Quality Assurance Project Plan for the Conservation Assessment and Prioritization System (CAPS)

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Conservation Assessment and Prioritization System (CAPS) Statewide Massachusetts Assessment: December 2020

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www.umasscaps.org

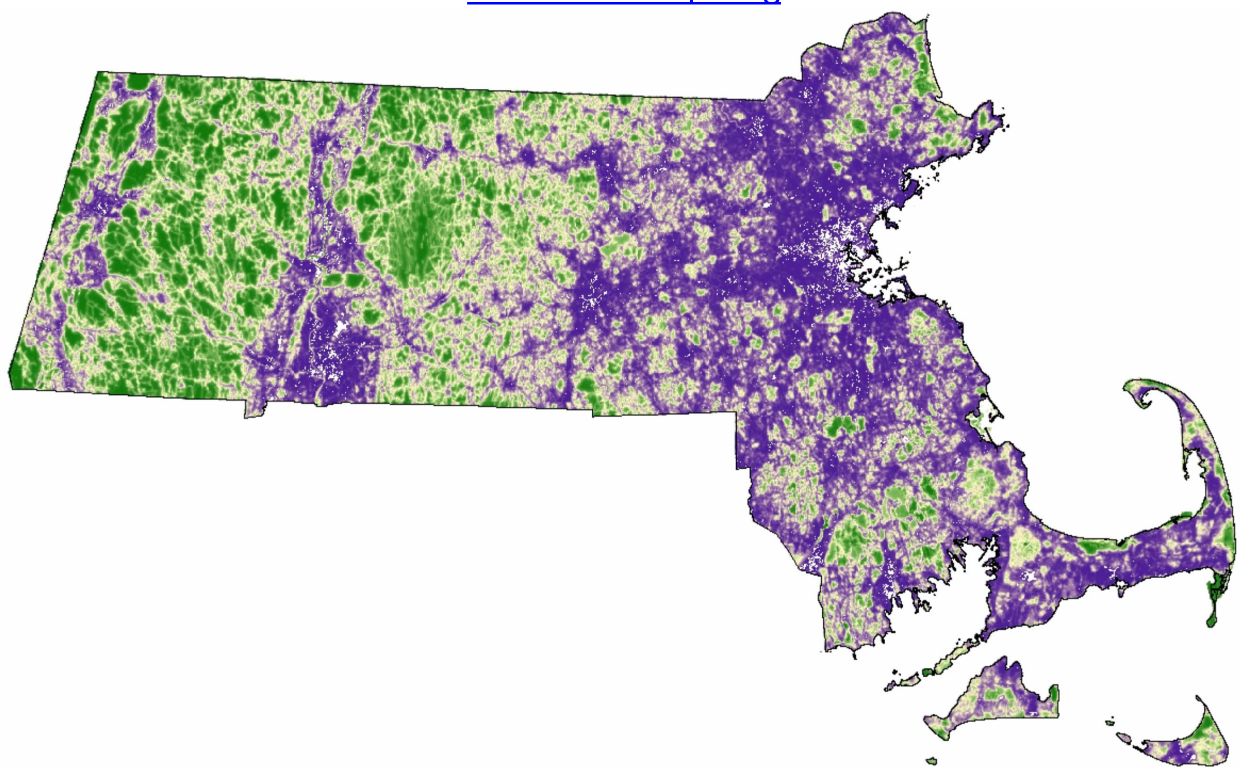

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Table of contents

Conservation Assessment and Prioritization System (CAPS) Statewide Massachusetts Assessment: December 2020

Introduction

The Conservation Assessment and Prioritization System (CAPS) is an ecosystem-based (coarse-filter) approach for assessing the ecological integrity of lands and waters and identifying and prioritizing land for habitat and biodiversity conservation (McGarigal et al. 2018). We define ecological integrity as the ability of an area to support biodiversity and the ecosystem processes necessary to sustain biodiversity over the long term. CAPS is an approach to prioritizing land for conservation based on the assessment of ecological integrity for various ecological communities (e.g., forest, shrub swamp, headwater stream) across the landscape.

In November 2011, the Landscape Ecology Program at the University of Massachusetts Amherst completed its first comprehensive, statewide assessment of ecological integrity using CAPS. In July 2015, we completed an updated version, with some new data, bug fixes, and several new metrics. We completed a revised version in November 2020 based on updated data, including a more recent, higher-quality land cover, new roofprint data representing all buildings, and improved traffic rate modeling (see Appendix A for details). Results from this assessment are available from our web site: www.umasscaps.org. The results are available in three formats.

- Georeferenced TIFF files (GeoTIFFs) for download and use with image viewers, web browsers or GIS software
- Maps (in PDF format) for each city and town in Massachusetts depicting Integrated Index of Ecological Integrity (IEI) scores
- Maps (in PDF format) depicting "Habitat of Potential Regional and Statewide Importance" as defined in MassDEP's "Massachusetts Wildlife Habitat Protection Guidance for Inland Wetlands"

Note that we have completed a similar CAPS analysis for the 13 states in the Northeast as part of the Designing Sustainable Landscapes (DSL) project (http://umassdsl.org/) using regionally-available source data. See Appendix B for a discussion of the differences between the Massachusetts and DSL models.

Overview of CAPS

The first step in the CAPS approach is the characterization of both the developed and undeveloped elements of the landscape. Developed land uses are grouped into categories such as various classes of roads and highways, different types of buildings (residential, commercial, agricultural, etc.), agricultural land, and other elements of the human dominated landscape. Undeveloped ("natural") land is mapped based on broad ecological community classification (e.g., forest, coastal beach, shrub swamp, salt marsh, pond).

With a base map depicting various classes of developed and undeveloped land, we then evaluate a variety of landscape-based variables ("metrics") for every point in the landscape. A metric may, for example, take into account the microclimatic alterations associated with "edge effects," intensity of road traffic in the vicinity, nutrient loading in aquatic ecosystems, or the effects of human development on landscape connectivity.

Metrics are applied to the landscape and then integrated in weighted linear combinations as models for predicting ecological integrity. This process results in a final Index of Ecological Integrity (IEI) for each point in the landscape based on models constructed separately for each ecological community. Intermediate results are saved to facilitate analysis—thus one can examine not only a map of the final indices of ecological integrity, but maps of road traffic intensity, connectedness, microclimate alterations, and so on. Note that metrics do not apply to developed land—all cells corresponding to developed land cover types are given an index of ecological integrity (IEI) score of zero, even though we recognize that some developed land may contribute to the conservation of biodiversity.

Among its many uses, the index of ecological integrity can be used alone or in combination with other approaches to identify and prioritize land for conservation. The index can be used, for example, to identify the top 10% or 30% of the land likely to provide the greatest ecological value over time and providing an effective and credible basis for strategic land conservation. It is important to note that the ecological integrity scores for land depend on the geographic extent of the analysis area. This is because the rescaling of the metrics is done to identify the best of the available lands, yet the "available lands" varies with geographic location and extent. Thus, the best example of a particular community within a certain geographic extent might be a relatively poor example when assessed over a much larger extent. For this reason, CAPS can rescale the index of ecological integrity to reflect conditions within geographic units that make up the full area of analysis. The Massachusetts CAPS assessment provides results at three geographic scales: statewide, major watersheds, and ecoregions.

A several years long field study found empirical support for CAPS metrics for stream macroinvertebrates, various taxa in forested wetlands, and (to a lesser extent) vascular plants and macroinvertebrates in salt marshes (McGarigal et al. 2013).

Project Area

This 2020 analysis was done for the entire Commonwealth of Massachusetts. Estuarine waters and salt ponds were included, but open ocean is not treated as a community by CAPS. Data limitations at state boundaries affect values near the borders with other states, though all of our metrics correct for edges (with the assumption that conditions beyond data edges are similar to those in the vicinity). Flow volume and stream sizes for rivers flowing into Massachusetts are accounted for, using flow accumulation data from the National Hydrography Dataset. Note that the Designing Sustainable Landscapes (DSL) project includes similar CAPS runs for 13 states in the Northeast, with a somewhat reduced set of metrics and some GIS data that is of poorer quality than those used in the Massachusetts CAPS analysis. See Appendix B for details.

Methods

Input Data

GIS data from a variety of sources were combined to create a base map depicting natural communities, developed land types, and roads. Appendix C describes the GIS data used. All data were mapped in 30 m rasters. The final land cover layer depicts natural communities, development and roads. See Appendix F for a description of natural communities, and Appendix I for the land cover classification. Other data layers depict subsets of this final land cover, including roads, railroads, and streams layers. A set of 23 Ecological Settings variables (Appendix E) describe abiotic, vegetative, and anthropogenic attributes of each cell. Finally, a number of ancillary layers were used by specific metrics. These include elevation, flow direction, flow resistance, and traffic rates.

CAPS Analysis

Once the input data layers are created, analysis in CAPS requires a model to be defined for each natural community or broad ecological system. Each community's model entails selecting a number of metrics and weighting them by importance for that community. This model parameterization process was originally done by three expert teams as part of the Housatonic watershed pilot project. An expert team for coastal communities met in 2010. Additional parameterization and some necessary modifications were done for this project by Kevin McGarigal, Scott Jackson, and Brad Compton. Andy Finton, Laura Marx, Alison Bowden, and Jessica Dietrich from The Nature Conservancy (TNC) provided valuable insights into parameters. The metrics selected for each of the communities and their relative weights are listed in Appendix G.

The parameterized model is run on the input layers using CAPS software, written at UMass by Brad Compton with software support by Eduard Ene and Ethan Plunkett. This software produces an output grid for each metric. Metrics fall into two groups: stressor metrics (such as road traffic, invasive plants, or nutrient enrichment), and resiliency metrics (similarity, connectedness, and aquatic connectedness). Stressor metrics measure anthropogenic stressors that reduce the integrity of a site, while resiliency metrics measure the intrinsic ability of a site to maintain its ecological integrity, despite the impact of anthropogenic stressors. Resiliency metrics, in reflecting the current landscape, do take into account anthropogenic stressors such as road traffic and impervious surfaces. The three resiliency metrics are based on the ecological distance among cells computed using the ecological settings variables described in Appendix E.

These output grids are rescaled, weighted, and combined into final index of ecological integrity (IEI) values. The IEI for each cell is a weighted combination of the metric outputs for that cell, based on the community in which the cell falls. Results are rescaled by percentiles, so that, for instance, the best 10% of marshes have values ≥ 0.90, and the best 25% have values ≥ 0.75. A separate analysis allows each cell to be assessed in the context of its watershed or ecoregion. For these analyses, the IEI is rescaled by percentiles within each watershed or ecoregion. For example, if IEI is rescaled by watershed, a marsh with a value of 0.85 would be interpreted as being in the 85th percentile of marshes for its watershed. When rescaling by the full extent (statewide), the high-valued forests are primarily in western Massachusetts. Rescaling by ecoregion or watershed spreads high forest IEI values more equitably across the state.

We rescaled results at three extents (full extent, rescaled by major watershed, and rescaled by ecoregion), plus a final integrated rescaling. The integrated rescaling uses the maximum score from statewide and watershed analyses for each cell in wetland and aquatic communities, and the maximum score from statewide and ecoregion analyses for cells in upland communities. The resulting IEI is then rescaled again by community to preserve the interpretation (i.e., the top 10% of integrated IEI values represent 10% of the landscape). See Table 1 for a summary of the various IEIs.

Table 1. Summary of different scalings of the Index of Ecological Integrity.

Grid name	Extent	Explanation
IEI	statewide	Each community is scaled across the full extent (statewide)
IEI_E	by ecoregion	Each community is scaled separately within each ecoregion
IEI_W	by watershed	Each community is scaled separately within each major watershed
IEI_I	integrated	IEI result for each community are integrated using combinations of statewide, watershed and ecoregion results

CAPS treats the results for each community separately, thus IEI should be compared only within communities. IEI is a relative measure, thus a shrubland may have a high IEI, meaning that it has high integrity compared to other shrublands—this does not imply that it is pristine, or that it has more integrity than, for instance, a medium-IEI wetland.

Data Accuracy and Limitations

The GIS data used in CAPS come from a variety of sources, and the quality of these data are variable. We integrated these data sources into a single land cover map, with several parallel data layers, including settings variables and other ancillary layers. We put considerable effort into integrating these input layers in ways that maximized the accuracy of available data, while making sure the final map generally makes sense, both visually and for use in the CAPS metrics. Because input data came from several different sources, we have no estimate of the accuracy of the final data set, nor of the effect errors in the base map may have had on final CAPS results.

Nobody should have any illusions that the base map presents a “true” depiction of the landscape—a comparison of the land cover with aerial photos or with familiar places will turn up errors in classification and position. Furthermore, the classification is fairly coarse, and distinctions between classes such as marsh and shrub swamp are necessarily arbitrary. Many of these communities change over time, so our snapshot based on data generated over several years may depict today’s beaver pond as yesterday’s forested wetland. The primary known issues with specific input layers are discussed in Appendix C.

We believe that the effects of many of the data errors will be relatively small. CAPS operates at fairly broad scales, looking at the effects of the surrounding landscape on any particular point. Small errors in classification and placement (small roads and streams omitted, marshes slightly shifted, small forest patches lost because of the grain of the map) will usually have minor effects on final results.

The coarseness of the classification scheme is perhaps a larger issue. Available data necessitated lumping many different forest communities into a single class; likewise, many rare and small-patch-forming communities were omitted. This leaves CAPS unable to compare patches of rich mesic forest to other patches of rich mesic forests, or to evaluate acidic rocky outcrops. To the extent possible given data limitations, the settings variables (Appendix E) are meant to distinguish among communities at a fine scale; these settings variables are used in the similarity, connectedness, and aquatic connectedness metrics.

It is important to keep in mind that CAPS is an assessment of ecological integrity—the ability of species and natural systems at a site to persist over time in the face of stressors. It is explicitly not a model of biodiversity per se, as many species (especially plants) thrive in anthropogenically disturbed areas that we do not rate high. Although such areas are important to conservation, we made the decision to focus on relatively natural areas that could be subject to land protection. Comprehensive action to protect biodiversity must include both protecting large areas of land with high ecological integrity (known as the “coarse filter” approach to conservation; Hunter et al. 1988) as well as protecting specific sites with rare species or high species richness, including anthropogenically modified sites (the "fine filter").

> The BioMap2 project, led by the Natural Heritage and Endangered Species Program of the MA Division of Fisheries and Wildlife and The Nature Conservancy, is a good example of a blueprint for conservation that combines both a coarse filter and fine filter approach. BioMap2 integrates CAPS analyses with element occurrences of exemplary natural communities, rare species, and other species of management concern, to identify core habitat and critical natural landscape that are essential for conserving biodiversity in the Commonwealth. For more information, to go https://www.mass.gov/service-details/biomap2-conserving-the-biodiversity-of-massachusetts-in-a-changing-world.

