Designing Sustainable Landscapes: Landscape Conservation Design

Item Type	article;article
Authors	McGarigal, Kevin;Compton, Brad;Plunkett, Ethan;DeLuca, Bill;Grand, Joanna
Download date	2025-03-16 19:56:26
Link to Item	https://hdl.handle.net/20.500.14394/10948

Designing Sustainable Landscapes: Landscape Conservation Design

A project of the University of Massachusetts Landscape Ecology Lab

Principals:

- Kevin McGarigal, Professor
- Brad Compton, Research Associate
- Ethan Plunkett, Research Associate
- Bill DeLuca, Research Associate
- Joanna Grand, Research Associate

With support from:

- North Atlantic Landscape Conservation Cooperative (US Fish and Wildlife Service, Northeast Region)
- Northeast Climate Science Center (USGS)
- University of Massachusetts, Amherst

Report date: 20 April 2018

Reference:

McGarigal K, Compton BW, Plunkett EB, DeLuca WV, and Grand J. 2017. Designing sustainable landscapes: landscape conservation design. Report to the North Atlantic Conservation Cooperative, US Fish and Wildlife Service, Northeast Region.

Table of Contents

1 Acknowledgements

Many individuals contributed to the development and application of the approach to landscape conservation design that we describe in this document, in particular the individuals involved in the Connect the Connecticut project help to pilot this approach in the Connecticut River watershed. We expressly acknowledge the following Connect the Connecticut participants and contributors: Mark Anderson, The Nature Conservancy; Georgia Basso, USFWS; Dee Blanton, USFWS; Rachel Cliche, USFWS; Patrick Comins, Audubon Connecticut; Randy Dettmers, USFWS; Jenny Dickson, CT DEEP; Catherine Doyle-Capitman, Cornell U.; David Eisenhauer, USFWS; Ken Elowe, USFWS; Renee Farnsworth, North Atlantic LCC; Andrew Fisk, CT River Watershed Council; Andy French, USFWS; Mitch Hartley, USFWS - Atlantic Coast Joint Venture; Jeff Horan, USFWS; Bob Houston, USFWS; Bill Jenkins, US EPA; Katie Kennedy, The Nature Conservancy; Anne Kuhn, US EPA; Bill Labich, Highstead Foundation; Tanya Lama, USFWS; Ben Letcher, USGS; Kim Lutz, The Nature Conservancy; Bridget Macdonald, North Atlantic LCC; Andrew MacLachlan, North Atlantic LCC; Maritza Mallek, USFWS - North Atlantic LCC; Christian Marks, The Nature Conservancy; Nancy McGarigal, USFWS; Andrew Milliken, USFWS - North Atlantic LCC; Marvin Moriarty, Friends of Conte Refuge; Pete Murdoch, USGS; David Paulson, MA Division of Fisheries and Wildlife; Lori Pelech, North Atlantic LCC; Dave Perkins, USFWS; Emily Preston, New Hampshire Fish and Game; BJ Richardson, USFWS; Chad Rittenhouse, U. of Connecticut; Ana Rosner, USGS; Scott Schwenk, North Atlantic LCC; Colleen Sculley, USFWS; Mike Slattery, USFWS; Eric Sorenson, VT Fish and Wildlife Dept.; Ken Sprankle, USFWS; Dave Stier, Springfield Science Museum; John Warner, USFWS; Tim Wildman, CT DEEP; Jed Wright, USFWS.

2 Problem Statement

The primary objective of the *Designing Sustainable Landscapes* (DSL) project is to develop a *Landscape Change, Assessment and Design* (LCAD) model for the *North Atlantic Landscape Conservation Cooperative* (NALCC) that will allow us to simulate changes to the landscape under a variety of alternative future scenarios (e.g., climate change, urban growth), assess affects of those changes to ecological integrity (coarse filter) and habitat capability for representative species, and inform landscape conservation design aimed at meeting biodiversity conservation goals (McGarigal et al 2017). In this document, we describe our current framework for *Adaptive Landscape Conservation Design* (hereafter, simply LCD), recognizing that this is a living document and the details of the LCD framework are likely to change frequently as we continue to review the pilot project in the Connecticut River watershed and extend LCD to the Northeast region.

For our purposes, we define LCD as:

> "A coordinated suite of conservation actions within a designated spatial and temporal extent intended to modify the landscape pattern for the purpose of conserving biodiversity while recognizing socio-cultural and economic constraints."

Specifically, we outline an adaptive approach to LCD that includes: 1) establishing conservation goals and objectives, 2) designing a spatially-explicit, multi-scale conservation strategy to meet the objectives, 3) implementing the conservation actions outlined by the strategy, 4) monitoring the conservation design for implementation and effectiveness, 5) evaluating the effectiveness of the conservation design in meeting the objectives, and 6) adjusting the conservation design as necessary to meet the conservation goals and objectives and/or modifying the conservation goals and objectives to reflect changing conditions. Note, we recommend an adaptive framework for LCD because the implementation of a conservation design is likely to take many years, during which time the science of conservation biology and landscape ecology will advance and the socio-cultural and economic environment for conservation will change. Consequently, it is paramount that LCD be flexible and adaptive.

In this document, we briefly outline the adaptive LCD framework, but focus on the technical details of creating the conservation design, which consists principally of an ecological network of tiered core areas, supporting landscapes, and connectors along with a suite of additional management and restoration priorities. In addition, we use the LCD pilot in the "Connect the Connecticut" River watershed project to illustrate the design process, but note that we have also applied this LCD process to the entire Northeast region as part of the Regional Conservation Opportunities Area (RCOA) project.

Importantly, **the approach we describe here focuses on LCD from an ecological perspective**; the full execution of LCD for any particular landscape will require establishing a multi-institutional, multi-stakeholder design team that integrates ecological as well as socio-cultural and economic concerns. It is also important to recognize that the LCD approach described here does not limit users' flexibility in interpreting and using the LCAD data products in other ways, as there are myriad ways in which to combine and interpret the products to meet user-specific needs. What we present here is merely one approach to LCD that, if adopted, will provide a consistent framework for conducting landscape conservation across the Northeast using LCAD and other data products.

Also, it is important to distinguish our LCD approach from other existing regional-scale conservation plans such as the Wildlands and Woodlands initiative for New England. Importantly, Wildlands and Woodlands is a superb **vision** for the conservation of New England's forest. It outlines a vision of what it may take to conserve the values and services that forests provide in New England, but it is not a spatially-explicit landscape design that details where conservation actions, such as protection of "wildlands" and "woodlands", should take place. **Our LCD complements the Wildlands and Woodlands vision statement by providing a spatially-explicit conservation design**, albeit based on different goals and objectives and using different terminology. In addition, our LCD focuses on the conservation of all ecological systems, including non-forested systems such as shrublands, wetlands and aquatic, and in its final implementation will encompass the entire Northeast Region (13 states plus Washington, DC).

The other major regional-scale conservation planning approach applied to the Northeast is The Nature Conservancy's (TNC) ecoregional planning. Importantly, TNC's ecoregional plans, developed separately for each ecoregion, offer a spatially-explicit landscape design that includes a portfolio of the most important places for the strategic conservation of biodiversity. These ecoregional plans largely adopt an ecosystem-based or "coarse-filter" approach for ensuring that biodiversity is conserved, under the assumption that if representative ecological settings are conserved that the vast majority of species will be as well. **Our LCD approach differs from TNC's ecoregional planning approach largely in the spatial resolution and methods by which we assess ecological value and determine conservation priorities.** In particular, our LCD uses a state-of-the-art method for assessing ecological integrity that incorporates numerous measures of intactness and resiliency at the high spatial resolution of 30 m, and also adopts a complementary ecosystem-based and focal species-based assessment into the final conservation design.

3 Adaptive Landscape Conservation Design Framework

In this section we provide a conceptual overview and very brief description of our adaptive LCD framework. Similar to an adaptive management framework, our adaptive LCD framework consists of a sequence of six major steps implemented in an iterative cycle (**Fig. 1**) and operating within a multi-scale framework. In this section we provide only a brief and general description of our adaptive LCD framework without getting too bogged down with details, since our primary purpose here is to provide context for the detailed description of the conservation design step (Step 2 in figure 1) in section 3.

Figure 1. Adaptive landscape conservation design framework.

3.1 Multi-scale, Hierarchical Framework

Because landscapes do not exist in isolation and conservation actions are required at multiple scales, we adopt a three-level hierarchical framework for LCD (**Fig. 2**), as follows:

- *Region* -- The broadest geographic context for LCD; useful for considering the importance of the focal landscape for ecological settings and species that extend beyond the geographic scope of the landscape, and for considering aspects of the conservation network such as connectivity that does not stop at the landscape boundary. The entire Northeast is the logical choice for the regional scale since this is the geographic scope of the DSL project.
- *Landscape* -- The focal scale for LCD and the primary scale for planning, analysis and reporting. This is the scale for establishing conservation goals and objectives, setting conservation targets, designing the conservation network, implementing the conservation actions, and monitoring and evaluating the network to determine if the objectives (and thus the goals) are being met. HUC 4 watersheds, such as the Connecticut River watershed, are a logical choice for the landscape scale.
- *Sub-landscape* -- Finer geographic units nested within the landscape to ensure that the core area network is well-distributed throughout the landscape. We propose to use HUC 6 watersheds for the delineation of sub-landscapes. The choice of a sub-landscape scheme is rather arbitrary and mainly serves to ensure that the core area network is well-distributed throughout the landscape. It would be adequate to use arbitrary units (e.g., square tiles) for this purpose; however, the use of watersheds provides a natural ecological unit that serves this purpose well and is both intuitive to managers and ecologically meaningful.

Importantly, there is no one universally acceptable scheme for selecting the scale of the landscape and sub-landscapes. Every scheme has its strengths and limitations. Moreover, given the diversity of interests within the conservation community, it is likely that the relevant geographies will vary among users. Thus, it is important to develop an adaptive LCD approach that can be customized to any geography and any multi-scale framework. The multi-scale framework we describe here is flexible in this regard: any geographic extent can be defined as the "landscape" and it can be subdivided into sub-landscapes at any scale on the basis of any criteria.

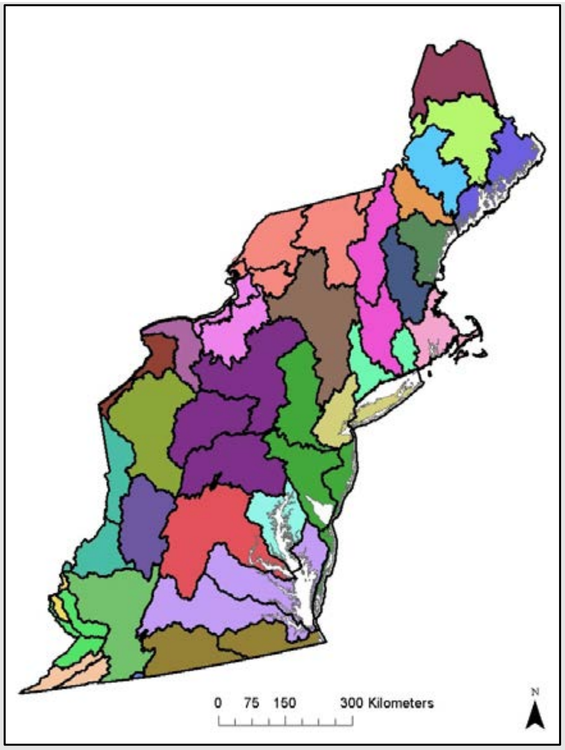


Figure 2. Multi-scale framework for landscape conservation design (LCD). Here, the focal scale for LCD is the HUC 4 level watershed (depicted by colored polygons), which is nested within the broader regional context defined as the Northeast Region, and within which sub-landscapes are defined based on watersheds at the HUC 6 level (depicted by bold outlined polygons).

3.2 Establish Conservation Goals and Objectives

The first step is to establish a set of biodiversity conservation goals and objectives for the landscape under consideration. Goals reflect desired future conditions. Objectives are tied to the goals and are specific, measurable, attainable, relevant and time-sensitive (or so-called S.M.A.R.T objectives). For consistency with the LCAD ecological assessment framework, we recommend the following goals and guidelines for setting objectives:

- *Goal 1: Ecological integrity* — The landscape sustains a diverse suite of intact, connected, and resilient ecosystems that provide important ecological functions and services that benefit society, such as clean water, flood protection, and lands for farming, forestry, and recreation.

  Objectives: The design team should determine a list of ecological functions (i.e., the natural ecological processes that occur within an ecosystem) and ecological services (i.e., the benefits to human society) that can be represented in terms of SMART (specific, measurable, achievable, relevant, and time-specific) objectives. The development of these objectives will require careful consideration and multi-disciplinary. Note, the objectives should pertain to specific ecological functions and services, and can optionally pertain to specific ecological settings.

- *Goal 2: Focal species* — The landscape sustains healthy and diverse populations of fish, wildlife, and plant species for the continuing benefit and enjoyment of the public.

  Objectives: The design team should determine one or more objectives pertaining to focal species' populations that can be represented in terms of SMART (specific, measurable, achievable, relevant, and time-specific) objectives. This will require careful consideration and multi-disciplinary input. Furthermore, the objective(s) need to accommodate the constraints imposed by climate change (e.g., a non-declining population objective may not be realistic or achievable if climate suitability for a species decreases).

Note, there is considerable confusion and differences of opinion about how to write SMART objectives to guide conservation design. On the one hand, objectives specified in terms of ecological functions and species' populations are clearly tied to the overarching goals and provide a strong basis for monitoring the network to determine if they are being met. However, such objectives do not easily translate into "how much of what and where" (i.e., the design) since the LCAD model and other data products available generally don't say anything specific about ecological functions or species' populations. In this case, the design is best viewed as a hypothesis about what it will take to achieve the stated objectives and a strategy (i.e., a set of conservation actions) about how to get there, but the only way to know if the conservation design is adequate is to implement it and monitor it to see if the objectives are being met. Here, the objectives inform but do not dictate the design and thus serve principally as the basis for establishing a monitoring plan to determine if the design is being successful.

On the other hand, objectives specified in terms of acreage of ecological settings and focal species habitat protected, managed and restored provide explicit directives for the design, and thus provide a clear and direct link between the objectives and the design, but may lack a strong and defensible connection to the goals. For example, if an objective of x acres of protected area in a particular ecological setting is achieved, this does not guarantee that the goal of sustaining ecological functions is achieved. Similarly, if an objective of x acres of suitable habitat protected or maintained (via management) for a particular focal species is achieved, this does not guarantee the goal of sustaining its population is achieved. Thus, we can be successful in meeting our objective but fail to achieve our goal. And one inviolate rule about the relationship between goals and objectives is that if the objectives are met it can be assumed that the goal is achieved. Consequently, while objectives specified in terms that are directly measurable (e.g., acres protected) may provide clear and explicit direction for the design, they may also provide a false sense of confidence in meeting the goals.

3.3 Create the Conservation Design

The second step is to create a conservation design to meet the objectives. Here, "design" refers to a comprehensive spatial strategy outlining what conservation actions to take and where (and potentially when). Importantly, the design represents a hypothesis about what conservation actions need to be taken and where for the objectives (and thus the goals) to be met, and thus its success can only be determined through objective-based monitoring (i.e., monitoring the measurable aspects of each SMART objective).

Our conservation design has four major components, as follows:

1) *Core areas* — The first major design component is the most critical element and involves identifying and prioritizing a network of (potentially tiered) core areas within each sub-landscape with the aim of protecting areas with high ecological value based on one or more of the following criteria: 1) high ecological integrity across all

ecological settings, emphasizing areas that are relatively intact (i.e., free from human modifications and disturbance) and resilient to environmental changes (e.g., climate change); 2) high capability to support a suite of representative wildlife species, emphasizing areas that provide persistent optimal habitat and climate conditions; 3) high potential for floodplain forest restoration along major rivers, emphasizing areas where geomorphic characteristics favor the development of floodplain forest; and 4) rare natural communities that support unique biodiversity, regardless of their landscape context. Note, the criteria above for selecting core areas is flexible and can include anything so long as consistent data are available for evaluating each criterion over the extent of the designated landscape. The four criteria above were selected for the Connect the Connecticut project illustrated here, but the RCOA application involved only the first, second, and fourth criteria due to lack of regional data on floodplain forest restoration potential. In addition, the exact composition and extent of the core area network will depend on user-specified conservation targets (e.g., how much of the landscape to include in core areas), but the final network of core areas, however they are defined, can be considered the most important locations for achieving the objectives. **Importantly**, the cores areas represent the best or most urgent places to start, but by themselves are unlikely to be sufficient to fully achieve the objectives. Moreover, core areas are places of particularly high ecological value based on the criteria above without regard to existing protected lands, and as delineated may not always represent logical or practical conservation units since they do not correspond to parcel boundaries or any other practical scheme such as roadless blocks.

2) *Connectors* — The second major design component involves connecting the core areas to facilitate ecological flows (e.g., movement of plants and animals) across the core area network (i.e., to ensure landscape connectivity). While there are many ways to achieve landscape connectivity (e.g., increasing the number and extent of core areas), here we focus on the creation of broad conservation corridors (or connectors) between core areas, including likely pathways of concentrated ecological flows (i.e., high conductance of plants and animals) between designated cores. Note, the connectors do not necessarily have high local ecological integrity; their value stems from their role in conducting flows of plants and animals between areas of high ecological integrity -- the core areas. Thus, high conductance rather than high integrity is the criterion for selecting connectors. In addition, connectors between aquatic core areas are not identified as such because they necessarily consist of the entire stream network between the cores.

3) *Conservation priorities and management needs* — The third major design component involves determining conservation priorities and active land management needs of individual core areas and/or connectors. Individual core areas and connectors contribute differently to the connectivity of the network due to their size and/or position in the network. Here we are concerned with prioritizing cores and connectors based on their importance to the network to help establish conservation priorities. Similarly, because individual cores and connectors are comprised of different ecological systems and provide habitat for different species, they may require different management actions to maintain their values. Indeed, there are many management actions designed to actively manipulate ecological systems and/or populations to

achieve conservation objectives (e.g., silvicultural treatments to create/maintain early-seral vegetation, hydrological controls to affect spawning habitat, prescribe burning to maintain fire-adapted ecosystems, etc.). Here we are concerned with identifying the important ecosystems and/or habitats in each core to aid in identifying the management needs. Lastly, because urban development, climate change and sea level rise are growing threat to biodiversity, there is a need to consider where these impacts are most likely to occur so that they might inform proactive conservation measures.

4) *Restoration opportunities* — The fourth major design component involves identifying and prioritizing opportunities to restore critical ecological functions (e.g., connectivity). Here we are referring to the restoration of ecological function via management actions designed to reduce or eliminate a stressor that is currently degrading that ecological function. For practical reasons, we currently limit our consideration to actions that aim to restore ecological connectivity, including: 1) prioritizing road-stream crossings for culvert upgrades to improve aquatic connectivity; 2) prioritizing dams for removal or installation of aquatic passage structures to improve aquatic connectivity; and 3) prioritizing placement of terrestrial road passage structures to improve terrestrial connectivity. Other restoration activities, such as prioritizing agricultural lands for wetland or forest restoration, are to be included in future phases of this project.

It is important to emphasize that each of the components listed above can be initially designed using the LCAD model and other external data products, but the final design of each component should be done after field verification (e.g., to confirm that the assigned ecological value to a location is not the result of a spatial data or modeling error) and consideration of other socio-cultural and economic considerations that lie outside the current scope of the DSL project.

3.4 Implement the Conservation Design

The third step is to implement (i.e., build and maintain) the conservation design using various tactics, such as 1) land protection (e.g., fee acquisition and conservation easements), 2) land management (e.g., active vegetation and water management), and 3) ecological restoration. Of course, the full implementation of adaptive LCD will require the use of additional tactics such as education, outreach, partnership, and monitoring that lie outside the current scope of the DSL project. Creating the conservation design is where science and the LCAD model can contribute; implementing the design is the responsibility of conservation practitioners.

3.5 Monitor the Conservation Network

The fourth step is to monitor the conservation design with regards to implementation, effectiveness and validation based on measurements of the user-specified conservation targets (implementation monitoring) and measurements of a suite of ecological indicators associated with the conservation goals and objectives (effectiveness and validation monitoring), as follows:

1) *Implementation monitoring* — This involves determining if the designated conservation targets associated with the conservation design have been met. Quite

simply, it involves tracking the total area protected and managed within the designated core-connector network and the number of restoration activities and comparing these figures to the specified targets.

2) *Effectiveness monitoring* — This involves determining if the conservation design is meeting the specified conservation objectives (and thus goals) from step 1. Effectiveness monitoring is much more difficult than implementation monitoring and ultimately requires a robust sampling design for each of the measurable conservation objectives. In particular, this will require some sort of systematic sampling of ecological functions (possibly by ecological system) in addition to sampling representative species populations throughout the landscape, with proper regard to issues of scale (spatial and temporal) and statistical power.
3) *Validation monitoring* — This involves testing hypotheses about ecological integrity and population viability and the assumptions that underpin the LCD. It is particularly useful to establish cause-effect relationships between the conservation targets (used to establish the conservation design) and the conservation goals and objectives. This helps advance knowledge of ecological systems and landscapes, which helps refine desired condition statements (i.e., conservation goals and objectives). Validated cause-effect relationships are the foundation for prediction, and are necessary to test scenarios about the effects of future landscape change (e.g., climate change) on ecological sustainability. In general, validation monitoring will involve scientific analysis of the same data collected for effectiveness monitoring.

3.6 Evaluate the Conservation Network

The fifth step is to evaluate the conservation network based on the monitoring results. Briefly, this step involves the scientific analysis and summary of the data collected from monitoring and is intended to quantitatively and qualitatively determine whether the conservation objectives (and thus the conservation goals) have been met and, if not, determine why not.

3.7 Adjust the Conservation Network

The final step is to adjust the conservation design based on the results of the monitoring and evaluation as needed to meet the conservation goals. Potential adjustments to the conservation design include modifying the conservation targets (e.g., increasing the area in designated cores, placing more weight on some ecological systems and/or species) and/or modifying the tactics used in each stage of the conservation design (e.g., increase land management in the core areas, increase the number of restoration activities in the connectors). Ultimately, regardless of whether the conservation targets are being met, it may be determined that the specified conservation objectives are not sufficient to meet the conservation goals, and they too may need to be modified. In an adaptive LCD framework, all aspects of the LCD are subject to modification over time as knowledge increases and ecological and cultural environments change.

4 Creating the Conservation Design

In this section we provide a detailed description of step 2 of our adaptive LCD framework -- creating the conservation design, with attention to the methods and metrics associated with each step of the design. This section is meant to serve as an outline of the workflow in the design step as developed and implemented for the Connect the Connecticut project, but its specific implementation could vary depending on the particulars of the landscape under consideration and decisions made by the landscape design team. Importantly, this section provides a methodological template for the design process, not the design itself -- which is the result of this process.

For organizational purposes, and to reflect differences in the methodology used to create the design pertaining to terrestrial and aquatic systems/species, we opted to split the design process into two major sections: 1) terrestrial landscape design, and 2) aquatic landscape design. However, these are not completely independent designs, but instead they should be viewed as complementary. Together, the terrestrial and aquatic landscape designs comprise the overall conservation design, and a complete description of the data products that constitute the complete design is included in Appendix B.

4.1 Terrestrial Landscape Design

For our purposes, terrestrial refers to all upland and wetland ecological systems and the corresponding representative wildlife species, recognizing that wetland systems are typically ecotones between upland and aquatic environments and thus defy simple classification. Nevertheless, because the majority of (but not all) organisms associated with wetlands are semi-aquatic and/or have life history stages that interact strongly with the terrestrial environment, we opted to treat wetlands in combination with uplands.

4.1.1 Criteria for selecting core areas

The exact composition and spatial configuration of the core area network will depend on user-specified conservation targets, but general criteria for creating the core area network include the following:

- *Representativeness* — Include in core areas the full complement of ecological settings (e.g., ecological systems) characteristic of the landscape extent under consideration. In other words, all ecological systems should be well represented in the core areas.
- *Redundancy* — Include in core areas redundant examples of each ecological setting. In other words, to the extent possible, each ecological setting (or ecological system) should be represented in multiple core areas to account for uncertainty in the fate of any single ecological patch.
- *Diversity* — Include in individual core areas a diversity of ecological settings (or ecological systems) to enhance within-core resiliency.
- *Ecological integrity* — Include in core areas places with high and persistent ecological integrity for the constituent ecological settings to ensure the protection of minimally-altered (i.e., intact), resilient and adaptive ecological systems now and into the future.

- *Species landscape capability* — Include in core areas enough area of high and persistent habitat capability and climate suitability for the designated representative species to provide the potential for robust populations now and into the future, recognizing that the core areas alone may not be sufficient to achieve population objectives.
- *Exceptional biodiversity value* — Include in core areas places with exceptional biodiversity value that may not otherwise be accounted for, including, in particular, places with high potential for floodplain forest restoration along major rivers and rare natural communities that support unique biodiversity. Note, there are many local sources of information on places of exceptional biodiversity value that are not available consistently at the regional scale and thus are not formally included in this design. This does not devalue or preclude the use of these additional pieces of information when applying the design to make local decisions. The core area network identified here can be supplemented with local information to expand on or form additional core areas as appropriate.
- *Distribution* — Ensure a well-distributed core area network across the landscape to facilitate ecological resiliency to uncertain future environmental change. Specifically, include in the core area network a wide range of sizes of core areas as necessary to protect the full range of integral ecological settings and representative species' habitat needs that also ensures that core areas are well-distributed across the landscape. For example, matrix-forming ecological systems (e.g., many forest types) and generalist species will likely require relatively large core areas, whereas small, patch forming ecological systems (e.g., wetlands, barren) and species with very specific habitat needs may require including relatively small core areas. Consequently, the distribution of core area sizes should accommodate the unique landscape context; however, all other things being equal, larger core areas should be prioritized over smaller ones. In addition, ensure that core areas are well-distributed throughout the entire landscape, recognizing the need to balance this against the need to select places of high ecological integrity and/or landscape capability for representative species. Note, sub-landscapes (e.g., HUC6 watersheds) provide the primary mechanism by which the distribution criterion is achieved at the landscape scale.

Importantly, to meet the above criteria it must be acknowledged that no one core by itself can achieve the goal of sustaining biodiversity. In particular, given the highly developed and fragmented landscape context of the Northeast, if we desire cores to be comprised largely of contiguous natural areas, then individual core areas are more often than not going to be too small to represent a minimum dynamic area (sensu Pickett and Thompson 1978) -- an area large enough maintain internal recolonization sources to minimize extinction risk. Of course, all other things being equal, the larger the core the better, and thus some cores will be quite large where the landscape context permits. Importantly, from this perspective, cores are not individual and separate ecological reserves, but rather they function collectively as a network to confer ecological integrity and conserve biodiversity at the scale of the entire landscape.

In addition, it is important to acknowledge that after considerable consideration we opted to define and delineate core areas as places of particularly high ecological value that meet the above criteria without regard to existing protected lands. In other words, we seek to identify an "ideal" core area network without bias towards existing protected lands. Existing protected lands may not represent places of particularly high ecological value based on the criteria above and thus we did not want to confound the meaning of "core" with "protected". Note, protected lands can serve as an overlay to the "ideal" solution to determine where additional conservation action is needed.

Finally, it is important to acknowledge that core areas as delineated to meet the above criteria may not always represent logical or practical conservation units, since they do not correspond to parcel boundaries or any other practical scheme such as road-bounded blocks. Core areas are places of particularly high value that meet the criteria above using the highest possible resolution of the data (i.e., 30 m cells). However, the delineation of core areas on a map should be treated as "fuzzy" boundaries and should not prevent or deter conservation in practice based on other real-world considerations. In practice, conservation actions can (and will necessarily) be directed towards more practical geographic units.

4.1.2 Strategy for building terrestrial core areas

There are many possible strategies for building terrestrial core areas to meet the objectives and the design criteria above. After considering many possibilities, ultimately we ended up with a single, two-stage strategy, as follows:

1) *Build initial ecosystem-based cores* — In the first stage, we select terrestrial core areas based solely on ecosystem-based considerations; i.e., without explicit consideration of individual representative species needs, but recognizing that ecosystem-derived cores contribute substantially towards meeting representative species' needs. Here, the goal is to identify the best places to conserve while ensuring redundant representation of all ecological and geophysical settings and places supporting unique biodiversity (e.g., rare communities).
2) *Build final species-complemented cores* — In the second stage, we extend the stage 1 core areas by building additional terrestrial core areas based solely on meeting representative species needs. Here, the goal is to identify the best places to conserve for each of the representative species by complementing what is already in cores from stage 1. Specifically, we add on to the stage 1 cores in such a way as to ensure that collectively the core areas capture a minimum amount of habitat (or landscape capability) for each representative species.

The details of this two-stage strategy are described in the following sections.

Importantly, we also put a constraint on the total extent to be included in terrestrial core areas. The constraint is specified as a percentage of the landscape extent and is flexible. There is no scientific basis or scientific census on "how much is enough" to conserve biodiversity. Indeed, if our goal were to maintain biodiversity at its current level, then it is reasonable to conclude that there should be no loss of natural areas. However, this is not practical, nor can we affirm that even this would be sufficient to sustain biodiversity as there are other drivers of landscape change affecting biodiversity besides human development. Therefore, rather than try to construct a core area network that captures "enough" to conserve biodiversity, which is an unknown and unknowable quantity, we instead choose an arbitrary constraint on how much to include in cores that emphasizes finding the very best places or the highest priorities for conservation action. Moreover, because of the difficulty of choosing a single arbitrary constraint on how much to include in cores, we also allow for multiple tiers of cores to be defined.

For example, in the Connect the Connecticut River project, we elected to create two tiers of cores. For **tier 1** cores, we set the constraint at **25%**, which was deemed to be large enough to serve as a lofty but realistic conservation goal and small enough to force the design to be highly strategic. In addition, we further specified that stage 1 cores (ecosystem-based) would comprise **20%** of the landscape and that stage 2 cores (species-based) would comprise the remaining **5%** to meet the overall constraint of **25%**. For **tier 2** cores, we set the constraint at **50%**, and specified that stage 1 ecosystem-based cores would comprise **40%** of the landscape and that stage 2 species-based cores would comprise the remaining **10%**, and that tier 1 cores would be nested entirely within tier 2 cores.

4.1.3 Create the ecosystem-based core area selection index

The first step in building terrestrial core areas is to create a "selection index" that integrates the different ecosystem-based values that core areas are intended to represent and reflects the design criteria described above. The selection index can be created from any number of data layers, but in the Connect the Connecticut River project, we combined the following spatial data products:

1) *(Weighted) index of ecological integrity (IEI)* — This data layer is an output of the LCAD model and represents relative ecological intactness (i.e., free from human modifications and disturbance) and resiliency (i.e., ability to recover from disturbance and stress) at the resolution of 30 m cells computed for both the current (2010) landscape and projected future (2030 or 2080) landscape. To learn more about *IEI*, see the technical document on integrity (McGarigal et al 2017). This index is (quantile) scaled by ecological system within each HUC6 watershed and thus discerns cells of relatively low (0) to high (1) integrity within each ecological system and watershed. The scaling by ecological system helps to ensure representativeness of all ecological systems. The scaling by HUC6 watershed helps to ensure that cores are well-distributed across the landscape. Note, because of the resiliency metrics currently included in *IEI*, this index is perhaps best viewed as addressing short-term resiliency on the scale of years to several decades, in contrast to the TNC resiliency index (see below). Moreover, each ecological system can optionally be assigned a weight to increase or decrease its likelihood of inclusion in the final core areas.

2) *TNC terrestrial resiliency (Resil)* — This data layer is a modified TNC product representing terrestrial ecological resiliency at the resolution of 30 m cells. To learn more about the TNC resiliency index, see Resiliency page at TNC's Conservation Gateway. This index is (quantile) scaled by geophysical settings (i.e., elevation and geological substrate) and thus discerns cells of relatively low (0) to high (1) resiliency within each geophysical setting within each HUC6 watershed. Note, this index differs from *IEI* in a couple of important and complementary ways. First, *IEI* is scaled by ecological system, whereas this index is scaled by geophysical setting. Thus, when combined these two indices strive to locate areas of high integrity representing the full suite of ecological systems and geophysical settings. Second, this index addresses

Box 1. Steps for deriving the terrestrial ecosystem-based core area selection index.

1) Derive *IEI*, quantile scaled by ecological system and HUC6 watershed.
2) Optionally, multiply *IEI* by user-specified ecological system weights.
3) Quantile scale weighted *IEI* by HUC6 watershed.
4) Set TNC terrestrial resiliency to nodata where *IEI* is nodata (i.e., developed cells).
5) Quantile scale TNC terrestrial resiliency by geophysical setting and HUC6 watershed.
6) For all terrestrial and wetland cells, set selection index = weighted mean of *IEI* (e.g., weight = 3) and TNC terrestrial resiliency (e.g., weight = 2).
7) For all headwater creek cells, set selection index = mean of *IEI* and USGS stream temperature tolerance index (see below).
8) For all other aquatic cells, set selection index = *IEI*.
9) Set selection index = 1 for any cells mapped as tier 1 floodplains or S1-S3 rare natural communities.
10) Quantile scale selection index by HUC6 watershed and set all nodata cells = 0.

resiliency to climate change by highlighting places with high elevation and landform diversity, under the assumption that a locally diverse and connected geophysical template will offer the greatest opportunities for systems/species to find suitable microclimates as the climate changes (i.e., a diverse abiotic stage will allow opportunities for species to redistribute themselves over time). Consequently, this index is best viewed as addressing long-term resiliency on the scale of decades to centuries. Lastly, this index does not apply to aquatic cells.

3) *TNC tier 1 floodplains* — This data layer is a modified TNC product representing areas with high potential for floodplain forest restoration along major rivers in the Connecticut River watershed, emphasizing areas where geomorphic characteristics favor the development of floodplain forest. Note, this layer is a binary indicator depicting tier 1 floodplain sites, defined as having the potential to be flooded at least once in a two-year period, at the resolution of 30 m cells and limited to where mapped tier 1 floodplain polygons do not overlay water or development as represented in the ecological systems map.

