opposite.
- index1Rank = rank of index1 (1 = max index1).
- index2 = index of importance of the core for the corresponding lotic system, defined as the percentage of the core's total selection index comprised of the corresponding system. The index ranges from 0-100.
- index2Rank = rank of index2 (1 = max index2).
- index3 = index of importance of the core for the corresponding lotic system, defined as the percentage of the system's total selection index across all cores found in the focal core. The index ranges from 0-100.
- index3Rank = rank of index3 (1 = max index3).
- index4 = index of importance of the core for the corresponding lotic system, defined as the difference between the system's average selection index in the focal core and its average selection index across all cores. The index ranges from -1 to 1; negative values indicate an average selection index in the focal core less than its average across all cores, whereas positive values indicate the opposite.
- index4Rank = rank of index4 (1 = max index4).

2. **Northeast lentic cores shapefile —** ESRI ArcGIS shapefile (polygons) including the attributes listed below for each polygon.
    - FID = ESRI assigned unique number (which we do not use) for each polygon.

- Shape = ESRI assigned feature type = "polygon".
- coreID = unique number (ID) assigned to the core. Note, each lentic core is assigned a unique coreID regardless of whether it is contiguous with a lotic core.
- areaHa = area (ha) of the core.
- system = the ecosystem type of the core.
- loonSum = sum of the loon landscape capability (LC) index in the core.
- loonMean = mean of the loon LC index in the core.

Detailed core area composition statistics

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Ecosystem table:

- coreID = unique number assigned to each core.
- systemName = name of the ecological system group as given in the ecological systems map.
- areaCount = number of 30 m cells in the core.
- areaHa = area (ha) of the corresponding system in the core.
- index1 = index of importance of the core for the corresponding lentic system, based on deviation of the observed sum of the selection index for the system from its expected value, which is based on the size of the core and the system's average selection index and proportional representation across all cores. The index ranges from 0 to unbounded on the upper end; <1 indicates observed value less than expected, whereas >1 indicates the opposite.
- index1Rank = rank of index1 (1 = max index1).
- index2 = index of importance of the core for the corresponding lentic system, defined as the percentage of the core's total selection index comprised of the corresponding system. The index ranges from 0-100.
- index2Rank = rank of index2 (1 = max index2).
- index3 = index of importance of the core for the corresponding lentic system, defined as the percentage of the system's total selection index across all cores found in the focal core. The index ranges from 0-100.
- index3Rank = rank of index3 (1 = max index3).
- index4 = index of importance of the core for the corresponding lentic system, defined as the difference between the system's average selection index in the focal core and its average selection index across all cores. The index ranges from -1 to 1;

negative values indicate an average selection index in the focal core less than its average across all cores, whereas positive values indicate the opposite.

- index4Rank = rank of index4 (1 = max index4).

3. **Northeast aquatic cores raster —** geoTIFF raster (30 m cells) with cell values listed below:

   10 = lotic seeds

   11 = lotic expansion

   12 = brook trout

   13 = Atlantic salmon

   14 = anadromous fish (any of the six focal species)

   20 = lentic seeds

   21 = loon

   This raster version is provided for those who wish to use these results for overlays or other further modeling; the shapefile versions are generally preferable for viewing. Note that sometimes lotic cores run through lakes that are also lentic cores; in those cases, we've coded them as lotic.

Literature Cited

McGarigal K, Compton BW, Plunkett EB, DeLuca WV, and Grand J. 2017. Designing sustainable landscapes products, including technical documentation and data products. https://scholarworks.umass.edu/designing_sustainable_landscapes/