CAPS is a comprehensive assessment (models are applied uniformly to all areas) and relies on data that are broadly available across Massachusetts. The Index of Ecological Integrity is meant to give a general estimate of the integrity of a site, but we recommend using it in conjunction with other data in order to get a fuller picture of ecological status of areas within Massachusetts, including:

- Sources of degradation that may be mapped but are difficult to model (e.g., toxic pollution)
- Sources of degradation that are not comprehensively mapped (e.g., past land use)
- Data that might suggested increased conservation value but that are not comprehensively mapped (e.g., certified vernal pools, rare species records or rare natural communities)
- Data that might suggest higher conservation value not related to ecological integrity (e.g., protected status, inclusion within an ACEC)
- Information on populations or habitat of species of conservation concern

Data preparation and CAPS analysis were performed in a large base of custom code written in several languages, primarily APL+Win (written by B. Compton), with some code in R (B. Compton and E. Plunkett), as well as Python (B. Compton), AML (B. Compton), and C++ (E. Ene).

Results

CAPS data and maps can be downloaded from our web site: www.masscaps.org (see Appendix J). CAPS results are available in three formats.

- Georeferenced TIFF files (GeoTIFFs). GeoTIFF files can be viewed using an image viewer, web browser, or with GIS software. GeoTIFFS are available for IEI, land cover, metrics, and ecological settings variables.
- Maps for each city and town in Massachusetts depicting the Integrated Index of Ecological Integrity (IEI_I) scores. These maps are in the form of high-resolution PDFs depicting areas in the top 50% of values using integrated IEI scores. Ecological communities are differentiated by color for the following categories: forest (green), non-forested uplands (orange), coastal uplands (yellow to brown), coastal wetlands (cyan) and freshwater wetlands and aquatic (blue). For all ecological community types darker colors indicating higher-valued cells.
- Maps depicting areas designated as “Habitat of Potential Regional and Statewide Importance” as defined in MassDEP’s Massachusetts Wildlife Habitat Protection Guidance for Inland Wetlands. These maps are available as high-resolution PDFs for each town and city. They are based on the integrated index of ecological integrity and depict all areas (not just regulated “resource areas”) that score in the top 40% for IEI_I. Areas so designated as “Habitat of Potential Regional and Statewide Importance” represent 40% of the undeveloped landscape as well as 40% of each ecological community (e.g. forest, shallow marsh, shrub swamp, forested wetland, salt marsh). These data are also available for download as a GeoTIFF.

CAPS results are best explored interactively, using a GIS that can display grids (e.g, ArcMap or QGIS). See Appendix J for information on downloading data. The most generally useful results are the land cover and IEI grids.

The land cover grid (Fig. 1) represents developed land and broad natural communities. Land cover classes and names are listed in Appendix I. The geoTIFF of land cover is already colored appropriately, so no separate legend file is required.

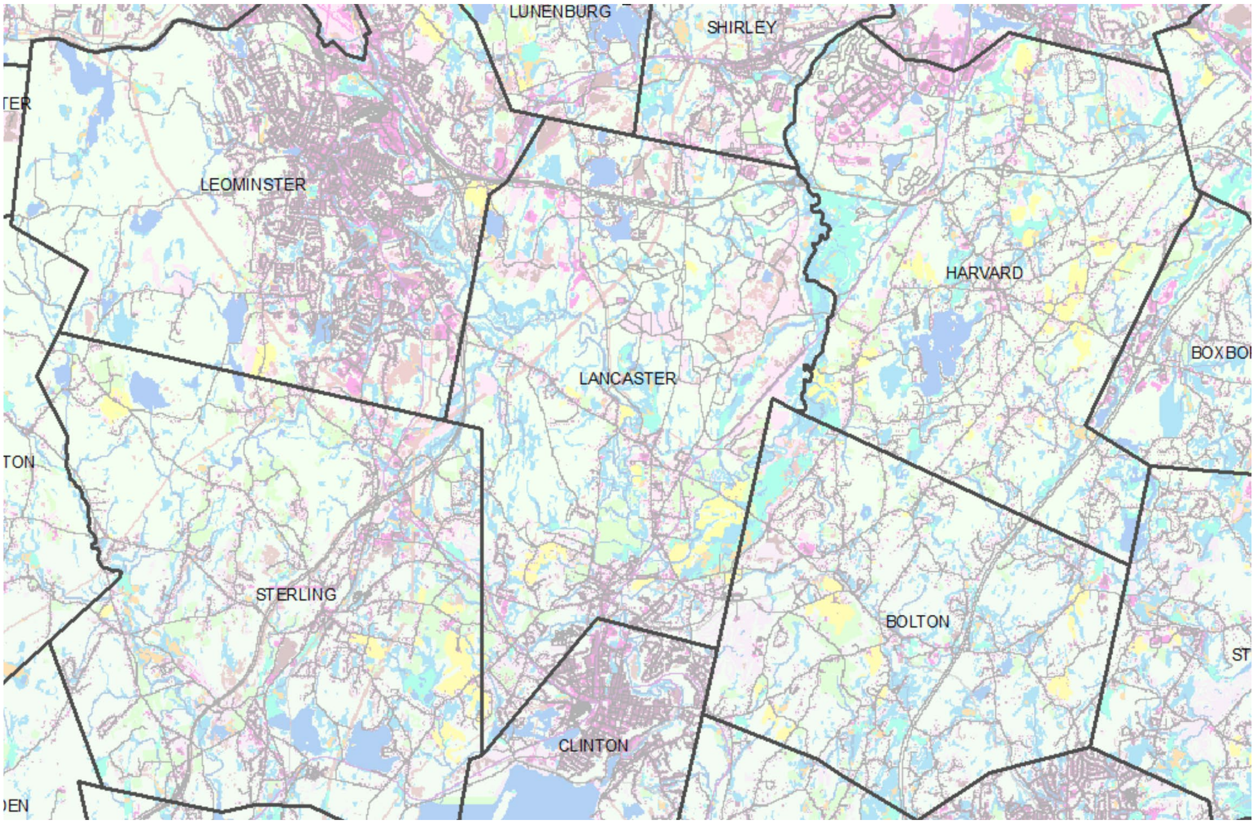

Fig. 1. Land cover for Lancaster and surrounding towns.

The IEI grids present the Index of Ecological Integrity at four scales: the entire project area (statewide), watershed, ecoregion, and integrated. Figures 2 through 5 show statewide IEI (Fig. 2), IEI scores rescaled by watershed (Fig. 3) and by ecoregion (Fig. 4), and integrated IEI (Fig. 5), with green indicating higher-valued cells and purple lower-valued cells. Note that in Figure 2 most of the high-value falls in forests in the western half of the state. In Figures 3, 4 and 5 the ecoregional and watershed scaling has reallocated the high IEIs across the state.

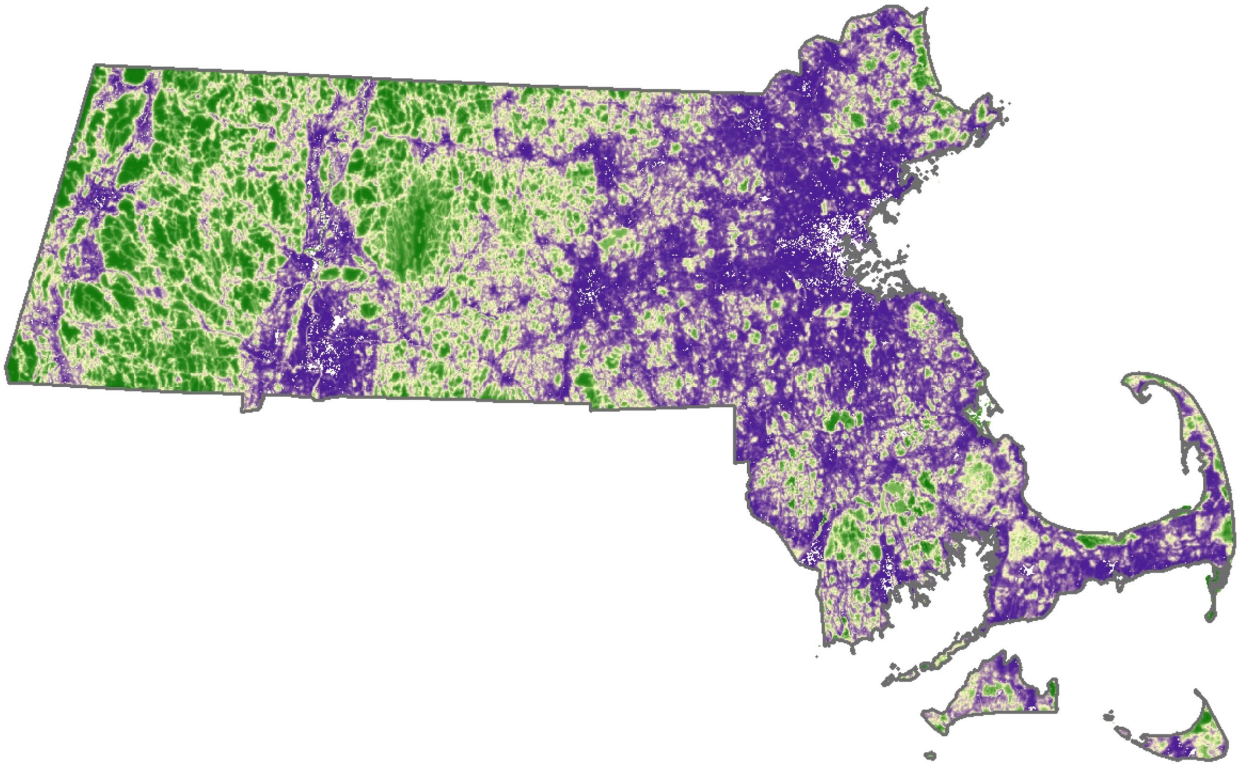

Fig. 2. Statewide IEI (IEI).

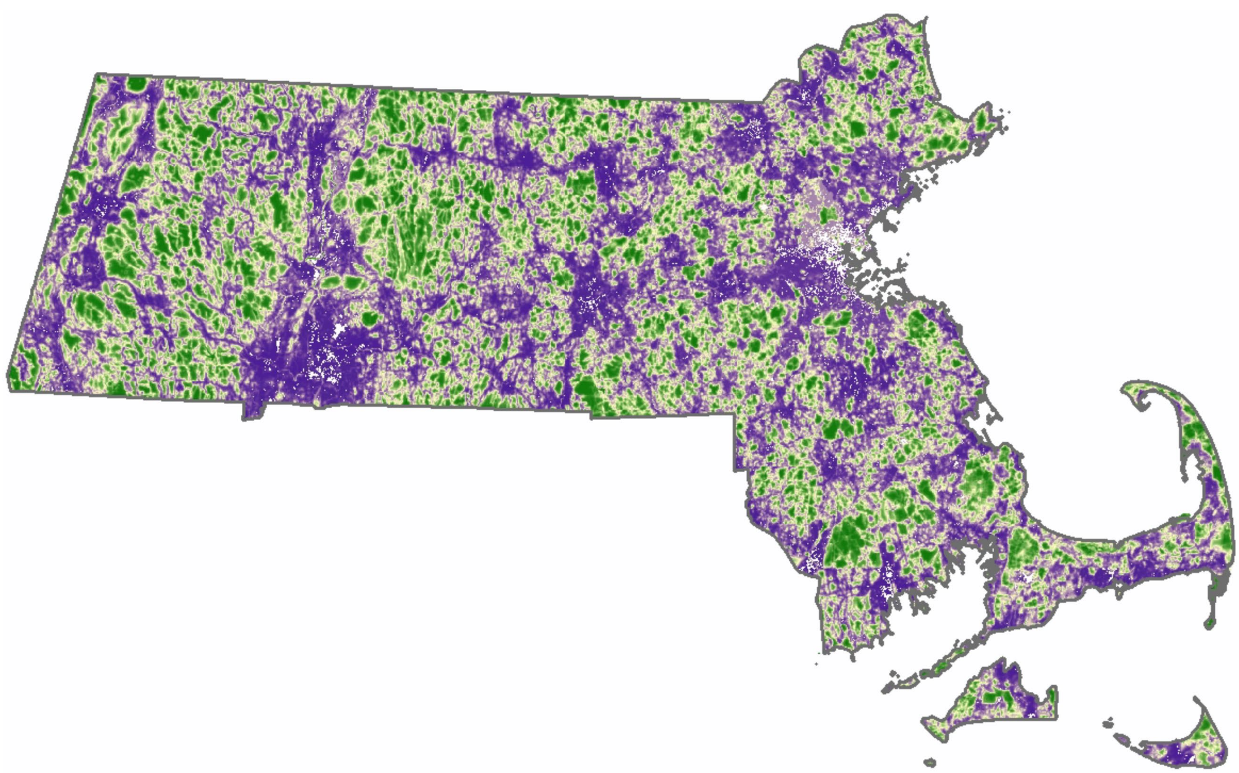

Fig. 3. IEI rescaled by Major Watershed (IEI_W).

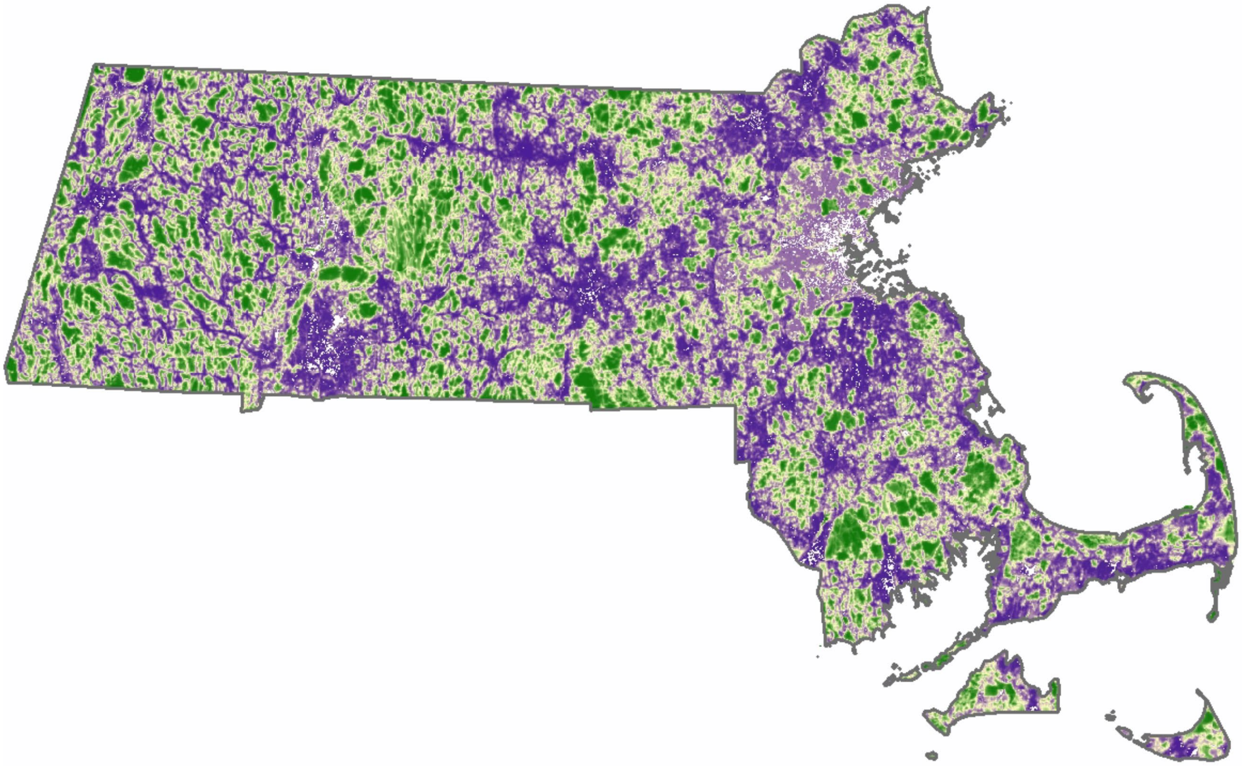

Fig. 4. IEI rescaled by Ecoregion (IEI_E).