4) *Rare natural communities* — This data layer represents a compilation of mapped rare natural communities listed by state heritage programs as S1 (extremely rare), S2 (rare), and S3 (uncommon), with definitions of S1-S3 varying slightly among states, and obtained from the four states within the Connecticut River watershed. Similar to tier 1 floodplains, this layer is a binary indicator depicting S1-S3 rare communities at the resolution of 30 m cells and limited to where mapped rare communities do not overlay water or development as represented in the ecological systems map.

For the Connect the Connecticut project, the terrestrial ecosystem-based core area selection index (tSI) was defined for all terrestrial and wetland cells as follows:

$$tSI = \begin{bmatrix} 1, floodplain\ or\ rare\ community\ cells \\ \dfrac{\left((w_1 \times IEI) + (w_2 \times Resil)\right)}{w_1 + w_2}, all\ other\ cells \end{bmatrix}$$

Thus, for terrestrial and wetland cells, the selection index was a weighted average of *IEI* and TNC terrestrial resiliency and was assigned the maximum value of 1 for any cell mapped as tier 1 floodplain or S1-S3 rare community. For aquatic cells (which are also included in this layer), the selection index was equal to *IEI*, except in headwater creeks where *IEI* was averaged with the USGS stream temperature tolerance index (see below). The actual process of weighting and combining the products is more complicated than this due to the need to maintain the quantile scaling properties of the final product (**Box 1**).

4.1.4 Build initial ecosystem-based cores

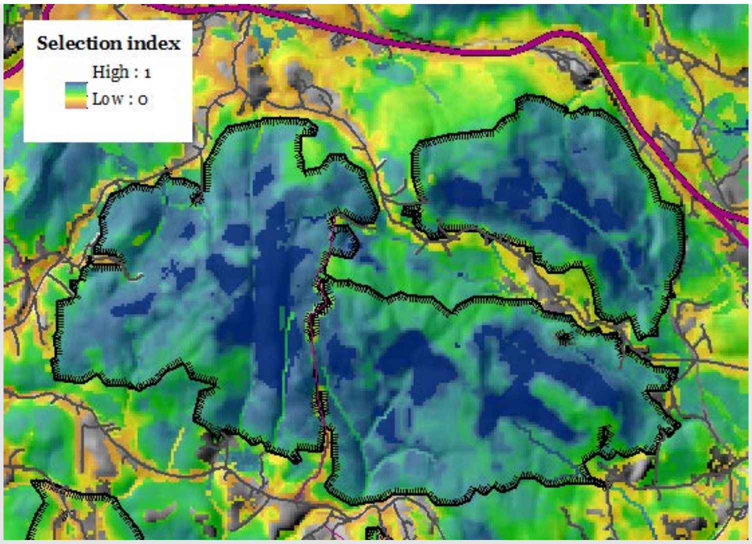


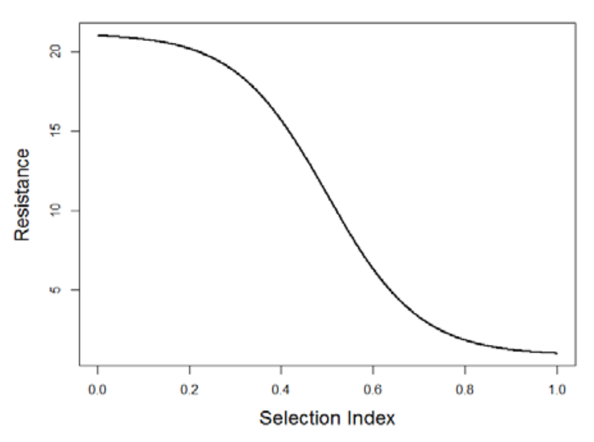
Figure 3. Terrestrial core areas (depicted by the bold polygons with feathered outlines) showing the initial "seeds" (dark blue) and the underlying terrestrial ecosystem-based corea area selection index (depicted as a gradient).

The next step is to build cores based on the terrestrial ecosystem-based core area selection index. The basic idea behind the core building algorithm is to select the very best places based on the selection index by "slicing" the surface above some threshold level, which should guarantee redundant representation of all terrestrial ecological systems and geophysical settings, and then "growing" out these "seed" areas through surrounding lower- valued areas to create larger, contiguous cores in which the highest-value places (i.e., the "seeds") are now buffered by moderately-valued places (**Fig. 3**). Growing a core area outward from the seed is constrained such that it spreads preferentially through cells with the highest value and does not cross major roads or medium-to-high density development. Note, as a result, smaller local roads and low-intensity development can and do occur within the core areas. The "growing" out process is terminated when the user-specified percentage of the landscape is included in the cores. The actual process of building the cores is somewhat more complicated than this (**Box 2**).

Recall, for the Connect the Connecticut project we created two tiers of core areas. Thus, we repeated the process above for each tier, using a larger slice for the second tier (0.9 versus 0.95) and terminating the core growing process at 40% of the landscape instead of 20% of the landscape.

Box 2. Steps for deriving the initial (stage 1) terrestrial ecosystem-based cores.

1) Slice the terrestrial ecosystem-based core area selection index above a threshold value (e.g., 0.95 for tier 1 cores). Note, this particular slice results in the top 5% of the landscape selected as initial "seeds".
2) Expand the seeds by 1 cell (30 m) to eliminate small gaps.
3) Drop any expanded seed that is less than a threshold size (e.g., 40 cells or 3.6 ha).
4) For each retained seed, build a resistant Gaussian kernel based on a specified bandwidth (e.g., 10 km extending out to a maximum distance of 10 km) and resistant surface, where resistance is based on a logistic function of the selection index, such that resistance ranges from 1 when the selection index is maximum (1) to a specified maximum (e.g., 21) when the selection index is minimum (0), as shown in the accompanying figure. In addition, major roads (motorway, primary road, and secondary road), dams, culverts/bridges, and medium-high intensity development are treated as absolute barriers to spread. As a result, cores grow outward from the expanded seeds preferentially through areas of high selection index out to a maximum distance of say 10 km, but do not cross major roads or medium-to-high intensity development.
5) Combine all of the resistant Gaussian kernels into a single surface representing the maximum kernel value at each cell.
6) Quantile scale the combined kernel surface and slice it at a threshold level that results in a specified percentage of the landscape being included within cores (e.g., 20% for tier 1 cores).



4.1.5 Build final species-complemented cores

The next step is to supplement the ecosystem-based (stage 1) cores with additional core area to partially meet the habitat needs of all representative terrestrial wildlife species. The basic idea behind this stage of the core building algorithm is to first determine how much of each species' targeted landscape capability (an index of habitat and climate suitability for each species) is already included in the ecosystem-based cores, and then build additional cores to ensure that a minimum proportion of each species' landscape capability target is included in the final set of cores. The landscape capability targets for the representative species are determined by the planning team. For the Connect the Connecticut project the targets were based on several criteria pertaining to threats, responsibility and rarity (see **Appendix A**).

The species-based (stage 2) cores are built sequentially, one at a time, by focusing on the species that are furthest from meeting their targets. After each new core is built, the species are re-weighted based on deviations between the species' landscape capability targets and the species' total landscape capability included in the cumulative set of cores. Thus, each new core strives to locate the best habitat for the species that are currently least well-represented in the cores. This process of building new species-based (stage 2) cores continues until a specified percentage of the landscape is included in the final set of cores (e.g., 25% for tier 1 cores). The actual process of building the final species-complemented terrestrial cores is somewhat more complicated than this (**Box 3**).

Recall that for the Connect the Connecticut project, we created two tiers of core areas. Thus, we repeated the process above for each tier. For tier 1, we took the 20% stage 1 ecosystem-based cores and in stage 2 added an additional 5% based on species needs to capture a total of 25% of the landscape. For tier 2, we took the 40% stage 1 ecosystem-based cores, unioned this with the tier 1 cores to ensure that all tier 1 cores get included in tier 2 (i.e., to ensure the spatially nested hierarchy of the tiered cores), and then added an additional amount based on species needs to capture a total of 50% of the landscape.

In addition, for the Connect the Connecticut project, the planning team decided to build separate cores (from the process described above) for the eastern meadowlark as a representative of grasslands birds. Briefly, these cores were derived by selecting a user-specified target of the best meadowlark habitat patches sufficient to capture 50% of the species total landscape capability index value in the watershed, which resulted in 1,448 additional cores representing an addition 1.15% of the CTR landscape.

4.1.6 Build supporting landscapes

The next (optional) step is to identify practical conservation units surrounding and supporting the core areas. The purpose of these "supporting landscapes" lands is two-fold: 1) to recognize the area surrounding the cores as potentially important to the maintenance of the ecological value in the core areas, and 2) to identify more practical conservation units for the focus of conservation actions.

While there are many possibilities for identifying and delineating supporting landscapes, for the Connect the Connecticut project we defined them as road-bounded "natural blocks" containing the tier 1 and 2 cores. Specifically, we defined our natural blocks as areas bounded by motorway, primary road, secondary road, tertiary, and local road, or medium-to-high intensity development. Thus, these natural blocks can (and do) contain tracks and low-intensity development (including agriculture). Any natural block containing any part of a tier 1 or 2 core was identified as a tier 3 supporting landscape unit. Thus, collectively, tier 3 includes all the natural blocks containing the tier 1 and 2 cores. Consequently, tier 1, 2 and 3 maintain a spatially-nested hierarchy (**Fig. 4**).

Box 3. Steps for deriving the final species-complemented terrestrial cores.

1) Compute the target number of landscape capability (LC) units for each species, as follows: multiply the total LC units in the landscape by the user-specified weight, given as a proportion (0-1). Call this "target LC".
2) Compute the target LC for each species for the current stage, where the number of stages is user-defined. Call this "stage LC". For example, 10 stages results in increments of 0.1, and the first stage LC = 0.1 × target LC, second stage LC = 0.2 × target LC, and so on.
3) Compute the total LC units for each species included in the current set of cores. Call this "core LC". Note, in the first iteration, this is based on the ecosystem-based (stage 1) cores.
4) Compute a weight for each species, as follows: 1 – (core LC /stage LC), set to zero if negative. This weight represents the proportional deviation from the stage target and goes to zero when the core LC ≥ stage LC.
5) Multiple the landscape capability grid for each species by the corresponding weight and sum across all species to produce a selection index.
6) Select a cell with the maximum selection index to form the "seed" of a new core. Note, this ensures that the core is located in a place that is likely to capture LC units for species with the greatest deviations between core LC and stage LC.
7) Build a resistant linear kernel from the "seed" based on a specified bandwidth (e.g., extending to a maximum distance of 40 km) and resistant surface, where resistance is based on a logistic function of the selection index, such that resistance ranges from 1 when the selection index is maximum (1) and, e.g., 81 when the selection index is minimum (0), similar to the curve shown in Box 2.

   In addition, major roads (motorway, primary road, and secondary road), dams, culverts/bridges, and medium-to-high intensity development are treated as absolute barriers to spread.

   As a result, the core grows outward from the seed preferentially through areas of high selection index out to a maximum distance, as specified above, but does not cross major roads or medium-to-high intensity development. In addition, the core grows to a larger extent (up to the maximum specified) when there is more extensive, contiguous high values of the selection index.
8) Repeat steps 2-6 until the full set of cores exceeds the stage LC for all species, and then switch to the next stage.
9) Repeat steps 2-7 until a specified percentage of the landscape is included in cores (e.g., 25%).
10) Assign a unique ID to each set of contiguous "core" cells.

4.1.7 Build connectors between cores

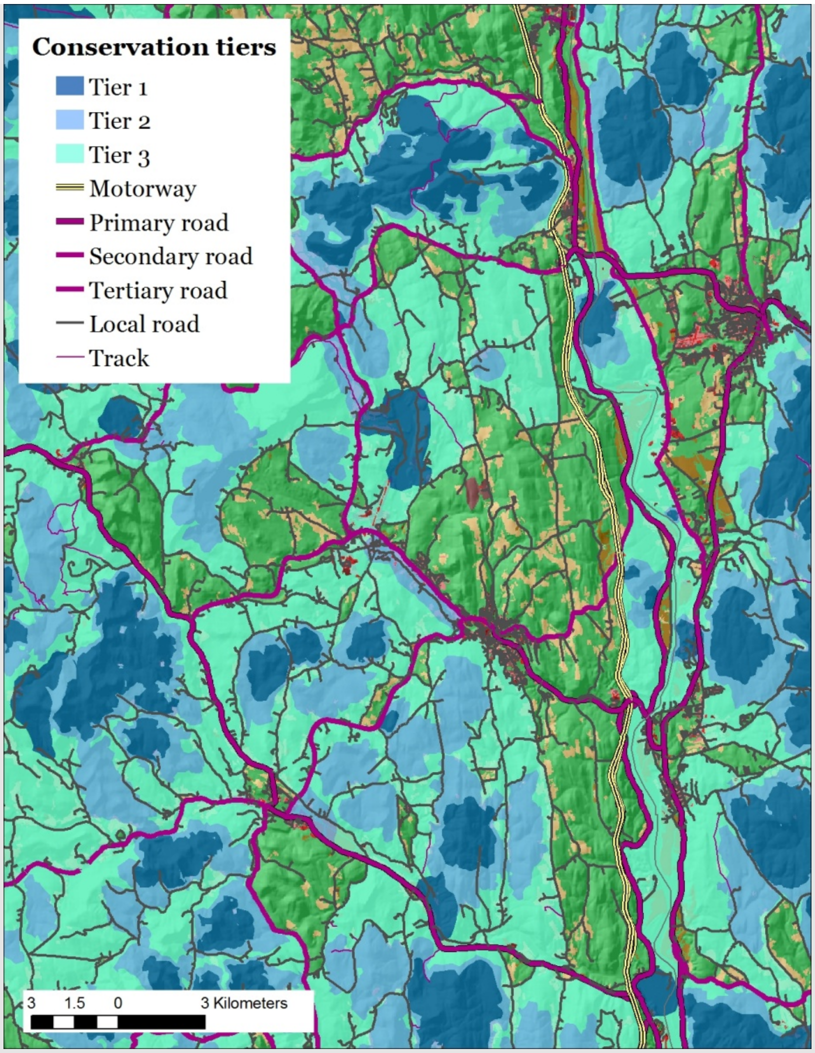


Figure 4. Tier 1 and 2 core areas and the corresponding tier 3 supporting landscapes overlaid by roads and with land use (no legend) in the background.

The next step is to build connectors among the terrestrial cores to facilitate ecological flows (e.g., movement of plants and animals) across the core area network (i.e., to ensure landscape connectivity). The basic idea is to build conservation corridors between core areas by identifying likely pathways of concentrated ecological flows (i.e., high conductance of plants and animals) between the cores. The connectors are built as part of the process of creating random low-cost paths (RLCPs) between pairs of cores, which is described in detail in the technical document on connectivity (McGarigal et al 2017). Briefly, we model thousands of RLCPs between each pair of cores, in which each path starts from a randomly selected ecological setting in the source core and tries to find a low-cost path to the same ecological system in the destination core (up to a maximum specified distance), where resistance (or cost) is based on ecological similarity to the cell of origin. RLCPs are created in both directions. Thus, the final set of paths reflects likely routes of movement of plants and animals associated with the ecosystem composition of the two cores. For each pair of nodes, we select a certain number of the best (highest probability of connectivity) paths, such that the larger, higher-quality, more connected cores get more paths between them, and then we buffer each of the selected paths by a specified width (e.g., 250 m) and combine the buffers to form the final connectors (**Fig. 5**). The actual process of building the connectors is somewhat more complicated than this (**Box 4**).

It is important to keep in mind several aspects of the final connectors:

1) The purpose of the connectors is to increase the resiliency of the core area network to uncertain changing land use and climate by facilitating the movement of plants and animals across the network (i.e., to promote connectivity). Thus, the connectors are

wider where more movement between cores is expected because of larger and closer core areas and a more favorable natural environment between them, however narrow corridors are maintained between even the smaller and more isolated cores up to a certain threshold in connectivity.

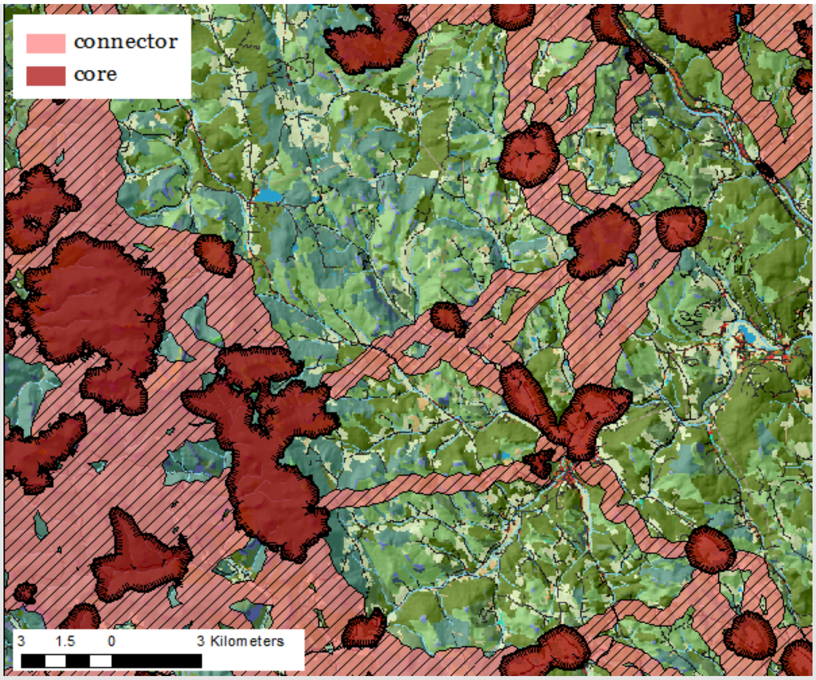


Figure 5. Connectors (hatched polygons) between terrestrial tier 1 core areas (bold polygons with feathered outlines) on a background of the ecological systems map (without a legend).

2) Connectors link nearby core areas along pathways that were created based on their ecological similarity to the ecosystems in the adjoining cores. Thus, connectors between core areas composed primarily of forest preferentially follow pathways dominated by forest, and connectors between core areas composed primarily of wetlands preferentially follow pathways via wetlands (often as stepping stones). Importantly, the connectors are based on ecological similarity and do not necessarily represent travel corridors for any individual species.

3) Connectors may traverse through areas of low-density development and cross roads of all classes, but they do not include high-intensity development.

4) Connectors are core-area dependent; i.e., they are defined only in reference to the specific set of core areas. Consequently, the connectors represent areas especially important to the connectivity of the designated core area network and thus their conservation value stems from the core area they seek to connect. If the core area network changes, the connectors will necessarily change too. Areas important to connectivity of the landscape as a whole independent of the core areas is better address in other ways and is currently under development.

5) Lastly, while connectors can be built for any set of cores, including multiple tiers of cores, for the Connect the Connecticut project we elected to build connectors only for the tier 1 cores since these are the highest priority areas and the area most likely to receive targeted conservation action.

Box 4. Steps for deriving the connectors between terrestrial cores.

1) For each pair of core areas within a threshold distance of each other (e.g., 20 km), build a large number (e.g., 1,000) random low-cost paths (RLCPs) in each direction.

2) Convert the functional length of each path (i.e., cost distance) to path probability of connectivity (*PC*) using a Gaussian density function based on a specified bandwidth (standard deviation, e.g., sd = 10 km). Note, the use of a Gaussian function results in the path *PC* decreasing non-linearly with increasing cost distance to more realistically represent dispersal ability.

4) Compute the link *PC* between cores by multiplying each path *PC* by the mean value of the two cores, where the value of each node is computed as the sum of the terrestrial ecosystem-based core area selection index, and averaging across all paths. As a result, larger, higher-quality (based on the sum of the selection index), more connected cores have a higher link *PC* (i.e., they have a higher probability of being connected).

5) Between each pair of cores (and in each direction), save up to 10 of the best (highest path *PC*) paths based on the square root of the link *PC*, as follows:

$$npaths = 10 \times \sqrt{link\ PC}$$

npaths	*link PC*
1	0.01
2	0.04
3	0.09
4	0.16
5	0.25
6	0.36
7	0.49
8	0.64
9	0.81
10	1.0

Note, the above procedure ensures that even poorly connected cores (due to landscape context), up to a certain threshold distance, end up with at least one path and that highly connected cores do not end up with a vast number of paths (resulting in extremely wide connectors).

6) Buffer each of the selected paths by a specified distance (e.g., 250 m) and combine the buffers (i.e., union) into the final connectors.

4.1.8 Assess importance of cores/connectors to the ecological network

The next step is to assess the importance of individual core areas and connectors to the ecological network. Unfortunately, measuring the contribution of each core/connector to the overall network is quite challenging because of the many different ways to consider "importance".

Core area importance — we measure the importance of individual cores as follows:

1) *ieiSum* = sum of the terrestrial ecosystem-based core area selection index and the corresponding rank (*ieiRank*), which is a reflection of both the size of the core and the quality of the cells within in it. Note, here, quality is based on ecosystem considerations; specifically, ecological integrity and biodiversity value as defined by the terrestrial ecosystem-based core area selection index. The basic idea behind this metric is that, all other things being equal, larger cores are more resilient than smaller cores and thus contribute more substantially to the resiliency of the overall network than smaller cores. Importantly, this metric does not explicitly consider how important the core is for representative species.
2) *import* = index of the importance of each core to the entire core area network based on its size/quality (as represented by *ieiSum*), proximity to other cores, and strategic position in the network, and the corresponding rank (*importRank*). Specifically, this index reflects how much the connectivity of the entire network, as measured by the network probability of connectivity (*PC*) metric, would be affected by its removal (see the technical document on connectivity, McGarigal et al 2017, for a detailed description of the *PC* metric). It gives the absolute decrease in the probability of connectivity (ΔPC) of the entire network. Note, because larger/higher quality cores contribute more substantially to network *PC*, this index is highly correlated with *ieiSum*.
3) *relImport* = index of the importance of each core to the entire core area network without considering core area value (*ieiSum*) in the calculation of ΔPC, and the corresponding rank (*relImpRank*). Note, in the standard calculation ΔPC is heavily influenced by core area value (i.e., size/quality of the individual cores). Here, we set core area value the same for all cores, thus removing the influence of core area size/quality. Consequently, *relImport* is an alternative to *import* for rating the relative importance of cores that gives more influence to core position in the network than core area value (size/quality).

<u>Link importance</u> — Because the buffered RLCPs between cores coalesce in various ways to form the final connectors, the linkages between individual pairs of cores are not readily distinguishable in the connectors (**Fig. 5**). Thus, it is not meaningful to measure the importance of each connector. However, we can measure the importance of the "link" between each pair of cores based on its contribution to the <u>network</u> probability of connectivity (*PC*) metric. Here, a "link" is an abstract entity, not a physical entity such as a connector. A link represents the total connectivity between two cores, which may be due to a combination of direct and indirect pathways between the cores. Direct pathways include RLCPs that traverse directly from one (source) core to the other (target) core. Indirect pathways include RLCPs that traverse between two or more non-target (stepping-stone) cores on route to the target core. Thus, a link is represented by many possible physical pathways and is a measure of how functionally connected two cores are. We measure link importance as follows:

1) *import* = index of the importance of each link (i.e., the connectivity between two cores) to the entire core area network based on its contribution to the network *PC* value, which reflects the size/quality (as represented by *ieiSum*) and proximity of the involved cores (including the source and target core, as well as any stepping-stone cores), the ecological resistance along the direct and indirect pathways between the

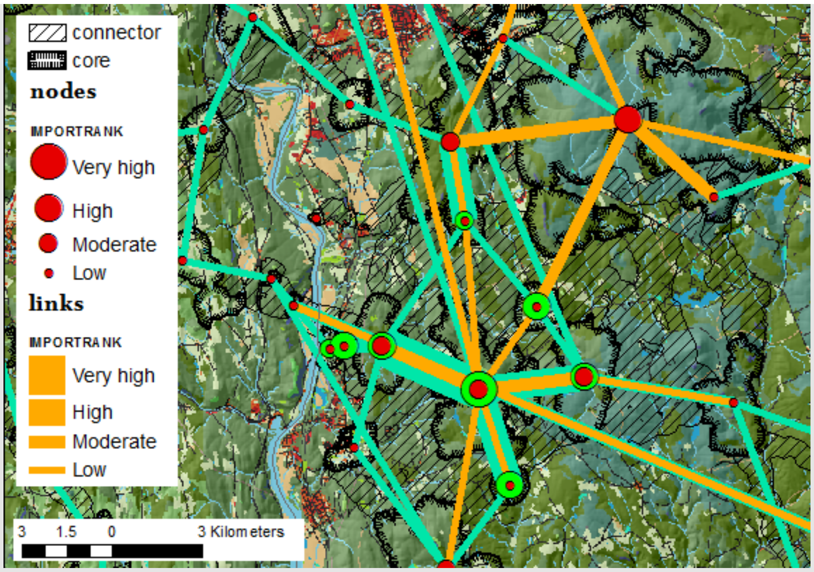


Figure 6. Relative importance of terrestrial cores (nodes) and links between terrestrial core areas (bold polygons with feathered outlines) on a background of the ecological systems map (without a legend).

cores, and the strategic position of the link in the entire network (i.e., is it the only link connecting one set of cores to another set of cores), and the corresponding rank (*importRank*). Specifically, this index reflects how much the connectivity of the entire network, as measured by the network *PC* metric, would be affected by its removal. It gives the absolute decrease in the probability of Connectivity (ΔPC) of the network. Note, because the link is not a physical entity, it can be difficult to translate this into physical connections on the ground. However, for practical application, it is reasonable to associate a link with the full set of connectors (direct and indirect) between the two cores, recognizing that in some special cases it may be possible to have a link with some measured importance (ΔPC) that does not have any physical connectors mapped due to limits we placed on mapping connectors.

2) *relImport* = index of the importance of each link to the entire core area network without considering core area value (*ieiSum*) in the calculation of ΔPC, and the corresponding rank (*relImpRank*). Note, it the standard calculation ΔPC is heavily influenced by core area value (i.e., size/quality of the individual cores). Here, we set core area value the same for all cores, thus removing the influence of core area size/quality. Consequently, *relImport* is an alternative to *import* for rating the relative importance of links that gives more influence to link position in the network than core area value (size/quality).

As an example, let's consider the cluster of cores and linkages depicted in **figure 6**. The cores are depicted by the bold feathered-outlined polygons with the red and green points (nodes) placed at the centroid of each core, and the links are depicted by the orange and blue straight lines between the nodes. The size of the circle/line reflects the importance of the core/link. The red nodes and orange lines depict the importance of each core/link based on the corresponding *import* indices. The green nodes and blue lines depict the importance of each core/link based on the corresponding *relImport* indices. In this example, the relatively large core area in the northeast has a high importance index and moderately important linkages to adjacent cores, reflecting the greater role of larger cores and their connections in the network *PC*. Conversely, the smaller set of cores to the southwest and the linkages among them are considerably more important based the *relImport* indices, reflecting their greater strategic importance in the network.

4.1.9 Determine management needs of cores/connectors

The next step is to determine the management needs of individual core areas (and connectors). Although there are numerous possibilities, here we focus on identifying the important ecosystems and representative species in each core area as the necessary first step in determining its management needs. In addition, we limit our consideration to core areas since the connectors often coalesce into somewhat meaningless spatial units. Once the important ecological systems and/or species are identified for a particular core area, it is incumbent on the manager to determine the appropriate management activities needed to maintain the core area value (see example below).

Ecosystem metrics:

- *index1* = deviation of the observed sum of the selection index for the i^{th} system in the j^{th} core (s_{ij}) from its expected value ($s_{exp(ij)}$), which is based on the size of the core and the system's average selection index and proportional representation across all cores, as follows:

  $$s_{\exp\,(ij)} = a_j \times \left({\sum_j s_{ij}} \Big/ {\sum_j a_{ij}} \right) \times \left({\sum_j a_{ij}} \Big/ {\sum_j a_j} \right)$$

  $$index1_{ij} = \frac{s_{ij}}{s_{\exp(ij)}}$$

  where a_{ij} = area (# cells) of the i^{th} system in the j^{th} core (excluding development). This index is a ratio and ranges from 0 (when a system is absent from a core) to unbounded on the upper end, where <1 indicates an observed value less than expected, and >1 indicates the opposite. Thus, an individual core is especially important for any ecological system with an index1 > 1, and the greater the value above 1 the more important the core is for that ecological system.

- *index1Rank* = rank of *index1* (1 = max *index1*) across all cores for each ecological system. Thus, for each ecological system, the core with the largest positive deviation from expected receives a rank of 1 and is therefore deemed the most important core for that system, the core with the second largest deviation from expected receives a rank of 2, and so on.

- *index2* = percentage of a core's total selection index comprised of each ecological system, as follows:

  $$index2_{ij} = {s_{ij}} \Big/ {\sum_i s_{ij}} \times 100$$

  The index is a percentage, ranging from 0 (when a system is absent from a core) to 100 (when a core is comprised entirely of that system), and thus provides a basic description of the composition of each core. The importance of a core for an ecological system increases with the value of this index.

- *index2Rank* = rank of *index2* (1 = max *index2*) across all cores for each ecological system. Thus, for each ecological system, the core with the highest percentage composition of that system receives a rank of 1, the core with the second highest percentage composition of that system receives a rank of 2, and so on.

- *index3* = percentage of an ecological system's total selection index across all cores found in each core, as follows:

$$index3_{ij} = {}^{s_{ij}}\!\big/_{\sum_j s_{ij}} \times 100$$

  The index is a percentage, ranging from 0 (when a system is absent from a core) to 100 (when a system is found only in that particular core). The importance of a core for an ecological system increases with the value of this index.

- *index3Rank* = rank of *index3* (1 = max *index3*) across all cores for each ecological system. Thus, for each ecological system, the core with the highest percentage concentration of that system receives a rank of 1, the core with the second highest percentage concentration of that system receives a rank of 2, and so on.
- *index4* = difference between an ecological system's average selection index in the focal core and its average selection index across all cores, as follows:

$$index4_{ij} = \left({}^{s_{ij}}\!\big/_{a_{ij}} \right) - \left({}^{\sum_j s_{ij}}\!\big/_{\sum_j a_{ij}} \right)$$

  The index ranges from -1 to 1, where negative values indicate an average selection index of a system in a core less than its average across all cores, and positive values indicate the opposite. This index indicates whether the cells of a system in a core are less than or greater than average in overall quality, and thus the importance of a core for ecological system increases with the value of this index.

- *index4Rank* = rank of *index4* (1 = max *index4*) across all cores for each ecological system. Thus, for each ecological system, the core with the highest average quality of cells for that system receives a rank of 1, the core with the second highest quality of cells for that system receives a rank of 2, and so on.

Species metrics:

1) *index1* = deviation of the observed sum of the *landscape capability* (*LC*) index for the i^{th} species in the j^{th} core (LC_{ij}) from its expected value ($LC_{exp(ij)}$), which is based on the size of the core and the species' average *LC* index across all cores, as follows:

$$LC_{\exp(ij)} = a_j \times \left({}^{\sum_j LC_{ij}}\!\big/_{\sum_j a_{ij}} \right)$$

$$index1_{ij} = \frac{LC_{ij}}{LC_{\exp(ij)}}$$

   where a_{ij} = area (# cells) of the i^{th} species in the j^{th} core (excluding development). This index is a ratio and ranges from 0 (when a species has no *LC* in a core) to unbounded on the upper end, where <1 indicates an observed value less than expected, and >1 indicates the opposite. Thus, an individual core is especially important for any species with an index1 > 1, and the greater the value above 1 the more important the core is for that species.

2) *index1Rank* = rank of *index1* (1 = max *index1*) across all cores for each species. Thus, for each species, the core with the largest positive deviation from expected receives a rank of 1 and is therefore deemed the most important core for that species, the core with the second largest deviation from expected receives a rank of 2, and so on.
3) *index2* = percentage of a core's total *LC* index comprised of each species, as follows:

$$index2_{ij} = {}^{LC_{ij}}\!\big/_{\sum_i LC_{ij}} \times 100$$

   The index is a percentage, ranging from 0 (when a species has no *LC* in a core) to 100 (when the total *LC* in a core is comprised solely of that species), and thus provides a basic description of the composition of each core. The importance of a core for a species increases with the value of this index.

4) *index2Rank* = rank of *index2* (1 = max *index2*) across all cores for each species. Thus, for each species, the core with the highest percentage composition of that species receives a rank of 1, the core with the second highest percentage composition of that species receives a rank of 2, and so on.
5) *index3* = percentage of a species' total *LC* index across all cores found in each core, as follows:

$$index3_{ij} = {}^{LC_{ij}}\!\big/_{\sum_j LC_{ij}} \times 100$$

   The index is a percentage, ranging from 0 (when a species has no *LC* in a core) to 100 (when a species' total *LC* across all cores is found only in that particular core). The importance of a core for a species increases with the value of this index.

6) *index3Rank* = rank of *index3* (1 = max *index3*) across all cores for each species. Thus, for each species, the core with the highest percentage concentration of that species' *LC* receives a rank of 1, the core with the second highest percentage concentration of that species' *LC* receives a rank of 2, and so on.
7) *index4* = difference between a species' average *LC* index in the focal core and its average *LC* index across all cores, as follows:

$$index4_{ij} = \left({}^{LC_{ij}}\!\big/_{a_{ij}}\right) - \left({}^{\sum_j LC_{ij}}\!\big/_{\sum_j a_{ij}}\right)$$

   The index ranges from -1 to 1, where negative values indicate an average *LC* index of a species in a core less than its average across all cores, and positive values indicate the opposite. This index indicates whether the cells of a species in a core are less than or greater than average in overall quality, and thus the importance of a core for a species increases with the value of this index.