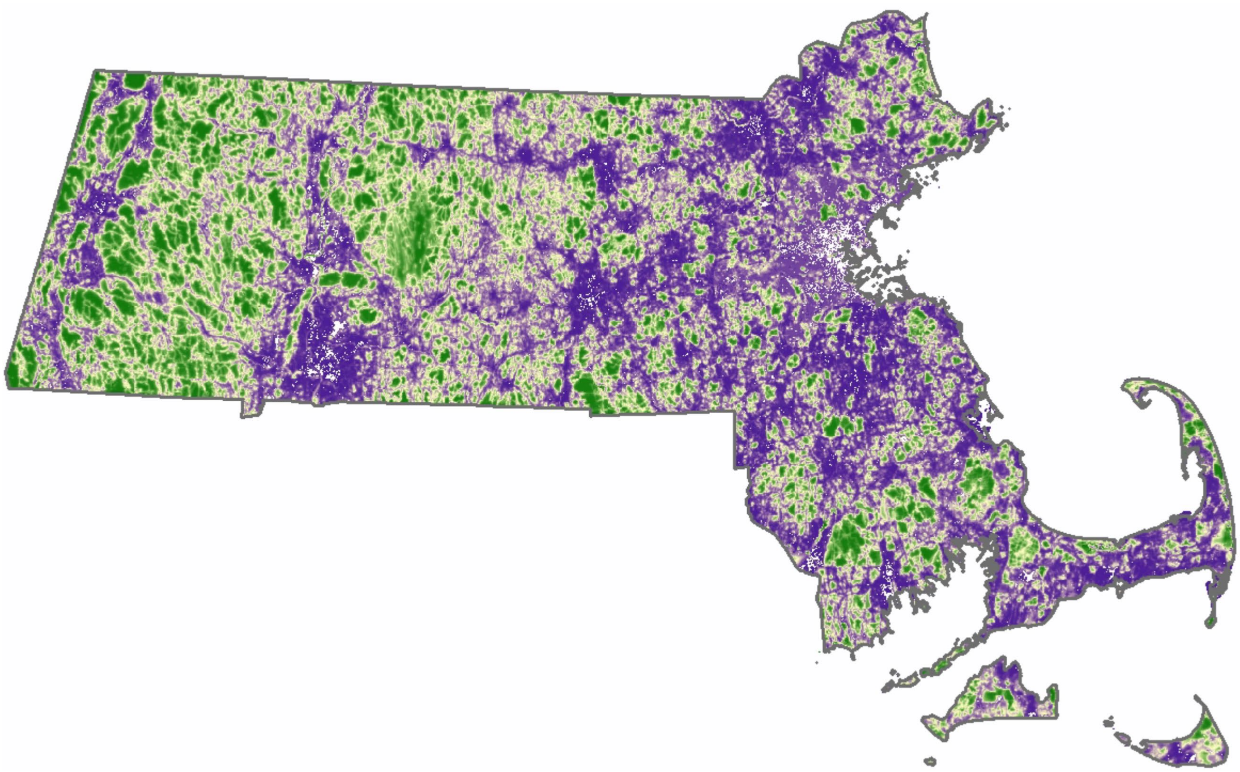

Fig. 5. Integrated IEI, a combination of statewide, watershed and ecoregionally scaled results (IEI_I).

Fig. 6. Index of ecological integrity (IEI) for Lancaster and surrounding towns, scaled to the entire project area (statewide). Green areas denote higher IEI values, purple denotes lower IEI, and white areas are developed land.

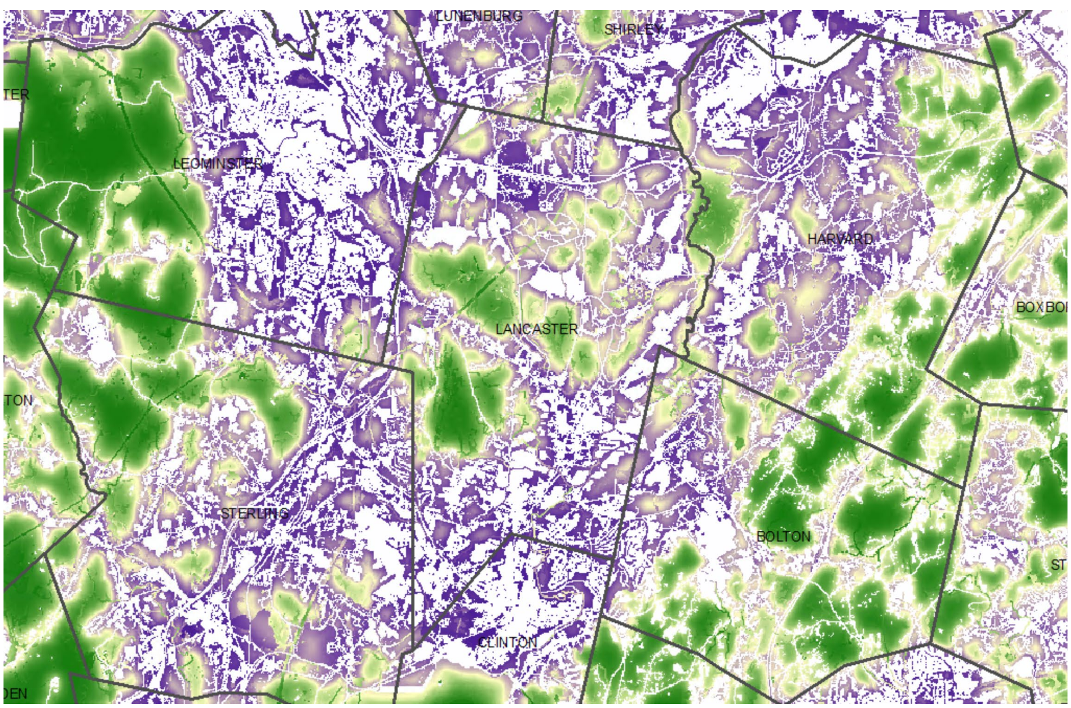

Fig. 7. Index of ecological integrity for Lancaster and surrounding towns, scaled by major watershed (IEI_W). Green areas denote higher IEI values, purple denotes lower IEI, and white areas are developed land.

Fig. 8. Index of ecological integrity for Lancaster and surrounding towns, scaled by ecoregion (IEI_E). Green areas denote higher IEI values, purple denotes lower IEI, and white areas are developed land.

Fig. 9. Index of ecological integrity for Lancaster and surrounding towns, integrated across full extent, watershed, and ecoregion (IEI_I). Green areas denote higher IEI values, purple denotes lower IEI, and white areas are developed land.

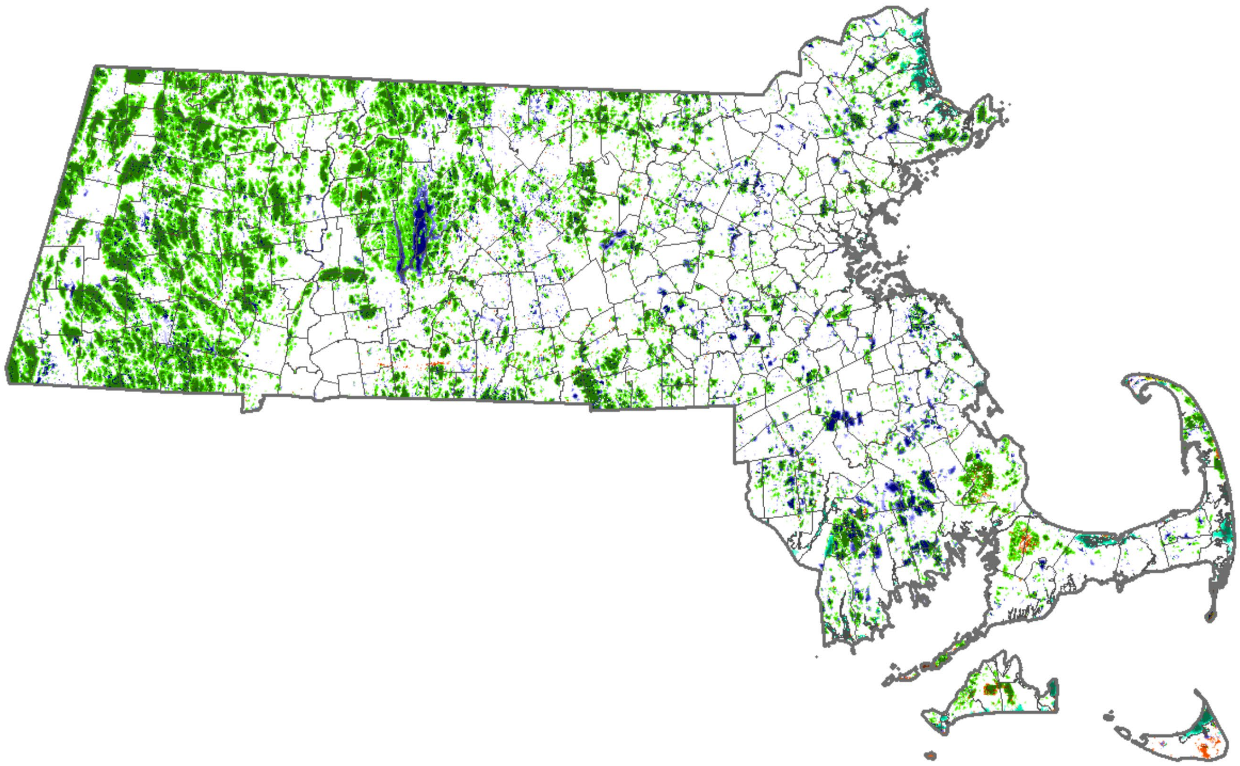

Fig. 10. Integrated IEI (IEI_I) depicted using a five-color scheme: forest (green), shrublands (orange), coastal upland (yellow to brown), freshwater wetlands and aquatic (blue) and coastal wetlands (cyan). For all community types, darker color represents higher IEI_I scores.

Figure 6 depicts the integrated IEI using a five-color scheme that makes it easier to differentiate among various groups of ecological communities. Because IEIs are scaled from 0 to 1 by percentiles within each community, images such as Figures 2 through 5 tend to be visually dominated by the values for forest communities because the landscape of Massachusetts is mostly forest. The five colors represent five broad groups of ecological communities: forest, shrubland, freshwater wetland and aquatic, coastal wetland and coastal upland. By using different colors to represent these five broad community types it is easier to recognize high-quality stream segments and patches of shrubland, wetlands and coastal communities that might otherwise go unnoticed among the large patches of forest throughout much of the state (Fig. 11 and 12).

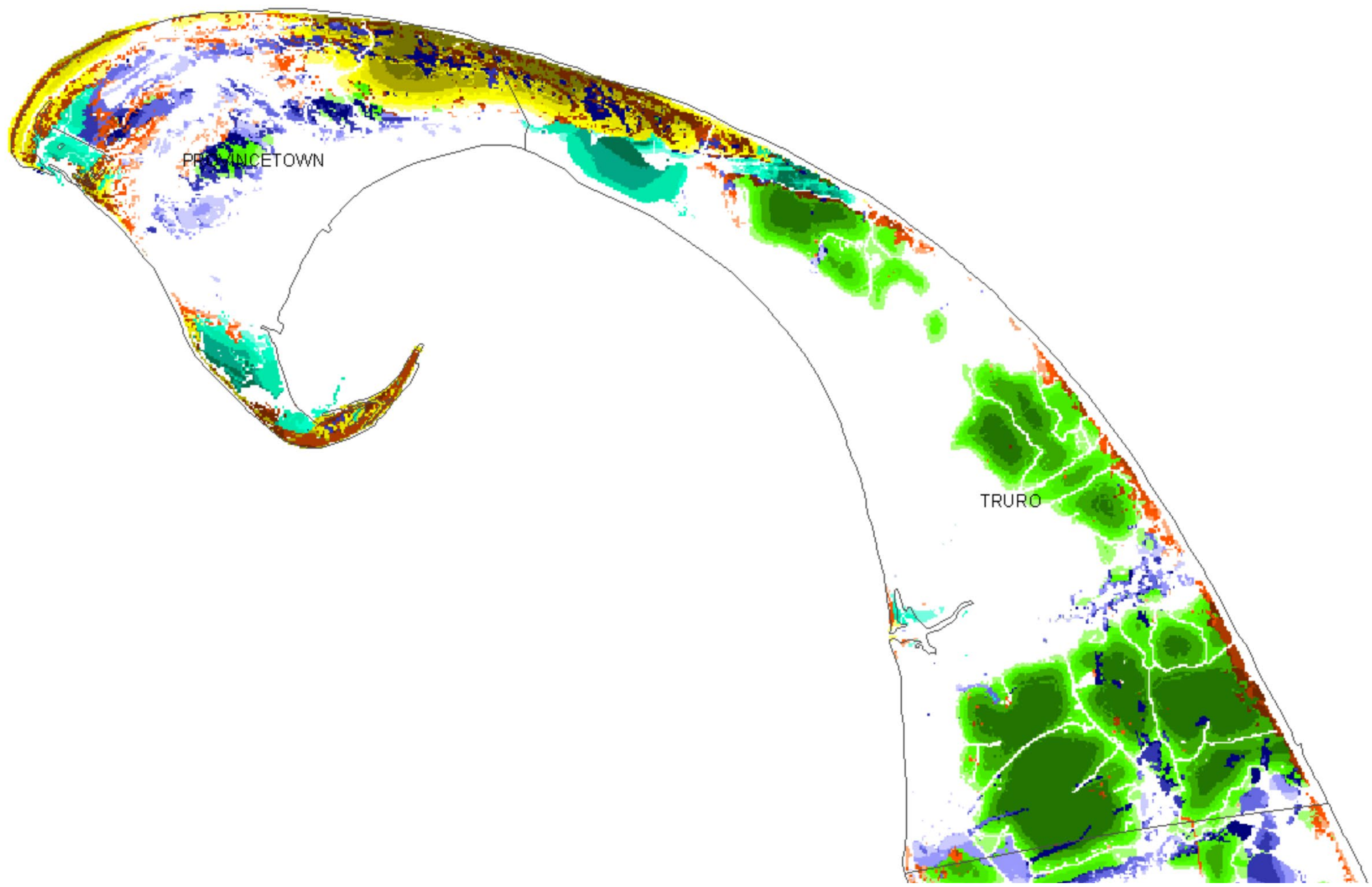

Fig. 11. Integrated IEI (IEI_I) for the towns of Provincetown and Truro depicted using a five-color scheme: forest (green), shrubland (orange), coastal upland (Yellow to brown), freshwater wetlands and aquatic (blue) and coastal wetlands (cyan). For all community types, darker colors denote higher IEI scores.

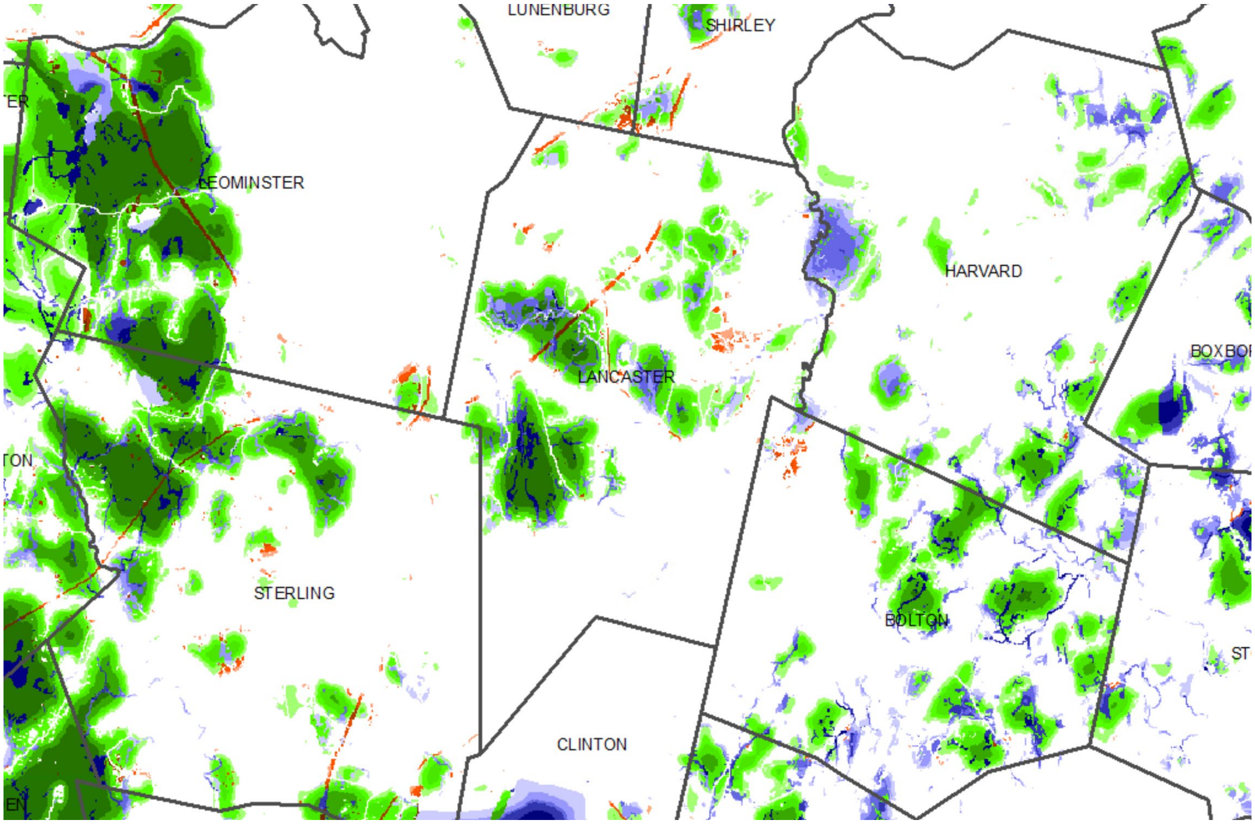

Fig. 12. Index of ecological integrity for Lancaster and surrounding towns, integrated across full extent, watershed, and ecoregion (IEI_I) depicted using a five-color scheme: forest (green), shrubland (orange), coastal upland (yellow to brown), freshwater wetlands and aquatic (blue) and coastal wetlands (cyan), and white areas are developed land.

High value areas that might be priorities for conservation can be highlighted by showing only those areas that fall in the top x% of IEI values, for instance the top 40% (IEI $\geq$ 0.60, Fig. 13). The "Important Habitat" maps produced for MassDEP use a 40% threshold. However, it is possible to view the CAPS results using other thresholds (e.g. top 10%, 25% or 50%).

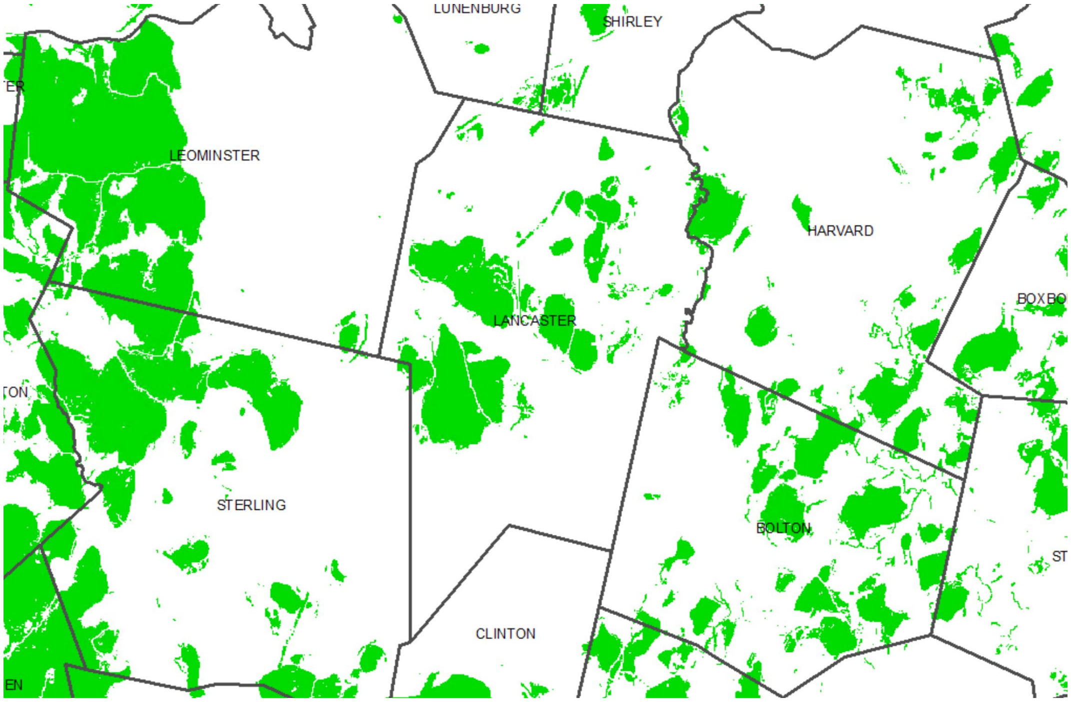

Fig. 13. Integrated index of ecological integrity (IEI_I), top 40%. This image shows the 40% of land area with the highest IEI_I scores for each community.

Finally, individual metrics may be examined and used for assessment and planning. The following images (Fig. 14-22) show the results of various CAPS metrics. Examining results of individual metrics can help users understand why areas were given a high or low IEI value, and can be used for specific purposes (e.g., identifying areas for water quality sampling or potential remediation/restoration).

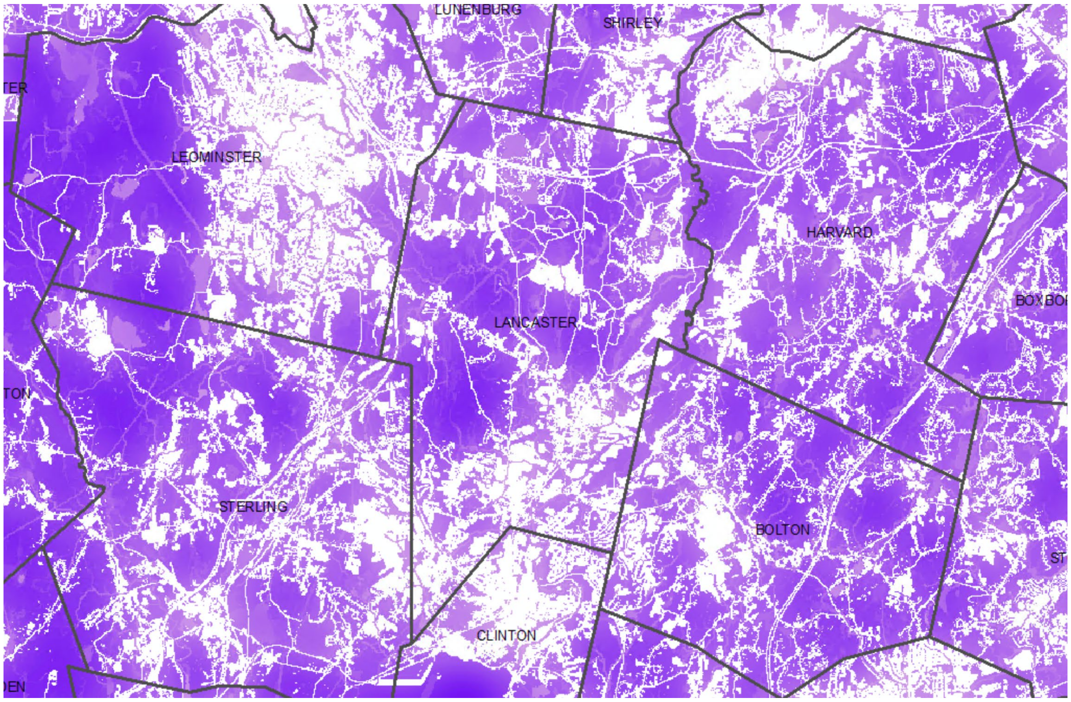

Fig. 14. Similarity metric for the Lancaster and surrounding towns. Darker areas are those more similar to areas nearby in the landscape.

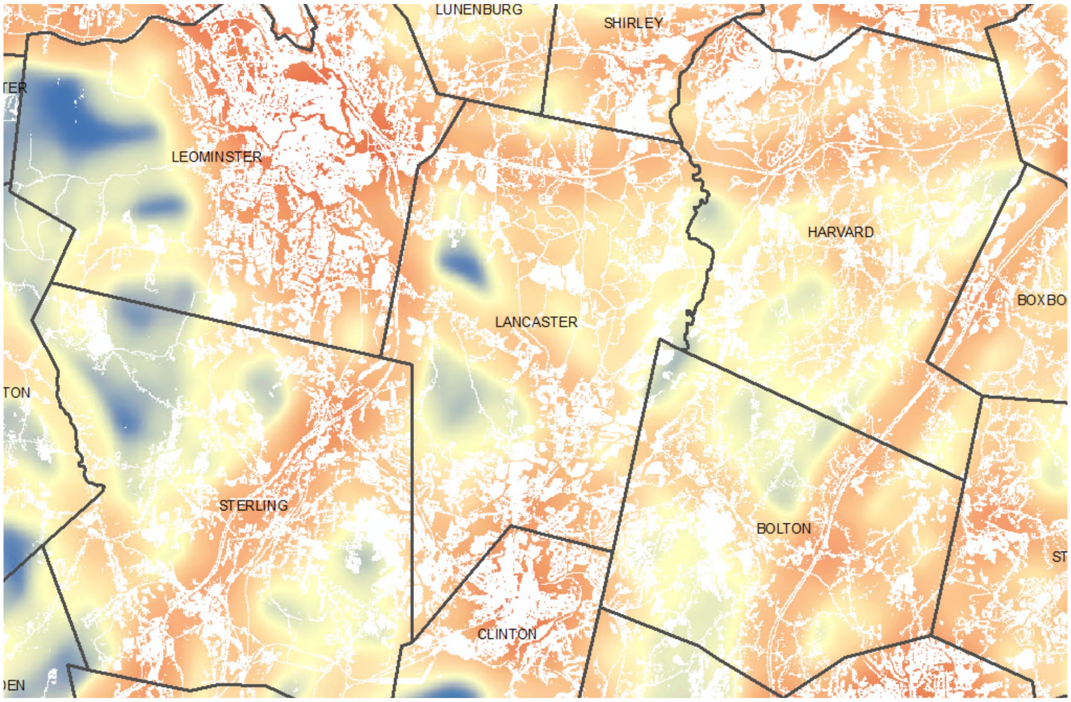

Fig. 15. Traffic intensity metric for the Lancaster and surrounding towns. Areas in darker red are more highly impacted by road and railroad traffic. Blue areas are relatively unaffected by traffic. White areas are developed land.

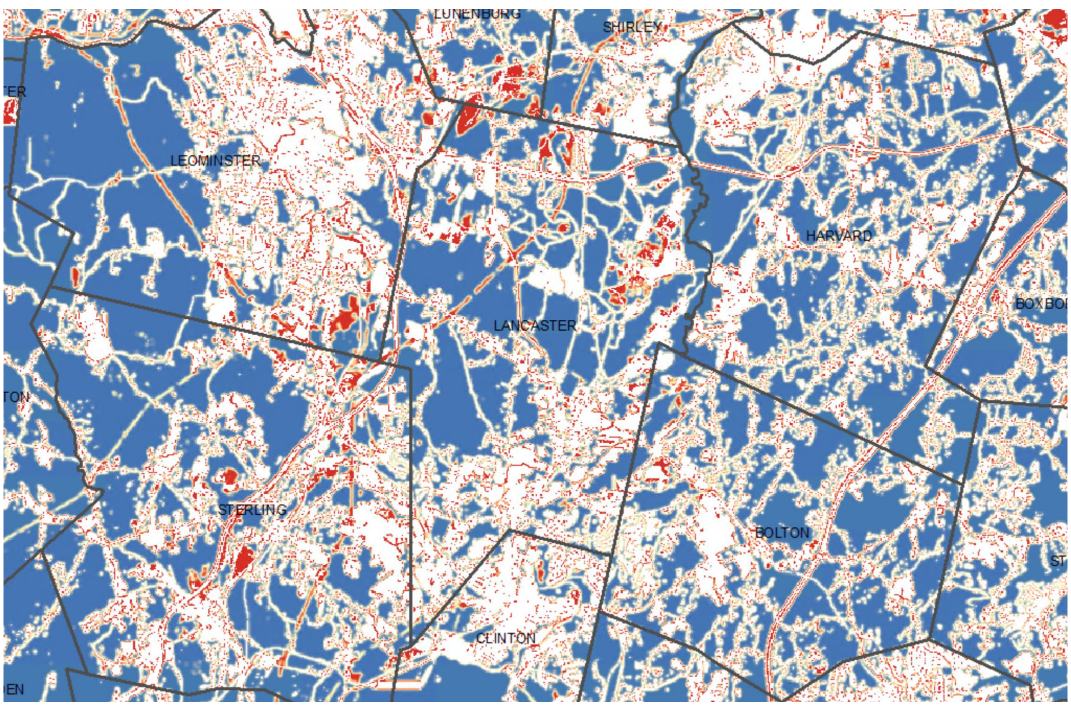

Fig. 16. Microclimate alteration metric for the Lancaster and surrounding towns. Areas in darker red are more highly impacted by microclimatic alterations due to edge effects (e.g. decreased moisture, higher wind, and more extreme temperatures). Blue areas are relatively unaffected by microclimatic alterations. White areas are developed land.