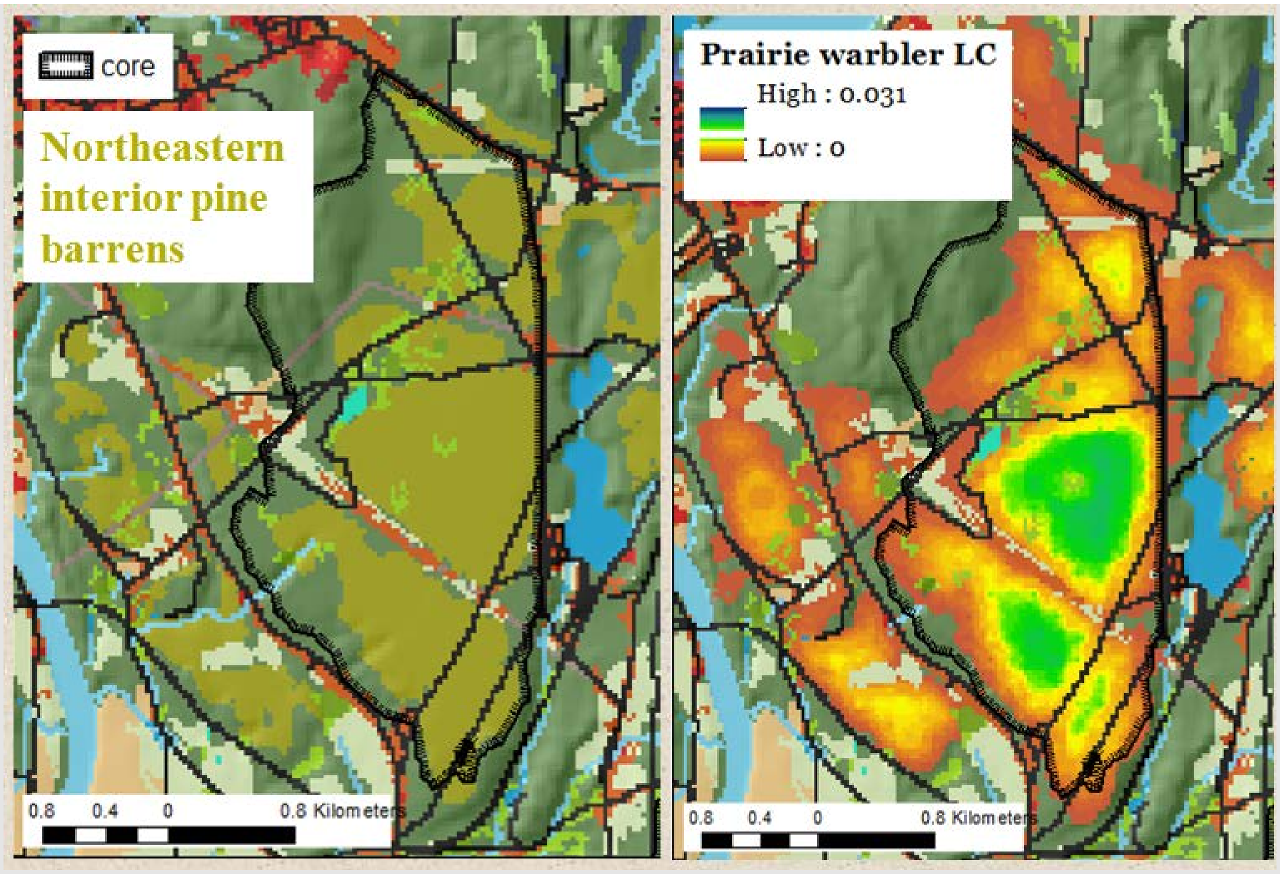


Figure 7. Sample core area centered on the Montague sand plains in Turners Falls Massachusetts depicting the ecological systems map (without a complete legend) in the left panel and the same map with the prairie warbler landscape capabilityindex overlaid in the right panel.

8) *index4Rank* = rank of *index4* (1 = max *index4*) across all cores for each species. Thus, for each species, the core with the highest average quality of cells for that species receives a rank of 1, the core with the second highest quality of cells for that species receives a rank of 2, and so on.

As an example, let's consider the core area depicted in **figure 7**. The most important terrestrial ecosystem in this core is "Northeastern interior pine barrens" with an index1 = 1,032, indicating that the total value of this system in this core is more than 1,000 times greater than expected. In addition, index2 = 61%, indicating that more than half of the ecosystem value of this core is attributable to this particular ecological system, and index3 = 83%, indicating that most of the value for this system across the entire core area network is found in this particular core. Not surprisingly, for all three of these indices this is the top-ranked core for this system. Lastly, index4 = 0.016, indicating that the average quality of this system in this particular core is above average for this system within the core area network, and this is the second highest ranked core for this index and this system.

Not surprisingly, this is also an especially important core area for the prairie warbler, which is a representative species for xeric, early-successional forests and shrublands, with an index1 = 197, indicating that the total landscape capability for this species in this core is 197 times greater than expected (ranked #1). However, index2 = 1.006, indicating that only 1% of the total *LC* value across all 14 representative species in this core is attributed to the prairie warbler, but this low value is almost entirely due to the scale of the *LC* values for this species, which ranges from 0 to only 0.031 in the Connecticut River watershed. Despite the low value of index2, this core is nonetheless the second ranked core for this index and this species. Index3 = 18%, indicating that almost one-fifth of the *LC* value for this species across the entire core area network is found in this particular core (ranked #1). Lastly, index4 = 0.006, indicating that the average quality of habitat for this species in this particular core is above average for this species within the core area network (ranked #1).

Clearly, this particular core is an extremely important core within the core area network for Northeastern interior pine barrens and associated species such as the prairie warbler. Knowing this, management of this core area to maintain these values would likely involve some combination of silvicultural treatments and prescribed burning to maintain the early-successional environment.

4.1.10 Incorporate future land use impacts

The next step is to incorporate future land use impacts, and development in particular, into the conservation design. We considered several options, including putting terrestrial core areas preferentially in places with lower risk of future development. While our approach remains flexible, for the Connect the Connecticut project it was decided that because future development is highly stochastic in where it occurs and, moreover, is something that can be prevented or diverted through proactive land conservation, that it was preferable to establish terrestrial cores in places that hold the greatest ecological value today and then work towards maintaining that value in the future through proactive conservation.

Consequently, we use a combination of the local and regional vulnerability of conductance indices, which are described in detail in the technical document on connectivity (McGarigal et al 2017), to identify places within the terrestrial cores and connectors (and elsewhere) that are at high risk of being developed in the future, since these might be places of high priority for immediate land protection (**Fig. 8**). Briefly, the two vulnerability indices are derived by combining the local and regional conductance indices, respectively, with the integrated probability of development between 2010-2080. The local and regional conductance indices reflect the likelihood of movement by plants and animals through a location independent of any designated cores and between the designated terrestrial cores, respectively. The integrated probability of development index is based on a custom urban growth model that accounts for the type (low intensity, medium intensity and high intensity), amount and spatial pattern of development, and represents the probability of development occurring sometime between 2010 and 2080 at the 30 m cell level. The local vulnerability of conductance index reflects the likelihood of development occurring in places that confer high conductivity at the scale of one to a few kilometers independent of the designated terrestrial cores, and thus it is best used to assess vulnerability within the cores, whereas the regional vulnerability of conductance index reflects the likelihood of development occurring in places that confer connectivity between terrestrial cores, and thus it is best used to assess vulnerability within the connectors. Together, the local and regional vulnerability of conductance indices can be used to focus attention on places within the ecological network that are important to the connectivity of the network and also at high risk of being developed in the future.

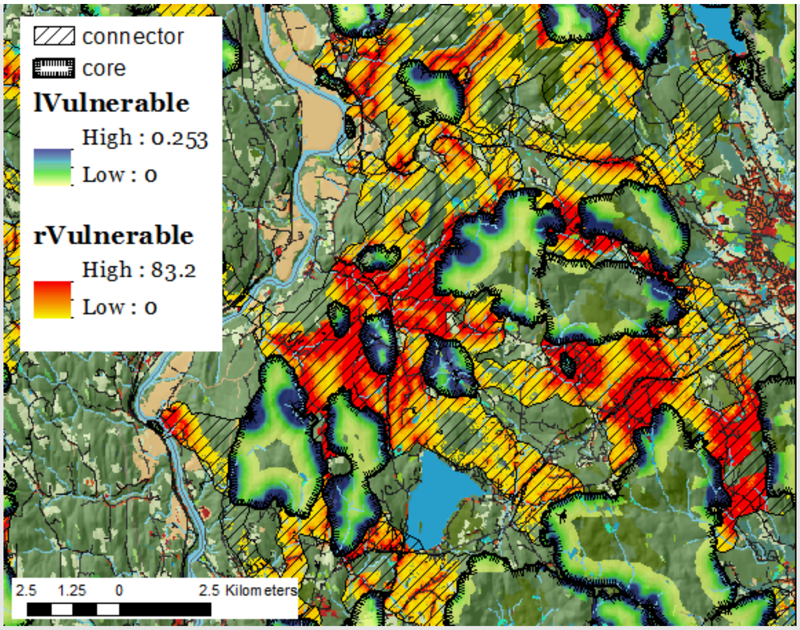


Figure 8. Vulnerability of conductance to future development depicted by a combination of the local vulnerability index (lVulnerable) within core areas and the regional vulnerability index (rVulnerable) within connectors. Areas in dark blue within cores and dark red within connectors have a high risk of future development.

4.1.11 Incorporate future climate change and sea level rise impacts

The next step is to incorporate future climate change and sea level rise impacts into the conservation design. Importantly, similar to future land use, we considered several options, including putting terrestrial core areas preferentially in places with lower risk of climate stress or inundation by sea level rise. Again, while our approach remains flexible, for the Connect the Connecticut project it was decided that because of the uncertainty associated with climate change and sea level rise impacts, that it was preferable to address these issues in other ways, in particular, by building a resilient ecological network and recognizing that climate change resiliency is being addressed at least partially through the following design components already in place:

1) Terrestrial core areas are located in places with high *IEI*, and thus represent places with high local connectedness and ecological similarity across the full range of ecological systems that should confer resilience to disturbance and stress (e.g., climate change) over the relatively short-term of, say, years to several decades.

2) Terrestrial core areas are located in places with high TNC terrestrial resiliency, and thus represent places with high local connectedness to diverse elevations and landforms across the full range of geophysical settings that should confer resilience to stress over the relatively long-term of, say, decades to centuries.

3) Connectors are designed to facilitate ecological flows (i.e., the movement of plants and animals) among the terrestrial core areas, including south-to-north movements, and should confer resiliency to disturbance and stress over the short- and long-term. The core-connector network, by representing the full gradient of ecological and geophysical settings and being largely connected, should act as a stage upon which organisms can shift and adapt to changing environmental conditions.

In addition to the design components above that indirectly address issues of climate change and sea level rise, we also include the climate stress and sea level rise metrics as separate products in the landscape design data package. These metrics are described in detail in the technical document on integrity (McGarigal et al 2017). Briefly, the climate stress metric is a measure of the estimated climate stress that may be exerted on a cell between 2010-2080 based on a climate niche model developed for the corresponding ecological system (i.e., how much is the climate of the focal cell moving away from the climate niche of the corresponding ecological system)(**Fig. 9**). Increasing values of the climate stress metric indicate that the corresponding ecological system is likely to experience climate conditions between 2010-2080 that are increasingly less similar to the climate conditions associated with the system's current geographic distribution, and thus there will likely be climate forcings to change the composition and structure of the plants and animals found at a site.

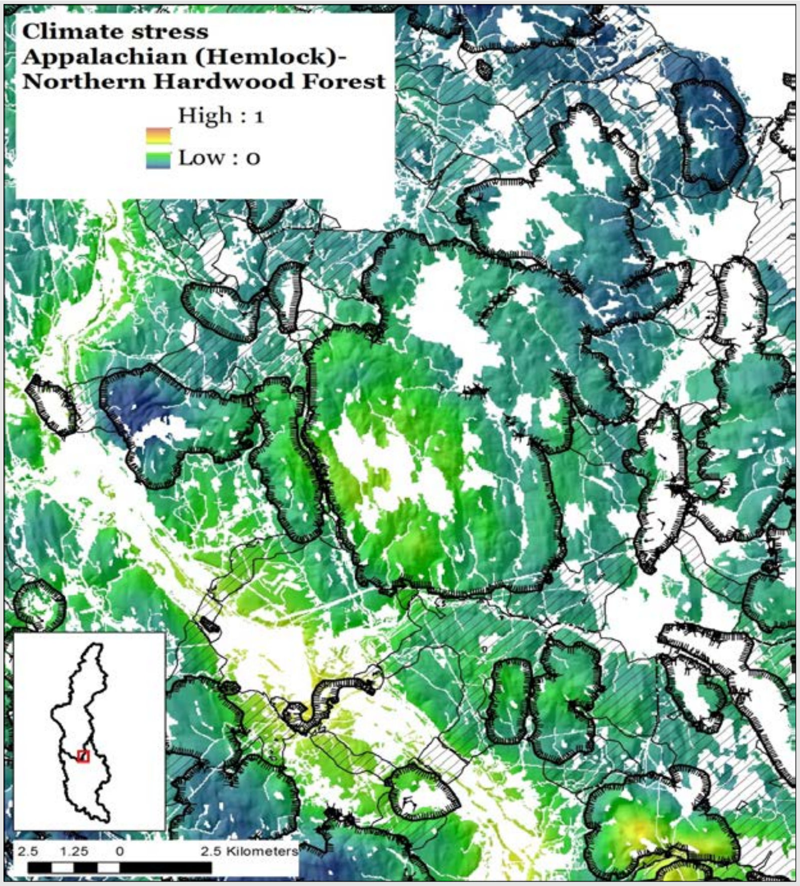


Figure 9. Climate stressor metric depicting the relative magnitude of predicted climate stress between 2010-2080 for the Appalachian (Hemlock)-Northern Hardwood Forest ecological system in a portion of the Connecticut River watershed, overlain by core areas (bold feathered-outlined polygons) and connectors (hatched polygons).

The sea level rise metric is based on a model developed by Rob Theiler and associates at USGS Woods Hole (Lentz et al. 2015), and is a measure of the probability of a focal cell being unable to adapt to predicted inundation by sea level rise between 2010-2080 (**Fig. 10**). Specifically, whether a site gets inundated by salt water permanently due to sea level rise or intermittently via storm surges associated with sea level rise clearly determines whether an ecosystem can persist at a site and thus its ability to support a characteristic plant and animal community. USGS examined future sea-level rise impacts on the coastal landscape from Maine to Virginia by producing spatially-explicit, probabilistic predictions using sea-level projections (based on an average of two climate change scenarios: RCP 4.5 and 8.5), vertical land movement (due to glacial isostacy) rates, elevation, and land cover data. The data span the coastal zone from an elevation of 5 m inland to -10 m offshore, and are provided here for the forecast year 2080.

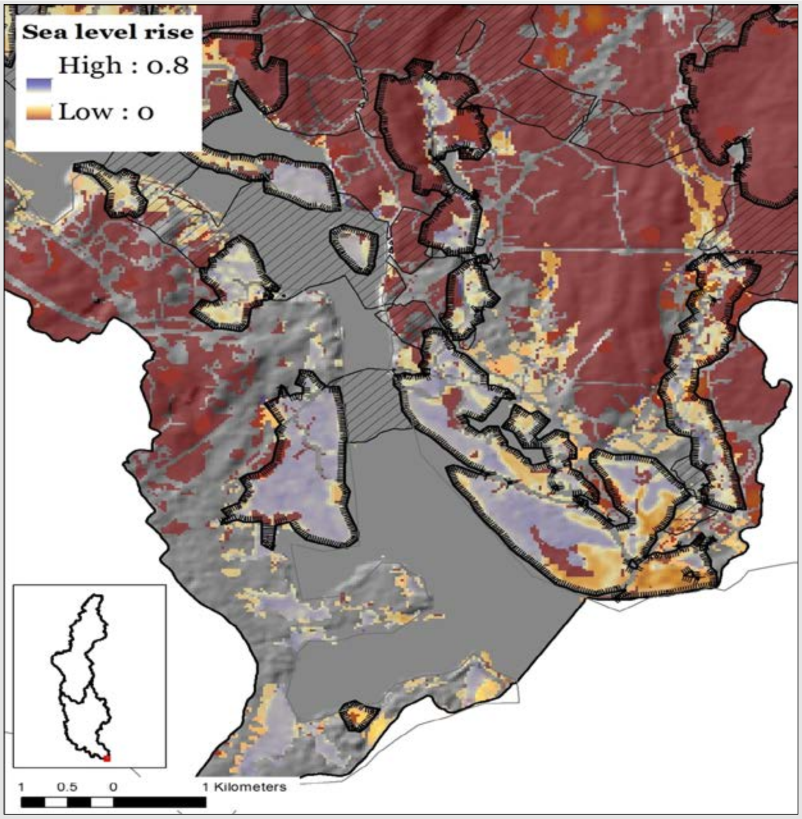


Figure 10. Sea level rise inundation metric depicting the relative likelihood of being unable to adapt to sea level rise between 2010-2080 for the mouth of the Connecticut River, overlain by core areas (bold feathered-outlined polygons) and connectors (hatched polygons).

In the sea level rise metric provided here, the raw coastal response metric produced by USGS is scaled and inverted so that a cell with high probability of exhibiting a dynamic (or adaptive) response to sea level rise gets a zero (low stress) and a cell with low probability of exhibiting a dynamic response gets a value approaching 1 (high stress). In addition, cells classified as sub-tidal are assigned nodata for consistency with other data products.

In addition, we also include the climate response index for each of the 14 representative terrestrial wildlife species as separate products in the landscape design data package. This index is described in detail in the technical detail on species (McGarigal et al 2017). Because land management practices to facilitate vegetation and wildlife distribution shifts due to climate change can be specific and vary greatly from management practices that do not consider climate change (Hulme 2005), understanding a species' likelihood of encountering novel climatic conditions is imperative.

Briefly, the climate response index is one of several different measures of landscape capability that reflect different decisions (or assumptions) regarding how to incorporate current versus future land use and climate changes. This particular index is computed as the mean future *LC* calculated with current habitat and predicted future climate in 2080 (averaged across RCP4.5 and RCP8.5 scenarios) within the project area. This index emphasizes places with high current habitat and climate capability that maintain or increase in climate suitability over time without regard to future changes in habitat capability (**Fig. 11**).

Together, the climate stress and sea level rise metrics and the climate response indices for the 14 representative terrestrial wildlife species can be used individually or in combination to focus attention on places within (or outside) the ecological network that are at high risk of being stressed by climate change or sea level rise in the future, and these might be places that warrant close monitoring for signs of ecological impacts.

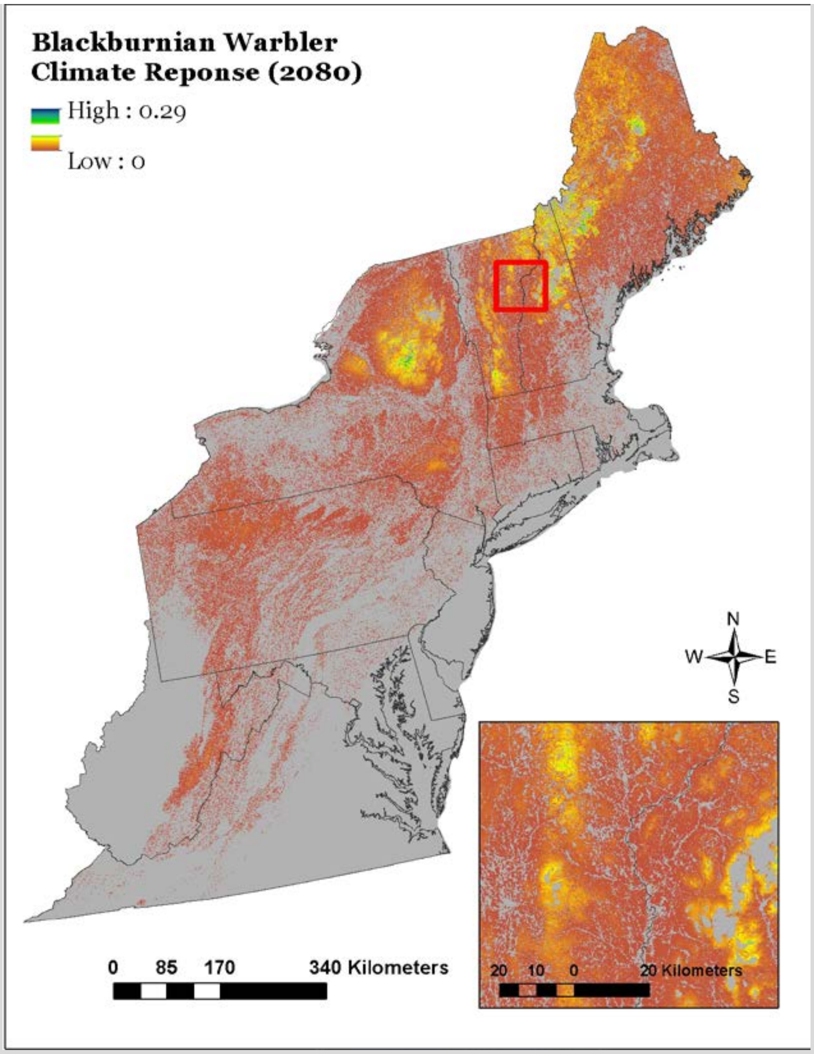


Figure 11. Example of a species' Climate Response index, defined as the mean future Landscape Capability index calculated with current habitat and predicted future climate in 2080 (averaged across RCP4.5 and RCP8.5 scenarios) within the project area. High values represent places with high current Landscape Capability that maintain climate suitability over time without regard to future changes in habitat capability. Shown here for the blackburnian warbler.

4.1.12 Restore terrestrial connectivity via road passage structures

The last step is to identify opportunities to restore terrestrial ecological functions. Although there are numerous possibilities, here we limit our consideration to the installation of terrestrial wildlife passage structures on roadways to improve terrestrial connectivity, which is described in detail in the technical document on connectivity (McGarigal et al 2017). Briefly, this product tabulates the results of a model in which each 300 meter segment of road outside of urban centers, and excluding minor roads receiving relatively little traffic, has a passage structure installed (virtually). Next, we (virtually) reduce the value of the terrestrial barrier and traffic setting variables by 90% for the road cells associated with the passage structure, one at a time. The predicted improvement in connectedness from the passage structure is then recorded. The delta, or difference, in the connectedness score, before and after the installation of the passage structure for each cell within the affected neighborhood, is computed and multiplied by the average index of ecological integrity (*IEI*) of the affected neighborhood. The weighting by *IEI* emphasizes the potential ecological benefits of a road passage structure in an area that is otherwise in good condition but depressed by the road barrier.

This index can be used on its own, but it can also be used in combination with the core-connector network to prioritize locations where the installation of a road passage structure may do the most good at improving the connectivity of the ecological network (**Fig. 12**).

Note, these road passage impact scores do not take into account other socio-economic considerations, such as the cost of a particular passage structure given local engineering considerations, which ultimately will determine the cost-benefit tradeoffs of any particular passage structure. Thus, this product is best used to direct field surveys of road crossings of interest, during which complete and accurate assessments can be made.

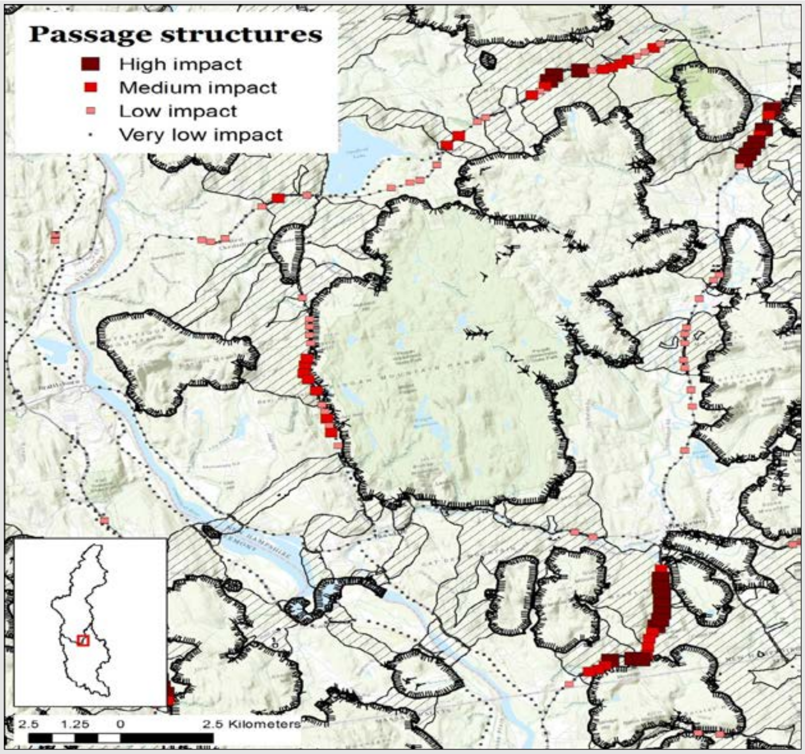


Figure 12. Terrestrial wildlife passage structure impacts on terrestrial connectivity for a network of roads in an area of the Connecticut River watershed, overlain by potential core areas (bold feathered-outlined polygons) and connectors (hatched polygons). Locations of high impact are places where there is potentially the greatest improvement in terrestrial connectivity from installing a wildlife pasage structure across the roadway.

4.2 Aquatic Landscape Design

For our purposes, aquatic refers to lotic (rivers and streams, including freshwater tidal rivers) and lentic (ponds and lakes) ecological systems and the corresponding representative wildlife species. Note, estuarine and marine intertidal systems are treated as wetlands and thus are included in the terrestrial landscape design, and estuarine and marine subtidal areas are not considered at all in this design.

4.2.1 Criteria for selecting aquatic core areas

The exact composition and spatial configuration of the aquatic core area network will depend on user-specified conservation targets, but general criteria for creating the aquatic core area network are similar to those previously specified for the terrestrial core area network, but with the following notable differences:

1) Additional emphasis is placed on the diversity criterion for lotic cores. Specifically, lotic cores are extended upstream and downstream from the initial "seed" cells (see below) with the explicit aim of creating contiguous networks that include a diversity of stream classes, which is deemed particularly important for the resiliency of aquatic systems.

2) Rare and/or critically important aquatic natural communities are not identified in the state heritage databases, and thus there are no designated places with exceptional biodiversity value to include in the aquatic core areas analogous to the terrestrial design.

Importantly, it must be acknowledged that lotic (or riverine) 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 sub-networks as 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.

4.2.2 Strategy for building aquatic core areas

There are many possible strategies for building aquatic core areas to meet the objectives and the design criteria. After considering many possibilities, and for consistency with the terrestrial design, ultimately we ended up with the same, two-stage strategy, as follows:

1) *Build initial ecosystem-based cores* — In the first stage, we select aquatic core areas based solely on ecosystem-based considerations; i.e., without explicit consideration of individual representative species needs, but recognizing that ecosystem-derived cores contribute substantially towards meeting the needs of representative species. Here, the goal is to identify the best places to conserve while ensuring redundant representation of all aquatic ecological systems. In addition, due to fundamental differences between lotic and lentic systems, we build stage 1 cores separately for lotic and lentic systems.

2) *Build final species-complemented cores* — In the second stage, we extend the stage 1 core areas and build additional aquatic core areas based solely on meeting representative species needs. Here, the goal is to identify the best places to conserve for each of the representative species by complementing what is already in cores from stage 1. Specifically, we add on to the stage 1 cores in such a way as to ensure that collectively the core areas capture a minimum amount of habitat (or landscape capability) for each representative species.

   Note, for the Connect the Connecticut project, aquatic representative species were limited to the brook trout in headwater creeks and a suite of five anadromous fish species (American shad, blueback herring, shortnose sturgeon, alewife, and sea lamprey) for portions of the mainstem and major tributaries of the Connecticut River from the mouth of the river upstream to the limit of passability for these species. However, population and/or habitat capability models were not available for the anadromous species, therefore a modified approach was used to address the needs of these species in the design (see below). In addition, no lentic representative species were included (due to the lack of data). Therefore, only stage 1 lotic cores were extended in stage 2.

The details of this two-stage strategy are described in the following sections.

Importantly, we also put a rough constraint on the total extent to be included in aquatic core areas. However, because of details in the core-building algorithm (see below), we are not able to precisely constrain the percentage of the aquascape included in cores. Nevertheless, the rough constraint achieved through calibration is specified as a percentage of the aquascape and is flexible. This rough constraint was set at ~**25%** for the Connect the Connecticut project, which was deemed to be large enough to serve as a lofty but realistic conservation goal and small enough to force the design to be strategic. For the lotic cores, we further specified that stage 1 cores (ecosystem-based) would comprise ~**20%** of the loticscape (based on stream length) and that stage 2 cores (species-based) would comprise the remaining ~**5%** to meet the overall constraint of **~25%**. Also, while feasible, for the Connect the Connecticut project we did not identify multiple tiers of aquatic cores as we did for terrestrial cores.

4.2.3 Create the ecosystem-based core area selection index

The first step in building aquatic core areas is to create a "selection index" that integrates the different ecosystem-based values that core areas are intended to represent and reflects the design criteria described above. The selection index can be created from any number of data layers, but for the purpose of the Connect the Connecticut project, we combined the following spatial data products:

1) *(Weighted) index of ecological integrity (IEI)* — See the previous description of this data layer in the terrestrial design. Note, *IEI* is quantile-scaled by ecological system and HUC6 watershed.

2) *USGS stream temperature tolerance (streamTolerance)* — This data layer is a modified USGS product representing stream temperature tolerance in headwater creeks based on a model developed by Dr. Ben Letcher and associates at the USGS Conte Anadromous Fish Lab. To learn more about USGS stream temperature tolerance, see Dr. Ben Letcher's website (www.lsc.usgs.gov/?q=cafb-ben-letcher). This index is a measure of the relative sensitivity of stream temperatures in headwater creeks to rising air temperatures. Specifically, the index is (quantile) scaled by HUC6 watershed so that the least tolerant headwater creek gets a 0 and the most tolerant gets a 1 within each HUC6 watershed.

The aquatic ecosystem-based core area selection index (aSI) is defined for all aquatic cells as follows:

$$aSI = \left[\begin{array}{c} \dfrac{\big((w_1 \times IEI) + (w_2 \times sT)\big)}{w_1 + w_2}, headwater\ creek\ cells \\ IEI, all\ other\ aquatic\ cells \end{array}\right]$$

where *sT* = streamTolerance index. Thus, for headwater creek cells, the selection index is a (weighted) average of *IEI* and streamTolerance, and for all other aquatic cells it is equal to *IEI*. The actual process of weighting and combining the products is slightly more complicated than this due to the need to maintain the quantile scaling properties of the interim and final product (**Box 5**).

Box 5. Steps for deriving the aquatic ecosystem-based core area selection index.

1) Derive *IEI*, quantile scaled by ecological system and HUC6 watershed.
2) Optionally, multiply *IEI* by user-specified ecological system weights and quantile-scale result by HUC6 watershed.
3) For aquatic cells except headwater creeks, set selection index = result from step 2.
4) For headwater creek cells, quantile scale USGS stream temperature tolerance by HUC6 watershed.
5) For headwater creek cells, compute weighted mean of *IEI* and USGS stream temperature tolerance index, quantile-scale result by HUC6 watershed, and set result = selection index.

4.2.4 Build initial ecosystem-based cores

The next step is to build cores based on the aquatic ecosystem-based core area selection index. Here, we build lotic cores separately from lentic cores owing to some fundamental differences between the treatment of contiguous stream networks and isolated ponds and lakes. However, the basic idea behind the core building algorithm in both cases is to select the very best places based on the selection index by "slicing" the surface above some threshold level, which should guarantee 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) are now buffered (**Fig. 13**).

Growing a core area outward from the seed is relatively straightforward for lentic cores (ponds and lakes). If the seed meets a minimum size threshold (e.g., 0.45 ha), then the seed is grown out to include the entire water body regardless of the selection index value for these cells. Thus, the water body (pond or lake) is treated as the logical unit for lentic cores.

Creating a lotic core is somewhat more complicated. Briefly, if the seed meets a minimum size threshold (e.g., 0.45 ha), then the seed is grown out by spreading upstream and downstream (including back upstream on tributaries) along the stream centerline such that it spreads further through cells with higher value (based on the selection index) and does not spread through lakes or past a dam (of any size). The final expanded seed must exceed a minimum total stream length threshold (e.g., 1 km) to become a lotic core. The actual process of building the lotic cores is of course considerably more complex (**Box 6**).

4.2.5 Build final species-complemented cores

The next step is to supplement the ecosystem-based (stage 1) cores with additional core area to meet the habitat needs of all representative aquatic species. The basic idea behind this stage of the core building algorithm is similar to the terrestrial cores -- compliment what is already captured in the stage 1 cores by expanding them or creating new cores to ensure that a minimum proportion of each species' landscape capability target is included in the final set of cores.

For the Connect the Connecticut project, we were not able to apply this algorithm for a few reasons. First, we had a single representative species for headwater creeks, the brook trout. Second, we had only binary occurrence of five anadromous fish species for the mainstem and major tributaries (i.e., we did not have a continuous landscape capability index). Lastly, we had no representative species for lentic. Therefore, for the Connect the Connecticut project, we modified the algorithm as follows.

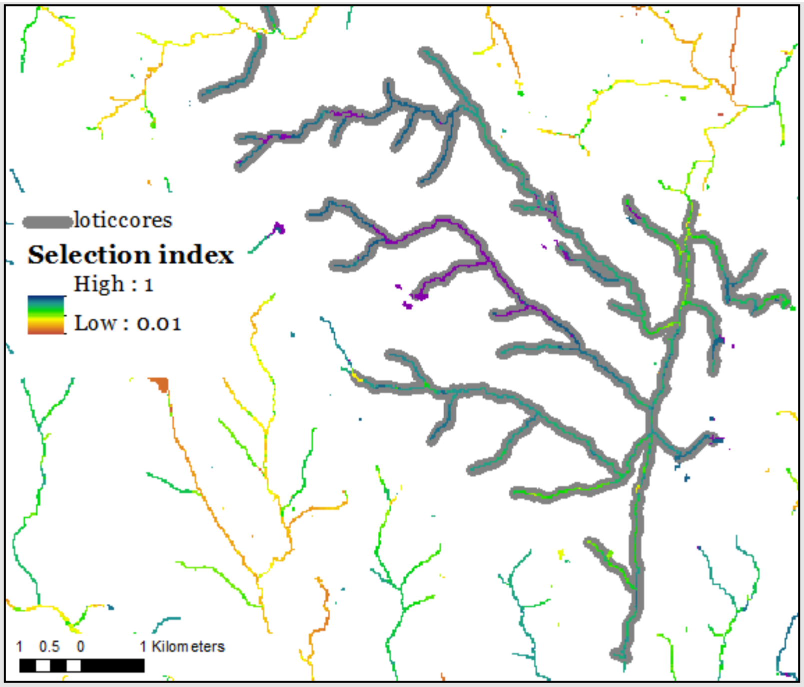


Figure 13. Lotic (riverine) core area showing the initial "seeds" (purple) and the final grown out core (gray), and the underlying aquatic ecosystem-based corea area selection index (depicted as a gradient) on the basis of which this core was derived.