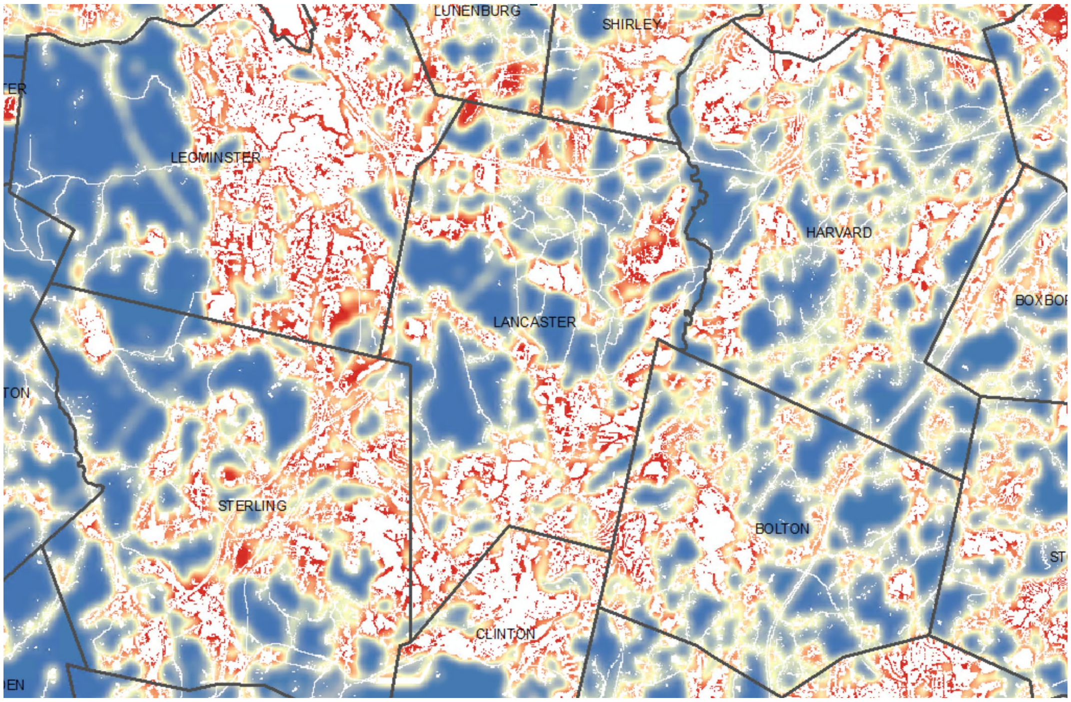

Fig. 17. Edge predator metric for the Lancaster and surrounding towns. Areas in darker red are more highly impacted by edge predators (raccoons, skunks, opossums, foxes). Blue areas are relatively unaffected by edge predators. White areas are developed land.

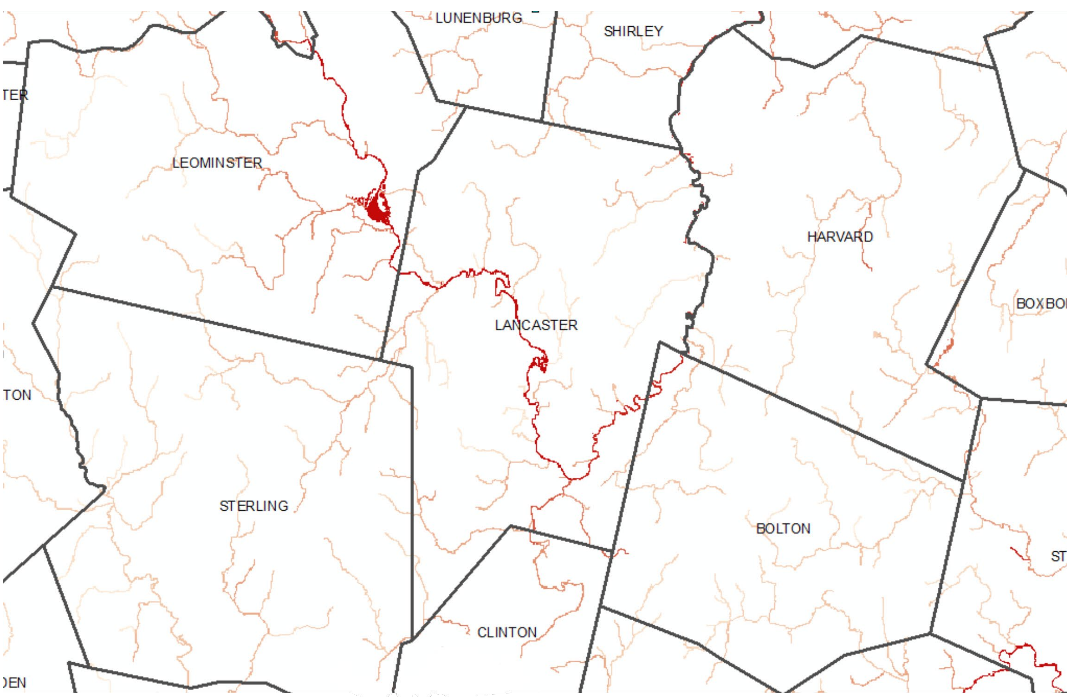

Fig. 18. Hydrologic alterations metric for the Lancaster and surrounding towns (applied only to streams and rivers). Darker streams indicate more severe alteration in flow regimes.

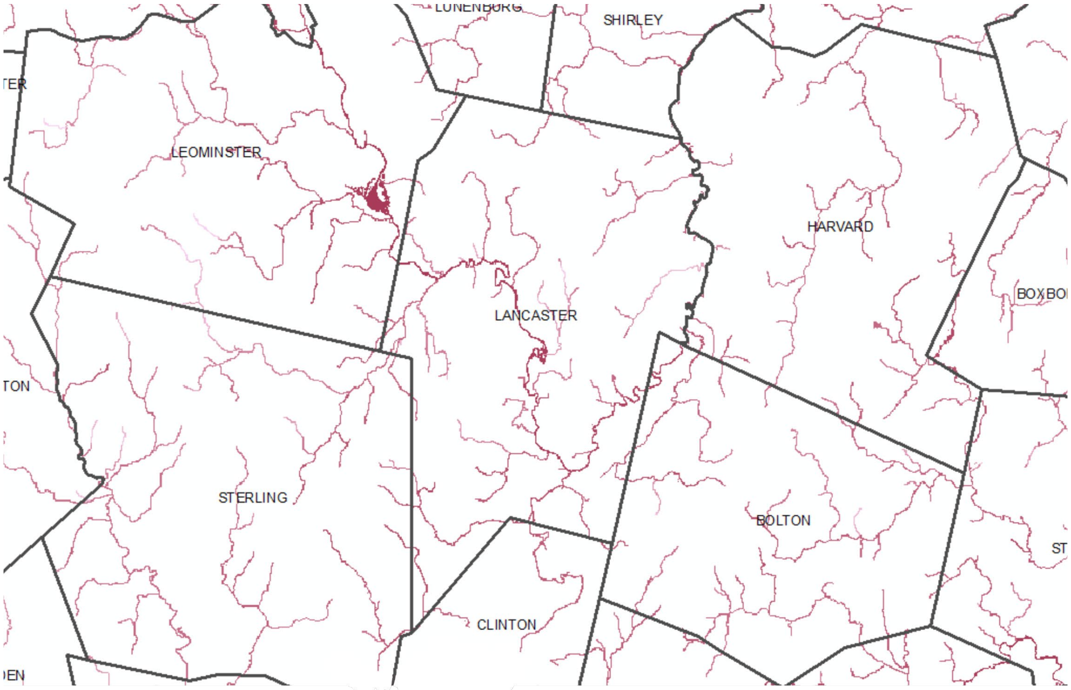

Fig. 19. Phosphorus enrichment metric for the Lancaster and surrounding towns (applied only to streams and rivers). Darker streams have higher levels of phosphorus.

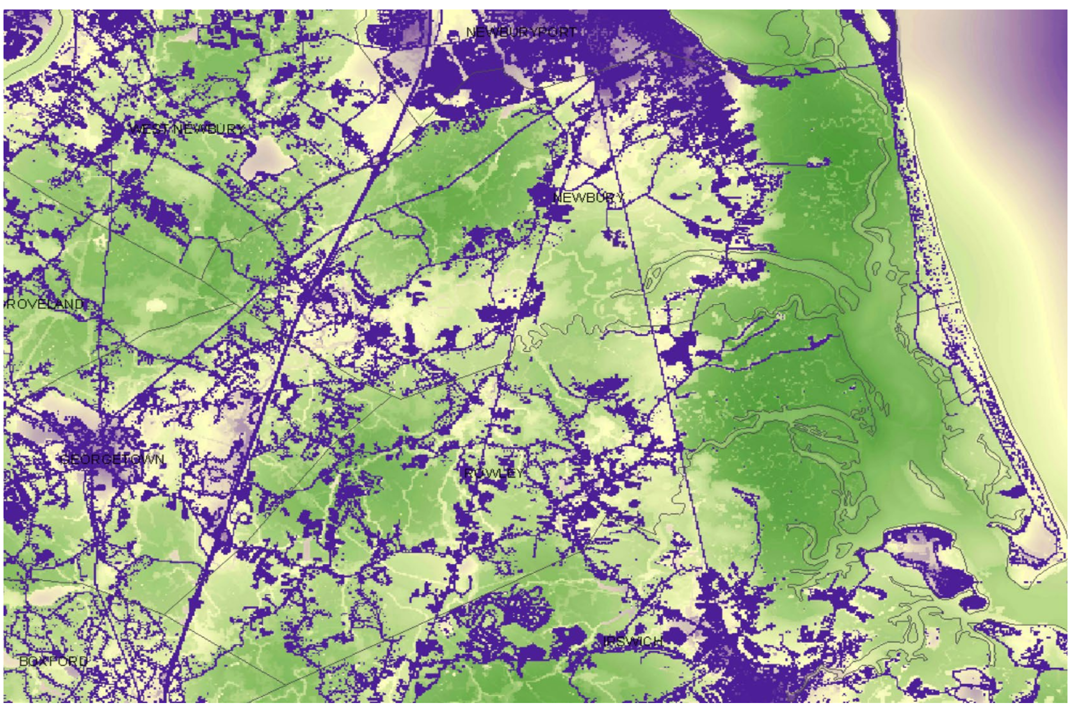

Fig. 20. Connectedness metric for an area on the north shore of Massachusetts. Areas in green colors are more interconnected with similar areas nearby than those depicted in yellow or purple. Developed land is dark purple.

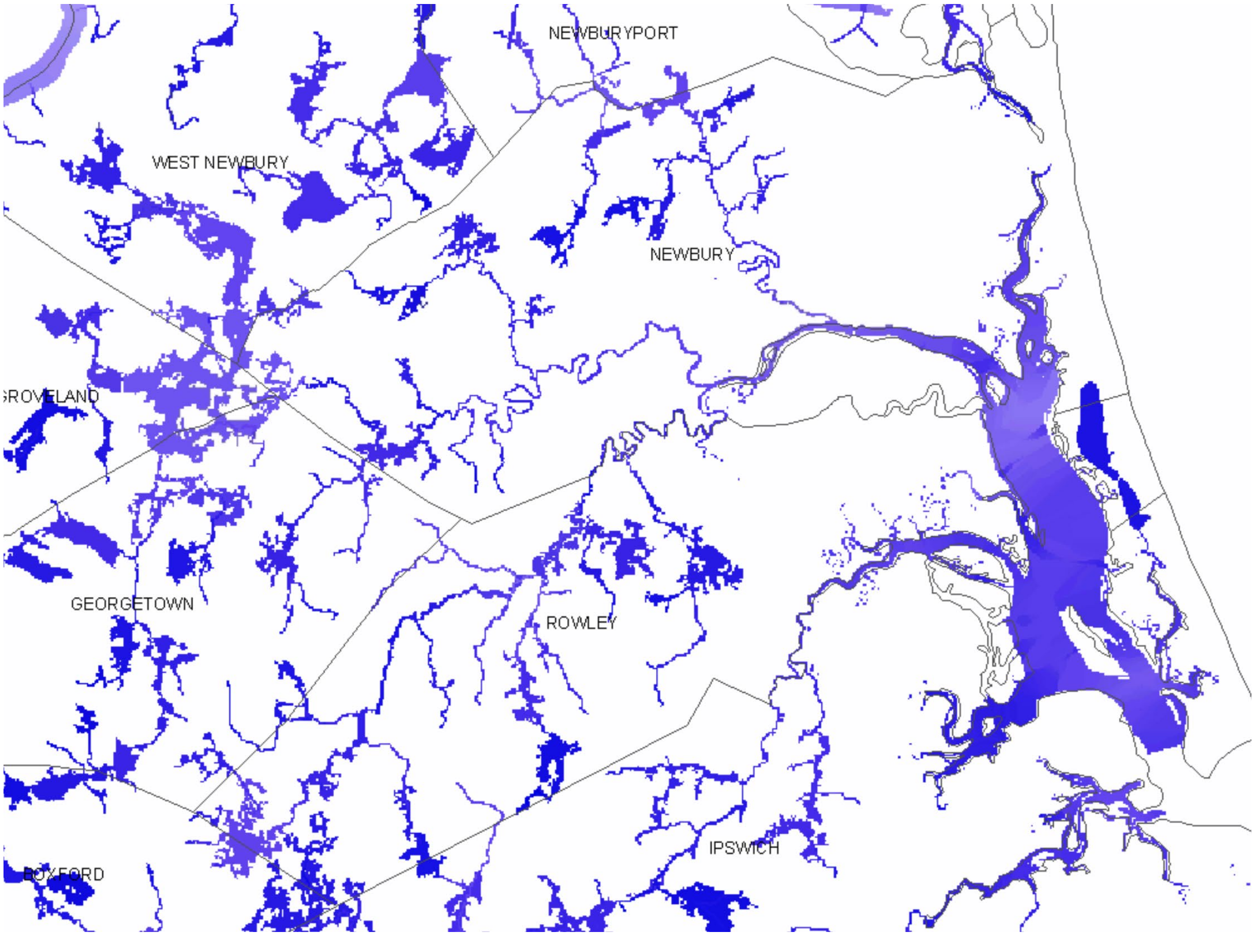

Fig. 21. Aquatic connectedness metric for an area on the north shore of Massachusetts. This metric is applied only to wetland and aquatic communities. Areas in darker blue are more interconnected with similar areas nearby than those depicted in lighter color. White areas are non-wetlands (uplands and developed land).

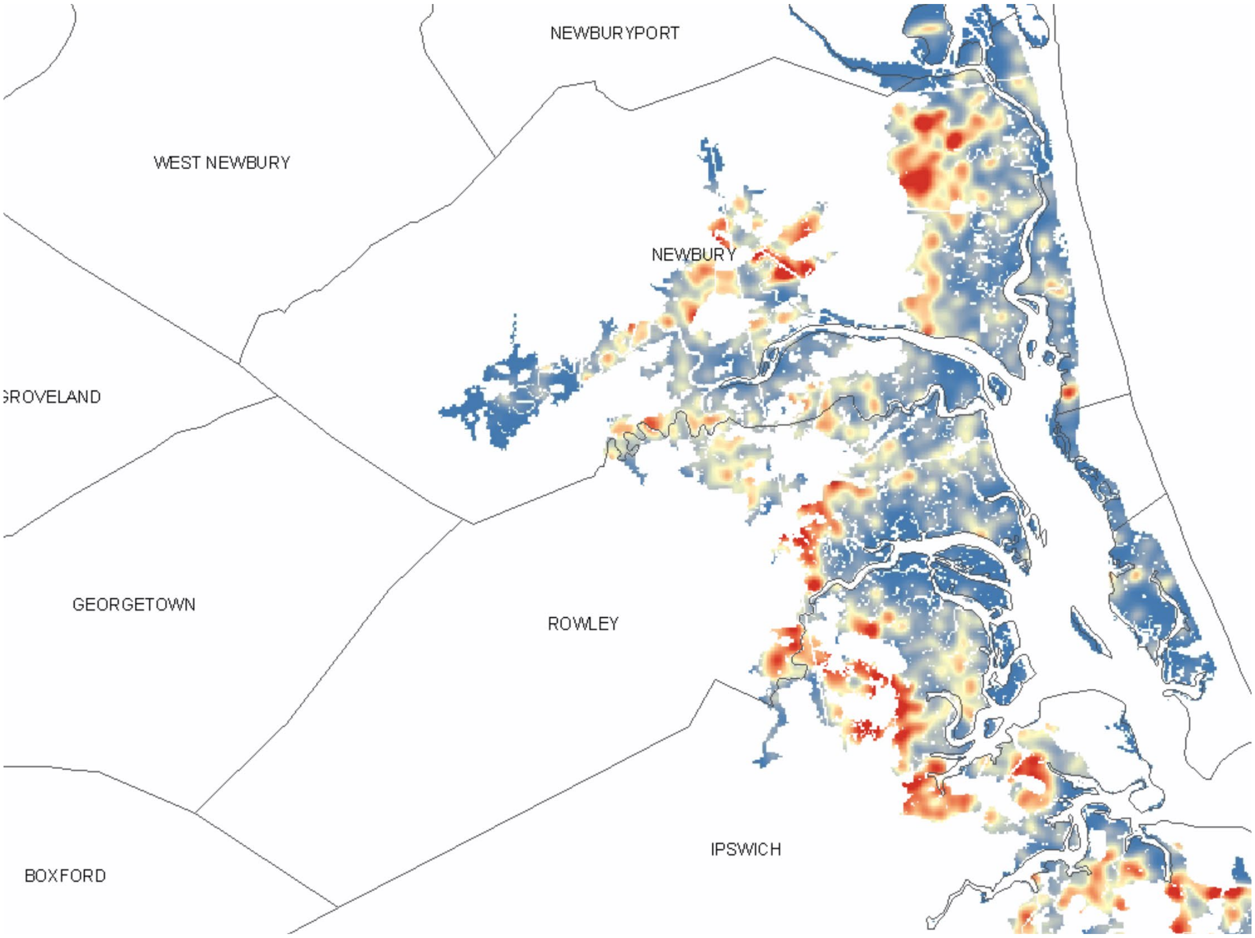

Fig. 22. Salt marsh ditching metric for an area on the north shore of Massachusetts. This metric is applied only to salt marshes. Areas in darker red are more highly impacted by ditching. Blue areas are relatively unaffected by salt marsh ditches.

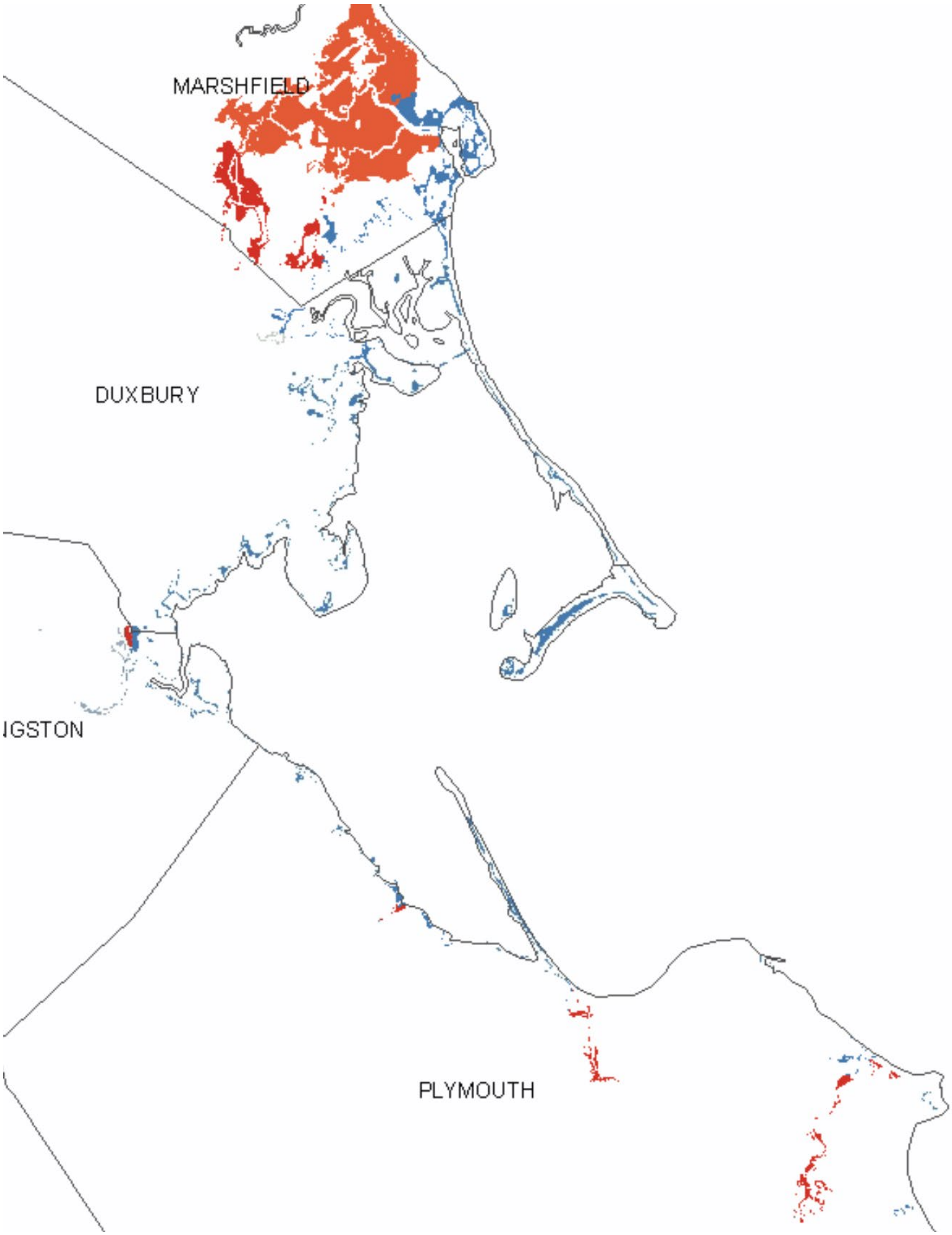

Fig. 23. Tidal restrictions metric for an area on the south shore of Massachusetts. This metric is applied only to wetland and aquatic communities, and is most useful in coastal areas. Areas in darker red are more highly impacted by tidal restriction. Blue areas are relatively unaffected by tidal restrictions. White areas are non-wetlands (uplands and developed land).

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Appendix A: Changes to CAPS in this version

Several changes were made to the CAPS data and software since the 2011 statewide run. Here are highlights:

New data. The biggest change in this version is the incorporation of new land cover and buildings data. MassGIS land cover/land use (2016) is a completely new representation of natural and developed land cover, replacing the old 2005 land use. MassGIS building structures (2019), also known as “roofprints” are a high-resolution representation of all buildings larger than 150 ft^2 in Massachusetts. The incorporation of these two new layers allows us to distinguish more clearly and precisely among buildings, pavement, and developed open space (yards, parks, and other semi-natural areas), as well as distinguish among several types of building uses. We’ve also incorporated new versions of data sources that have been updated since the 2011 run, including MassDOT roads (2018), trains (2015), MassGIS protected open space (2020; used in road traffic processing), NRCS soils (2012), and TNC dams (2017). We have replaced MassDOT’s discontinued model of road traffic rates with our own model, based on road segments with measured traffic. Road-stream crossings (2020) have been updated to reflect the new data and additional field surveys of more than 4800 crossings by the North Atlantic Aquatic Connectivity Collaborative (NAACC). Additionally, a number of new data sources were included to support the new metrics. See Appendix C: Input Data Layers for details on these changes.

New metrics. Hydrologic alterations, nitrogen enrichment, phosphorus enrichment, and boat traffic. The hydrologic alterations metric estimates anthropogenically-induced low and high flow on streams and rivers (due to dam storage, impervious surface, and water discharges). Nitrogen and phosphorus enrichment metrics estimate anthropogenic inputs of these two nutrients into streams and rivers (from impervious surfaces, water discharges, septic systems, urban areas, croplands, and cranberry bogs). Boat traffic is a measure of the effects of commercial and recreational boat traffic on coastal shoreline ecosystems. See Appendix D: Landscape Metrics for details on new metrics.

Dropped metrics. Our old nutrient enrichment metric was replaced by the two new empirically-based metrics, nitrogen enrichment and phosphorus enrichment. These new nutrient metrics are based on empirical modeling. They only apply to streams, not wetlands or waterbodies. Wetland buffer insults was dropped from this version. This metric measured the percentage of the 33 m statutory buffer around wetlands that contained impervious surface. Compared to other metrics, it was obsolete in two ways: it was a patch-based metric, giving a single value to an entire wetland basin, regardless of size; and it incorporated stressors in a fixed buffer (based on regulatory, rather than ecological, considerations) as opposed to the variable-width kernel buffers we use elsewhere. Furthermore, this metric performed poorly in an empirical study (McGarigal et al. 2013).

Changed metrics. The original tidal restrictions metric used data from field-measured restrictions to estimate the decrease in tidal inundation in meters. Many of these field surveys were made at remediation sites where culverts have since been upgraded to allow more natural tidal flow. As a result, given new land cover data, the regression model that powered this estimate no longer holds. We’ve fallen back to the approach used for the thirteen-state Designing Sustainable Landscapes project, where the tidal restrictions metric gives an index to the modeled degradation from downstream tidal restrictions, without tying it to an estimate of the change in water levels.

New community models. Community models have been expanded to include the four new metrics, and crosswalked to new communities.

Bug fixes and improvements. This version reflects several bug fixes and improvements in metrics and the way data were prepared.

Appendix B: Relationship with Designing Sustainable Landscapes

In addition to the Massachusetts CAPS assessment, we have produced a regional version of CAPS for 13 states in the northeast (most recently completed in 2019) as part of the Designing Sustainable Landscapes (DSL) project (McGarigal et al. 2018; umassdsl.org). The DSL project contributed a major part of U.S. Fish and Wildlife's Nature's Network (naturesnetwork.org). This appendix summarizes the differences between MA CAPS 2020 and DSL 2019.

- MA CAPS is based on data only for Massachusetts, while DSL is based on data for 13 states, so the DSL version will be more correct near state borders (for the MA CAPS analysis we use edge correction near data edges, which assumes that the other side of the border is similar), and DSL provides regional context—for instance regional IEI is scaled across all states in the region.
- DSL includes a large number of models in addition to CAPS: habitat capability models for 31 focal wildlife species, future projections of urban growth, climate change, and sea level rise, and a Landscape Conservation Design (LCD).
- The DSL land cover is based on The Nature Conservancy's Ecological Systems Map, with much greater thematic richness of natural systems, including a richer aquatic classification that includes water temperature and trophic level for lentic waterbodies.
- MA CAPS is based on generally higher-quality data, including land cover, roofprints, traffic rates, soils, and the digital elevation model, while DSL uses data that are regionally-available, and often of lower quality.
- MA CAPS has several metrics not available regionally: hydrologic alterations, nitrogen enrichment, phosphorus enrichment, salt marsh ditching, beach ORVs, beach pedestrians, coastal hardened structures, and boat traffic. MA CAPS drops the more generalized and poorer quality nutrient enrichment metric in favor of high-quality nitrogen and phosphorus metrics.

The DSL website (umassdsl.org) provides detailed descriptions of metrics and settings variables, which are similar or identical to the versions used in Massachusetts CAPS, although several Massachusetts CAPS metrics (listed above) were not included in the regional DSL project.

Appendix C: Input Data Layers

This section describes the source input data to CAPS, with a brief listing of major errors and limitations and of modifications we made to the data listed for each source. All data are the most recent available as of summer 2020. Most of these data are available from MassGIS (https://www.mass.gov/orgs/massgis-bureau-of-geographic-information).

MassGIS 2016 land cover/Land use (2019) - This is the source for most developed land and and natural types in the land cover. Natural communities include forest, shrublands, and various wetlands. MassGIS created this layer by combining NOAA's Coastal Change Analysis Program (C-CAP) land cover data with MassGIS' Standardized "Level 3" Parcels layer. The original from MassGIS is a high-resolution polygon coverage with separate values for land cover and land use. We reprojected the data to Mass State Plane, and converted it to a 30 m grid to align with the rest of our data. After extensive evaluation, we crosswalked the combined layer into our raw land cover, which captures developed and natural land cover types that are meaningful for the CAPS analysis. We also derived an impervious surface layer from this source. We combined our raw land cover with several other layers to make capsland, our final land cover: roofprints (representing all buildings), roads, railroads, streams, vernal pools, power lines (as shrubland), dams, and road-stream crossings.

Notes

- Wetlands now are mapped in the 2016 land cover by NOAA's C-CAP (2016). In previous versions of CAPS, our wetlands came from DEP wetlands (2005), which were photo-interpreted and of high quality, but outdated, based on aerial photos from as long ago as the 1990s. As a result, many beaver-created and impacted wetlands were mismapped. The new NOAA wetlands have less thematic richness, not distinguishing between shallow and deep marsh, and dropping the bog class (bogs are usually mapped as marsh, shrub swamp, or sometimes, aquatic bed). We didn't think the new "aquatic bed" class was terribly reliable nor meaningful for our purposes, so we reclassified aquatic bed to lake or pond. Cranberry bogs are no longer separately mapped; in this analysis, these are usually mapped as cropland. We brought in vernal pools from our 2011 land cover; these are based on Natural Heritage's potential vernal pool layer.
- As in previous versions, we split open water into lotic and lentic based on a model that used the shape of polygons to distinguish rivers from lakes and ponds, followed by thorough hand-checking and editing. We further split lentic into lakes and ponds based on the size of the waterbody (ponds are < 8 ha). This was based on a logistic regression of sizes of lakes and ponds in the National Wetlands Inventory, because NWI distinguishes between lakes and ponds, whereas 2016 land cover depicts all open water as one class. Rivers and streams are mapped by size and gradient, as in previous versions (see below). We used our 2011 classification of ocean (with misalignment correction) to remap the generic open water class to ocean.
- Sea cliff, rocky intertidal, and vegetated dune are no longer mapped.
- In conjunction with roofprints, we were able to split developed land into buildings, pavement (mapped as impervious), and the new class, developed open space.