For lentic systems, we simply treated the ecosystem-based cores as the final cores.

For lotic systems, we treated the headwater creeks separately from the mainstem and major tributaries. For headwater creeks, we complemented the stage 1 ecosystem-based cores with additional headwater creeks based on the best predicted brook trout habitat; i.e., headwater creeks with the highest probability of brook trout occurrence based on a model developed by Ben Letcher and associates at the USGS Conte Anadromous Fish Lab. Specifically, we add headwater creeks sequentially starting with the highest probability of brook trout occurrence and continue until a specified threshold percentage of the headwater creek loticscape was met (e.g., 25%). In this manner, we ensured that the best headwater creeks for brook trout were included as lotic cores. For mainstem and larger rivers, we simply included the portions of the mainstem and major tributaries of the Connecticut River from the mouth of the river upstream to the limit of passability for American shad, blueback herring, shortnose sturgeon, alewife, and sea lamprey.

Consequently, the final set of lotic cores included a certain percentage of the riverine network based on ecosystem-based criteria (i.e., representative areas of relatively high ecological integrity across all aquatic ecosystem types), plus additional areas representing important year-round habitat for brook trout in headwater creeks and important migration and/or spawning habitat for several focal anadromous fish in the large and medium rivers.

Box 6. Steps for deriving the initial (stage 1) aquatic ecosystem-based cores.

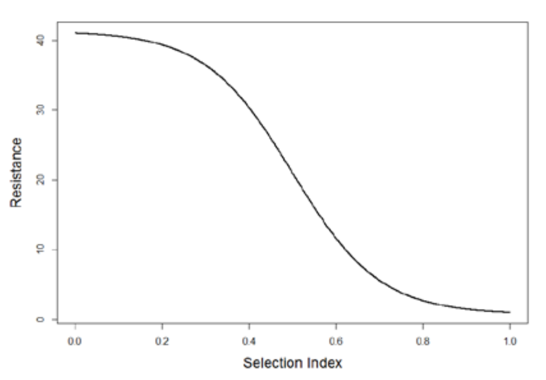
Lentic cores:

1) For lentic cells only, slice the aquatic ecosystem-based core area selection index above a threshold value (e.g., slice = 0.86). Note, this particular slice results in the top 4% of the lenticscape selected as initial "seeds".
2) Expand the seeds by 1 cell (30 m) to eliminate small gaps.
3) Drop any expanded seed that is less than a threshold size (e.g., 5 cells or 0.45 ha).
4) Grow out these expanded seeds to the extent of the containing water body (pond or lake) and let the entire water body be the final lentic core. Note, because we expand seeds to include entire water bodies, we have no a priori means of constraining the lentic cores to encompass a certain percentage of the lenticscape. Consequently, the final solution requires some calibration to select the slice that results in roughly meeting the target.

Lotic cores:

1) For lotic centerline cells only, slice the aquatic ecosystem-based core area selection index above a threshold value, (e.g., slice = 0.93). Note, this particular slice results in the top 7% of the loticscape selected as initial seeds.

   Importantly, the slice is subjective and reflects a balance between selecting the best locations and the number/size of cores. For example, if the core area target is 20% of the loticscape, a slice of the continuous selection index surface at 0.8 would in fact capture the top 20% of the loticscape, but it would contain numerous small, disjunct stream segments, even as small as a single cell. Slicing the surface at 0.93 takes the top 7% as a starting point to ensure the best of the best is captured, but then grows these out to capture an additional 13% such that the final cores represent longer sections of stream. Given a rough constraint on the total percentage of the loticscape to include in cores, there is a tradeoff between longer cores containing a mixture of lower-valued cells and shorter cores of higher value. The "right" balance is obtained through calibration by trying different slices and subjectively evaluating the results.
2) Expand the seeds by 1 cell (30 m) to eliminate small gaps.
3) Drop any expanded seed that is less than a threshold size (e.g., toosmall = 5 cells or ~150 m, since it pertains to centerline cells only).
4) For each retained seed, build a resistant Gaussian kernel based on a specified bandwidth (e.g., 20 km) and resistant surface, where resistance is based on a logistic function of the selection index, such that resistance ranges from 1 when the selection index is maximum (1) to a specified maximum (e.g., 40) when the selection index is minimum (0), as shown in the figure below.



Box 6. Continued.

Note, the combination of kernel bandwidth and the logistic resistance function determines how far the core will spread through low-valued cells. Smaller bandwidth and greater maximum resistance will result in less spread through low-valued cells.

In addition, lakes are assigned a constant high resistance (e.g., 50) and dams are assigned an infinite resistance (i.e., complete barrier) such that lotic cores almost never spread through a lake, but they will often spread through a small pond, and they are always truncated by a dam.

As a result, lotic cores grow upstream and downstream from the expanded seeds up to a specified maximum stream distance (e.g., 20 km) depending on the value of the selection index along the way and the specified maximum resistance, and they often incorporate the centerlines through small ponds.

5) Combine all of the resistant Gaussian kernels into a single surface depicting cells as either provisional core or not. Note, kernels from nearby seeds frequently coalesce into larger aggregated provisional cores.

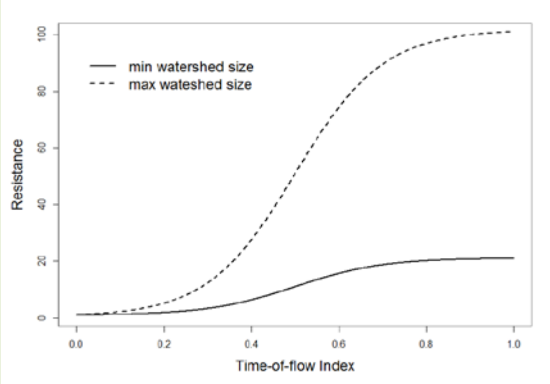
6) Drop any provisional core that is less than a threshold size (e.g., 33 cells or ~990 m). Note, the number of cells is a proxy for stream length since the provisional cores are derived from centerline cells only. This step gets rid of places where a seed does not grow large enough because of a poor landscape context.

4.2.6 Build terrestrial buffers for the aquatic cores

The next step is to build terrestrial buffers for the aquatic cores. It is generally accepted that the integrity of the aquatic environment is strongly determined by the condition of the surrounding terrestrial environment, especially within the corresponding watershed. Thus, it is insufficient to identify aquatic cores without also explicitly recognizing the influential terrestrial environment. Although there are many possible ways to conceptualize and define buffers for aquatic systems, we opted to define the buffer as the area estimated to have a strong influence on the integrity of the aquatic core based on watershed processes. Specifically, from this watershed-based perspective, the buffer represents the area hydrologically connected to the aquatic core through surface runoff and instream flow processes, such that anthropogenic stressors within the buffer are most likely to adversely impact the integrity of the aquatic core. Importantly, this watershed-based buffer represents places upstream and upslope of the aquatic core where human activities such as development, and point and non-point pollution, etc., may have a strong impact on the ecological condition of the core. Unlike the cores themselves, the buffers do not necessarily represent areas of high ecological integrity; rather, they represent areas likely to have a strong influence on the cores through watershed-based processes.

Box 7. Steps for deriving the watershed-based buffers for aquatic cores.

1) For the downstream most cell of each aquatic (lotic and lentic) core and each of the cells in the core receiving inflow from outside the core, build a resistant linear kernel based on a specified bandwidth (e.g., 20 km) and resistant surface, where resistance is based on a logistic function of the range rescaled (0-1) time-of-flow (see the technical document on integrity, McGarigal et al 20017, for details on the time-of-flow model), such that resistance ranges from 1 when the time-of-flow is zero (i.e., at the core) to a specified maximum (e.g., 20-100) when the time-of-flow is the maximum across all kernels and that varies as a function of watershed size, as shown in the figure below.

   Note, the bandwidth determines the maximum distance upstream and upslope the kernel can extend (if resistance is equal to 1 everywhere), and the logistic function determines how rapidly the kernel shrinks with increasing time-of-flow and watershed size.

   Here, time-of-flow values (model derived) are first range rescaled (0-1) such that the values range from zero at cells in aquatic cores to 1 at the cell with the greatest absolute time-of-flow across all kernels built across all cores. These range-rescaled time-of-flow values are then transformed into resistance values based on the logistic function such that: 1) the minimum time-of-flow (i.e., cells in the core) results in a resistance of 1, and 2) resistance increases with increasing time-of-flow (i.e., cells farther upstream and upslope of the core) and increasing watershed size. The maximum resistance increases with the logarithm of watershed size, such that the resistant linear kernel decreases more rapidly for cores with larger watersheds. This results in the zone of influence being relatively narrow along large rivers and extending to the full catchment on smaller headwater creeks.

2) Take the maximum resistant kernel value for every cell. As a result, all aquatic core cells have the maximum value (determined by the bandwidth) and the values decrease upstream and upslope based on their relative time-of-flow to the "closest" aquatic core cell.

3) Range rescale (0-1) the resistant kernel values from #2, such that the maximum kernel value (at the cores) receives a 1 and the minimum kernel value at the periphery of the zone of influence receives a zero.

Briefly, for each lotic and lentic core, we create a watershed buffer based on a time-of-flow model that extends as a gradient upstream and upslope from the core varying distance depending on slope and land cover. Areas immediately upstream and upslope of the core

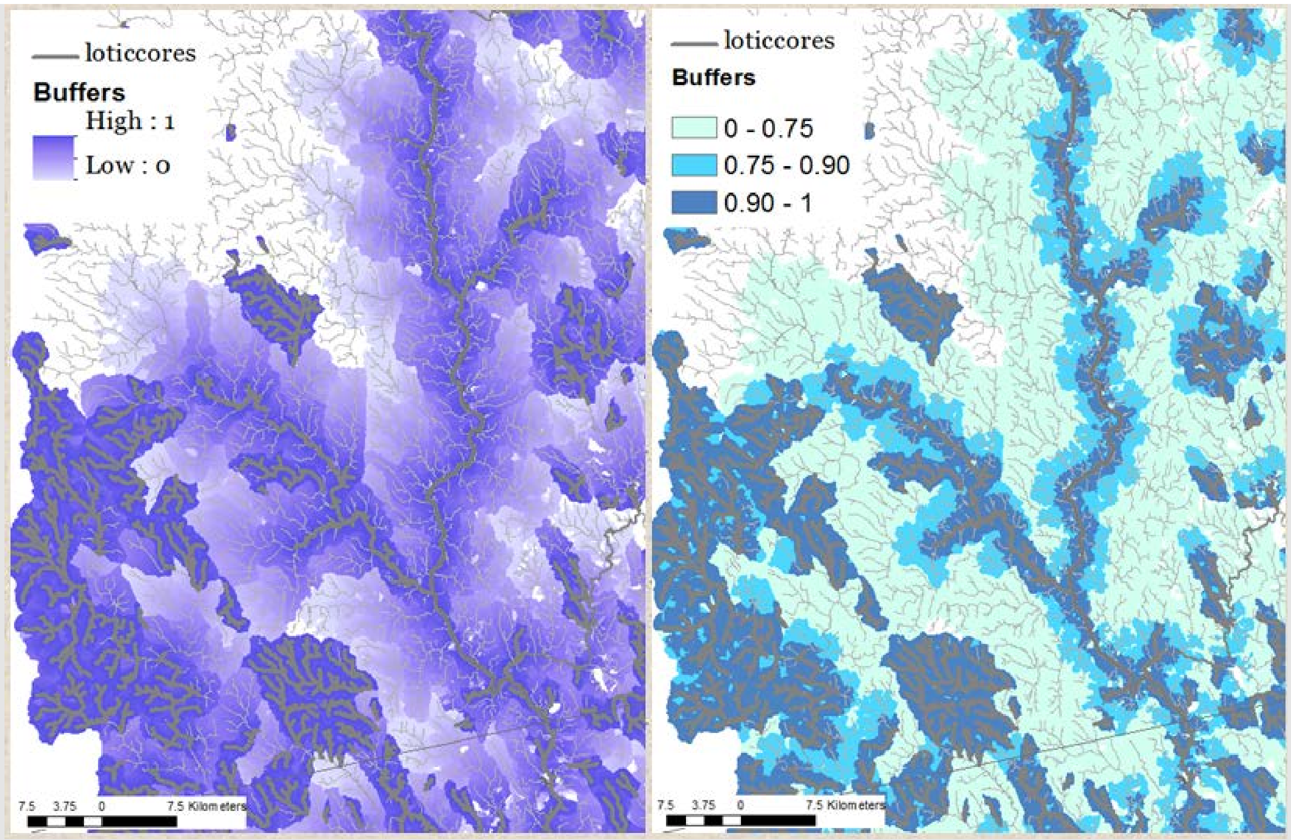


Figure 14. Watershed-based buffer zones for aquatic cores (shown here for lotic cores only), depicted as a graduated zone of influence (left figure) varying from 1 at the core to 0 at the periphery of the zone of influence and tiers of influence (right figure) in which the break-points for the tiers can be defined at any levels depending on objectives.

have the greatest influence (i.e., shortest time-of-flow). The influence decreases much faster across land than water so that the buffer typically extends much farther upstream than upslope from the core. Thus, the buffer does not represent a discrete zone distinguishing "inside" from "outside" of the buffer. Rather, it represents a graduated zone of influence in which cells upstream and closer to the core have greater influence. Cells in the upland and farther from the stream, especially on flat slopes with forest cover, have less influence. In addition, the graduated zone of influence increases in size with decreasing stream size. As such, the zone of influence on larger rivers tends to be relatively narrow, whereas the zone of influence on headwater creeks tends to be wider and typically encompasses the entire upstream catchment. The actual process of building the watershed buffers is considerably more complex (**Box 7**).

Note, although the watershed buffers are presented as an absolute gradient of decreasing influence with increasing distance upstream and upslope of the cores, it is important to recognize that the gradient depicted is relative. Moreover, the gradient is scaled to extend progressively greater distances upslope on increasingly smaller streams (see **Box 7**).

Because this graduated zone of influence can be difficult to visualize and interpret, it may be more useful to threshold the gradient at one or more levels to depict tiered zones of influence that are more akin to conventional fixed-width buffers (**Fig. 14**).

4.2.7 Assess importance of cores to the ecological network

The next step is to assess the importance of individual core areas to the ecological network. Unfortunately, measuring the contribution of each core to the overall network is challenging because of the many different ways to consider "importance". Recall that we treat the terrestrial cores/connectors as a network and use the probability of connectivity (*PC*) metric as a way to measure the relative importance of each core/connector to the network. While this approach could be applied to the aquatic core area network, we deemed it less meaningful for the aquatic cores for the following reasons:

1) Unlike the terrestrial core area network, which is two-dimensional in space, the aquatic core area network is for the most part (the exception being isolated ponds) a dendritic linear network for which the *PC* metric makes less sense.
2) The entire riverine network links together the designated cores and, as such, all links are inherently important to the network. The designated cores are simply sections of the network that are in relatively better ecological condition and representative of the full suite of aquatic ecological systems. It seems meaningless to claim that any one link is more important than another, other than the obvious conclusion that the lower the position in the dendritic network (i.e., closer to the mouth of the watershed) the greater the number of connections that rely on it. This is embodied in the concept of "link magnitude", in which each link is attributed by the number of links above it in the dendritic network. For example, two terminal streams with link magnitude of 1 combine to form a link magnitude of 2, and with the addition of another link magnitude 1 stream it becomes a 3, and when it combines with say another link magnitude 3 stream it becomes a 6, and so on until the mouth of the watershed.
3) The most important issue pertaining to the relative importance of places in the aquatic network is arguably aquatic connectivity, and this issue is perhaps better addressed through the critical linkage analysis below by evaluating the relative affect of individual road-stream crossings (e.g., culverts) and dams (the major anthropogenic impediments) on aquatic connectivity.

Consequently, all aquatic cores are considered equally important and thus no attempt is made to differentiate among individual cores in this regard.

4.2.8 Determine management needs of cores

The next step is to determine the management needs of individual core areas. Managing to maintain or improve the integrity of aquatic cores and the focal species they support is multi-faceted and includes managing factors affecting the hydrologic regime (e.g., water control structures, discharges and withdrawals, impervious land use, etc.), thermal regime (e.g., riparian vegetation), water quality (e.g., point and non-point pollution), and aquatic connectivity (e.g., culverts and dams). Unfortunately, it is beyond the current scope of this project to address these important management concerns for individual cores (although see below for connectivity issues). Instead, here we focus on simply identifying the important ecosystems in each core area. Given the composition of each core and the especially important ecosystems in each core, it is incumbent on the manager to determine the management activities needed to maintain the core area value. For this purpose, we compute the ecosystem metrics described previously for terrestrial cores. Note, we do not compute the comparable metrics for species (as in the terrestrial cores) because it is preferable to use the individual data layers for brook trout and anadromous fish for this purpose (see Appendix B).

As an example, let's consider the lotic core area depicted in **figure 13** that includes approximately 66 km of stream length comprised almost entirely of cold, headwater creeks. The most important aquatic ecosystem in this core is "Stream (headwater/creek) cold high" (i.e., high gradient, cold, headwater stream) with an index1 = 1.727, indicating that the total value of this system in this core is roughly 1.7 times greater than expected, which is ranked 151 out of 620 lotic cores. In addition, index2 = 75.319, indicating that 75% of the ecosystem value of this core is attributable to this particular ecological system (rank = 163), and index3 = 1.353, indicating that 1.35% of the value for this system across the entire core area network is found in this particular core (rank = 8). Lastly, index4 = 0.053, indicating that the average quality of this system in this particular core is above average for this system within the core area network (rank = 185). Thus, while this core is dominated by high-gradient, cold headwater creek of better than average quality for the entire network, it is clearly not exceptional based on these rankings.

Not surprisingly, this is also an important core area for the brook trout, which is a representative species for headwater creeks, with a landscape capability index ranging from 90-92 throughout the core, indicating that this core includes headwaters with >90% probability of brook trout occurrence.

Overall, this particular core is an above average example of a cold, headwater creek system, dominated by high-gradient creeks interspersed with scattered moderate- and low-gradient reaches, and offers excellent brook trout habitat with a very high likelihood of occurrence under current habitat and climate conditions. Knowing this, management of this core area to maintain these values would likely involve maintaining forest cover in the contributing watershed, especially in the riparian zone, preventing the degradation of water quality by adverse land uses, and ensuring that stream connectivity is not disrupted in the future (e.g., from failed culverts on road-stream crossings).

4.2.9 Incorporate future land use impacts

The next step is to incorporate future land use impacts, and development in particular, into the conservation design. Importantly, we considered several options, including putting aquatic core areas preferentially in places with lower risk of future development. While our approach remains flexible, for the Connect the Connecticut project it was decided that because future development is highly stochastic in where it occurs and, moreover, is something that can be prevented or diverted through proactive land conservation, that it was preferable to establish aquatic cores in places that hold the greatest ecological value today and then work towards maintaining that value in the future through proactive conservation.

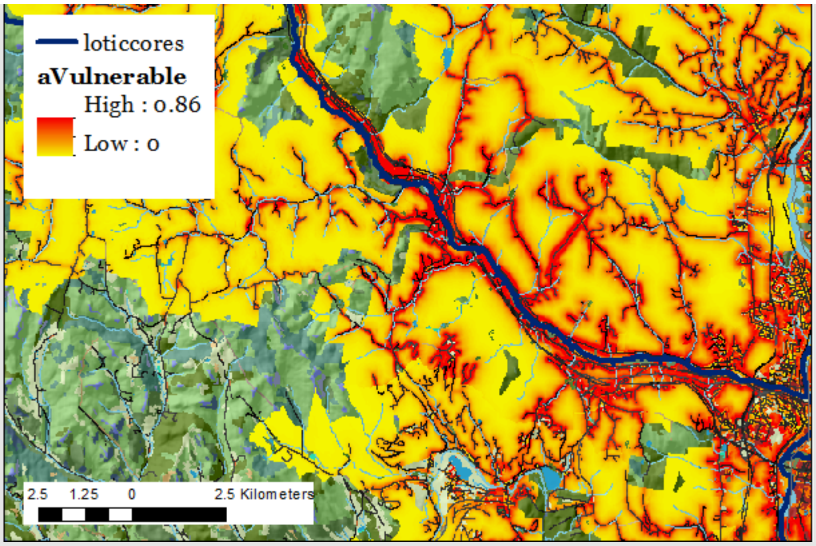


Figure 15. Aquatic core vulnerability to future development index (aVulnerable) within the graduated zone of influence (a.k.a. watershed buffers) of lotic cores. Areas in dark red have a high risk of future development in uplands that have a strong influence on the integrity of the lotic cores.

Consequently, we use the aquatic core vulnerability to future development index (aVulnerable) to identify terrestrial places within the zone of influence of the aquatic cores that are at high risk of being developed in the future, since these might be places of high priority for immediate land protection (**Fig. 15**). Briefly, the aquatic core vulnerability index is derived by multiplying the watershed-based buffers for aquatic cores (i.e., graduated zone of influence) and the integrated probability of development between 2010-2080 (as described previously for the terrestrial design and described in detail in association with the local vulnerability index in the technical document on connectivity (McGarigal et al 2017). The resulting index reflects the likelihood of development occurring in places that are likely to have a large influence (based on watershed processes) on the integrity of the aquatic cores. Note, this vulnerability index is core-dependent; i.e., it identifies places where development is most likely to have the greatest impact on the integrity of the aquatic cores, but it does not address vulnerability to development for the entire aquascape. A core-independent vulnerability index has been conceived but not yet developed due to excessive computational burdens of the proposed algorithm.

4.2.10 Incorporate future climate change and sea level rise impacts

The next step is to incorporate future climate change and sea level rise impacts into the conservation design. Importantly, we considered several options, including putting aquatic core areas preferentially in places with lower risk of climate stress or inundation by sea level rise. Unfortunately, our options for addressing climate stress in aquatic systems are currently extremely limited since the only information we have available pertains to the effect of predicted air temperature increases on stream temperature in headwater creeks. Ultimately, it was decided that because of the uncertainty associated with climate change and sea level rise impacts, that it was preferable to primarily address these issues in other ways, in particular, by recognizing that climate change resiliency is being addressed at least partially through the following design components already in place:

1) Aquatic core areas are created in places with high *IEI*, and thus represent places with high local connectedness and ecological similarity across the full range of aquatic ecological systems that should confer resilience to disturbance and stress (e.g., climate change) over the relatively short-term of, say, years to several decades.

2) Aquatic core areas in headwater creeks are preferentially located in places with high *IEI* and high tolerance of stream temperature to future increases in air temperature as measured by the USGS stream temperature tolerance index (see below).
3) Aquatic core areas preferentially consist of mini stream networks that include a diversity of lentic and lotic systems, and thus represent places with relatively high local connectedness to diverse aquatic ecological settings that should confer resilience to stress over the relatively long-term of, say, decades to centuries.
4) Improving aquatic connectivity is perhaps the single most important conservation action for climate change resiliency. Connectivity is essential for the movement of aquatic plants and animals among aquatic core areas and throughout the entire aquatic network, and should confer resiliency to disturbance and stress over the short- and long-term. A highly connected aquatic network, by facilitating access to the full gradient of ecological and geophysical settings, should act as a stage upon which organisms can shift and adapt to changing environmental conditions. Identifying and prioritizing dam removal and culvert upgrades to improve aquatic connectivity (see below) therefore indirectly addresses climate change resiliency.

In addition to the design components above that either indirectly or directly (in the case of using the stream temperature tolerance index to select core areas in headwater creeks) address issues of climate change, we also include the sea level rise metric as a separate product in the landscape design. This metric is described in detail in the technical document on integrity (McGarigal et al 2017) and was briefly described above in association with terrestrial core areas (see **Fig. 10**). This metric has the same application with aquatic core areas, although its interpretation is slightly different. For aquatic systems (above the sub-tidal zone), which are already inundated by water, the sea level metric indicates the likelihood of increased inundation, as opposed to likelihood of a dynamic response. In other words, if a site is already under water, the only impact of sea level rise can be increased inundation, which nonetheless alters the ecological condition of the site.

Recall that for the terrestrial design we also include the climate response indices for each of the 14 representative wildlife species as separate products. Unfortunately, on the aquatic side, currently we have only a single species, brook trout, with a distribution model that lends itself to predicting future climate impacts. Here, we include the brook trout climate response index, derived from a model developed by Ben Letcher and associates at the USGS Conte Anadromous Fish Lab, as a separate product in the design. This index is equal to the predicted future probability of occurrence in 2080 based on current habitat conditions and future climate conditions (averaged over two future climate scenarios: RCP 4.5 and 8.5). This index emphasizes places with high current habitat capability that are most likely to maintain suitable climate conditions in the future (**Fig. 16**).

Together, the sea level rise metric and the brook trout climate response index can be used individually or in combination to focus attention on places within (or outside) the ecological network that are at high risk of being stressed by future sea level rise or climate change, respectively, and these might be places that warrant close monitoring for signs of ecological impacts.

4.2.11 Restore aquatic connectivity via dam removals and culvert upgrades

The last step is to identify opportunities to restore aquatic ecological functions. Although there are numerous possibilities, here we limit our consideration to removing dams and upgrading road-stream crossings to improve aquatic connectivity, which is described in detail in the technical document on connectivity (McGarigal et al 2017) and only briefly described here.

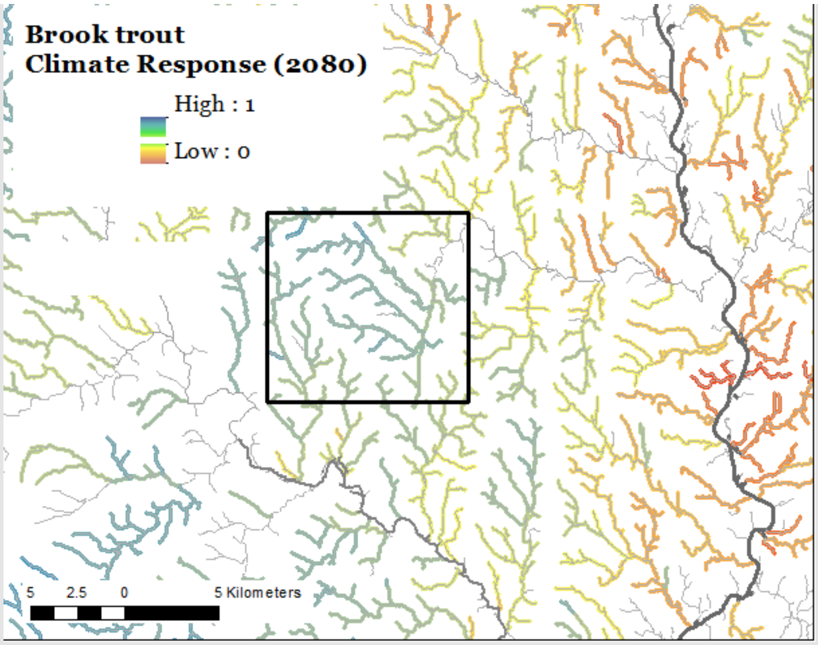


Figure 16. Brook trout climate response index, defined as the mean future Landscape Capability index calculated with current habitat and predicted future climate in 2080 (averaged across RCP4.5 and RCP8.5 scenarios) within the project area. High values represent places with high current Landscape Capability (probability of occurrence in this case) that maintain climate suitability over time without regard to future changes in habitat capability. The box outline shows the area depicted in **figure 13**.

With regards to dam removals, this product tabulates the results of a model in which each dam is systematically removed (virtually), one at a time, and the predicted improvement in aquatic connectedness from the removal is recorded. The delta, or difference, in the aquatic connectedness score, before and after the bridge removal for each cell within the affected neighborhood, is computed and multiplied by the average index of ecological integrity (*IEI*) of the affected neighborhood. Therefore, improvements are scored higher where conditions are not highly degraded and dam removal may have greater ecological benefits.

With regards to upgrading culverts at road-stream crossings, this product tabulates the results of a model in which each road-stream crossing is systematically upgraded (virtually) to a bridge having the minimum aquatic barrier score, one at a time, and the predicted improvement in aquatic connectedness from the upgrade is recorded. The delta, or difference, in the aquatic connectedness score, before and after the crossing upgrade for each cell within the affected neighborhood, is computed and multiplied by the average *IEI* of the affected neighborhood. The weighting by *IEI* emphasizes the potential ecological benefits of a culvert upgrade in an area that is otherwise in good condition but depressed by the crossing structure. Conversely, the score is lower where conditions are already so degraded that an upgrade would not improve local ecosystem conditions.

These indices can be used on their own, but they can also be used in combination with the aquatic cores to prioritize locations where a dam removal or culvert upgrade may do the most good to improve further the condition of the aquatic cores. However, note that these indices do not take into account socio-economic considerations, such as the use of a particular reservoir (e.g., drinking water supply) or the economic cost of the project given local engineering considerations, that ultimately will determine the cost-benefit tradeoffs of any particular restoration project. Thus, these products are best used to direct local comprehensive assessments to places where these restoration actions might do the most good at improving aquatic connectivity. Also, given the large number of dams and road-stream crossings, it may be useful to bin the dams/culverts into categories representing high, medium and low impact, or simply threshold the score (or its rank) at some level to highlight the highest priority dams/culverts (**Fig. 17**).

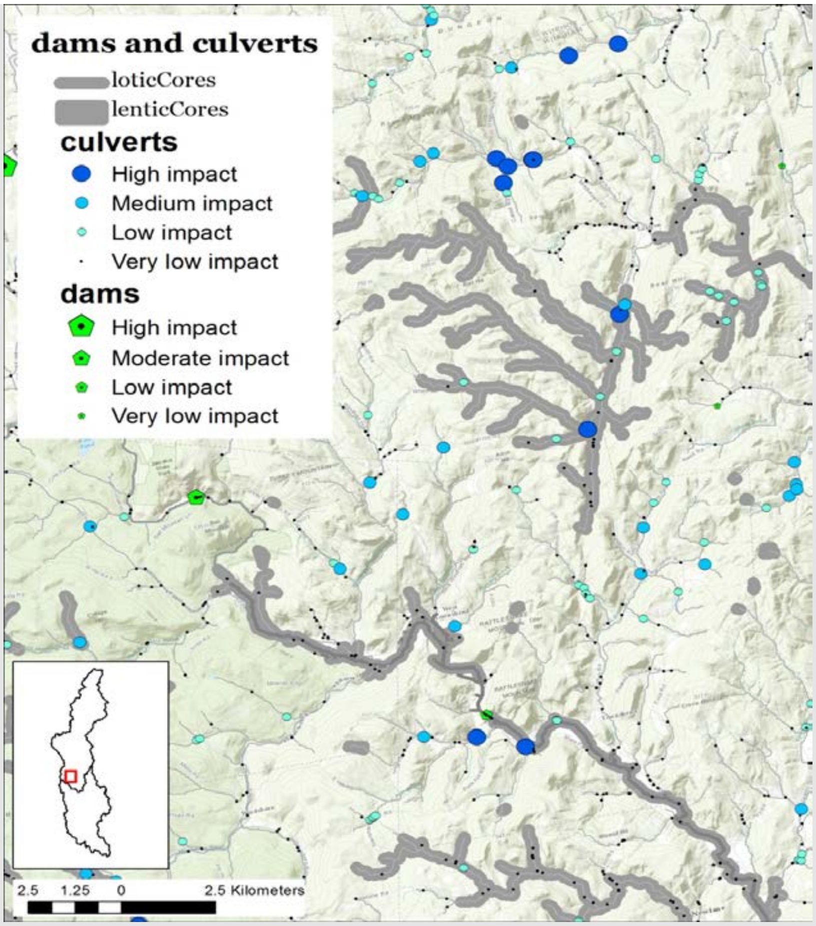


Figure 17. Dam removal and culvet upgrade impact scores in four tiers representing very low to high impact on aquatic connectivity overlaid on the stream network and potential aquatic core areas.

5 Scope and Limitations

There are myriad ways to approach landscape conservation design and none are perfect. All approaches suffer from incomplete and imperfect data, and any approach must navigate a pathway through numerous options for what information to include and at what scales, and how to include it, leading to nearly infinite variations on a process for LCD. Consequently, it is imperative that any LCD approach clearly identify the scope and limitations of the chosen approach. Here, we identify the scope and some of the major limitations of our LCD approach.

5.1 Scope

Here, we describe the scope of our LCD approach, with particular attention to where and when our approach should be used. Note, the items listed below were all discussed previously in this document but are summarized here for added emphasis.

1) We developed our LCD approach for application in northeastern North America. Specifically, we devised an approach that makes sense for the ecological and anthropogenic setting of the Northeast, and this permeates all aspects of the approach. For example, human land use, in particular urban growth, and climate change are deemed to be the overriding drivers of landscape change and the principal threats to biodiversity in the Northeast. Consequently, the landscape change and assessment model focuses on these stressors and landscape change drivers; other potential stressors and drivers such as anthropogenically-altered natural disturbance regimes (e.g., fire), which are major drivers in other areas (e.g., western North America), are not included at this time. Note, while our approach is developed for application in the Northeast, with appropriate modifications and/or extensions (e.g., including natural disturbance regimes and their modification as a major stressor/driver), our approach could easily be extended to have broader geographic application.

2) Our approach emphasizes LCD at regional to sub-regional spatial scales. Specifically, although we devised an approach that incorporates information across a broad range of spatial scales (from local to regional), we emphasized building an approach that provides a consistent regional or sub-regional perspective on biodiversity conservation. From a practical standpoint, this means including relevant ecological data that is consistently available at the regional scale and excluding otherwise highly relevant ecological data that is available only locally. For example, many states maintain spatial databases with much improved data layers (e.g., improved roads data) and additional data layers (e.g., maps of unique ecological features such as vernal pools or rare and endangered species locations) that are not consistently available at the regional scale. We chose to build an approach that relies on data consistently available across the region, which comes at the cost of not always making use of the best available information that exists locally. Note, as these improved data layers and additional data layers become available at the regional scale, our approach can easily be modified to incorporate this information. Importantly, because of the regional perspective embodied in our approach, it is intended to complement and supplement local conservation planning efforts that rely on detailed and specific local information.