- The new grasslands class were a mess. In mainland Massachusetts, where there are very few natural grasslands, the majority of areas mapped as grassland were really developed open space: baseball fields, pastures, mowed lawns surrounding sewage plants, solar farms, gravel pits, and cranberry bogs. Some heavily-cut forests were also mapped as grasslands. On the Cape and Islands, natural grasslands were usually correctly mapped, but unfortunately, on the order of half of areas mapped as grasslands were really developed open space. Given the importance of grasslands in areas where they occur, we kept grasslands on the Cape and Islands, despite the errors of commission. In mainland Massachusetts, we converted all mapped grasslands to developed open space. In addition, large areas of forest on the Prescott Peninsula in the Quabbin were inexplicably mapped as grassland (these areas were far larger than any areas of forest harvest, and have not been heavily cut in recent decades). We converted all bogus grasslands on the Prescott Peninsula to forest.
- Coastal dunes were typically mapped in MassGIS 2016 land cover as developed open space or barren land. We rectified dunes by taking areas mapped by the 2005 DEP wetlands as coastal dune or vegetated dune and mapped by 2016 land cover as developed open space or barren land and converting them to coastal dune (with some effort to correct for misalignment). Vegetated dune areas are typically mapped as grassland.
- We remapped barren land that falls on or near coastal beaches, tidal flats, or ocean in the 2005 DEP wetlands to beach or mudflat.
- Powerlines, which were previously mapped as “powerline shrubland,” were typically mapped in MassGIS 2016 land use as shrubland, pasture, or grassland, but also as forest or other classes. We changed areas under 2005 powerlines that were mapped by 2016 land cover as pasture, grassland, developed open space, barren land, or forest to shrubland.
- The new barren land class is something of a garbage can. Although it no doubt makes sense from a spectral mapping standpoint, it doesn’t in an ecological sense. It represents a mix of gravel pits, talus slopes, coastal beaches, sea cliffs, lakeshores, and anthropogenic edges. After pulling out dunes, beaches and powerlines (see above), we mapped remaining areas of barren land as bare land, and excluded it from estimates of ecological integrity, as these areas are primarily anthropogenic.
- Nomans Land (an island southeast of Martha’s Vinyard) was totally omitted in the MassGIS data. We brought it in from the 2011 Massachusetts CAPS land cover.
- There are several known errors in the landcover due to errors in the 2016 land cover. The only errors we specifically fixed were several large areas of forest mapped as grassland on the Prescott Peninsula, as these were so egregious. Notable errors include some large areas of recently managed pitch pine and scrub-oak in the Montague Sandplains being mapped as developed open space, heavily cut forests mapped as developed open space, and small areas of trees in the middle of urbanized areas being mapped as forests (the original C-CAP data sometimes maps individual trees as forest!).

Roofprints – We used the MassGIS 2016 building structures (2019) to represent buildings. Combined with the MassGIS land cover representation of impervious surfaces (which we interpret as pavement in cells without roofprints) and developed open space (managed semi-natural space such as lawns, parks, and cemeteries), roofprints give us a more finely detailed and accurate representation of various types of development. We combined roofprints with MassGIS land use to distinguish six types of buildings: commercial, industrial, agricultural, residential, recreational, and public buildings.

Note that the MassGIS roofprints seem to be of higher quality than the Microsoft Bing roofprints we used for the region-wide DSL project, which itself is of fairly high quality—certainly far better than any representation of development we've had access to in the past.

Potential vernal pools – We used photo-interpreted Potential Vernal Pools from MassWildlife's Natural Heritage and Endangered Species Program.

- Potential vernal pools that fell within a terrestrial type were treated as a single pixel pool (30 m × 30 m). When a potential vernal pool fell within a wetland mapped by DEP, we retained DEP's classification.
- Because of the inherent difficulty of identifying vernal pools from aerial photography, this layer contains many errors of commission and omission. Because there is no other data source for this important community (certified vernal pools are still quite limited and highly biased by search effort), we used these data with caveats.
- We moved vernal pools that fell in the same cell as a road over one cell to fall alongside the road in our land use. We used an algorithm that looked at the vector data to move the pool to the correct side of the road.

MassGIS networked hydro centerlines, NHD stream network – We used the MassGIS networked stream centerlines for the mainland, and filled in the Cape and islands with edited versions of NHD centerlines.

- We edited these data to repair a significant number of breaks in the network, as the CAPS watershed metrics require a connected network.
- We deleted the dense (and meaningless) network of channels in cranberry bogs, instead connecting streams flowing through bogs with straight lines passing through the bogs. These dense channels made it impossible to represent flow in a 30 m grid.
- We deleted the ditches in salt marshes for similar reasons. Streams that flowed into DEP salt marshes were retained, and any stream that originated within a salt marsh was deleted.
- We extended stream mouths all the way to the ocean
- We added stream centerlines to our land cover grid in areas that were mapped as uplands to represent smaller (1st and 2nd order) stream communities
- We burned stream centerlines into the flow grid to force streams and rivers to prevent small DEM errors from misdirecting streams and rivers
- Because stream centerlines were digitized at varying densities, resulting in bias that affected our aquatic connectedness metric, we dropped all streams with a watershed of less than 30 ha. This has the effect of removing parts of the smaller headwater streams throughout, while making stream density more consistent.

MassGIS 5 m Digital Elevation Model – The DEM is the basis of several of our terrain-based settings variables, and of the flow used for our watershed metrics. We used the 5 m DEM because its accuracy, consistency, and overall quality was much higher than the older 30 m DEM and the DEM from the National Elevation Dataset (NED). We used the DEM to create a flow direction grid, the source of flow accumulation and $CaCO_3$ settings variables, and watershed metrics. The DEM was also used to model tides and tidal restrictions, solar exposure, and the slope and gradient settings variables.

- We sampled this DEM up to 30 m for all analyses
- For flow modeling (flow-based settings variables and watershed metrics), we filled depressions in the DEM

Flow direction – The D8 (single-direction) flow direction grid was derived from the depressionless 30 m DEM. We then burned stream centerlines into the flow grid to ensure that stream and riverbeds are represented correctly. This was an iterative processes that entailed finding loops introduced by errors in stream centerlines, correcting them, and repeating the process. Flow direction is used for watershed metrics, and also for the $CaCO_3$ content settings variable.

Flow accumulation – We built a FD8 (multiple-direction) flow accumulation grid from the flow grid and DEM. This process allows a cell to flow to multiple downslope cells, giving much more realistic flow patterns in mid-slopes. Flow accumulation is used for the settings variables wetness and flow volume.

- We estimated the watershed area of streams flowing into Massachusetts from the 2009 National Elevation Dataset (NED) flow accumulation grid.

Aquatic resistance – We modified the approach of Randhir et al. (2001) to build a time-of-travel grid for each cell in the project area, based on land cover, slope, flow, and stream gradient. This grid was used to define the influence area within the watershed of each point for our watershed metrics.

Dams – Dams are from Northeast Aquatic Connectivity Assessment Project (NACAP) version 2 (2017). They were processed to fall on our DSL stream centerlines by Ethan Plunkett, and adjusted to match the Massachusetts stream centerlines (which are very similar).

Protected open space – We selected permanently protected open space (lev_prot = “P”) from the February 2020 MassGIS protected and recreational open space layer. These data are used to adjust road traffic rates in parks and state forests.

Roads and road traffic – Roads are from the 2018 MassDOT 1:5000 Roads layer (via MassGIS). Roads were reclassified into five types (expressway, primary highway, secondary highway, light duty road, and unpaved road) based on original road classes as well as surface type for unpaved roads.

Traffic rates are a mess in the 2018 roads layer. Traffic rates were measured in the field for many roads, especially larger roads. For unmeasured roads, MassDOT assigned arbitrary fixed traffic rates, varying nonsensically by region; e.g., 1000 in much of western Massachusetts, 898 in Springfield, 1069 in Pittsfield. The previous traffic rate model used by MassDOT (which seemed pretty good) has been dropped. As traffic rates are important to both the traffic and connectedness (and to a lesser extent, similarity) metrics, the data as delivered weren't acceptable for CAPS, so we built a suite of road traffic models ourselves.

We treated the traffic rates differently for each road class:

Expressways (class 1) – as most expressways were measured in the field, only a handful of segments were missing traffic rates. We filled these in by hand from either the opposite lane or adjacent road segments.

Primary highways (class 2) – we fit primary highways using a quantile regression to fit median traffic rates from a number of variables including kernels of development at various scales, kernels of road density at varying scales, kernels of agriculture and of protected open space, and interpolations of class 2 traffic rates. We used AIC to select the best model, which included two interpolations of class 2 traffic for non-missing road segments (an inverse distance weighted interpolation and a kriged interpolation). We stratified our sample to prevent overrepresentation of more common traffic rates. We assessed all fits with a large holdout sample, and got an excellent fit, with a log-log R^2 of 0.8998. As class 2 highways are relatively sparse on the landscape and many segments were surveyed, to a great extent the interpolations had the effect of correctly filling in missing traffic rates from nearby surveyed samples.

Secondary highways (class 3) – we fit secondary highways using the same approach as for primary highways. The best-fitting model used inverse distance weighted interpolation of class 3 and class 4 traffic rates, a kriged interpolation of class 4 traffic rates, and a kernel of class 3 road density. The fit was pretty good, with a log-log R^2 on the holdout set of 0.6322.

Light duty roads (class 4) – the quantile regression model we used for class 2 and 3 roads performed poorly for light duty roads, so we ended up using a Random Forest model to fit traffic rates from kernels of development, agriculture, open space, inverse-distance weighted class 2, 3, and 4 interpolations of traffic rates, kriged class 2, 3, and 4 traffic rates, and kernels of class 2 and 3 road density. The R^2 was 0.6135.

Unpaved roads (class 5) – vanishingly few unpaved roads had measured traffic rates, and many of these were obviously classification errors, so it was impossible to model traffic rates for unpaved roads from the sampled roads. Instead, we applied the model for light duty roads and multiplied estimated traffic rates by 20%. We of course had no basis to pick this discount, other than knowing intuitively that dirt roads typically have much lower traffic than paved roads. The results are of unknown accuracy, but are clearly far better than the absurdly high rates assigned regionally by MassGIS.

As in previous versions, we changed the traffic rate for all unpaved roads that run through permanently protected open space to 10. This fixes the wild overestimates of traffic on gated, discontinued, and little-used roads through parks and state forests such as Myles Standish, the Quabbin, and many other state forests and other large conservation areas.

Railroads – From the 2015 MassGIS trains layer. Railroads were mapped in three classes: railroad, abandoned railbed, and rail trail.

- We deleted linework where abandoned rails were shown underwater in the Quabbin, and where railroads run through major tunnels (the Hoosac tunnel)
- We integrated rail traffic into our traffic rates layer by assigning traffic rates for commuter, passenger, and freight lines, based on estimates of the number of cars for each railroad type, estimated average number of daily freight and commuter trains, and number of daily passenger trains from schedules, and expert team assignment of the relative impact of a train car to an automobile.
- We estimated the number of tracks in each rail line from GIS data for use in the terrestrial barriers settings variable.

Road-stream crossings – Bridge and culvert locations were estimated from the intersections of stream centerlines with road and railroad linework. For each crossing, we obtained aquatic and terrestrial passability scores from the North Atlantic Aquatic Connectivity Collaborative (NAACC). We used field-surveyed scores where available (scores were downloaded on July 26, 2020), and estimated scores elsewhere using a random forest model developed by Ethan Plunkett.

- Bridges and culverts on small, unmapped streams and unmapped roads are omitted.
- Bridges and culverts on streams with < 30 ha watersheds are omitted because we trimmed streams with very small watersheds to reduce bias from inconsistent effort by USGS when they digitized streams.
- Crossing scores are based on a modeling approach with rather wide confidence intervals; furthermore, models of target scores are based on expert opinion rather than empirical passability data.
- Aquatic passability is used for the aquatic barriers settings variable.
- Terrestrial passability is used in the connectedness metric to allow connectivity under roads and railroads at stream crossings.

Tidal regime – Tidal regime is estimated from a logistic regression of salt marshes (from 2015 MassGIS land cover) vs. uplands from the DEM and interpolated tide range from 120 NOAA tide stations. This gives a grid depicting the expected tidal influence at each point. Tidal regime is used as a settings variable, and also as an input to the tidal restrictions metric.

Tidal restrictions – Potential tidal restrictions are modeled at road-stream crossings (the intersection of stream centerlines with road and railroad linework) in the coastal area. In previous versions, we modeled the severity of tidal restrictions based on 75 measured tidal restrictions from field work done by CZM and DEP using a regression of the ratio of the area of expected salt marsh above each restriction (areas where the tidal regime suggest salt marshes) to the area of salt marsh mapped by DEP above each restriction ($P < 0.001$; $r^2 = 0.41$). However, many of these field-measured restrictions were at remediation sites where culverts have been upgraded in the past 15 or 20 years; as a result, given new landcover, our regression no longer fits. We now use the same approach to modeling tidal restrictions as used by the DSL project, described here: http://jamba.provost.ads.umass.edu/web/lcc/dsl/metrics/DSL_documentation_tidal_restrictions.pdf. Note that many restrictions occur where there are no roads or railroads, for instance at tide gates; we were unable to capture such restrictions

Imperviousness – Impervious surfaces are from the 2016 MassGIS land cover/land use. We converted the impervious, roofprint, and roads shapefiles to 1 m rasters, after buffering roads by class to represent typical road widths. We combined these layers, and converted them to percent impervious within each 30 m cell.

Soils – Soil depth, pH, and texture are from NRCS digital soil maps. We used 1:25,000 SSURGO soils data where possible. In Franklin and Plymouth counties, SSURGO pH data were spotty, so we layered SSURGO pH on top of the more complete but more generalized STATSGO (1:250,000) values.

- Soil texture was classified on an ordinal scale of 1-6, where 1 is organic, and 2-6 range from fine to coarse textured. Values were lumped based on texture classes such as “silt loam” or “very fine sandy loam.” Soil texture was not supplied for open water or urban areas.
- Soil pH was based on the representative pH for each soil type. pH values are fairly coarse, with missing values for urban areas, open water, and many other areas. Soil pH for Franklin and Plymouth counties were a mixture of low-resolution STATSGO and high-resolution but incomplete SSURGO data.
- Soil depth is the expected depth to bedrock, dense, or cemented layers. We log-transformed soil depth for the soildepth settings variable. Soil depth is missing for open water and is set to zero for some mountainous areas and other apparently arbitrary areas.

Calcium – We used the geology field from TNC’s Ecological Land Units for calcareous and moderately calcareous near-surface bedrock. (The original source for this dataset is USGS, available on MassGIS; TNC has reclassified lithology). Our $CaCO_3$ settings variable uses these values directly for terrestrial areas, and uses a flow accumulation model for wetlands and open water.

- Lithology is mapped at scales ranging from 1:100,000 to 1:500,000, so fine details and smaller inclusions are omitted, and spatial accuracy is poor.

Wind speed, wind power – Wind speed and power data are modeled by TrueWind Solutions LLC. Wind speed is available from MassGIS; we obtained wind power (in 16 cardinal directions) from the UMass Wind Energy Center. Original data are at 200 m resolution; we downsampled these data to 30 m by interpolation.

- Our wind exposure settings variable is based on wind speed at an elevation of 30 m.

- The wave exposure settings variable uses directional window power at 50 m combined with reach to estimate potential wave exposure along the coast.