3) Our approach is currently limited to the ecological dimension of LCD. Specifically, we devised an approach that (at least currently) considers only ecological information and does not explicitly consider socio-cultural and economic information. Of course, the latter is ultimately critical to the successful implementation of LCD, as conservation does not happen in a socio-cultural and economic void. In part, the choice to focus exclusively on the ecological dimension of LCD is practical, owing to the expertise of the Designing Sustainable Landscapes (DSL) team and the difficulty of obtaining relevant socio-cultural and economic information at relevant spatial and temporal scales, but it also reflects a desire to build a LCD that is in some sense "ideal" for the conservation of biodiversity. In other words, we sought an approach that would provide a benchmark for biodiversity conservation unfettered by the socio-cultural, economic and political realities of real-world conservation.

4) Related to the previous item, our approach to LCD emphasizes using ecological data at ecologically relevant spatial/temporal scales without bias towards the existing conservation real estate. Specifically, our approach seeks to identify the places with the greatest ecological value with respect to ecological integrity and landscape capability for representative wildlife species using the highest resolution data available (i.e., mostly 30 m), but without regards to what is already in the conservation real estate portfolio (e.g., existing secured lands). We recognize that one approach to LCD is to account for what already exists in the conservation real estate and then add to this portfolio in a complementary fashion. This has the appeal that it builds on the de facto conservation design that is already in place. However, because many of the existing secured lands that are part of the de facto conservation design do not offer much in the way of assessed ecological value, we did not want to bias the design in this manner. Instead, our approach seeks to identify an "ideal" conservation portfolio, and while this does not explicitly incorporate the existing conservation real estate, it does provide perhaps a better design target for meeting the biodiversity conservation goals. Note, this does not mean that existing secured lands should be ignored in practice, but rather that they can and should be used as an overlay to our design to inform local conservation actions.

5) Our approach to LCD involves a complementary ecosystem- and species-based approach. Specifically, our approach emphasizes the use of ecological integrity as a coarse filter for biodiversity conservation, but accommodates the use of individual species (e.g., representative species) as a complement. The choice of ecosystems versus species as the basis to identify conservation priorities is fundamental to any LCD approach, and is often a point of disagreement among conservation practitioners. Neither approach is more right or wrong, they are simply different ways to achieve the goal of biodiversity conservation and each has strengths and weaknesses. Our approach is flexible in this regard and allows for the use of either approach by itself or the complementary use of both.

6) Our approach to LCD emphasizes conservation actions directed at land protection and ecological restoration, with only minor attention to land management. Specifically, our design focuses on identifying places of high ecological value for ecosystems and representative wildlife species, including for example creating a network of core areas, for which land protection is the implied conservation tactic. In addition, our design

identifies opportunities for restoring aquatic and terrestrial connectivity (e.g., dam removals, culvert upgrades, terrestrial road passage structures). Unfortunately, our design currently offers little in terms of direct guidance for land management actions, other than identifying which ecosystems and/or species are important in any particular area. This largely stems from the complexity of determining where and what kind of management action is most needed to meet the multi-facetted ecological goals of the design. However, we recognize the importance of management to meet conservation goals; therefore, this should be a focus of future work to improve our LCD approach. In addition, identifying management needs (what and when) for particular places should be a focus of the implementation step of our adaptive LCD (**Fig. 1**, step 3).

7) Our approach to LCD emphasizes short- to moderate-range planning on the order of one to several decades. Specifically, our LCD approach relies heavily on data products derived from the Landscape Change, Assessment and Design (LCAD) model developed as part of the DSL project, and this model currently involves forecasting landscape changes and ecological conditions to the year 2080. Options exist in our approach for incorporating information pertaining the to the current landscape condition and this 65-year forecast in conditions. We recognize the need to consider longer-term forecasts and the need to conserve biodiversity for future generations in perpetuity, but our current data and ability to make reliable forecasts currently limits us to a shorter planning horizon. Consequently, our LCD approach is adaptive and is intended to be continuously monitored and modified to accommodate new data and changing environmental as well as socio-cultural and economic conditions.

5.2 Major Limitations

Here, we list some of the major limitations of our LCD approach. Note, this is not a comprehensive list of all the limitations, as this list would be too extensive. Rather, this is a list of the most important limitations that affect the use and interpretation of the results and that should be the focus of future efforts to improve the LCD approach.

1) Our LCD approach relies heavily on models to assess ecological values. For example, we use a model to assess the ecological integrity of every location and another model to assess the landscape capability to support of each representative wildlife species. And one thing that is true of all models is that they are only as good as the input data. Unfortunately, the spatial data (GIS data) that these models rely on are fraught with errors, including both misclassifications and misalignments. This is especially true for many of the regional datasets that we employ, because there is usually a trade-off between extent and local accuracy; broader spatial coverage (e.g., regional or national extent) usually means lower accuracy at the finest spatial resolution (e.g., 30 m grid cell). Consequently, the results are often wrong at the finest resolution of the data (30 m) even though they may be quite meaningful at a slightly coarser resolution. For this reason, the LCD products should not be scrutinized for accuracy too carefully at the finest resolution of the data (30 m), and any depicted boundaries (e.g., core area and connector boundaries) should be viewed as "fuzzy" boundaries (i.e., merely general places to focus attention).

2) As noted above, our approach relies heavily on models to assess ecological values. We deem models necessary and useful because they are the only way to assign values to places that have not been sampled/observed in the field and they are the only way to make forecasts of future landscape conditions. Moreover, we recognize that "essentially, all models are wrong, but some are useful" (Box and Draper 1987). Implied in this quote is that models are necessary simplifications of reality and thus do not, indeed cannot, mathematically represent the full complexity of reality. The models employed in our LCD approach are no different; they are incomplete and overly simplified representations of reality. For example, our model for computing the index of ecological integrity (*IEI*) contains from 6-16 individual stressor and resiliency metrics (out of 19 available) that capture many different aspects of the landscape that affect ecological integrity. Each of these metrics makes use of the best available, regionally consistent spatial data and uses state-of-the art algorithms to summarize the data, but in most cases the metric is nonetheless a gross simplification of the particular stressor-response function. For example, the road salt metric measures the intensity of road salt application in the watershed above an aquatic focal cell based on road class (as a surrogate for road salt application rates) and a time-of-flow kernel. Clearly, road class is not a perfect surrogate for salt application rates that can vary dramatically among towns based on local policies and bylaws, information that is not readily available across the region, and the time-of-flow model certainly does not account for all the real-world intricacies of topography, soils and vegetation that affect how water and suspended materials move across the surface and sub-surface. Thus, the road salt metric is an incomplete representation of this particular stressor. Nevertheless, it is the best that we can do with existing spatial data and this is deemed better than not considering road salt as a stressor.

   In addition, there are known stressors that are not explicitly being represented due to the lack of available data or the complexity of modeling the particular stressor-response process. For example, alteration of instream flow by dams and culverts is an important process affecting aquatic ecosystems, yet this is an exceedingly difficult thing to quantify given available data, especially because the anthropogenic modification of flow must be decoupled from the natural factors affecting flow. As a result, this important stressor is not included in the current suite of metrics. Consequently, *IEI* is an incomplete representation of the factors affecting local ecological integrity, and it always will be because we will never be able to perfectly and completely represent all the factors affecting ecological integrity.

   The important point here is that our models are imperfect and therefore they will often not get it quite right, and this will lead to an imperfect and imprecise landscape design. This is OK if we accept that the design can be wrong, but still useful.

3) As mentioned above, our approach currently considers urban growth and climate change as the major stressors and landscape change drivers, which we deemed appropriate as the initial focus for the Northeast. However, we recognize that there are other important stressors and drivers in the Northeast that should be addressed for a more comprehensive solution to LCD. For example, timber harvest is a major anthropogenic disturbance to forests in the Northeast, especially in some parts of the Northeast (e.g., northern New England), and it can play a significant role in regulating

vegetation composition and structure and thus habitat conditions for many wildlife species. Our current approach treats timber harvest collectively with other natural vegetation disturbance processes (e.g., ice/wind, insects/pathogens) as a purely stochastic process, which does not adequately account for the spatial predictability of timber harvest in areas managed intensively for wood products (e.g., industrial forest lands). Consequently, our currently ecological assessment may overestimate or underestimate the ecological values assigned to each location. Adding these additional anthropogenic and natural vegetation disturbance processes to the landscape change and assessment model should be a priority for future improvements to our LCD approach.

6 Literature Cited

Anderson MG, M Clark, and A Olivero Sheldon. 2012. Resilient sites for terrestrial conservation in the Northeast and mid-Atlantic region. The Nature Conservancy, Eastern Conservation Science. 168 pp.

Box GEP, and NR Draper. 1987. Empirical Model-Building and Response Surfaces. Wiley. 424 pp.

Lentz EE, SR Stippa, ER Thieler, NG Plant, DB Gesch, and RM Horton. 2015. Evaluating coastal landscape response to sea-level rise in the northeastern United States—Approach and methods: U.S. Geological Survey Open-File Report 2014–1252, 26 p., http://dx.doi.org/10.3133/ofr20141252.

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/

Pickett STA, and JN Thompson. 1978. Patch dynamics and the design of nature reserves. Biological Conservation 13:27-37.

Appendix A. Representative species weighting criteria

The purpose of this appendix is to describe the criteria for weighting representative species in the Connect the Connecticut project; specifically, to assign Landscape Capability targets for use in creating terrestrial core areas (see text for details). In the following matrix, the categories of "threats", "responsibility", and "rarity" are criteria the planning agreed would be useful for the purposed of weighting species. "Population Objective" is included in this table to right of the final weight to indicate that this column is not used in the final weight for species, but is presented for purposes of easily comparing how weights relate to population objectives. "Societal/ecological value" is a criterion that was discussed by the planning team; it was determined to have value in communicating value of conservation actions but would not be used in weighting species.

The notation format in this matrix is to use "+" to indicate elevated concern, responsibility, or value due to rarity for a given species (rows) based on the criteria (columns). "0" is intended to indicate neutral rarity, responsibility or concern for a species, and "-" is intended to indicate reduced concern, responsibility, or rarity for a species, relative to the other species.

Species	Habitat Guild	Threats*					Responsibility		Rarity	**Weight** Sum of weighted "+" and "-" entries across 8 columns to the left (% of LC to be captured in final selection index for core areas)	Population Objective	Societal (S) / Ecological (E) value (NOTE: these qualities will be used in communicating value of conservation actions, but not used in weighting criteria)
		Experienced significant population loss? A: in CRW B: Range-wide (based on population trends from BBS or other source)	Facing significant habitat threats excluding development (includes 1,2,3,4): A: in CRW, B: Range-wide	Facing significant non-habitat threats (includes 5,6,7,8): A: in CRW, B: Range-wide	Climate[9] vulnerability in CRW? (based on change in climate niche envelope projected for year 2080: >50% reduction = "+")	Vulnerability to urban growth[10,11] in CRW? (based on change in LC due to urban growth projected in year 2080)	High regional responsibility for the Northeast? (based on % of total regional Landscape Capability w/i Northeast Region occurring in CRW: >10% of LC = "+")	High global responsibility? (based on % of global population in CRW; % of global population in Northeast Regional also listed for reference)	Regionally rare? (based on acres of suitable habitat within region as estimated by LC models: <1M acres = "+", >15M = "-", >50M = "- -")			
	Weight contribution of criteria	A: 0.50 B: 0.25	A: 1.0 B: 0.5	A: 0.50 B: 0.25	0.5	1.0	0.50	0.25	0.5			
American	Young forest	A: +	A: +, B: +		0		A: 0	0 3% in CRW	0	+2.25	+	+ (S), + (E) hunted/early

Woodcock	w/openings	-0.4% in BCR14 -4.9% in BCR30^ B: + -1.8%^	[1,4] lack of (appropriate) disturbance/ forestry [moderate Severity, moderate Immediacy, high Spatial Extent]		-6.6%		5.3% of LC in NE	17% in NE	9 million acres	(72.5%)	Increase 50%	successional
Blackburnian Warbler	Mature mixed forest	A: 0 0.4% in BCR14 -1.4% in BCR30 B: 0 0.1%		A: +, B: + [6]Hemlock wooly adelgid [mod, mod, mod]	+ -70.2%		A: + 11% of LC in NE	0 3% in CRW 15% in NE	- 30 million acres	+1.25 (62.5%)	0 Maintain	+ (S) Aesthetics
Blackpoll Warbler	Spruce-fir forest	A: 0 -0.7% in NE B: + -3.8%^	A: + [2]wind energy B: 0	A: +, B: + [7]acidification, mercury	+ -93.7%		+ 15% of LC in NE	0 low global resp.	+ 900,000 acres	+3.5 (85%)	0 Maintain	+ (E) Spruce-fir
Eastern Meadowlark	Pastures & grasslands	A: + -6.7% in BCR14^ -6.9% in BCR30^ B: + -3.4%^	A: +, B: + [1,2] habitat loss to ag, energy [mod-high, high, high]		0 43.7%		0 0.7% of LC in NE	0 0.1% in CRW 3% in NE	0 10 million acres	+2.25 (72.5%)	+ Increase 50%	+ (S) Aesthetics
Louisiana Waterthrush	Riparian forest	A: 0 -1.0% in BCR14 0.1% in BCR30 B: 0 0.4%	A: 0, B: + mining & shale drilling [mod, high, mod]	A: +, B: + [6,7]Pollution, invasive plants [mod, high, mod]	0 94.7%		0 3.5% of LC in NE	0 2% in CRW 33% in NE	0 4 million acres	+1.25 (62.5%)	0 Maintain	+ (E) riparian
Marsh Wren	Freshwater & tidal marshes	A: 0 1.6% in BCR14 -1.6% in BCR30 B: 0 2.0%		A: +, B: + [6,7]Pollution, invasive plants	0 176.7%		0 0.5% of LC in NE	0 0.4% in CRW 1% in NE	+ 800,000 acres	+1.25 (62.5%)	0 Maintain	+ (E) fresh & tidal wetlands

				[mod, high, mod]									
Northern Waterthrush	Forested wetlands	A: 0 -1.2% in BCR14 -1.0% in BCR30 B: 0 0.5%			+ -76.1%		0 2.1% of LC in NE	0 0.3% in CRW 0.5% in NE	0 2 million acres	+0.5 (55%)	0 Maintain	+(E) forest wetlands
Ruffed Grouse	Young forest	A: 0 0.2% in BCR14 -0.5% in BCR30 B:0 -0.4%			+ -69.0%		0 9.1% of LC in NE	0	-- 60 million acres	-0.5 (45%)	0 Maintain	+ (S) hunted
Wood Duck	Swamps & floodplain forest	A: 0 3.0% in BCR 14 1.0% in BCR 30 B: 0 2.0%			0 136.9%		0 2.0% of LC in NE	0	0 2 million acres	0 (50%)	0 Maintain	+(S), +(E) hunted/wetland
Wood Thrush	Mature decid. forest	A: + -4.6% in BCR14^ -2.8% in BCR30^ B: + -2.1%^	A: 0, B: 0	A: +, B: + [7]acidification calcium depl. [mod, high, high]	0 -1.6%		0 6.8% of LC in NE	0 4% in CRW 30% in NE	- - 70 million acres	+0.5 (55%)	+ Increase 50%	+(S) Aesthetics, iconic sounds
Wood Turtle	Forested streams & adj. uplands	A: +, B: + likely declining?	A: +, B: + [1]agriculture practices [mod, mod, high]	A: +, B: + [5,7] collecting, sedimentation, pollution [mod, mod, mod]	0 -14.0%		??	??	0 2 million acres	+3.0 (80%)	0 Maintain? (or incr.?)	+ (E) Forest streams
Black Bear	Large tracts of forest	A: 0, B: 0					0 6.4% of LC in NE	0 Low global	- - 100 million	-1.0 (40%)	0 Maintain	+(E) large tracts

								responsibility	acres			
Moose	Large tracts of mixed forest w/wetlands	A: 0, B: 0			+[#]		??	0	??	0.5 (55%)	0 Maintain	+(E), +(S) large tracts w/wetlands hunted/iconic
Prairie Warbler	Pine barrens & young forest	A: + -4.3% in BCR30^ B: + -2.1%^	A: +, B: + [1,4] lack of (appropriate) disturbance [mod, high, high]		0 (not likely to be negatively affected)		0	0 0.7% in CRW 18.1% in NE	0 1 million acres	2.25 (72.5%)		

^indicates statistically significant population trend

although modeling results are not currently available for projected change in climate envelope for Moose, the planning team reach agreement that many of the issues (e.g., disease) facing Moose specifically had a significant climate change aspect to them and that climate change is an appropriate threat to highlight for the suite of species represented by Moose.

* Threats: the following categories of threat (reflecting the IUCN threats framework) were evaluated with regard to their current or future impact on the representative species and their suites of represented species. The threats columns in the weighting matrix reflect the following groupings of these threats and the numerical superscripts in matrix refer to these threat categories:

Habitat Threats

1) ***Agriculture & Forestry*** (crop & livestock farming, tree plantations, logging/timber harvesting)
2) ***Energy production & mining*** (drilling, mining, renewable energy development & production)
3) ***Geological events*** (volcanos, earthquakes, avalanches)
4) ***Natural system modifications*** (increased disturbance, disturbance suppression, surface or ground water management/removal)

Non-habitat Threats

5) ***Biological Resource Use*** (hunting, collecting, gathering, control)
6) ***Invasive & Other Problematic Species and Genes*** (invasive/alien species, disease, genetic material)
7) ***Pollution*** (sewage, urban run-off, oil spills, mining run-off, excess nutrients, sedimentation, herbicides, pesticides, garbage/solid waste, acid rain, mercury, light/thermal/noise pollution)
8) ***Human Intrusions and Disturbance*** (recreational activities, military activities)

Threats Evaluated Separately:

9) ***Climate change and severe weather*** (habitat shifts, drought, temperature extremes, increased storms)
10) ***Residential & commercial development*** (residential & commercial development, tourism/recreation area development)
11) ***Transportation & service corridors*** (roads, railroads, utility lines, flight paths)

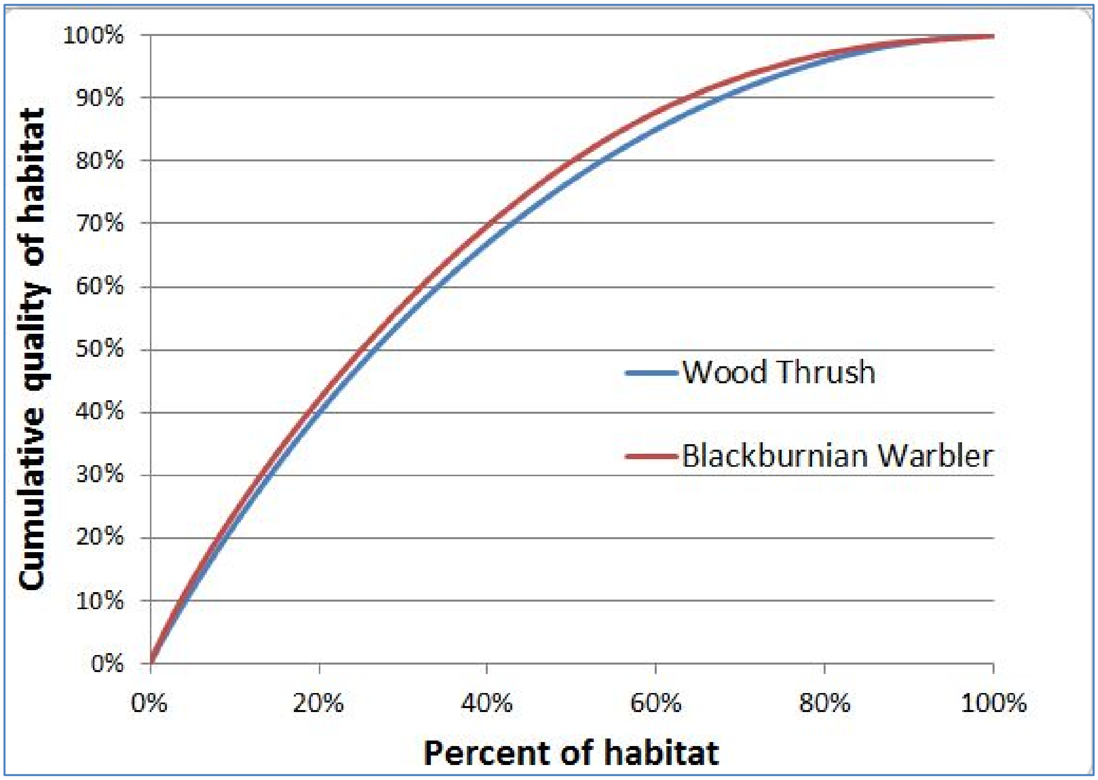
These threat categories are able to be evaluated separately because of the climate change and urban growth modeling work being done as part of Designing Sustainable Landscapes project and therefore are represented by their own columns in the weighting matrix and are not included in the general habitat threats column.

Final weights are calculated by multiplying the weight contribution of each criterion by the "+", "0", or "-"entries in each column and then summing across the eight columns to the left of the "Weight" column. Weight contributions were assigned following these guidelines:

1) threats within the CRW receive twice the weight of range-wide threats because they are directly impacting individuals of the species within the Watershed;

2) habitat threats receive twice the weight of non-habitat threats because the landscape conservation design process is intended to directly influence habitat conservation activities but its influence on non-habitat conservation activities will be less direct;
3) vulnerability to urban growth receives twice the weight of vulnerability to climate change because of higher certainty about impacts and more direct nature of impacts from urban growth, while impacts from climate change have higher uncertainty and could be less direct.

Final weights would then be applied to the optimization process for creating the final, combined selection index for core areas based on the species Landscape Capability models such that the % of cumulative landscape capability captured in core areas is larger for species with increased weight compared to species with neutral or decreased weight. The initial assumption is that neutral weight should equate to capturing the top 50% of habitat quality for those species for which the population objective is to maintain their current population level. See graph below for an example of how cumulative quality of habitat (as reflected by Landscape Capability) relates to percent of habitat necessary to capture that level of habitat quality. The final weights from the matrix would then be multiplied by 10 and added to the neutral index of 50% of habitat quality to reflect either increase of decreased concern, responsibility, or rarity of the different species.



Appendix B. Landscape Conservation Design Data Products

6.1 Purpose

The purpose of this appendix is to provide a brief summary of the data layers included in the landscape conservation design (LCD) package developed for the Connect the Connecticut River project (www.connecttheconnecticut.org), which served as a pilot for developing the LCD approach.

The Connect the Connecticut LCD is intended to focus conservation actions, including land protection, management, and restoration where it will likely do the most good towards conserving biodiversity within the landscape. The Connect the Connecticut LCD provides a watershed-based conservation design to complement or supplement conservation planning done at local or finer extents. Importantly, although the Connect the Connecticut LCD offers a way to strategically focus limited conservation resources, by itself it is not sufficient as a total solution to biodiversity conservation in the watershed. This design serves as a starting point that should be used in combination with other sources of information to direct conservation.

The Connect the Connecticut LCD is not a single product or map. Rather, it is a package of data products that collectively identify terrestrial core areas and connectors, aquatic core areas and their watershed-based buffers, and restoration opportunities for dam removal, culvert upgrades, and terrestrial wildlife road passage structures. This package also includes a variety of supporting data layers that separately provide information on the ecological value of all lands and waters regardless of their inclusion in the core area network.

6.2 Disclaimer

The spatial data products comprising the Connect the Connecticut LCD and described in this document were produced by the UMass Designing Sustainable Landscapes (DSL) Project (McGarigal et al 2017) in collaboration with the North Atlantic LCC and the Connecticut River Watershed Landscape Conservation Design partnership, with a few exceptions, as noted below.

- These products were developed to test procedures for landscape conservation design that could be extended to the entire Northeast region. These products are now being provided to collaborating partners for review and thus should be viewed as interim pending the outcome of the review process.
- This document provides a brief abstract on each of the data products to facilitate their immediate use and interpretation by the Connect the Connecticut LCD partners. Complete and detailed technical documentation is available for all products at the DSL project website.

- The products described here include only those data products deemed essential to the description of the Connect the Connecticut LCD. A more comprehensive set of data products derived for the entire region are available via the DSL project website.

6.3 Overview of Data Products

The Connect the Connecticut LCD data package consists of several tables and a large number of separate spatial data (GIS) layers. Each of these products is summarized in a separate abstract below. In these abstracts, terms in **bold** are defined in greater detail in a glossary available from the DSL website. The entire data package can be downloaded from the DSL project website (see link above) or individual products can be downloaded from the North Atlantic LCC website or through their Databasin site.

Although the data products can be used individually or any combination, to facilitate the use of this package, it is helpful to organize the products into three broad groups: 1) terrestrial design products, 2) aquatic design products, and 3) base maps and other ancillary layers, as described below. Tables are provided as comma-delimited text files (.csv) and can be viewed using any spreadsheet (e.g., Excel). GIS layers are provided as geoTIFFs (.tif), in the case of rasters, or ESRI shapefiles (.shp), in the case of vector data, both of which can be viewed using ArcGIS (or other GIS software). An ArcMap project (ctrLCD.mxd) with full symbology is included in the package for convenience in getting started.

Important: the abstracts for each of the LCD products below were developed as documentation for the Connect the Connecticut project. Similar LCD products have been developed for the entire Northeast region and more detailed documentation is available for each of these products on the DSL website.

6.3.1 Terrestrial design products

The following data products relate directly to the terrestrial landscape design, and the relationship among the corresponding GIS layers is illustrated in **figure A1**. Most of these products are available from the DSL products repository (McGarigal et al 2017) or can otherwise be obtained from the authors:

- Terrestrial core-connector network (tCoreNet.shp)
- Terrestrial core tiers (tCoreTiers.shp)
- Grassland bird cores (grasslandCores.shp)
- Terrestrial core areas - ecosystem summary (tCoreEcoSum.csv)
- Terrestrial core areas - species summary (tCoreSpeciesSum.csv)
- Species landscape capability (*species*LC.tif)
- Species climate zones (*species*CZ2080.tif)
- Species climate response (*species*CR2080.tif)
- Terrestrial ecosystem-based core area selection index (tSelectionIndex.tif)
- USGS stream temperature tolerance (streamTolerance.tif)
- Weighted index of ecological integrity (iei.tif)
- TNC terrestrial resiliency (tResiliency.tif)

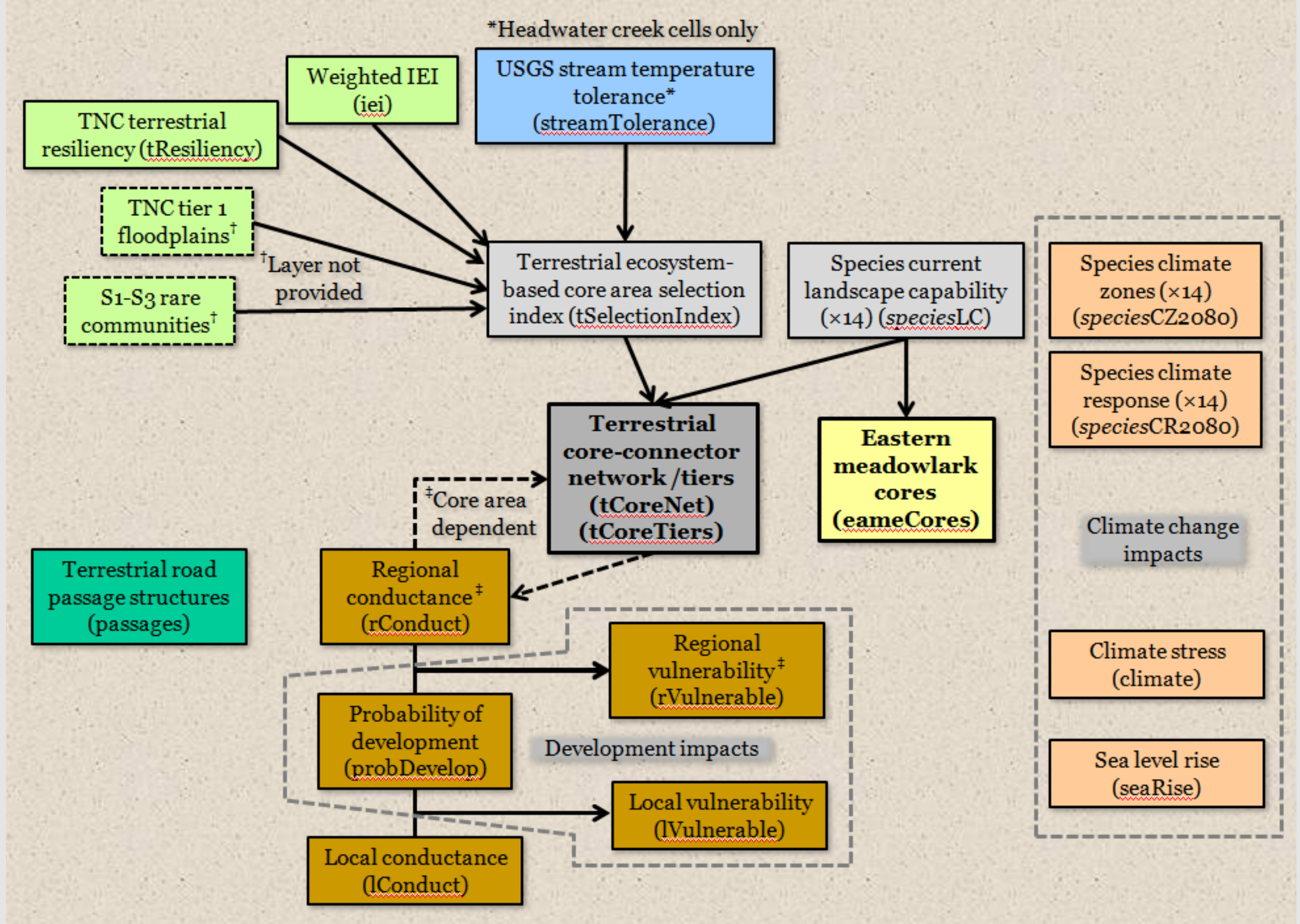


Figure A2. Relationship among the GIS data layers pertaining to the conservation of the terrestrial landscape.

- Regional conductance (rConduct.tif)
- Probability of development (probDevelop.tif)
- Regional vulnerability of conductance (rVulnerable.tif)
- Local conductance (lConduct.tif)
- Local vulnerability of conductance (lVulnerable.tif)
- Climate stress (climate.tif)
- Sea level rise (seaRise.tif)
- Terrestrial road passage structure impacts (passages.shp)

Perhaps the most important products of the terrestrial landscape design are the terrestrial core-connector network (**tCoreNet.shp**), terrestrial core tiers (**tCoreTiers.shp**), and grassland bird cores (**grasslandCores.shp**). These products represents a synthesis of ecological information and are designed to provide strategic guidance for conserving natural areas, and the fish, wildlife, and other components of biodiversity that they support within the CTR watershed. The tCoreNet.shp layer represents the tier 1 (highest priority) core areas and the connectors between them. The tCoreTiers.shp layer provides a three-tiered, spatially-nested hierarchy in which tier 1 cores (representing 25% of the landscape) are nested within tier 2 cores (representing 50% of the landscape), which are nested within tier 3 supporting landscapes (representing 77% of the landscape). The grasslandCores.shp layer represents a set of separate cores developed for eastern meadowlark as a representative of grassland birds. All of the remaining data layers either: 1) provide additional detailed information on why particular areas were included as core areas, 2) provide useful overlays to enhance the interpretation of the core-connector network (e.g., to help prioritize areas within the network), or 3) complement the core-connector network and tiered cores by providing seamless and continuous ecological valuation of the landscape independent of the core area network (e.g., to identify places with ecological value outside of the designated network).

The core areas are created from a combination of the 14 representative species landscape capability indices (***species*LC.tif**), which is a measure of the relative habitat capability and climate suitability for the corresponding species, and the terrestrial ecosystem-based core area selection index (**tSelectionIndex.tif**). tSelectionIndex.tif is derived from a combination of: 1) USGS stream temperature tolerance (**streamTolerance.tif**), for headwater creeks only, which is a measure of the tolerance of stream temperature to future increases in air temperature; 2) weighted index of ecological integrity (**iei.tif**), which is a composite measure of local intactness and short-term resiliency based on ecological systems; 3) TNC terrestrial resiliency (**tResiliency.tif**), which is a measure of long-term resiliency based on geophysical settings; 4) TNC tier 1 floodplains (layer not provided), representing high priorities for floodplain forest restoration; and 5) state Heritage S1-S3 rare communities (layer not provided). Note, all of the layers contributing to tCoreNet.shp and tCoreTiers.shp are stand-alone products that can be interpreted independently of the derived cores.

The terrestrial tier 1 core area network is the basis for modeling regional conductance (**rConduct.tif**), which is a measure of connectivity between cores, during which the connectors between the tier 1 cores are also created (hence the feedback loop to tCoreNet.shp in the figure. rConduct.tif is combined with the integrated probability of development (**probDevelop.tif**), which is a measure of the relative probability of development between 2010-2080, and regional irreplaceability (not provided) to create the regional vulnerability of conductance layer (**rVulnerable.tif**), which indicates places important to network connectivity that are at risk of future development. Note, both rConduct.tif and rVulnerable.tif are completely core area dependent and thus can only be interpreted in conjunction with the designated cores.

Local conductance (**lConduct.tif**) is a separate, stand-alone product that measures local connectivity at the scale of one to a few kilometers, similar to the individual ecological integrity metrics that comprise weighted *IEI*. lConduct.tif is combined with probDevelop.tif to create the local vulnerability of conductance layer (**lVulnerable.tif**), which indicates places important to local connectivity independent of the core areas that are at risk of future development. Note, although lConduct.tif and lVulnerable.tif can be interpreted in conjunction with tCoreNet.shp, they are stand-alone products derived independently of the designated cores.

Terrestrial road passage structure impacts (**passages.shp**) represent opportunities for improving or restoring terrestrial connectivity by installing road passage structures. Note, although passages.shp can be interpreted in conjunction with tCoreNet.shp and tCoreTiers it is a stand-alone product derived independently of the designated cores.

Lastly, to derive the core area network, the Connect the Connecticut LCD planning team opted to use data layers representing the current landscape condition. In this scenario, climate change impacts are incorporated indirectly into the selection of core areas via the *IEI* and TNC terrestrial resiliency indices, which in combination identify currently intact, ecologically connected and geophysically diverse areas that should confer resiliency to climate change over both the short and long term. However, metrics that incorporate climate change directly, such as the climate stressor and sea level rise metrics, and the individual species climate response indices were not used to derive the core areas. Consequently, these layers are provided as overlays to help inform the design. Briefly, the climate zones for each of the 14 representative species (***species*CZ2080.tif**) depict three zones: 1) zone of persistence, representing places where the climate is suitable today and is expected to remain suitable through 2080, 2) zone of contraction, representing places where the climate is suitable today but is expected to become unsuitable by 2080, and 3) zone of expansion, representing places where the climate is unsuitable today but is expected to become suitable by 2080. Similarly, the climate response index for each of the 14 representative species (***species*CR2080.tif**) indicates places with both suitable habitat and climate today and where climate is expected to remain suitable at least out to 2080. Climate stress (**climate.tif**) and sea level rise (**seaRise.tif**) are two ecological integrity metrics that directly measure climate-induced stress on ecological systems. Note, although all of these climate change impact layers can be interpreted in conjunction with tCoreNet.shp, they are stand-alone products derived independently of the designated cores.

6.3.2 Aquatic design products

The following data products relate directly to the aquatic landscape (a.k.a. "aquascape"), and the relationship among the corresponding GIS layers is illustrated in **figure A2**. Most of these products are available from the DSL products repository (McGarigal et al 2017) or can otherwise be obtained from the authors:

- Lotic (river and stream) cores (loticCores.shp)
- Lotic core areas - ecosystem summary (aCoreEcoSum.csv)
- Lentic (lake and pond) cores (lenticCores.shp)
- Brook trout current probability of occurrence (brookTroutLc.shp)
- Anadromous fish index (anadromous.shp)
- Aquatic ecosystem-based core area selection index (aSelectionIndex.tif)
- USGS stream temperature tolerance (streamTolerance.tif)
- Weighted index of ecological integrity (ieiAquatic.tif)
- Aquatic buffers (aquaticBuffers.tif)
- Aquatic core vulnerability to development (aVulnerable.tif)
- Dam removal impacts (dams.shp)
- Culvert upgrade impacts (culverts.shp)

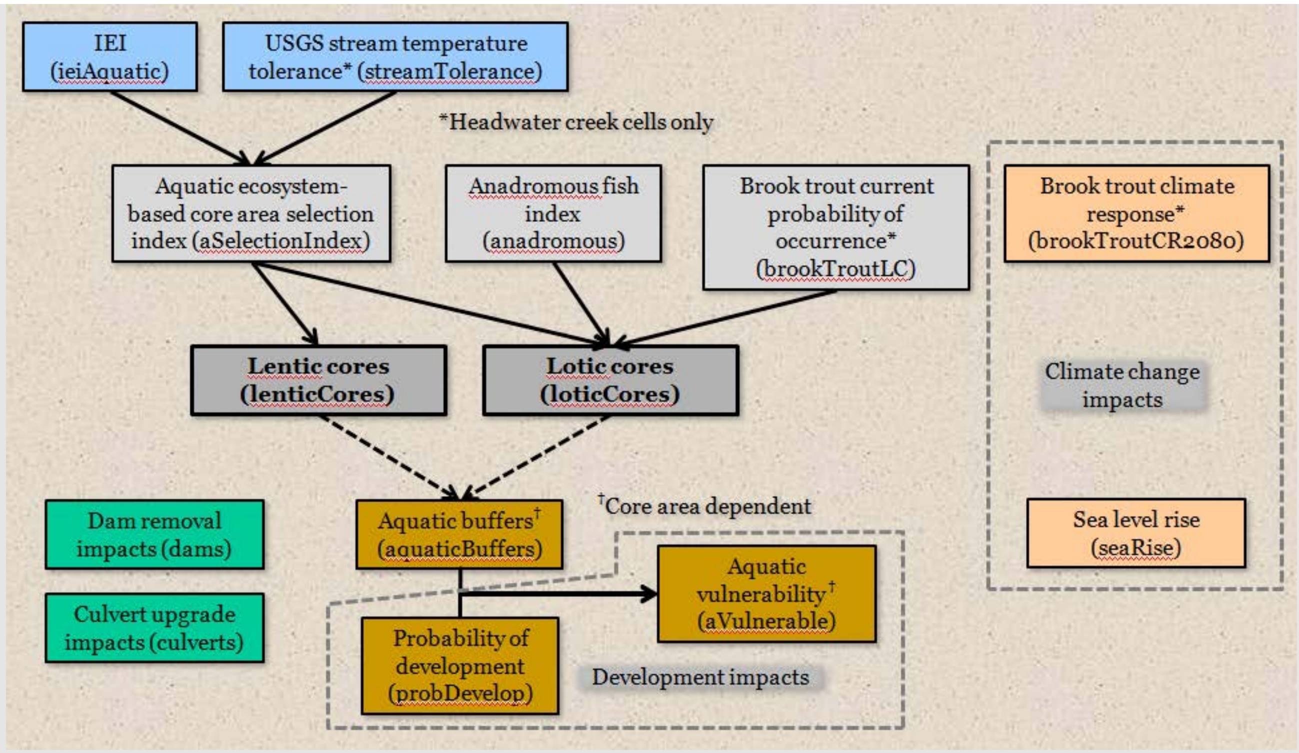


Figure A3. Relationship among the data layers pertaining to the conservation of the aquascape.

- Brook trout climate response (brookTroutCR2080.shp)
- Sea level rise (seaRise.tif)

Perhaps the most important products of the aquatic landscape design are the lotic (i.e., river and stream) cores (**loticCores.shp**) and lentic (lake and pond) cores (**lenticCores.shp**), although the latter is an interim product and should be viewed with caution (as discussed in the abstract below). Similar to the terrestrial core-connector network, the aquatic cores represent a synthesis of ecological information and are designed to provide strategic guidance for conserving aquatic environments and the fish, wildlife, and other components of biodiversity that they support within the CTR watershed. All of the remaining data layers either: 1) provide additional detailed information on why particular areas were included as core areas, 2) provide useful overlays to enhance the interpretation of the core areas (e.g., to help prioritize areas within the cores), or 3) complement the core area network by providing seamless and continuous ecological valuation of the aquascape independent of the core area network (e.g., to identify places with ecological value outside of the designated cores).

The lotic cores are derived from a combination of: 1) anadromous fish index (**anadromous.shp**), which is a binary measure of the lower mainstem and major tributaries open to migration by five select anadromous fish species; 2) brook trout current probability of occurrence (**brookTroutLc.shp**) for headwater creeks only, and 2) aquatic ecosystem-based core area selection index (**aSelectionIndex.tif**). aSelectionIndex.tif is derived from a combination of: 1) USGS stream temperature tolerance (**streamTolerance.tif**), for headwater creeks only, as described above, and 2) weighted index of ecological integrity (**ieiAquatic.tif**), as described above but shown for aquatic cells only (all non-aquatic cells are set to nodata). Note, we did not apply weights to aquatic systems, hence it is technically unweighted *IEI*. Note, streamTolerance.tif and ieiAquatic.tif are both stand-alone products that can be interpreted independently of the derived cores.

Lentic cores are derived solely from aSelectionIndex.tif and thus from iei.tif (since streamTolerance.tif applies only to headwater creeks).

The aquatic cores are the basis for deriving aquatic buffers (**aquaticBuffers.tif**), which represent graduated zones of influence (based on watershed processes) upstream and upslope of the cores. aquaticBuffers.tif is combined with **probDevelop.tif** (described above) to create the aquatic core vulnerability to future development layer (**aVulnerable.tif**), which indicates places in the uplands with a strong influence on the integrity of the aquatic cores that are at risk of future development. Note, aquaticBuffers.tif and aVulernable.tif are both completely core area dependent and thus can only be interpreted in conjunction with the designated aquatic cores.

Dam removal impacts (**dams.shp**) and culvert upgrade impacts (**culverts.shp**) represent opportunities for improving or restoring aquatic connectivity by either removing a dam or upgrading a road-stream crossing structure to the equivalent of a bridge, respectively. Note, although both dams.shp and culverts.shp can be interpreted in conjunction with loticCores.shp and lenticCores.shp, they are stand-alone products derived independently of the designated cores.

Lastly, as noted above, to derive the core area network, the Connect the Connecticut LCD planning team opted to use data layers representing the current landscape condition. Thus, direct climate change impacts are not incorporated into the selection of aquatic core areas. Whereas the climate stress metric (climate.tif) does not apply to aquatic ecosystems, the sea level rise metric (**seaRise.tif**) does. SeaRise.tif is an ecological integrity metric that directly measures the adaptive capacity of coastal systems to predicted sea level rise and is included here as overlay. Note, although seaRise.tif can be interpreted in conjunction with loticCores.shp, it is a stand-alone product derived independently of the designated cores.

6.3.3 Base maps and other ancillary layers

Several additional GIS layers are included in the package as base layers or overlays to facilitate viewing and interpreting the landscape design products. Most of these products are available from the DSL products repository (McGarigal et al 2017) or can otherwise be obtained from the authors:

- Land cover (DSLland.tif) -- depicts ecological systems (and their aggregation into formations) which is foundational to the ecosystem- and species-based assessment products, and thus can be useful for investigating the ecosystem composition of the core-connector network.
- TNC geophysical setting (geoSetting.tif) -- depicts TNC's geophysical settings which is the basis for scaling the corresponding resiliency index, which is used in the terrestrial

ecosystem-based core area selection index and thus the selection of the terrestrial core areas.

- Stream class (streamClass.shp) -- continuous vector representation of streams classified into ecosystems, which can be useful for investigating the ecosystem composition of the lotic cores and also as a backdrop or transparent overlay on other raster products.
- Roads (roads.shp) -- attributed roads within the CTR watershed.
- Secured lands (secure.shp) -- TNC secured lands database depicting parcels with some form of permanent protection from development, which can be useful for determining which places of value, e.g. in the core-network, are already protected.
- State boundaries (statesNer.shp) -- boundaries of the 13 states plus Washington, DC, comprising the Northeast region.
- HUC 6 watershed boundaries (huc6Ctr.shp) -- boundaries of the two HUC 6-level sub-watersheds comprising the CTR watershed.
- HUC 8 watershed boundaries (huc8Ctr.shp) -- boundaries of the 13 HUC 8-level sub-watersheds comprising the CTR watershed.
- Hillshade (hillshade.tif) -- raster hillshading derived from a digital elevation model, useful as a backdrop for viewing some of the layers to highlight the topography when they are displayed using partial transparency.

6.4 Individual Data Products

6.4.1 Terrestrial core-connector network (tCoreNet.shp)

Description

This GIS product represents a set of terrestrial tier 1 **core areas** and the **connectors** between them. In combination with the aquatic core areas (see loticCores.shp and lenticCores.shp), they spatially represent the ecological network derived from the Connect the Connecticut LCD project. The network is designed to provide strategic guidance for conserving natural areas, and the fish, wildlife, and other components of biodiversity that they support within the Connecticut River watershed.

Core areas serve as the foundation of the conservation design. They reflect decisions by the Connect the Connecticut LCD planning team about the highest priority areas for sustaining the long-term ecological values of the watershed, based on currently available, regional-scale information. Terrestrial core areas represent the following:

1) areas of relatively high ***ecological integrity*** across all terrestrial and wetland ecosystem types, emphasizing areas that are relatively intact (i.e., free from human modifications and disturbance) and resilient to environmental changes (e.g., climate change). Integrity has the potential to remain high, both in the short-term due to connectivity to similar natural environments, and in the long-term due to proximity to diverse landforms and other geophysical settings;
2) areas of relatively high current habitat value (**landscape capability**) for a suite of 14 representative terrestrial wildlife species, emphasizing areas that provide the best habitat and climate conditions today;
3) areas of high potential for **floodplain forest restoration** along major rivers, emphasizing areas where geomorphic characteristics favor the development of floodplain forest; and
4) areas of **rare terrestrial natural communities** that support unique biodiversity, regardless of their landscape context; inclusive of communities listed by state heritage programs as S1 (extremely rare), S2 (rare), and S3 (uncommon), with definitions of S1-S3 varying slightly among states.

Core areas are built from focal areas with high value based on one or more of the attributes listed above. These "seed areas" are expanded to encompass surrounding areas that provide additional ecological value and resilience to both short- and long-term change. These surrounding areas within the core areas are typically of high to moderate ecological value. To maintain a coherent shape and size, in some cases core areas contain low-intensity development and minor roads, but high-intensity development and major roads are excluded. Collectively, terrestrial tier 1 core areas encompass 25% of the Connecticut River watershed area, as decided by the partnership. A total of 1,120 core areas have been identified, ranging in size from 8 to 26,515 ha, with an average size of 600 ha.

Connectors represent “corridors” that could facilitate the movement of plants and animals (i.e., ecological flow) between terrestrial core areas. These connectors increase the resiliency of the core area network to uncertain changing land use and climate. They are wider where more movement between cores is expected because of larger and closer core areas and a more favorable natural environment between them. Connectors primarily link adjoining core areas where there is the greatest similarity in ecosystems; they do not necessarily represent travel corridors for any individual species. Connectors may traverse through areas of low-density development and cross roads of all classes, but they do not include high-intensity development. Connectors are not identified between core areas that are greater than 10 km apart. Collectively, connectors encompass an additional 23% of the Connecticut River watershed area.

Considerations for Using Data Layer

The terrestrial tier 1 core-connector network can serve as a starting point for a regional conservation network that can be used in combination with other sources of information to direct action. Indeed, terrestrial core areas and connectors are not the only places of high ecological value deserving of conservation attention. Other suggestions include:

- Use in combination with other data layers to identify additional areas of high ecological value. Layers to consider include: 1) terrestrial ecosystem-based core area selection index (see tSelectionIndex.tif), 2) index of ecological integrity (see iei.tif), 3) The Nature Conservancy's (TNC) terrestrial resiliency index (see tResiliency.tif), and 4) individual species landscape capability index (see *species*LC.tif).
- Use in combination with the secured lands layer (secure.shp) to identify the places in the network that remain unsecured from development, and thus could represent priorities for land protection.
- Use in combination with the probability of development layer (see probDevelop.tif) and local and regional vulnerability layers (lVulnerable.tif, rVulnerable.tif) to identify places in the core-connector network that are relatively vulnerable to future development, and thus could represent priorities for land protection.
- Identify overlap between this network and resource priorities identified at the state or local level, but that are not available across the entire watershed (e.g., from State Wildlife Action Plans, towns, and land trusts), to further rank areas for land protection.

Although the terrestrial tier 1 core areas and connectors are presented as discrete entities, it is important to recognize that their boundaries are, in fact, "fuzzy" and are best interpreted as general places to focus attention.

Lastly, the tier 1 cores and connectors can and do include some low-intensity development, minor roads and agriculture. For the core areas, this is the result of growing out the cores from the highest-valued seed areas in which we elected to allow only major roads and medium-to-high intensity development to serve as barriers to spread. For the connectors, this is the result of the necessity of moving through such developed areas when moving between cores embedded in a developed landscape context.

GIS Formats and Definitions

ESRI shapefile (polygons); including the following attributes for each polygon.

- FID = ESRI assigned unique number (which we do not use) for each polygon.
- Shape = ESRI assigned feature type = "polygon".
- coreID = connectors all have an ID of 1, each core has a unique ID > 1.
- Type = indicator designating the polygon as: "Tier 1 core", "Tier 2 core", "Tier 3 supporting landscape", or "connector".
- centroidX = easting for the centroid of the core.
- centroidY = northing for the centroid of the core.
- areaCount = size of the core area in number of cells (30x30 m); this includes any developed cells.
- areaHa = size of the core area in hectares; this includes any developed area.
- ieiSum = sum of the terrestrial core area selection index (see tSelectionIndex.tif), which is a reflection of both the size of the core and the quality of the cells within in it.
- ieiRank = rank of ieiSum (1 = max ieiSum).
- import = index of the importance of each core to the entire core area network based on its size/quality (as represented by ieiSum), proximity to other cores, and strategic position in the network. Specifically, it is an index reflecting how much the connectivity of the entire network would be affected by its removal. It gives the absolute decrease in the Probability of Connectivity (ΔPC) of the network.
- importRank = rank of import (1 = largest ΔPC).
- relImport = index of the importance of each core to the entire core area network without considering node value (i.e., sum of the core area selection index) in the calculation of ΔPC. Note, ΔPC is heavily influenced by node value. Thus, relImport is an alternative to import10k for rating the relative importance of cores that gives more influence to node position in the network than node value.
- relImpRank = rank of relImport (1= largest relImport).
- floodplain = percentage of the core comprised of TNC's tier 1 floodplains.
- rareCom = percentage of the core comprised of S1-S3 rare communities as defined and mapped by the state Heritage Programs.
- system1, system2, system3 = The top three terrestrial or wetland ecological systems for which the core is particularly important. In other words, for these systems 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 systems listed here reflect the systems for which the core is especially important, but are not necessarily the most abundant systems in the core. A complete listing of the relative importance of the core for all ecological systems,

including the relative abundance of systems within the core, is available separately in the Ecosystem table described below.

- species1, species2, species3 = The top three representative species for which the core is particularly important. In other words, for these species the cumulative climate response index (lc.tif) within the core is greater than expected (from a statistical perspective) given its distribution across the entire core area network. Note, the species listed here reflect the species for which the core is especially important, but are not necessarily the species with the highest total landscape capability in the core. A complete listing of the relative importance of the core for all species, including the total landscape capability in the core attributed to each species (index2, see below), is available in the Species table described below.
- scenario = internal use (file directory) to track the specific core area scenario.

Detailed core area composition statistics

Detailed composition statistics are available for each core and are divided into ecosystems and species tables (see files in the tCoreStats 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 or species. In all cases, larger values indicate greater importance.

Ecosystem table:

- coreID = unique number assigned to each core.
- systemName = name of the ecosystem as given in the ecological systems map (developed classes are not included).
- areaCount = number of cells of the corresponding system in the core. Note, because developed classes were excluded, the sum of areaCount across systems in the core as listed in this table may be less than the core area size as given in the layer attributes.
- areaHa = hectares of the corresponding system in the core.
- index1 = index of importance of the core for the corresponding 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 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 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 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).
- scenario = internal use (file directory) to track the specific core area scenario.

Species table:

- coreID = unique number assigned to each core.
- speciesName = name of the representative species.
- sumLC = sum of the landscape capability (LC) index for corresponding species. For scenarios considering future climate conditions, the species' climate response (CR) index is used as the LC index, except for black bear which does not have a climate model and thus current LC is used instead.
- index1 = index of importance of the core for the corresponding species, based on deviation of the observed sum of the LC/CR index for the species from its expected value, which is based on the size of the core and the species' average LC/CR index 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 species, defined as the percentage of the core's total LC/CR index comprised of the corresponding species. The index ranges from 0-100.
- index2Rank = rank of index2 (1 = max index2).
- index3 = index of importance of the core for the corresponding species, defined as the percentage of the species' total LC/CR 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 species, defined as the difference between the species' average LC/CR index in the focal core and its average LC/CR index across all cores. The index ranges from -1 to 1; negative values indicate an average LC/CR 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).
- scenario = internal use (file directory) to track the specific core area scenario.

6.4.2 Terrestrial core tiers (tCoreTiers.shp)

Description

This GIS product represents a three-tiered, spatially-nested hierarchy of terrestrial **core areas** and **supporting landscapes**. More specifically, this layer depicts the terrestrial tier 1 cores (as in tCoreNet.shp), (encompassing 25% of the landscape), nested within tier 2 cores (encompassing 50% of the landscape), nested with tier 3 supporting landscapes (encompassing 77% of the landscape). The tiers reflect the arbitrariness in selecting thresholds for designating priority areas. Tier 1 represents a highly strategic scenario designed to target the very best, highest priority core areas. Tier 2 represents a more liberal scenario and a correspondingly more lofty conservation goal. Tier 3 represents the road-bounded blocks containing the tier 2 cores, in which all road classes except tracks and medium-to-high intensity development function as boundaries. Tier 3 areas, as defined, are intended to represent more practical on-the-ground conservation units and provide the supporting landscape necessary to ensure maintenance of the ecological values of the tier 1 and 2 cores in the future.

Considerations for Using Data Layer

The tiered cores provide spatial context for the strategic tier 1 core-connector network. Importantly, tier 2 and 3 identify places of ecological importance outside of the tier 1 core area network that can be used in combination with other sources of information to direct action (see tCoreNet for suggestions).

Although the tiered core areas are presented as discrete entities, it is important to recognize that their boundaries are, in fact, "fuzzy" and are best interpreted as general places to focus attention.

Lastly, as noted previously for the tier 1 cores and connectors, all three tiers can and do include some low-intensity development, minor roads and agriculture (see previous discussion).

GIS Formats and Definitions

ESRI shapefile (polygons); including the attributes described previously in tCoreNet.shp for each tier 1 polygon and each tier 2 multi-part polygon. Note, the tier 2 polygons may be multi-parted, consisting of several disjunct polygons surrounding one or more embedded tier 1 polygons. For convenience, these multi-part tier 2 polygons have been dissolved so that the attribute table contains a single row for each disjunct tier 2 core. However, to view the information associated with an individual tier 2 core when using the "identify" button in ArcMap, you must click on a part of the tier 2 core outside of the embedded tier 1 polygon. In addition, the tier 2 attributes do not contain the floodplain and rareCom fields as these are entirely contained within tier 1 cores.

6.4.3 Grassland bird cores (grasslandCores.shp)

Description

This GIS product represents a set of terrestrial **core areas** for grassland birds based on eastern meadowlark as a representative species for grassland birds. In combination with the terrestrial tier 1 and 2 core areas (see tCoreNet.shp and tCoreTiers.shp), they spatially represent the ecological core area network derived from the Connect the Connecticut LCD project. The Connect the Connecticut LCD planning team decided that eastern meadowlark and the grassland birds they represent warranted separate treatment from the other terrestrial representative species due to their unique association with a culturally created and maintained habitat. Consequently, eastern meadowlark and the grassland birds they represent were not explicitly included in the derivation of the tier 1 and 2 core areas. However, some grasslands did get included in the tier 1 and 2 cores areas due to other considerations, such as meeting the needs of other representative species (e.g., wood turtle) that also use grasslands to some extent, and growing out cores from their seeds through lower-valued areas that included grasslands.

Grassland bird cores were derived from the eastern meadowlark landscape capability (eameLc.tif) layer, which is a measure of habitat capability and climate suitability for the species. Briefly, for each disjunct patch of habitat (defined as contiguous cells having landscape capability index >0.03), we computed the maximum landscape capability index value. Next, we rank-ordered the habitat patches from highest value to lowest maximum value and selected the top number of patches in which the cumulative landscape capability value (i.e. ,the sum of the landscape capability index in the patches) equalled 50% of the species' total landscape capability value for the CTR watershed. Thus, the final set of 1448 grassland bird cores captured 50% of the landscape capability for this species and represented 1.15% of the CTR landscape.

Considerations for Using Data Layer

The terrestrial tiered cores and connectors in combination with the grassland bird cores can serve as a starting point for a regional conservation network that can be used in combination with other sources of information to direct action (see tCoreNet for suggestions).

Although the grassland bird core areas are presented as discrete entities, it is important to recognize that their boundaries are, in fact, "fuzzy" and are best interpreted as general places to focus attention.

Lastly, as noted previously for the tier 1 cores and connectors, all three tiers can and do include some low-intensity development, minor roads and agriculture (see previous discussion).

GIS Formats and Definitions

ESRI shapefile (polygons); including the following attributes for each polygon:

- FID = ESRI assigned unique number (which we do not use) for each polygon.
- Shape = ESRI assigned feature type = "polygon".

6.4.4 Terrestrial core areas: ecosystem summary (tCoreEcoSum.csv)

Description

This table provides a quantitative summary of the ecosystem composition of the terrestrial tier1 and 2 core areas relative to the entire landscape. The table contains a single row for each ecological system occurring in the landscape and the following columns (fields):

- ecosystem = ecological system (note, ecosystem here is based on the field named 'sumgroupname' in the ArcGIS raster distributed by TNC named 'syst_ne130930' , or the field named 'habitat' in the ArcGIS raster distributed by TNC named 'syst_ne141611').
- formation = ecological formation, consisting of closely related ecosystems.
- landscapeHa = total hectares of the system in the landscape.
- T1CoreHa = total hectares of the system in the terrestrial tier 1 core areas.
- T1PercentArea = percentage of the system's landscape extent occurring in the terrestrial tier 1 core areas = coreHa/landscapeHa×100.
- T1PercentSi = percentage of the system's total selection index occurring in the terrestrial tier 1 core areas; i.e., what percent of the system's cumulative selection index across the entire landscape is encompassed by the terrestrial cores.
- T2CoreHa = total hectares of the system in the terrestrial tier 2 core areas (inclusive of tier 2).
- T2PercentArea = percentage of the system's landscape extent occurring in the terrestrial tier 2 core areas = coreHa/landscapeHa×100 (inclusive of tier 1).
- T2PercentSi = percentage of the system's total selection index occurring in the terrestrial tier 2 core areas; i.e., what percent of the system's cumulative selection index across the entire landscape is encompassed by the terrestrial tier 2 cores (inclusive of tier 1).

6.4.5 Terrestrial core areas: species summary (tCoreSpeciesSum.csv)

Description

This table provides a quantitative summary of the representative species composition of the terrestrial tier 1 and 2 core areas relative to the entire landscape. The table contains a single row for each of the 14 representative terrestrial species and the following columns (fields):

- speciesName = representative species name.
- target = conservation target established by the planning team, expressed in terms of the proportion of the species' total current landscape capability targeted for inclusion in the terrestrial core areas. However, because we put a constraint on the total area of the landscape in terrestrial core areas (25%), these targets must be viewed as relative weights.
- landscapeLc = sum of the species' current (2010) landscape capability index across the entire landscape.
- T1CoreLc = sum of the species' current (2010) landscape capability index across the terrestrial tier 1 core areas.
- T1PercentLc = percentage of the species' current (2010) landscape capability index across the entire landscape contained within the terrestrial tier 1 core areas = coreLc/landscapeLc×100.
- T2CoreLc = sum of the species' current (2010) landscape capability index across the terrestrial tier 2 core areas (inclusive of tier 1).
- T2PercentLc = percentage of the species' current (2010) landscape capability index across the entire landscape contained within the terrestrial tier 2 core areas = coreLc/landscapeLc×100 (inclusive of tier 1).

6.4.6 Species landscape capability (*species*LC.tif)

Description

This GIS product represents the **landscape capability** index for each of the 14 representative terrestrial wildlife species, provided as separate data layers for each species. See the technical documentation on species (McGarigal et al 2017) for a detailed description of the landscape capability index and associated data products, including links to abstracts of each species' landscape capability model. The layer names are prefixed by the species acronym (e.g., blbwLc.tif for the blackburnian warbler landscape capability index). Landscape capability is an integrated measure of habitat capability, climate suitability and species' prevalence, and is based on a unique model developed for each species (see the separate abstracts to learn more about each species' model). Note, there are several different landscape capability indices that reflect different decisions (or assumptions) regarding how to incorporate current versus future land use and climate changes. The layer provided here is based on the current landscape capability index which does not explicitly consider future land use or climate. The landscape capability index for the 14 representative terrestrial wildlife species is a major input to the building of terrestrial cores (see tCoreNet.shp).

Considerations for Using Data Layer

These layers provide a seamless and continuous valuation of landscape capability for each of the 14 representative terrestrial wildlife species. Importantly, these layers provide an ecological valuation of areas, both inside and outside designated core areas, and thus they can be used to identify places of high ecological value for one or more representative species outside of designated core areas that are also deserving of conservation attention. It is important to recognize that the landscape capability index provided here is in its raw scale form, and both the range and distribution of values varies dramatically among species, reflecting idiosyncrasies of each species' model. Consequently, the landscape capability index is not comparable across species. It can only be used separately for each species to evaluate the relative capability of one location against another to support that species.

It is important to note that the landscape capability index is not an estimate of occupancy. It does not give the probability than a cell will be occupied by the species. Rather, it is an index of the relative capability of a site to support reproduction and survival of the focal species in a home range centered on that cell. Other suggestions include:

- Use in combination with the species climate zones (see *species*CZ2080.tif) and climate response index (see *species*CR2080.tif) to evaluate the change in each species' landscape capability due to predicted climate change.
- Use in combination with the secured lands layer (see secure.shp) to identify places with high ecological value for one or more representative terrestrial wildlife species that remain unsecured from development, and thus could represent priorities for land protection.
- Use in combination with the integrated probability of development (see probDevelop.tif) and local vulnerability (see lVulnerable.tif) layers to identify places of

high value for one or more representative terrestrial wildlife species that are relatively vulnerable to future development, and thus could represent priorities for land protection.

<u>GIS Formats and Definitions</u>

Geotiff raster (30 m cells); cell value = landscape capability index; ranges from 0 (developed) to a theoretical maximum of 1 (but the observed maximum is often much less).

6.4.7 Terrestrial ecosystem-based core area selection index (tSelectionIndex.tif)

Description

This GIS product represents the selection index used to create terrestrial ecosystem-based cores. The selection index is a continuous surface in which every cell is assigned a value (0-1) based on its relative ecological integrity and/or biodiversity value within each HUC6 watershed. Specifically, for all terrestrial and wetland cells, the selection index is a composite index derived from a weighted combination of the 1) weighted index of ecological integrity (*IEI*; see iei.tif), 2) TNC's terrestrial resiliency index (see tResiliency.tif), and a binary representation of 3) TNC's tier 1 floodplains and 4) S1-S3 rare natural communities as defined and mapped by the state Natural Heritage programs. For aquatic cells (which are also included in this layer), the index is equal to *IEI*, except in headwater creeks where *IEI* is averaged with USGS's stream temperature tolerance index (see streamTolerance.tif). In addition, to enhance the establishment of a well-distributed network of core areas for connectivity and climate adaptation, both *IEI* and TNC resiliency are stratified within each of the two HUC6 subwatersheds within the Connecticut River watershed. Specifically, *IEI* is scaled by ecological system such that it ranges from 0 (low) to 1 (high) within each ecological system within each HUC6 watershed. TNC's resiliency index is scaled such that it ranges from 0 (low) to 1 (high) within each geophysical setting class within each HUC6 watershed. Consequently, high values of the selection index represent all ecological systems and geophysical settings. Terrestrial core areas are created, in part, by choosing cells above a certain index value and spreading outwards from these "seeds" to build larger, buffered cores of relatively high ecological value.

Considerations for Using Data Layer

This layer provides a seamless and continuous valuation of ecological integrity and biodiversity value based on regionally available and consistent spatial data that reflects decisions by the Connect the Connecticut LCD planning team. Importantly, this layer provides an ecological valuation of areas both inside and outside designated core areas, and thus it can be used to identify places of high ecological value outside of designated core areas that are also deserving of conservation attention. The primary conservation application of this data layer is likely to be in conjunction with the terrestrial core network (see tCoreNet.shp and tCoreTiers.shp); see the description for tCoreNet.shp for application suggestions.

As an intermediate product in the development of tCoreNet.shp and tCoreTiers.shp, this product also is useful in understanding how the four component products described earlier in this section are integrated and how the core areas are generated. Note, cells representing TNC's tier 1 floodplains or the state's S1-S1 rare natural communities are assigned the maximum selection index of 1.

It is important to recognize that this selection index is scaled by HUC6 watershed so as to indicate the relative ecological integrity and/or biodiversity value within each HUC6 watershed.

GIS Formats and Definitions

Geotiff raster (30 m cells); cell value = terrestrial core area selection index; ranges from 0 (developed) to 1 (maximum ecological value).

6.4.8 USGS stream temperature tolerance (streamTolerance.tif)

Description

This GIS product represents a scaled version of the headwater stream temperature tolerance index based on a model developed by Dr. Ben Letcher and associates at the USGS Conte Anadromous Fish Lab, which is a measure of the relative sensitivity of stream temperatures to rising air temperatures. Specifically, sensitivity is measured by the slope of the linear relationship between air and stream temperatures during the spring season when air temperatures are rising. A steeper slope indicates that stream temperature responds faster to air temperature change, while a shallow slope indicates that stream temperature is more independent of air temperature change. Lower values (i.e., shallower slopes) are interpreted as being more tolerant under climate change, possibly because of groundwater influence or other factors. Conversely, streams with higher slopes are likely to be more impacted by increased air temperatures.

In the layer provided here, the raw rising slope index is inverted and (quantile) scaled by HUC6 watershed so that the least tolerant headwater creek (steepest slope) gets a 0 and the most tolerant (shallowest slope) gets a 1 within each watershed. This form of scaling has an intuitive interpretation, because the value of the index expresses the proportion of cells in the same watershed with a value less than or equal to that value. Thus, a value of 0.9 in a cell means that it has a score that is greater than 90% of all the headwater creek cells in that watershed, and all the cells with >0.9 values comprise the best 10% of all headwater creek cells within the watershed. USGS stream temperature tolerance index, as scaled here, is a major component of the aquatic core area selection index (see aSelectionIndex.tif) in headwater creeks. To learn more about USGS stream temperature tolerance, see Dr. Ben Letcher's website (www.lsc.usgs.gov/?q=cafb-ben-letcher).

Considerations for Using Data Layer

This layer provides a seamless and continuous valuation of stream temperature tolerance in headwater creeks. Importantly, this layer provides an ecological valuation of areas both inside and outside designated lotic core areas, at least within headwater creeks, and thus it can be used to identify places of high ecological value outside of designated core areas that are also deserving of conservation attention. Note, it is important to recognize that the layer provided here is not identical to the version developed by USGS because it has been inverted and (quantile) scaled by HUC6 watershed (as described above) for consistency with other landscape design products. A suggestion for combining this dataset with another dataset in the package is:

- Use in combination with the weighted index of ecological integrity (see iei.tif) to gain a more comprehensive evaluation of ecological integrity in headwater creeks.

GIS Formats and Definitions

Geotiff raster (30 m cells); cell value = USGS stream temperature tolerance index, rescaled; ranges from 0 (developed) to 1 (maximum ecological value).

6.4.9 Weighted index of ecological integrity (iei.tif and ieiAquatic.tif)

Description

This GIS product represents the weighted **index of ecological integrity** (*IEI*), which is a measure of relative intactness (i.e., freedom from human modifications and disturbance) and resiliency to environmental change (e.g., as caused by disturbance and climate change). Raw *IEI* is a composite index derived from 19 different landscape metrics that measure different aspects of intactness and resiliency. For the derivation of this layer, raw *IEI* is (quantile) scaled by ecological system and HUC6 watershed so that the poorest cell of each ecological system gets a 0 and the best gets a 1 within each watershed. In the layer provided here, scaled *IEI* has been modified to reflect weights assigned to each ecological system by the planning team, such that the final index gives more emphasis to certain terrestrial and wetland ecological systems deemed more vulnerable or in greater need of conservation (e.g., wetlands, alpine, boreal upland forest). Note that weights were not applied to aquatic systems. Thus, ieiAquatic.tif, which is provided for convenience in displaying the results of the aquatic conservation design but is otherwise equivalent to iei.tif except that it only has values for aquatic cells (all non-aquatic cells are set to nodata), is technically unweighted *IEI*. Weighted *IEI* is a major component of the terrestrial and aquatic core area selection indices (see tSelectionIndex.tif and aSelectionIndex.tif, respectively) and thus the terrestrial and aquatic network of core areas (see tCoreNet.shp, tCoreTiers.shp, loticCores.shp and lenticCores.shp).

Considerations for Using Data Layer

This layer provides a seamless and continuous valuation of ecological integrity based on regionally available and consistent spatial data that reflects decisions by the planning team. Importantly, this layer provides an ecological valuation of areas both inside and outside designated core areas, and thus it can be used to identify places of high ecological value outside of designated core areas that are also deserving of conservation attention. It is important to recognize that the *IEI* index provided here is scaled so as to indicate the relative ecological integrity value of cells within each HUC6 watershed (as described above) for consistency with other landscape design products. Other suggestions include:

- Use in combination with the terrestrial and aquatic core area products (see links above) to identify places of high ecological value outside of designated cores.
- Use in combination with the secured lands layer (see secure.shp) to identify places with high ecological value that remain unsecured from development, and thus could represent priorities for land protection.
- Use in combination with the integrated probability of development (see probDevelop.tif) and local vulnerability (see lVulnerable.tif) layers to identify places of high value that are relatively vulnerable to future development, and thus could represent priorities for land protection.
- Use in combination with TNC's terrestrial resiliency index (see tResiliency.tif) to gain a more comprehensive evaluation of ecological integrity. Specifically, use weighted *IEI* as an assessment of intactness and short-term resiliency based on connectivity to an

ecologically similar neighborhood, and use TNC's resiliency index as an assessment of long-term resiliency based on connectivity to diverse landforms and elevations.

GIS Formats and Definitions

Geotiff raster (30 m cells); cell value = *IEI*; ranges from 0 (developed) to 1 (maximum ecological value).

6.4.10 TNC terrestrial resiliency (tResiliency.tif)

Description

This GIS product represents a scaled version of the terrestrial resiliency index developed by Mark Anderson and associates at The Nature Conservancy (Anderson et al 2012), which is a measure of the relative long-term resiliency of a site based on connectivity to a diversity of landforms, elevations and wetlands. Specifically, in the Northeast, sites are compared with other sites of the same geophysical setting based on geology, elevation zone, and ecoregion. Within each geophysical setting class, sites are compared with respect to two metrics: 1) landscape diversity, which refers to the number of microhabitats and climatic gradients available within a given area based on the variety of landforms, elevation range, and wetland density, and 2) local connectedness, which refers to the accessibility of neighboring natural areas.

In the layer provided here, the raw resiliency index is (quantile) scaled by geophysical setting class and HUC6 watershed so that the poorest cell of each geophysical setting gets a 0 and the best gets a 1 within each watershed. This form of scaling has an intuitive interpretation, because the value of the index expresses the proportion of cells in the same geophysical setting and watershed with a value less than or equal to that value. Thus, a value of 0.9 in a cell means that it has a resiliency score that is greater than 90% of all the cells of the same geophysical setting in that watershed, and all the cells with >0.9 values comprise the best 10% of all cells across all geophysical settings within the watershed. TNC's resiliency index, as scaled here, is a major component of the terrestrial core area selection index (see tSelectIndex.tif) and thus the terrestrial core area network (see tCoreNet.shp and tCoreTiers.shp). To learn more about TNC's resiliency index, see: Resiliency page at TNC's Conservation Gateway.

Considerations for Using Data Layer

This layer provides a seamless and continuous valuation of terrestrial resiliency based on the geophysical template as defined and implemented in TNC's terrestrial resiliency index. Importantly, this layer provides an ecological valuation of areas both inside and outside designated core areas, and thus it can be used to identify places of high ecological value outside of designated core areas that are also deserving of conservation attention. Note, it is important to recognize that the layer provided here is not identical to the version distributed by TNC because it has been (quantile) scaled by geophysical setting and HUC6 watershed (as described above) for consistency with other landscape design products. Other suggestions include:

- Use in combination with the terrestrial core area network (see link above) to identify places of high ecological value outside of designated cores.
- Use in combination with the secured lands layer (see secure.shp) to identify places with high ecological value that remain unsecured from development, and thus could represent priorities for land protection.
- Use in combination with the integrated probability of development (see probDevelop.tif) and local vulnerability (see lVulnerable.tif) layers to identify places of

high value that are relatively vulnerable to future development, and thus could represent priorities for land protection.

- Use in combination with the weighted index of ecological integrity (see iei.tif) to gain a more comprehensive evaluation of ecological integrity. Specifically, use weighted *IEI* as an assessment of intactness and short-term resiliency based on connectivity to an ecologically similar neighborhood, and use TNC's resiliency index as an assessment of long-term resiliency based on connectivity to diverse landforms and elevations.

GIS Formats and Definitions

Geotiff raster (30 m cells); cell value = TNC resiliency index, rescaled; ranges from 0 (developed) to 1 (maximum ecological value).

6.4.11 Regional conductance (rConduct.tif)

Description

This GIS product represents the **regional conductance** index, which is a measure of the total potential amount of movement of plants and animals (ecological flow) through a cell from nearby terrestrial core areas at the scale of a few to ten kilometers. Regional conductance increases with the size and proximity of nearby cores, because larger cores produce larger numbers of plants and animals and the probability of an individual getting to any particular location decreases with distance from the source. Regional conductance also reflects the resistance of the focal cell and intervening cells between the nearby cores based on their ecological dissimilarity to the cells in the nearby cores. For example, a forest cell between largely forested cores would have higher regional conductance than if it were lake. Regional conductance differs from local conductance (see lConduct.tif) in that it is based on a designated core area network and measures the amount of ecological flow between the designated cores.

Considerations for Using Data Layer

This layer provides a seamless and continuous index of conductance between designated terrestrial cores. Importantly, this metric is contingent upon the a priori designation of core areas and thus is primarily useful in the context of landscape conservation design. In particular, this product can be used to identify places that confer connectivity between cores and thereby contribute to the connectivity of the entire regional core area network. As with local conductance, the absolute value of regional conductance is not particularly meaningful, nor does it necessarily reflect connectivity between cores for any single species.

Regional conductance can be used in combination with local conductance to identify places that confer greater connectivity to the terrestrial core area network. Use local conductance within cores and regional conductance between cores (note that the two products are scaled differently and thus the absolute values cannot be compared between products).

GIS Formats and Definitions

Geotiff raster (30 m cells); cell value = local conductance; ranges from near 0 (no conductance) to a theoretical maximum of 1 (but the maximum observed value is typically quite small).

6.4.12 Probability of development (probDevelop.tif)

Description

This GIS product represents the integrated probability of development between 2010-2080 based on a custom urban growth model that accounts for the type (low intensity, medium intensity and high intensity), amount and spatial pattern of development. This index represents the probability of development occurring sometime between 2010 and 2080 at the 30 m cell level. The projected amount of development in an area is downscaled from county level forecasts based on a U.S. Forest Service 2010 Resources Planning Act (RPA) assessment. The type and pattern of development is based on models of historical development and is influenced by factors such as geophysical conditions (e.g., slope, proximity to open water), existing secured lands, and proximity to roads and urban centers.

Considerations for Using Data Layer

This layer provides a seamless and continuous representation of the integrated probability of development between 2010-2080. This product can be used in combination with any of the other design products that reveal places of high ecological value to indicate places of ecological value that are at risk of development and thus may warrant land protection. This product also can be used to identify places at risk of future development independent of designated core areas and any formal landscape conservation design. Although this index is a true probability, it is perhaps best used in a relative manner to compare values from one location to another.

Precautions apply in using this dataset:

- Probability of development is highest near existing roads in part because the urban growth model does not attempt to predict the building of major new roads and the development associated with them.
- At the 30m cell level there are known gross errors in the National Land Cover Dataset (NLCD) from which development is mapped and the probability of development is modeled. Therefore, this layer is best used as a general indication of where development is likely to occur; results at the cell level are not expected to be highly reliable.

GIS Formats and Definitions

Geotiff raster (30 m cells); cell value = probability of development; ranges from 0 (e.g., secured land, water, already developed) to a theoretical maximum of 1.

6.4.13 Regional vulnerability of conductance (rVulnerable.tif and rVulnConnectors.tif)

Description

This GIS product represents the regional vulnerability of conductance index, which reflects the likelihood of development occurring in places that confer connectivity between terrestrial cores. Specifically, regional vulnerability is the product of the regional conductance index (i.e., total amount of ecological flow through a cell from nearby terrestrial cores; see rConduct.tif), regional irreplaceability index (i.e., proportion of the total ecological flow between nearby terrestrial cores that flows through each cell), and the integrated future probability of development between 2010-2080 (see probDevelop.tif). Cells with relatively low regional conductance and where flow is relatively dispersed have low vulnerability regardless of their risk of development, since regional connectivity will not be degraded too much if they get developed. Regional vulnerability is greatest where there is high regional conductance and where the flow is concentrated; i.e., in narrow "corridors" of ecologically similar areas with relatively low levels of current development between large nearby cores, and where there is also relatively high probability of development in the future.

Considerations for Using Data Layer

This layer provides a seamless and continuous representation of the vulnerability to development of cells important to the connectivity of the terrestrial core area network. The regional vulnerability index is computed for every cell, whether it is between terrestrial cores or within a core, but the index is primarily useful for assessing the vulnerability of cells between cores. Moreover, the index is best used in a relative manner to compare values from one location to another. Importantly, this index is contingent upon the a priori designation of core areas and thus is primarily useful in the context of landscape conservation design. In particular, this layer may be especially useful for identifying places within the designated connectors that are highly vulnerable to development. For this reason, the data package includes a separate GIS layer (rVulnConnectors.tif) in which rVulnerable.tif has been clipped to the extent of the connectors.

Precautions outlined for the integrated probability of development layer (see probDevelop.tif) also apply to this layer. Consequently, this layer is best used as a general indication of where regional connectivity is most vulnerable to development.

GIS Formats and Definitions

Geotiff raster (30 m cells); cell value = regional vulnerability index; ranges from 0 (e.g., secured land, water, already developed) to <100.

6.4.14 Local conductance (lConduct.tif)

Description

This GIS product represents the **local conductance** index, which is a measure of the total potential amount of movement of plants and animals (ecological flow) through a cell from neighboring cells as a function of the ecological similarity between the focal cell and neighboring cells at the scale of one to a few kilometers. The conductance of a focal cell is affected by the amount of development and ecological similarity of its neighborhood (within one to a few kilometers) as well as the resistance of the focal cell itself (i.e., its ecological dissimilarity to neighboring cells). Conductance increases as the proportion of the neighborhood that is undeveloped increases, as the ecological similarity among neighboring cells increases, and as the ecological similarity between the focal cell and its neighbors increases. For example, a forested cell surrounded by forested cells would have high conductance, whereas a forest cell surrounded by aquatic and wetland cells would have lower conductance, and a forested cell surrounded by development would have the least conductance.

Considerations for Using Data Layer

This layer provides a seamless and continuous index of local conductance that is independent of any designated core area network. Thus, this product can be used to identify places that confer connectivity at the local scale (one to a few kilometers) independent of designated core areas and any formal landscape conservation design. Note, it is best to consider the relative values from one location to another rather than trying to interpret the absolute value of conductance. In addition, local conductance is based on ecological similarity between locations and thus may not reflect connectivity for any single species.

Local conductance can be used in combination with regional conductance (see rConduct.tif) to identify places that confer greater connectivity to the terrestrial core area network. Use local conductance within cores and regional conductance between cores (note that the two conductance products are scaled differently and thus the absolute values cannot be compared).

GIS Formats and Definitions

Geotiff raster (30 m cells); cell value = local conductance; ranges from near 0 (no conductance) to a theoretical maximum of 1.

6.4.15 Local vulnerability of conductance (lVulnerable.tif and lVulnCores.tif)

Description

This GIS product represents the local vulnerability of conductance index, which reflects the likelihood of development occurring in places with high local conductance. Specifically, this index is computed as the product of the integrated probability of development between 2010-2080 (see probDevelop.tif) and the local conductance index (see lConduct.tif). Thus, cells that confer high local conductivity at the scale of one to a few kilometers that also have a high probability of development are most vulnerable. Conversely, cells that confer high local conductivity but have a low probability of development are relatively less vulnerable.

Considerations for Using Data Layer

This layer provides a seamless and continuous representation of the vulnerability of cells important to local connectivity being developed between 2010-2080. The local vulnerability index is computed for every cell independent of designated core areas and any formal landscape conservation design, and it is best used in a relative manner to compare values from one location to another. This layer can be used to identify important places -- those that confer local connectivity -- at risk of future development independent of designated core areas. However, this layer can also be used in a complementary manner with the regional vulnerability layer, whereby regional vulnerability is used to assess vulnerability between core areas (or just in the designated connectors: rVulnConnectors.tif) and local vulnerability is used to assess vulnerability within core areas. For this reason, the data package includes a separate GIS layer (lVulnCores.tif) in which lVulnerable.tif has been clipped to the extent of the terrestrial cores.

Precautions outlined for the integrated probability of development layer (see probDevelop.tif) also apply to this layer. Consequently, this layer is best used as a general indication of where local connectivity is most vulnerable to development.

GIS Formats and Definitions

Geotiff raster (30 m cells); cell value = local vulnerability index; ranges from 0 (e.g., secured land, water, already developed) to a theoretical maximum of 1.

6.4.16 Species climate zones (*species*CZ2080.tif)

Description

This GIS product represents the climate zones for each of the 14 representative terrestrial wildlife species, provided as a separate data layer for each species. See the technical document on species (McGarigal et al 2017) for a detailed description of the climate zones and other species data products. Climate zones are derived by intersecting the species' current and future climate niche envelopes (CNE) averaged across RPC 4.5 and 8.5 climate change scenarios. The CNE is a binary representation of where the species is expected to occur due solely to climate suitability (i.e., ignoring habitat). Climate zones depict three distinct zones of uncertainty in the predicted future distribution of a species based solely on climate suitability: 1) *zone of persistence* - overlap of the current and future CNE; thus, where the climate is suitable today and is expected to remain suitable through 2080, and consequently where we have high confidence in the species' predicted future occurrence; 2) *zone of contraction* - current CNE outside of the future CNE; thus, where the future climate is no longer predicted to be suitable, and consequently where we have lower confidence in the species' predicted future occurrence due to unknown population time lags and other factors; and 3) *zone of expansion* - future CNE outside of the current CNE; thus, where the future climate becomes suitable but is not currently suitable, and consequently where we have lower confidence in the species' predicted future occurrence due to unknown population time lags and other factors. These climate zones are an attempt to depict the extent to which a species distribution is expected remain stable, contract or expand due solely to predicted climate changes through 2080 (i.e., ignoring habitat changes). Climate zones for the 14 representative terrestrial wildlife species were not used as an input to the building of terrestrial cores (see tCoreNet.shp and tCoreTiers.shp), but are provided as an overlay to help inform the design with respect to potential climate change impacts.

Considerations for Using Data Layer

These layers provide a seamless and continuous valuation of expected changes in climate suitability for each of the 14 representative terrestrial wildlife species. Importantly, these layers provide an ecological valuation of areas, both inside and outside designated core areas, and thus they can be used to identify places of high ecological value for one or more representative species outside of designated core areas that are also deserving of conservation attention. It is important to recognize that the climate zones depicted here reflect the expected changes in a species 'potential' distribution due solely to changes in climate suitability; they do not reflect changes in a species distribution driven by habitat alterations. Consequently, the climate zones should not be interpreted as a species distribution map, but rather as a quick and easy way to visually assess the degree to which future climate conditions are expected to improve or worsen for a species. In addition, note that because black bear is a wide-ranging species, it does not have a climate suitability model, and thus it does not have climate zones.

Other suggestions include:

- Use in combination with the species current landscape capability index (see *species*LC.tif) and climate response index (see *species*CR2080.tif) to evaluate the change in each species' landscape capability due to predicted climate change.
- Use in combination with the secured lands layer (see secure.shp) to identify places with high ecological value for one or more representative terrestrial wildlife species (e.g., zone of persistence or expansion) that remain unsecured from development, and thus could represent priorities for land protection.
- Use in combination with the integrated probability of development (see probDevelop.tif) and local vulnerability (see lVulnerable.tif) layers to identify places of high value for one or more representative terrestrial wildlife species that are relatively vulnerable to future development, and thus could represent priorities for land protection.

GIS Formats and Definitions

Geotiff raster (30 m cells); cell value = climate zone; ranges from 0-3, as follows:

0 = outside of any climate zone

1 = zone of contraction

2 = zone of expansion

3 = zone of persistence

6.4.17 Species climate response (***species*CR2080.tif**)

Description

This GIS product represents the climate response index for each of the 14 representative terrestrial wildlife species, provided as a separate data layer for each species. See the technical document on species (McGarigal et al 2017) for a detailed description of the climate response index and other species data products. Climate response is one of several different measures of landscape capability that reflect different decisions (or assumptions) regarding how to incorporate current versus future land use and climate changes. The climate response index is based on the current landscape capability (see *species*LC.tif) and predicted climate conditions in 2080 (averaged between RCP 4.5 and 8.5 scenarios). Specifically, this index is derived from the product of (1) current habitat conditions (reflecting current land use patterns) and (2) climate suitability in 2080. The climate response index is an attempt to emphasize areas that provide the best habitat and climate conditions today and where future climate conditions through 2080 are likely to remain suitable. The climate response index for the 14 representative terrestrial wildlife species was not used as an input to the building of terrestrial cores (see tCoreNet.shp and tCoreTiers.shp), but is provided as an overlay to help inform the design with respect to potential climate change impacts.

Considerations for Using Data Layer

These layers provide a seamless and continuous valuation of landscape capability based on the climate response index for each of the 14 representative terrestrial wildlife species. Importantly, these layers provide an ecological valuation of areas, both inside and outside designated core areas, and thus they can be used to identify places of high ecological value for one or more representative species outside of designated core areas that are also deserving of conservation attention. It is important to recognize that the climate response index provided here is in its raw scale form, and both the range and distribution of values varies dramatically among species, reflecting idiosyncrasies of each species' model. Consequently, the climate response index is not comparable across species. It can only be used separately for each species to evaluate the relative capability of one location against another to support that species. In addition, note that because black bear is a wide-ranging species, it does not have a climate suitability model, and thus it does not have a climate response index.

It is important to note that the climate response index is not an estimate of occupancy. It does not give the probability than a cell will be occupied by the species. Rather, it is an index of the relative capability of a site to support reproduction and survival of the focal species in a home range centered on that cell taking into consideration future climate suitability. Other suggestions include:

- Use in combination with the species current landscape capability index (see *species*LC.tif) to evaluate the change in each species' landscape capability due to predicted climate change.
- Use in combination with the secured lands layer (see secure.shp) to identify places with high ecological value for one or more representative terrestrial wildlife species

that remain unsecured from development, and thus could represent priorities for land protection.

- Use in combination with the integrated probability of development (see probDevelop.tif) and local vulnerability (see lVulnerable.tif) layers to identify places of high value for one or more representative terrestrial wildlife species that are relatively vulnerable to future development, and thus could represent priorities for land protection.

GIS Formats and Definitions

Geotiff raster (30 m cells); cell value = climate response index; ranges from 0 (developed) to a theoretical maximum of 1 (but the observed maximum is often much less).

6.4.18 Climate stress (climate.tif)

Description

This GIS product represents the climate stress metric, which is a measure of the estimated climate stress that may be exerted on a focal cell in 2080. Specifically, the climate stress metric reflects the 2080 departure from the current climate conditions that a cell may be exposed to in relation to its current climate niche breadth. Essentially, this metric measures the magnitude of climate change stress at the focal cell based on the climate niche of the corresponding ecological system (based on 2010) and the predicted change in climate (i.e., how much is the climate of the focal cell moving away from the climate niche of the corresponding ecological system) between 2010-2080 based on the average of two climate change scenarios: RCP 4.5 and 8.5. Cells where the predicted climate suitability in the future decreases (i.e., climate is becoming less suitable for that ecological system) are considered stressed, and the stress increases as the predicted climate becomes less suitable based on the ecological system's current climate niche model. Conversely, cells where the predicted climate suitability in the future increases (i.e., climate is improving for that ecological systems) are considered unstressed and assigned a value of zero.

Considerations for Using Data Layer

This layer provides a seamless and continuous index of climate stress independent of any designated core area network. Thus, this product can be used to identify places that are likely to experience climate stress in the future independent of designated core areas and any formal landscape conservation design. Other suggestions include:

- Use in combination with the sea level rise metric (see seaRise.tif) to identify places within coastal systems that are predicted to become doubly stressed by both climate change (via air temperature and precipitation) and sea level rise.
- Use in combination with the terrestrial core area network (see tCoreNet.shp and tCoreTiers.shp) to identify places within designated cores that are likely to face stress from climate stress in the future.

Precautions apply in using this dataset:

- Because climate niche models are developed and applied separately for each ecological system, it is best to consider climate stress separately for each ecological system. Abrupt changes in the absolute value of the climate stress metric between adjacent cells is likely to be due to changes in the underlying mapped ecological system; it does not reflect an abrupt change in the absolute climate stress. Consequently, it is best to use an ecological system mask when viewing the results.
- This layer reveals the magnitude of climate change stress; it does not reveal places where climate suitability is improving for a particular system.
- Although it does not affect the Connect the Connecticut LCD, it is worth noting that we excluded the climate stressor metric for ecological systems that range beyond the southern edge of the Northeast region to avoid building climate niche models on a small portion of the system's range.

GIS Formats and Definitions

Geotiff raster (30 m cells); cell value = climate stress index; ranges from 0 (no change or improving climate suitability between 2010-2080) to 1 (100% decrease in climate suitability between 2010-2080). Note, this is equivalent to (climateNiche2010.tif - climateNiche2080) × climateNiche2010, and set to zero if negative.

6.4.19 Sea level rise (seaRise.tif)

Description

This GIS product represents the sea level rise metric based on a model developed by Rob Theiler and associates at USGS Woods Hole, which is a measure of the probability of a focal cell being unable to adapt to predicted inundation by sea level rise. Specifically, whether a site gets inundated by salt water permanently due to sea level rise or intermittently via storm surges associated with sea level rise clearly determines whether an ecosystem can persist at a site and thus its ability to support a characteristic plant and animal community. USGS examined future sea-level rise impacts on the coastal landscape from Maine to Virginia by producing spatially-explicit, probabilistic predictions using sea-level projections (based on an average of two climate change scenarios: RCP 4.5 and 8.5), vertical land movement (due to glacial isostacy) rates, elevation, and land cover data. The data span the coastal zone from an elevation of 5 m inland to -10 m offshore, and are provided for the forecast year 2080.

In the layer provided here, the raw coastal response metric produced by USGS is scaled and inverted so that a cell with high probability of exhibiting a dynamic (or adaptive) response to sea level rise gets a zero (low stress) and a cell with low probability of exhibiting a dynamic response gets a value approaching 1 (high stress). In addition, we set all cells classified as sub-tidal to nodata for consistency with other products. To learn more about USGS's coastal response model, see Lentz et al. (2015).

Considerations for Using Data Layer

This layer provides a seamless and continuous index of the capacity of a site to adapt to sea level rise independent of any designated core area network. Thus, this product can be used to identify places that are likely to experience stress from sea level rise in the future independent of designated core areas and any formal landscape conservation design. Note, it is important to recognize that the layer provided here is not identical to the data product distributed by USGS because it has been scaled to range 0-1 and inverted so that larger values indicate greater stress -- for consistency with other stressor metrics. Other suggestions include:

- Use in combination with the climate stress metric (see climate.tif) to identify places within coastal systems that are predicted to become doubly stressed by both climate change (via air temperature and precipitation) and sea level rise.
- Use in combination with the terrestrial core area network (see tCoreNet.shp and tCoreTiers.shp) to identify places within designated cores that are likely to face stress from sea level rise in the future.

A precaution applies in using this dataset. Because sea level rise predictions at the 30 m cell level are highly dependent on the mapped elevation above sea level, the model predictions are highly pixelated due to noise in the digital elevation model. In addition, some sections of the coast do not have LIDAR-enhanced digital elevation models (DEM) in the National Elevation Dataset used here, and thus there is often a notable seam or abrupt change in the predicted coastal response that is an artifact of the DEM and not reflective of reality. Lastly, because the predicted coastal response is highly dependent on the mapped ecological system, errors in the ecological systems map translate into errors in the sea level rise metric at the 30 m cell level. For these and other reasons, this layer is best used as a general indication of where sea level rise is likely to cause problems; results at the cell level are not expected to be highly reliable.

GIS Formats and Definitions

Geotiff raster (30 m cells); cell value = sea level rise index; ranges from 0 (no sea level impacts expected between 2010-2080) to a theoretical maximum of 1 (100% probability of an inundation response between 2010-2080), although in practice the maximum is never realized.

6.4.20 Terrestrial road passage structure impacts (passages.shp)

Description

This GIS product represents opportunities to restore connectivity for terrestrial wildlife by building road passage structures. Specifically, this product tabulates the results of a model in which each 300 meter segment of road outside of urban centers, and excluding minor roads receiving relatively little traffic, has a passage structure installed (virtually). Next, we (virtually) reduce the value of the terrestrial barrier and traffic setting variables by 90% for the road cells associated with the passage structure, one at a time. The predicted improvement in connectedness from the passage structure is then recorded. The delta, or difference, in the connectedness score, before and after the installation of the passage structure for each cell within the affected neighborhood, is computed and multiplied by the average index of ecological integrity (*IEI*) of the affected neighborhood. The weighting by *IEI* emphasizes the potential ecological benefits of a road passage structure in an area that is otherwise in good condition but depressed by the road barrier.

Considerations for Using Data Layer

The restoration score (impact) is an index of the potential improvement in local connectedness to be achieved in places where it matters most -- where the current ecological integrity is not already severely degraded. Based on these restoration scores and the corresponding ranks, road segments can be prioritized for restoration. Note, these road passage restoration scores do not take into account other socio-economic considerations, such as the cost of a particular passage structure given local engineering considerations, which ultimately will determine the cost-benefit tradeoffs of any particular passage structure. Given the large number of potential road crossings, it may be useful to bin the road crossings into categories representing high, medium and low impact, or simply threshold the restoration (impact) score or its rank (see below) at some level to highlight the highest priority road crossing locations.

This layer may best be used to direct field surveys of road crossings of interest, during which complete and accurate assessments can be made. It can also be used in combination with the terrestrial core-connector network (see tCoreNet.shp and tCoreTiers.shp) to identify places where road crossing improvements and restoration may have the added benefit of improving the integrity of the designated terrestrial cores or improving the conductance of the connector.

Use of this layer should be done considering the scope and limitations of this dataset:

- Because of known data gaps and errors inherent in the source data, the data layer should be used cautiously. The roads data are known to include both errors of omission (i.e., missing roads) and commission (i.e., false roads). Terrestrial barrier scores are intended to reflect the physical and psychological impediments to wildlife movement across roads; the scores are assigned by road class (e.g., primary road, secondary road, or local road) based on the average physical characteristics of each road class, but they do not take into account local information (due to the lack of data) about the actual physical character of the road, nor do they account for other sources of physical barriers to wildlife movement such as Jersey barriers and fencing. The interpolated road traffic rates that are used to estimate wildlife mortality rates have substantial uncertainty (noisiness); thus, the modeled traffic rate may not accurately reflect the actual traffic rate on a road segment.

- The road passage restoration score represents the potential gain in local connectivity from installing a single wildlife passage structure without considering other potential nearby restoration actions to improve connectivity. Due to the computational challenges, we did not consider the benefit of installing multiple road passage structures in nearby locations. However, it is quite possible that there would be synergy in installing multiple structures, and this should be considered in prioritizing any location for restoration.
- The road passage restoration scores do not take into account the combined benefits of installing a terrestrial wildlife passage structure at a road-stream crossing, and thereby increase both terrestrial connectedness and aquatic connectedness with the same structure. Clearly, all other things being equal, placing a road passage structure at a close-by road-stream crossing makes sense since the potential gains in connectivity are much greater.

<u>GIS Formats and Definitions</u>

ESRI shapefile (points); including the following attributes for each point:

- FID = ESRI assigned unique number (which we do not use) for each point.
- Shape = ESRI assigned feature type = "point".
- passageid = unique number assigned to each road segment.
- x_coord= easting.
- y_coord= northing.
- base = sum of connectedness in the vicinity of the road segment under the current conditions without a passage structure.
- alt = sum of connectedness in the vicinity of the road segment after installing (virtually) the road passage structure.
- delta = (alt – base)*1000, the potential improvement in connectedness from installing the road passage structure.
- impact = delta weighted by the average Index of Ecological Integrity of the affected neighborhood.
- impactLn = natural log of impact.
- rank = rank of impact (out of 25,989 passages).
- RANK_LBL = classification of terrestrial road passage locations based on "rank" as follows:
    - High impact = rank 1-500

- Medium impact = rank 501-1,500
- Low impact = rank 1,501-3,500
- Very low impact = rank 3,501-25,989

6.4.21 Lotic (river and stream) cores (loticCores.shp)

Description

This GIS product represents the set of lotic (river and stream) **core areas**. In combination with the lentic (lake and pond) cores (see lenticCores.shp) and terrestrial cores and connectors (see tCoreNet.shp and tCoreTiers.shp), they spatially represent the ecological network derived from the Connect the Connecticut LCD project. The network is designed to provide strategic guidance for conserving natural areas, and the fish, wildlife, and other components of biodiversity that they support, within the Connecticut River watershed.

Core areas serve as the foundation of the conservation design. They reflect decisions by the Connect the Connecticut LCD planning team about the highest priority areas for sustaining the long-term ecological values of the watershed, based on currently available, regional-scale information. Lotic cores represent the following:

1) streams of relatively high **ecological integrity** across all lotic (i.e., riverine) ecosystem types, emphasizing rivers and streams that are relatively intact (i.e., free from human modifications and disturbance locally and within the upstream catchments) and resilient to environmental changes (e.g., climate change). Integrity has the potential to remain high, both in the short-term due to the connectivity to similar natural environments within the riverine network, and in the long-term for headwater streams due to the relative insensitivity of stream temperature to air temperature changes;
2) headwater streams of relatively high current habitat value (i.e., **landscape capability**) for **brook trout**, emphasizing streams that provide the best habitat conditions under current climate conditions; and
3) Large and medium rivers that provide habitat for **anadromous fish**, including the portions of the mainstem and major tributaries of the Connecticut River from the mouth of the river upstream to the limit of passability for American shad, blueback herring, shortnose sturgeon, alewife, and sea lamprey.

Core areas are built from focal areas with high value based on one or more of the attributes listed above. These "seed areas" are expanded upstream and downstream to include areas that provide additional ecological value and resilience to long-term change and to encompass a minimum of 1 km in stream length. Consequently, the cores may include sections of lower-valued streams and extend beyond road-stream crossings; however, they do not extend past dams.shp. Collectively, lotic core areas encompass 28% of the total stream length in the CTR watershed, as decided by the partnership. A total of 523 lotic core areas have been identified, ranging in stream length from 1 to 442 km, with an average stream length of 16 km.

Considerations for Using Data Layer

This set of lotic core areas can serve as a starting point that can be used in combination with other sources of information to direct specific management and conservation actions or decisions. Although the lotic cores are presented as discrete entities, it is important to recognize that their boundaries are, in fact, "fuzzy" and are best interpreted as general places to focus attention. Lotic cores are not the only places of high ecological value within the riverine network deserving of conservation attention. Suggestions for combining the lotic core network with other sources of information include:

- Use in combination with the foundational data layers to identify additional areas of high ecological value. Layers to consider include: 1) aquatic ecosystem-based core area selection index (see aSelectIndex.tif), 2) index of ecological integrity (see iei.tif), 3) USGS headwaters stream temperature tolerance index (see streamTolerance.tif), and 4) brook trout current probability of occupancy (see brookTroutLc.shp).
- Use in combination with landscape capability layers for other stream-dependent representative species, such as Louisiana waterthrush and wood turtle (see *species*LC.tif), to identify core areas with additional ecological value.
- Use the aquatic buffers layer (see aquaticBuffers.tif) to identify places predicted to have a strong influence on the ecological integrity of the lotic cores; i.e., places where anthropogenic disturbances may adversely affect the lotic cores through watershed processes such as nutrification and sedimentation.
- Use in combination with the dam removal impacts layer (see dams.shp) and culvert upgrade impacts layer (see culverts.shp) to identify places where the integrity of the aquatic cores is limited by dams and/or culverts, and thus may represent priorities for restoration.

Use of the aquatic core network should be done considering the scope and limitations of this dataset:

- For convenience, the size of each core area is expressed in terms of stream length, but note that the core 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.tif).
- It is critical to remember that lotic cores are in large part derived from the index of ecological integrity (see iei.tif), which is scaled from relatively low to high separately for each ecological system within each HUC6 watershed. Consequently, the best areas available for each ecological system is captured by the lotic cores. However, this does not mean that the areas selected are always unimpaired. For example, the best available area for a cool, medium-sized river may be quite degraded since these are areas that tend to be developed if not otherwise in conservation ownership.

GIS Formats and Definitions

ESRI shapefile (polylines); including the following attributes for each polyline. Note, for convenience, this attribute table is also included as a separate table (aCoreStats.csv):

- FID = ESRI assigned unique number (which we do not use) for each polygon.
- Shape = ESRI assigned feature type = "polyline".
- coreID = unique number (ID) assigned to the core. Lotic cores contiguous with or connected by lentic cores are considered to be a single lotic core and assigned a single coreID.
- type = indicator designating the polyline as "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 ecosystems 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.
- scenario = internal use (file directory) to track the specific core area scenario.

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 lotic core (see files in the aCoreStats 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 ecosystem 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).
- scenario = internal use (file directory) to track the specific core area scenario.

6.4.22 Lotic (river and stream) core areas: ecosystem summary (aCoreEcoSum.csv)

Description

This table provides a quantitative summary of the ecosystem composition of the lotic (river and stream) cores relative to the riverine aquascape. The table contains a single row for each ecological system occurring in the aquascape and the following columns (fields):

- ecosystem = ecological system. Note, wetland and lentic (lake and pond) systems are often included, as often lotic cores extend along stream centerlines through these systems.
- formation = ecological formation, consisting of closely related ecosystems.
- landscapeKm = total approximate stream length (km) of the system in the aquascape.
- coreKm = total approximate stream length (km) of the system in the lotic cores.
- percentLength = percentage of the system's total approximate stream length in the aquascape occurring in the lotic cores = coreKm/landscapeKm×100.
- percentSi = percentage of the system's total selection index across the aquascape occurring in the lotic cores; i.e., what percent of the system's cumulative selection index across the entire aquascape is encompassed by the lotic cores.

6.4.23 Lentic (lake and pond) cores (lenticCores.shp)

Description

This GIS product represents the set of lentic **core areas**. In combination with the lotic cores (see loticCores.shp) and terrestrial cores and connectors (see tCoreNet.shp and tCoreTiers.shp), they spatially represent the ecological network derived from the Connect the Connecticut LCD project. The network is designed to provide strategic guidance for conservation of natural areas, and the fish, wildlife, and other components of biodiversity that they support, within the Connecticut River watershed.

Core areas serve as the foundation of the conservation design. They reflect decisions by the CT River LCD planning team about the highest priority areas for sustaining the long-term ecological values of the watershed, based on currently available, regional-scale information. Lentic cores represent the following:

1) lakes and ponds of relatively high **ecological integrity**, emphasizing lakes and ponds that are relatively intact (i.e., free from human modifications and disturbance locally and within the water body catchment) and resilient to environmental changes (e.g., climate change) due to their size and connectivity to similar natural environments.

Lentic core areas are built from focal areas in ponds and lakes with high ecological integrity. These "seed areas" are expanded to include the entire water body in order to create logical conservation units. Consequently, the larger lentic cores may include partially-developed shorelines. Collectively, lentic core areas encompass 27% of the total area of ponds and lakes in the CTR watershed, as decided by the partnership. Note, Quabbin Reservoir, which itself comprises 20% of the total area of ponds and lakes in the CTR watershed, was not included as a lentic core in this scenario. A total of 1,206 lentic core areas have been identified, ranging in size from 0.06 to 1,323 ha, with an average size of 11.7 ha.

Considerations for Using Data Layer

The lentic cores are based on a simple classification of lentic systems into ponds (<8 ha) and lakes (≥8 ha) due to the lack of a more detailed classification at the time of this analysis. Thus, they do not account for other environmental factors, such as depth, trophic status, and water chemistry that can influence the composition, structure and function of lentic systems. In addition, there are no representative species included for lentic systems to complement the ecological integrity assessment. As such, the selection of lentic cores should be viewed as very preliminary and as an interim solution until a more detailed classification and assessment of lentic systems can be completed. Other suggestions include:

- Use in combination with the index of ecological integrity (see iei.tif) to identify other ponds and lakes with high ecological value.
- Use in combination with landscape capability layers for other lentic-associated representative species, such as moose and wood duck (see *species*LC.tif), to further understand the potential ecological value of the lakes and ponds.

- Use in combination with the lotic cores (see loticCores.shp) to identify contiguous networks of high-valued lentic and lotic systems; i.e., places where lentic cores are connected to lotic cores.

GIS Formats and Definitions

ESRI shapefile (polygons); including the following attributes 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 assigned to each core. Note, each lentic core is assigned a unique coreID regardless of whether it is contiguous with a lotic core.
- area = area (hectares) of the corresponding core.

6.4.24 Brook trout current probability of occurrence (brookTroutLc.shp)

Description

This GIS product represents the probability of occurrence of brook trout in headwater creeks based on current habitat and climate conditions. Brook trout are a representative species for cool/cold headwater creeks. This layer was derived from a model developed by Ben Letcher and associates at the USGS Conte Anadromous Fish Lab. Specifically, this index represents the species' current probability of occurrence, presented as an integerized range from 0 (low=0% probability of occurrence) to 100 (high=100 % probability of occurrence). The brook trout probability of occurrence model is applied only to headwater creeks. Note, the brook trout current probability of occurrence is analogous to the landscape capability index developed for representative terrestrial wildlife species (see *species*LC.tif); it represents the suitability of habitat and climate conditions today. This index is an input into the selection of core areas (see loticCores.shp) in headwater creeks along with the Index of Ecological Integrity (see iei.tif).

Considerations for Using Data Layer

This layer provides a seamless and continuous valuation of current habitat and climate suitability for brook trout in headwater creeks. Importantly, this layer provides an ecological valuation of areas both inside and outside designated lotic cores, and thus it can be used to identify places of high value for brook trout outside of designated lotic cores that are also deserving of conservation attention. It is important to recognize that the book trout selection index as distributed here is not scaled by HUC6 watershed like some of the other products used to create cores; nevertheless, the highest-valued headwater creeks within each HUC6 watershed are selected to complement what has already selected from the ecosystem-based approach to create the final set of lotic cores. Furthermore, the brook trout occupancy model is applied at the scale of small catchments (rather than 30m x 30m cells), and thus this layer has a coarser resolution than the analogous landscape capability indices developed for the representative terrestrial wildlife species.

GIS Formats and Definitions

ESRI shapefile (polylines); including the following attributes for each polyline:

- FID = ESRI assigned unique number for each polyline.
- Shape = ESRI assigned feature type = "polyline".
- index = value of the brook trout current probability of occurrence; range 0-100.

6.4.25 Anadromous fish index (anadromous.shp)

Description

This GIS product identifies large and medium rivers within the Connecticut River watershed that provide habitat for five anadromous fish species: American shad, blueback herring, shortnose sturgeon, alewife, and sea lamprey. Habitat includes the mainstem and major tributaries of the Connecticut River from the mouth of the river upstream to the limit of passability for these species. This layer is derived from a product entitled "diadromous fish habitat in the Connecticut River watershed" developed in 2010 by The Nature Conservancy, Connecticut River Basin Program. Digital data updates were performed by Renee Farnsworth working with USFWS personnel through the NALCC. Specifically, river segments identified and known to be accessible to the five species listed above were extracted from the diadromous data layer, and each river segment was assigned a score from 1-5 indicating the number of species having known access to the segment. In addition, each segment was scored as “free-flowing,” “impounded” or “unknown.” All river sections with a score >0 for the five focal species are included in the final set of lotic cores (see loticCores.shp).

Considerations for Using Data Layer

This layer provides a seamless and continuous indication of river accessibility for the five anadromous fish species and an indication of whether each section is free-flowing or not. Importantly, it is not an indication of habitat suitability for any life stage for any of the focal species, as it does not account for habitat characteristics such as flow, water temperature, and substrate. Moreover, it is not a comprehensive indicator of riverine accessibility for all diadromous species, as there are other diadromous species that access other portions of the riverine network.

GIS Formats and Definitions

ESRI shapefile (polylines); including the following attributes for each polyline:

- FID = ESRI assigned unique number for each polyline.
- Shape = ESRI assigned feature type = "polyline".
- riverFlow = "free flowing", "impoundment", or NA.
- numSpp = number of focal anadromous.shp fish species having access to the segment; range 1-5.

6.4.26 Aquatic ecosystem-based core area selection index (aSelectionIndex.tif)

Description

This GIS product represents the selection index used to create aquatic ecosystem-based cores. The selection index is a continuous surface in which every cell is assigned a value (0-1) based on its relative ecological integrity within each HUC6 watershed. Specifically, the selection index is equal to the index of ecological integrity (see iei.tif), except in headwater creeks where it is the average of *IEI* and USGS's stream temperature tolerance index (see streamTolerance.tif). Aquatic core areas are created, in part, by choosing cells above a certain index value and spreading from these "seed areas" through adjacent aquatic cells to build larger, buffered cores of relatively high ecological value.

Considerations for Using Data Layer

This layer provides a seamless and continuous valuation of ecological integrity based on regionally available and consistent spatial data that reflects decisions by the planning team. Importantly, this layer provides an ecological valuation of areas both inside and outside designated core areas, and thus it can be used to identify places of high ecological value outside of designated core areas that are also deserving of conservation attention. The primary conservation application of this data layer is likely to be in conjunction with the aquatic core network; see the descriptions for the lotic (loticCores.shp) and lentic cores (lenticCores.shp) for application suggestions as well as additional usage considerations.

As an intermediate product in the development of tCoreNet.shp and tCoreTiers.shp, this product also is useful in understanding how *IEI* and stream temperature tolerance were integrated and how the core areas were generated.

It is important to recognize that the selection index is scaled by HUC6 watershed so as to indicate the relative ecological integrity value within each HUC6 watershed.

GIS Formats and Definitions

Geotiff raster (30 m cells); cell value = aquatic core area selection index; ranges from near 0 (low ecological value) to 1 (maximum ecological value) for aquatic cells (including centerlines through wetlands) and is ‘nodata’ elsewhere.

6.4.27 Aquatic buffers (aquaticBuffers.tif)

Description

This GIS product represents **buffers** around the aquatic (lotic and lentic) cores. Aquatic buffers spatially represent the areas estimated to have a strong influence on the integrity of the aquatic cores based on watershed processes. Specifically, the buffers represent areas hydrologically connected to the aquatic cores through surface runoff and instream flow processes, such that anthropogenic stressors within the buffers are likely to adversely impact the integrity of the aquatic cores. Importantly, the buffers represent places upstream and upslope of the cores where human activities such as development, and point and non-point pollution, etc., may have a strong impact on the ecological condition of the cores. Unlike the cores, therefore, the buffers do not necessarily represent areas of high ecological integrity.

Buffers are established for all aquatic cores (both lotic and lentic) based on a time-of-flow model that extends as a gradient upstream and upslope from the cores, varying in distance depending on slope and land cover. Areas immediately upstream and upslope of the cores have the greatest influence (i.e., shortest time-of-flow). The influence decreases much faster across land than water so that the buffer typically extends much farther upstream than upslope from the core. Thus, the buffer does not represent a discrete zone distinguishing "inside" from "outside" of the buffer. Rather, it represents a graduated zone of influence in which cells upstream and closer to the core have greater influence. Cells in the upland and farther from the stream, especially on flat slopes with forest cover, have less influence. In addition, the graduated zone of influence increases in size with decreasing stream size. The zone of influence on larger rivers tends to be relatively narrow, whereas the zone of influence on headwater creeks tends to be wider and often encompasses the entire upstream catchment.

Considerations for Using Data Layer

Overall, aquatic buffers are best interpreted as a way to focus attention on generally where in the watershed human disturbance will likely have the greatest influence on the integrity of the aquatic cores. Although the buffers are presented as an absolute gradient of decreasing influence with increasing distance upstream and upslope of the cores, it is important to recognize that the gradient depicted is relative. Moreover, the gradient is thresholded to extend progressively greater distances upslope on increasingly smaller streams. Because this graduated zone of influence can be difficult to visualize and interpret, it may be more useful to threshold the gradient at one or more levels to depict tiered zones of influence that are more akin to conventional fixed-width buffers. A suggestion for combining this dataset with another dataset in the package is:

- Use in combination with the probability of development layer (see probDevelop.tif) to identify places where development is both likely and predicted to have a strong influence on the ecological integrity of the aquatic cores, and thus may represent priorities for land protection and/or management.

GIS Formats and Definitions

Geotiff raster (30 m cells); cell value = the magnitude of influence based on the time-of-flow model; values range from 1 (maximum influence) at the core to zero 0 (no influence) at the cell with the least influence (i.e., furthest upstream and upslope of the core).

6.4.28 Aquatic vulnerability to development (aVulnerable.tif)

Description

This GIS product represents the aquatic vulnerability to development index, which reflects the likelihood of development occurring in places in the uplands that are likely to impact the aquatic cores. Specifically, aquatic vulnerability is the product of the aquatic buffers, which represent the areas estimated to have a strong influence on the integrity of the aquatic cores based on watershed processes (see aquaticBuffers.tif), and the integrated future probability of development between 2010-2080 (see probDevelop.tif). Cells with relatively low watershed influence on the aquatic cores have low vulnerability regardless of their risk of development, since the integrity of the cores will not be degraded too much if they get developed. Aquatic vulnerability is greatest where there is high watershed influence; i.e., uplands in close proximity to the cores as the water flows, and where there is also relatively high probability of development in the future.

Considerations for Using Data Layer

This layer provides a seamless and continuous representation of the vulnerability to development of cells that are especially important to the integrity of the designated aquatic cores based on watershed processes. The index is best used in a relative manner to compare values from one location to another. Importantly, this index is contingent upon the a priori designation of core areas and thus is primarily useful in the context of landscape conservation design. In particular, this layer may be especially useful for identifying places within the landscape in close proximity (as the water flows) to the designated aquatic cores that are highly vulnerable to development.

It is important to recognize that due to the intrinsically highly connected nature of aquatic systems, and riverine systems in particular, that adverse human land uses anywhere in the entire watershed will impact the integrity of the aquatic environment and the designated aquatic cores within. This layer is intended to highlight where those adverse land uses will likely have the greatest affect on the designated aquatic cores.

Precautions outlined for the integrated probability of development layer (see probDevelop.tif) also apply to this layer. Consequently, this layer is best used as a general indication of where the uplands are most vulnerable to development impacts on the designated aquatic cores.

GIS Formats and Definitions

Geotiff raster (30 m cells); cell value = aquatic vulnerability index; ranges from 0 (e.g., secured land, water, already developed, outside the watershed buffer zone of the designated aquatic cores) to <1.

6.4.29 Dam removal effects (dams.shp)

Description

This GIS product represents potential opportunities to restore aquatic connectivity by removing dams. Specifically, this product tabulates the results of a model in which each dam is systematically removed (virtually), one at a time, and the predicted improvement in aquatic connectedness from the removal is recorded. The delta, or difference, in the aquatic connectedness score, before and after the bridge removal for each cell within the affected neighborhood, is computed and multiplied by the average index of ecological integrity (see iei.tif) of the affected neighborhood. Therefore, improvements are scored higher where conditions are not highly degraded and dam removal may have greater ecological benefits.

Considerations for Using Data Layer

The dam removal effect score (effect) is an index of the potential improvement in local aquatic connectedness to be achieved in places where it matters most -- where the current ecological integrity is not already severely degraded. Based on these scores and the corresponding ranks, dams can be prioritized for restoration.

Importantly, these scores do not quantify benefits to anadromous fish from dam removal associated with migratory habitat; users interested in tools that address anadromous fish benefits may wish to investigate other products such as the Northeast Aquatic Connectivity Project led by The Nature Conservancy along with Northeast state fish and wildlife agencies.

Also, these scores do not take into account other socio-economic considerations, such as whether the impoundment is a public drinking water supply, which ultimately will determine the cost-benefit tradeoffs of any particular dam removal. Given the large number of dams, it may be useful to bin the dams into categories representing high, medium, low, and very low effect (as we have done in the rank_lbl attribute of the shapefile, see below), or simply threshold the score or its rank (see below) at some level to highlight the highest priority dams.

This layer may best be used to direct field surveys of dams of interest, during which complete and accurate assessments can be made. It can also be used in combination with the lotic (loticCores.shp) and lentic cores (lenticCores.shp) to identify places where dam removal may have the added benefit of improving the integrity of the designated aquatic cores.

Use of this layer should be done considering the scope and limitations of this dataset:

- The actual restoration potential of a dam may be quite different than the modeled estimate. For example, unmapped dams certainly exist and affect the real-world aquatic connectivity not reflected in our scores. Incomplete and/or inaccurate data on dam height and other attributes (such as the partial breach of the dam) result in incorrect estimates of aquatic passability. Also, for many dams with incomplete data, especially the smaller dams, we are forced to make an assumption about dam height and also to assume that the dam has not been breached. In addition, unreliability of data on fish passage structures forced us to omit this factor from consideration in the model. Because of these known data gaps and errors inherent in the source data, the data layer should be used cautiously.

- The dam removal effect score represents the potential gain in local aquatic connectivity from removing each dam without considering other natural or anthropogenic barriers (e.g., waterfalls, culverts) or potential nearby restoration actions to improve connectivity. Of course, dams often do not exist as isolated barriers. The score of a dam is dependent to some extent on the degree to which natural barriers and road-stream crossings nearby on the same waterway are also acting as barriers to movement. For example, removal of a dam will result in less improvement in connectivity if there is an undersized culvert a short distance from the dam than if no movement barriers are nearby. The undersized culvert will continue to depress aquatic connectedness even after the dam is removed. Unfortunately, evaluating the combined (and possibly synergistic) effect of multiple restoration activities, such as removing the dam and upgrading the nearby undersized culverts, is computationally beyond the scope of this project, but should be taken into account when prioritizing dam restoration opportunities in practice.

<u>GIS Formats and Definitions</u>

ESRI shapefile (points); including the following attributes for each point:

- FID = ESRI assigned unique number (which we do not use) for each point.
- Shape = ESRI assigned feature type = "point".
- damid = unique number assigned to each dam.
- x_coord= easting.
- y_coord= northing.
- dam = name of dam.
- damheight = structural height of dam (m).
- base = sum of aquatic connectedness in vicinity in current condition.
- alt = sum of aquatic connectedness after removing (virtually) the dam.
- delta = (alt – base)*1000, the potential improvement in aquatic connectedness from removing (virtually) the dam.
- rank = rank of effect (out of 1,365 dams).
- rank_lbl = classification of dams based on "rank" as follows:
  - High effect = rank 1-50
  - Medium effect = rank 51-150
  - Low effect = rank 151-350
  - Very low effect = rank 351-1,365

- effect = delta weighted by the average Index of Ecological Integrity of the affected neighborhood.
- effect_ln = natural log of effect.

6.4.30 Culvert upgrade impacts (culverts.shp)

Description

This GIS product represents opportunities to restore aquatic connectivity by upgrading culverts. Specifically, this product tabulates the results of a model in which each road-stream crossing is systematically upgraded (virtually) to a bridge having the minimum aquatic barrier score, one at a time, and the predicted improvement in aquatic connectedness from the upgrade is recorded. The delta, or difference, in the aquatic connectedness score, before and after the crossing upgrade for each cell within the affected neighborhood, is computed and multiplied by the average index of ecological integrity (see iei.tif) of the affected neighborhood. The weighting by *IEI* emphasizes the potential ecological benefits of a crossing upgrade in an area that is otherwise in good condition but depressed by the crossing structure. Conversely, the score is lower where conditions are already so degraded that an upgrade would not improve local ecosystem conditions.

Considerations for Using Data Layer

The culvert upgrade impact score (impact) is an index of the potential improvement in local aquatic connectedness to be achieved in places where it matters most -- where the current ecological integrity is not already severely degraded. Based on these scores and the corresponding ranks, road-stream crossings can be prioritized for restoration. Note, these scores do not take into account other socio-economic considerations, such as the cost of a particular upgrade given local engineering considerations, that ultimately will determine the cost-benefit tradeoffs of any particular crossing upgrade. Given the large number of road-stream crossings, it may be useful to bin the crossings into categories representing high, medium and low impact, or simply threshold the score or its rank (see below) at some level to highlight the highest priority crossings.

This layer may best be used to direct field surveys of road-stream crossing of interest, during which complete and accurate assessments can be made. It can also be used in combination with the lotic (loticCores.shp) and lentic cores (lenticCores.shp) to identify places where crossing improvement may have the added benefit of improving the integrity of the designated aquatic cores.

Use of this layer should be done considering the scope and limitations of this dataset:

- The actual restoration potential of a road-stream crossing may be quite different than the modeled estimate, especially in cases where the model predicts the crossing to be a bridge when in fact it is a culvert. Perhaps the biggest concern is the lack of information about aquatic passability for most road-stream crossings. Less than 1% of the road-stream crossings within the Northeast region have been assessed in the field. We use this field-based assessment where it exists (www.streamcontinuity.org), but for the vast majority of road-stream crossings that have not been assessed in the field, we are obliged to predict whether the crossing is a culvert or bridge and then assign the mean passability score for surveyed culverts or bridges, accordingly. Another example of potential errors is the existence of “phantom” road-stream crossings erroneously generated by the intersection of roads and streams data in GIS. Because of these known data gaps and errors inherent in the source data, the data layer should be used cautiously.

- The culvert upgrade impact score represents the potential gain in local aquatic connectivity from upgrading each road-stream crossing to a bridge with the minimum aquatic barrier score. This does not consider other natural or anthropogenic barriers (e.g., waterfalls, culverts) or potential nearby restoration actions to improve connectivity. Of course, road-stream crossing often do not exist as isolated barriers. The score of a road-stream crossing is dependent to some extent on the degree to which natural barriers and other road-stream crossings and dams nearby on the same waterway are acting as barriers to movement. For example, a culvert upgrade will result in less improvement in connectivity if there is a dam or an undersized culvert a short distance from the crossing, compared to that same crossing without other movement barriers nearby. Unfortunately, evaluating the combined (and possibly synergistic) effect of multiple restoration activities, such as removing the nearby dam and upgrading the nearby undersized culverts, is computationally beyond the scope of this project. However, this should be taken into account when prioritizing culvert restoration opportunities in practice.
- For the road-stream crossings assessed in the field, we use an algorithm developed by the River and Stream Continuity Partnership (2010, www.streamcontinuity.org) for scoring crossing structures according to the degree of obstruction they pose to aquatic organisms. Of course, as with any such algorithm, it cannot deal effectively with the myriad species-specific constraints on passability that affect the entire aquatic community. Thus, the score must be viewed as a generalized index on aquatic passability and cannot be used to infer passability for any single species.

GIS Formats and Definitions

ESRI shapefile (points); including the following attributes for each point:

- FID = ESRI assigned unique number (which we do not use) for each point.
- Shape = ESRI assigned feature type = "point".
- crossingid = unique number assigned to each crossing.
- x_coord= easting.
- y_coord= northing.
- group = unique number for paired/grouped crossings, for example with divided highways.
- groupsize = number of crossings in the group (usually 1, sometimes 2, rarely more).
- anysurvey = 1 if any of the crossings in the group were field surveyed.
- surveyed = 1 if the focal crossing was field surveyed.
- base = sum of aquatic connectedness in the vicinity of the crossing with the crossing structure in its current condition.

- alt = sum of aquatic connectedness in the vicinity of the crossing after upgrading (virtually) the culvert.
- delta = (alt – base)*1000, the potential improvement in aquatic connectedness from upgrading (virtually) the culvert.
- impact = delta weighted by the average Index of Ecological Integrity of the affected neighborhood.
- impact_LN = natural log of impact.
- aquatic = aquatic passability score derived either from field measurements (if surveyed) or set equal to the mean score for surveyed culverts.shp or bridges (depending on whether it is predicted to be a culvert or bridge).
- bridge = indicator of whether crossing is observed/predicted to be a culvert = 0 or bridge =1.
- rank = rank of impact (out of 27,141 crossings).
- RANK_LBL = classification of road-stream crossings based on "rank" as follows:
    - High impact = rank 1-500
    - Medium impact = rank 501-1,500
    - Low impact = rank 1,501-3,500
    - Very low impact = rank 3,501-27,141

6.4.31 Brook trout climate response (brookTroutCR2080.shp)

Description

This GIS product represents the climate response index for brook trout in headwater creeks based on current habitat and current and future climate conditions. Brook trout are a representative species for cool/cold headwater creeks. This layer was derived from a model developed by Ben Letcher and associates at the USGS Conte Anadromous.shp Fish Lab. Specifically, this index is the average of the current probability of occurrence (see brookTroutLc.shp) and the future probability of occurrence in 2080 (averaged over two future climate scenarios: RCP 4.5 and 8.5), presented as an integerized range from 0 (low) to 100 (high) probability of persistent occurrence. The brook trout climate response is applied only to headwater creeks, as used in the probability of occurrence model. Note, the brook trout climate response index, as computed, is analogous to the climate response index (see *species*CR2080) developed for representative terrestrial wildlife species; it represents the suitability of habitat and climate conditions today and where future climate conditions are likely to remain suitable for brook trout. This index is an input into the selection of core areas (see loticCores.shp) in headwater creeks along with the Index of Ecological Integrity (see iei.tif).

Considerations for Using Data Layer

This layer provides a seamless and continuous valuation of current habitat and persistent climate suitability for brook trout in headwater creeks. Importantly, this layer provides an ecological valuation of areas both inside and outside designated lotic cores, and thus it can be used to identify places of high value for brook trout outside of designated lotic cores that are also deserving of conservation attention. It is important to recognize that the book trout climate response index as distributed here is not scaled by HUC6 watershed like some of the other products used to create cores; nevertheless, the highest-valued headwater creeks within each HUC6 watershed are selected to complement what has already selected from the ecosystem-based approach to create the final set of lotic cores. Furthermore, the brook trout occupancy model is applied at the scale of small catchments (rather than 30m x 30m cells), and thus this layer has a coarser resolution than the analogous climate response indices developed for the representative terrestrial wildlife species.

GIS Formats and Definitions

ESRI shapefile (polylines); including the following attributes for each polyline:

- FID = ESRI assigned unique number for each polyline.
- Shape = ESRI assigned feature type = "polyline".
- index = value of the brook trout selection index; range 0-100.

6.4.32 Ecological systems map (DSLland.tif)

Description

This GIS product represents a version of the ecological systems map (ESM+), originally derived by TNC and modified for the Designing Sustainable Landscapes (DSL) project. Major modifications include improvements to the classification and mapping of roads, development, streams, and coastal wetlands. In this map, ecological systems are hierarchically organized such that at the finest level cells are classified into ecological systems (or ecosystems), which are aggregated into formations. Thus, the map can be symbolized to depict the distribution of ecological units at either the ecosystem or formation level.

Considerations for Using Data Layer

This layer is the foundation for much of the ecological assessment in the DSL project. Indeed, the derived DSL products, such as the terrestrial and aquatic core area networks (see tCoreNet.shp, tCoreTiers.shp, loticCores.shp and lenticCores.shp), cannot be understood without reference to this layer. In particular, the weighted index of ecological integrity (see iei.tif), which forms an important basis for the selection of terrestrial core areas, is scaled by ecological system as depicted in this layer. Similarly, the representative species landscape capability indices (see *species*LC.tif), which also form an important basis for the selection of terrestrial core areas, universally use ecological systems in the habitat capability component of the individual species' models. Ultimately, an important objective of the terrestrial and aquatic core area networks is to identify an integral network of places that include redundant representation of all ecological systems, which are as delineated by this layer.

GIS Formats and Definitions

Geotiff raster (30 m cells); attributed as follows:

- OID = ESRI assigned unique number (meaningless).
- Value = unique number assigned to each ecological system.
- Count = number of cells of the corresponding ecological system.
- ecosystem = ecological system (note, ecosystem here is based on the field named 'sumgroupname' in the ArcGIS raster distributed by TNC named 'syst_ne130930' , or the field named 'habitat' in the ArcGIS raster distributed by TNC named 'syst_ne141611').
- formation = ecological formation, consisting of closely related ecosystems.
- index = arbitrary number assigned for internal use to facilitate sorting of ecological systems.

6.4.33 TNC geophysical setting (geoSetting.tif)

Description

This GIS product represents TNC geophysical settings as used in the TNC terrestrial resiliency index (see tResiliency.tif), which is used in the terrestrial ecosystem-based core area selection index and thus the selection of the terrestrial core areas. To learn more about this product and TNC's resiliency index, see: Resiliency page at TNC's Conservation Gateway.

Considerations for Using Data Layer

This layer is the basis for scaling the TNC terrestrial resiliency index. Specifically, the resiliency index is (quantile) scaled within each geophysical setting class within each HUC6 watershed. To better understand the scaled resiliency index as used in the terrestrial ecosystem-based core area selection index, this layer can be used as a mask to view one geophysical setting class at a time.

GIS Formats and Definitions

Geotiff raster (30 m cells); attributed as follows:

- OID = ESRI assigned unique number (meaningless).
- Value = unique number assigned to each geophysical setting class.
- Count = number of cells of the corresponding geophysical setting class.
- setting = geophysical setting class (see TNC documentation, link above, for descriptions of each setting class).

6.4.34 StreamClass.shp (streamClass.shp)

Description

This GIS product represents a classified version of the stream network in which streams are classified and mapped along centerlines, even through wetlands and lentic systems, to provide a contiguous, classified stream network. This product differs from the ecological systems map (see DSLland.tif) in that this layer 1) is a vector versus raster representation of streams (i.e., lines versus cells) and 2) has streams classified as lotic systems throughout, whereas wetlands and lentic systems take precedence in the ecological systems map. This layer is provided for the sole purpose of facilitating the display (in GIS) and mapping of landscape design products, as it is much easier to visualize vector features than raster features for narrow linear features such as streams.

Considerations for Using Data Layer

This layer is for the purpose of displaying the contiguous, linear stream network. Note, however, that centerlines through wetlands and lentic systems are evaluated as wetland and lentic systems, respectively, in the ecological assessment that forms the basis for the landscape conservation design. It may be useful in combination with the aquatic core area selection index, brook trout selection index, and USGS stream temperature tolerance index to better understand the ecological setting (i.e., lotic system) of any particular place that is evaluated with these additional products.

GIS Formats and Definitions

ESRI shapefile (polylines); attributed as follows:

- FID = ESRI assigned unique number to each line segment.
- Shape = ESRI assigned feature type = "polyline".
- class = unique number assigned to each ecological system.
- descrip = ecological system name.

6.4.35 Roads (roads.shp)

Description

This GIS product represents an attributed road network. Each road segment is attributed with a variety of attributes from the Open Street Map data source. Here, the attribute ROADCLASS is our main interest (see below), which can be symbolized meaningfully and then displayed as an overlay on the other landscape design products to enhance the interpretation.

Considerations for Using Data Layer

This layer is included for the purpose of displaying the road network as an overlay to the other landscape design products.

GIS Formats and Definitions

ESRI shapefile (polylines); with many attributes, but here we are considering the single attribute ROADCLASS with the following values:

1 = Motorway
2 = Primary road
3 = Secondary road
4 = Tertiary road
5 = Local road
6 = Track

6.4.36 Secured lands (secure.shp)

Description

This GIS product represents TNC's secured lands data (inclusive of all GAP status levels: 1-4, 9, and 39), which strives to include all legally or for all practical purposes permanently protected lands in the eastern 18 U.S. states. It is compiled annually from over sixty sources. For the most part, it is a combination of public land information maintained by each state and private conservation land information compiled by TNC's state field offices. TNC staff in each state office compile the dataset for their state, assign the securement status to each tract, and fill out the other standard fields (e.g., designation, acres, ownership type). The completed state datasets are then compiled by the regional science office and quality checked for consistency and discrepancies. Each year, the data set is posted for public use and submitted to the Protected Areas Database U.S. (PAD US) and National Conservation Easement database to become part of the national datasets of protected lands. The layer provided here is a snapshot of the dataset as of 2011.

Considerations for Using Data Layer

This layer is provided here in its original form for convenience to be used as an overlay for the other landscape conservation design products. In particular, the secured lands layer can be overlaid on the terrestrial core-connector network to determine what has already been protected and what still needs protection. Note that this layer is current through 2011, and therefore, may omit parcels protected more recently. Updates to this data layer can be found on the Secured Lands page at TNC's Conservation Gateway. In addition, as a rule, open water is not represented in this layer as secured, which may reflect the real-world difficulty of determining how to consider open water with respect to securement from development.

GIS Formats and Definitions

ESRI shapefile (polygons); including a variety of attributes for each polygon as defined in the reference listed above.

6.4.37 State boundaries (statesNer.shp)

Description

This GIS product represents boundaries of the 13 states plus Washington, DC, comprising the Northeast region.

Considerations for Using Data Layer

This layer is included for the purpose of displaying the state outlines as an overlay to the other landscape design products.

GIS Formats and Definitions

ESRI shapefile (polygons); attributed as follows:

- FID = ESRI assigned unique number to each polygon.
- Shape = ESRI assigned feature type = "polygon".
- state = name of the state.
- id = sequential numeric id (1-14) assigned to each state.

6.4.38 HUC 6 watershed boundaries (huc6Ctr.shp)

Description

This GIS product represents boundaries of the two HUC6 watersheds (or basins) in the Connecticut River watershed. Note, HUC6 watersheds were used to scale the core area selection indices in order to provide an even distribution of core area between watersheds.

Considerations for Using Data Layer

This layer is included for the purpose of displaying the HUC6 outlines as an overlay to the other landscape design products.

GIS Formats and Definitions

ESRI shapefile (polygons); with numerous attribute.

6.4.39 HUC 8 watershed boundaries (huc8Ctr.shp)

Description

This GIS product represents boundaries of the 14 HUC8 watersheds (or subbasins) in the Connecticut River watershed. Note, HUC8 watersheds were not used in any capacity to derive the landscape design products.

Considerations for Using Data Layer

This layer is included for the purpose of displaying the HUC8 outlines as an overlay to the other landscape design products.

GIS Formats and Definitions

ESRI shapefile (polygons); with numerous attribute.

6.4.40 Hillshade (hillshade.tif)

Description

This GIS product represents boundaries of the 14 HUC8 watersheds (or subbasins) in the Connecticut River watershed. Note, HUC8 watersheds were not used in any capacity to derive the landscape design products.

Considerations for Using Data Layer

This layer is included for the purpose of displaying the HUC8 outlines as an overlay to the other landscape design products.

GIS Formats and Definitions

Geotiff raster (30 m cells); cell value = hillshading index; ranges 0-254 based on 315 degree azimuth angle of the light source and 45 degree altitude angle of the light source above the horizon; consequently northwest slopes receive higher values and southeast slope receive lower values.