Salinity – Our salinity settings variable has three classes:

- Saltwater: areas mapped in MassGIS land cover (2016) as ocean.
- Brackish: areas mapped in DEP wetlands (2005) as salt marsh, areas mapped as open water tidal, brackish, or salt pond (poly_code = 9) in DEP wetlands, and additional areas photo-interpreted as brackish for this project by Mike McHugh at MassDEP.
- Freshwater: anything that is not saltwater or brackish.

Public beaches – MassGIS's marine beaches. Used for the beach pedestrians metric.

Beach off-road vehicles – Area where off-road vehicles congregate and park on beaches were mapped by Nathalie Regis and Mike McHugh at MassDEP for this project. Areas of intensive ORV use on beaches were mapped based on information from DEP and CZM personnel as well as photointerpretation of beaches in the MassGIS DPH marine beaches layer. These data are used for the Beach ORVs metric.

Recreational beach parking lots – Parking lots for access to recreational beaches were photo-interpreted by Nathalie Regis and Mike McHugh at MassDEP for this project. All parking lots that appeared to serve recreational beaches mapped in the MassGIS marine beaches layer were delineated. Data were modified based on review by experts at MassDEP and CZM. These data are used for the beach pedestrians metric.

Salt marsh ditches – Ditches in salt marshes were photo-interpreted for this project by Nathalie Regis and Mike McHugh. This layer is used for the salt marsh ditching metric.

Coastal structures – Seawalls, jetties, groins, bulkheads, revetments, and breakwaters were originally obtained for most of the Massachusetts coast in field surveys by CZM. These surveys omitted some areas where access was not feasible. Omitted areas were completed based on photointerpretation by Nathalie Regis and Mike McHugh using orthophotos and oblique aerial photography. Coastal structures are used in the coastal structures metric.

Boat traffic – Marine and estuarine boat traffic were estimated from three sources: 2012 Automatic Identification Systems (AIS) data, 2007-8 Vessel Monitoring System (VMS) data, and 2010-2012 Recreational Boater Routes (RBR). These layers were combined in a model developed by Marc Carullo (CZM), and Michael McHugh and James Sprague (MassDEP).

Minimum winter temperature, growing season degree-days – Temperature data were obtained by downscaling modeled PRISM weather data via interpolation. Data are 30-year normals centered on 1985.

- The minimum winter temperature settings variable is the minimum of the coldest day in January or February.

- The growing season degree-days settings variable is based on the sum of monthly mean temperatures above a threshold of 10˚ C and below a threshold of 30˚ C.

Layers for hydrologic alterations and nutrient enrichment. Several datalayers were used for the three new stream metrics developed by Elizabeth Homa (Homa et al. 2013). Layers include: minimum annual temperature, mean annual temperature, annual precipitation, December precipitation, humidity (PRISM), MassGIS land use (2005), NLCD imperviousness (National Land Cover Dataset), water discharges (Massachusetts Sustainable Yield Estimator database, USGS), septic systems (1990 U.S. Census), percent sand (NRCS STATSGO soils, 1997), and dam storage (TNC dams layer). We used the original data the regressions models were built on rather than the newest data used elsewhere, as updating the data could have had unknown effects on the models, and some values (such as dam storage) are not available in our newest data.

Ecoregions – EPA ecoregions for Massachusetts are from MassGIS. We modified these data slightly to include all coastal cells. Ecoregions are used for IEI rescaled by ecoregions (IEI_E) and integrated IEI (IEI_I).

Watersheds – Major watersheds are from MassGIS. We modified these data slightly to include all coastal cells. Watersheds are used for IEI rescaled by watersheds (IEI_W) and integrated IEI (IEI_I).

Appendix D: Landscape Metrics

This appendix describes the landscape metrics available in CAPS. These metrics are weighted and combined separately for each community, using the community model listed in Appendix F. Detailed descriptions of the DSL versions of most of these metrics are available at umassdsl.org; see Appendix B for more information.

Metric name	Grid name	Description
Stressor Metrics		
Development & roads		
Habitat loss	habloss	Measures the intensity of habitat loss caused by all forms of development in the neighborhood surrounding the focal cell, based on a logistic function of Euclidean distance. *Data source*: land cover
Watershed habitat loss	whabloss	Measures the intensity of habitat loss caused by all forms of development in the neighborhood upstream from the focal cell, based on the aquatic distance from the focal cell using on a time-of-flow model. *Data source*: land cover, streams, flow direction, watershed resistance
Road traffic	traffic	Measures the intensity of road traffic (based on measured road traffic rates) in the neighborhood surrounding the focal cell, based on a logistic function of distance. *Data source*: land cover, traffic rates
Mowing & plowing	mowplow	Measures the intensity of agriculture in the neighborhood surrounding the focal cell, based on a logistic function of distance. This metric is a surrogate for mowing/plowing rates (which are a direct source of animal mortality). *Data source*: land cover

Metric name	Grid name	Description
Microclimate alterations	edges	Measures the adverse effects of induced (human-created) edges on the integrity of patch interiors; that is, factors that negatively intrude on the patch from its surroundings. The edge effects metric is based on the "worst" edge effect among all adverse edges in the neighborhood surrounding the focal cell, where each adverse edge is evaluated using a "depth-of-edge" function in which the "effect" is scaled using a logistic function of distance. *Data source*: land cover
Pollution		
Road salt	salt	Measures the intensity of road salt application in the watershed above an aquatic focal cell weighted by road class and the modeled "influence value" for each cell, which is the aquatic distance from the focal cell based on a time-of-flow model This metric is a surrogate for road salt application rates. *Data source*: land cover, streams, flow direction, watershed resistance
Road sediment	sediment	Measures the intensity of road sediment production in the watershed above an aquatic focal cell weighted by road class (i.e., size, substrate, gradient) and the modeled "influence value" for each cell, which is the aquatic distance from the focal cell based on a time-of-flow model. This metric is a surrogate for road sediment production rates. *Data source*: land cover, streams, flow direction, watershed resistance

Metric name	Grid name	Description
Nitrogen enrichment	nitrogen	Measures the percent increase in nitrogen in streams due to anthropogenic sources in the watershed of the focal cell. Excess nitrogen can be an important pollutant in freshwater and estuarine streams. This metric is based on an empirical model developed by Elizabeth Homa (Homa et al. 2013). This metric is not available for the Cape and Islands, due to a paucity of empirical data for these hydrologically distinct areas. This metric only applies to streams, not wetlands or lentic waterbodies. *Data source*: land cover, streams, flow direction, watershed resistance, minimum annual temperature, imperviousness, water discharges, percent of households in each town with septic systems.
Phosphorus enrichment	phosphorus	Measures the percent increase in phosphorus in streams due to anthropogenic sources in the watershed of the focal cell. Excess phosphorus can be an important pollutant in estuarine streams. This metric is based on an empirical model developed by Elizabeth Homa (Homa et al. 2013). This metric is not available for the Cape and Islands, due to a paucity of empirical data for these hydrologically distinct areas. This metric only applies to streams, not wetlands or lentic waterbodies. *Data source*: land cover, streams, flow direction, watershed resistance, minimum annual temperature, annual precipitation, water discharges.
Biotic alterations		
Domestic predators	cats	Measures the intensity of development associated with sources of domestic predators (e.g., cats) in the neighborhood surrounding the focal cell, based on a logistic function of distance to development classes. This metric is a surrogate for domestic predator abundance measured directly in the field. *Data source*: land cover

Metric name	Grid name	Description
Edge predators	edgepred	Measures the intensity of development associated with sources of human commensal mesopredators (e.g., raccoons, skunks) in the neighborhood surrounding the focal cell, based on a logistic function of distance to development classes. This metric is a surrogate for mesopredator abundance measured directly in the field. *Data source*: land cover
Invasive plants	badplants	Measures the intensity of development associated with sources of terrestrial and aquatic non-native invasive plants in the neighborhood surrounding the focal cell, based on a logistic function of distance to development classes. This metric is a surrogate for non-native invasive plant abundance measured directly in the field. *Data source*: land cover
Invasive earthworms	worms	Measures the intensity of development associated with sources of non-native invasive earthworms in the neighborhood surrounding the focal cell, based on a logistic function of distance to development classes. This metric is a surrogate for non-native invasive earthworm abundance measured directly in the field. *Data source*: land cover
Hydrological alterations		
Hydrologic alterations	hydroalt	Measures the mean percent change in streamflow due to anthropogenic alterations in hydrology across eleven exceedance probabilities representing a range of low to high annual flows for each focal stream cell. This metric is based on an empirical model developed by Elizabeth Homa (Homa et al. 2013). This metric is not available for the Cape and Islands, due to a paucity of empirical data for these hydrologically distinct areas. *Data source*: land cover, streams, flow direction, minimum annual temperature, mean humidity, mean December precipitation, percent sand, imperviousness, dam storage, water discharges.

Metric name	Grid name	Description
Imperviousness	imperv	Measures the intensity of impervious surface in the watershed above the focal cell, based on imperviousness and the modeled “influence value” for each cell, which is the aquatic distance from the focal cell based on a time-of-flow model. *Data source*: land cover, streams, flow direction, watershed resistance, percent imperviousness
Dams	damint	Measures the number of dams in the watershed above an aquatic focal cell weighted by dam size and the modeled “influence value” for each cell, which is the aquatic distance from the focal cell based on a time-of-flow model. *Data source*: land cover, streams, flow direction, watershed resistance, dams
Coastal metrics		
Salt marsh ditching	ditches	Measures the magnitude of hydrologic alteration leading to loss of water features and/or marsh subsidence around the focal cell due to ditching, based on a standard kernel density estimate of nearby drainage ditches. *Data source*: land cover, photo-interpreted salt marsh ditches
Coastal structures	jetties	Measures the proximity of the focal cell to up-gradient manmade jetty/groin, based on a logistic function of distance to nearest up-gradient jetty/groin; applied only to certain land cover types (e.g., beaches, intertidal flats). *Data source*: land cover, field-checked and photo-interpreted coastal structures
Beach pedestrians	beachpeds	Measures the intensity of beach pedestrian traffic at the focal cell, based on a standard kernel density of pedestrians. *Data source*: land cover, public beaches, photo-interpreted beach parking lots

Metric name	Grid name	Description
Beach ORVs	beachORVs	Measures the intensity of beach ORV traffic based on proximity of focal cell to ORV beaches. *Data source*: land cover, beach ORV parking areas
Boat traffic	boats	Measures the impact related to motion disturbance, noise and boat wakes (rather than more local impacts such as propeller wash or discharges of pollutants). This metric is based on a model developed by Marc Carullo (CZM) and Michael McHugh and James Sprague (MassDEP). *Data source*: land cover, Automatic Identification Systems (AIS) data, Vessel Monitoring System (VMS) data, and Recreational Boater Routes (RBR).
Tidal restrictions	tideres	Measures the magnitude of alteration to the tidal hydrology of the focal cell due to tidal restrictions. *Data source*: land cover, tides settings variable, tide range, estimated tidal restriction points (road/stream and railroad/stream crossings), flow direction.
Resiliency Metrics		
Connectedness	connect	Measures the disruption of habitat connectivity caused by all forms of development between each focal cell and surrounding cells as well as the “resistance” of the surrounding undeveloped landscape, as well as the similarity of surroundings. A hypothetical organism in a highly connected cell can reach a large area of ecologically similar cells with minimal crossing of “hostile” cells. This metric uses a least-cost path algorithm to determine the area that can reach each focal cell, incorporating each cell’s similarity to the focal cell. *Data source*: land cover, ecological settings variables
Aquatic connectedness	aqconnect	An aquatic version of the connectedness metric, measuring connectivity along streams and rivers. Aquatic connectedness includes the resistance from culverts, bridges and dams for organisms that are primarily aquatic. *Data source*: land cover, streams, ecological settings variables

Metric name	Grid name	Description
Similarity	sim	Measures the amount of similarity between the ecological setting at the focal cell and those of neighboring cells, weighted by a logistic function of distance. Similarity is based on the ecological distance between the focal cell and each neighboring cell, where ecological distance is a multivariate distance across all ecological setting variables. *Data source*: land cover, ecological settings variables

Appendix E: Ecological Settings Variables

This appendix lists the ecological settings variables. These 23 spatial variables are meant to represent the important ecological attributes of each point in the landscape. They were selected for their ecological importance, subject to data availability. These variables are used in the Similarity, Connectedness, and Aquatic Connectedness metrics. See Appendix G for their grid names, weights, and parameterization. Detailed descriptions of the DSL versions of most of these settings variables are available at umassdsl.org; see Appendix B for more information.

Biophysical attribute	Biophysical variable (grid name)	Description
Temperature	Growing season degree-days (degdays)	Degree-days is a heuristic tool for predicting vegetation growth; calculated by taking the sum of daily temperatures above a threshold (10°C). *Units & range*: 0-n °days *Source*: PRISM
	Minimum winter temperature (mintemp)	The minimum temperature (°C) reached in the winter sets the northern range limit for many plants and animals. *Units & range*: °C, unbounded *Source*: PRISM
Solar energy	Incident solar radiation (sun)	Solar radiation is a principal determinant of plant growth; calculated based on slope, aspect, and topographical shading. *Units & range*: arbitrary, unbounded *Source*: modeled from DEM and lat/long
Chemical & physical substrate	Soil pH (soilph)	Soil pH measures acidity, which affects nutrient uptake by plants. *Units & range*: 0-14 pH *Source:* NRCS SSURGO and STATSGO soils
	Soil depth (soildepth)	Soil depth (cm) affects communities primarily because shallow soils (usually on steep slopes or ridgetops) limit deep-rooted plants. *Units & range*: 0-n cm *Source:* NRCS SSURGO soils

Biophysical attribute	Biophysical variable (grid name)	Description
	Soil texture (soiltex)	Soil texture, ranging from organic soils through clay to gravelly sand affects plants, many soil-dwelling invertebrates and some vertebrates. *Units & range*: ordinal, 1 (organic) through 6 (coarse textured) *Source:* NRCS SSURGO soils
	Water salinity (salinity)	Salinity measures the salt content of water in aquatic settings and is an important determinant of the ecological community. *Units & range*: in three broad classes: fresh, brackish, and saltwater *Source*: from photo-interpretation (saltwater from DEP wetlands, brackish from DEP)
	Substrate mobility (substrate)	Substrate mobility measures the *realized* mobility of the physical substrate, due to both substrate composition (i.e., sand) and exposure to forces (wind and water) that transport material, and is an important attribute of certain dynamic systems (e.g., coastal dune systems). *Units & range*: an index of mobility, ranging from 1 = stable to 10 = highly mobile *Source*: land cover
	$CaCO_3$ content (calcium)	Calcium content of the soil and water influences buffering capacity (and hence susceptibility to acidification) among other things; calculated based on the composition of the soil and underlying bedrock. *Units & range*: % calcareous at cell (terrestrial) or % calcareous for the watershed (aquatic) *Source*: TNC's lithology (near surface bedrock)

Biophysical attribute	Biophysical variable (grid name)	Description
Physical disturbance	Wind exposure (wind)	Wind exposure measures the exposure to sustained high winds, which can be an important determinant of plant community development under extreme conditions (e.g., Krumholtz vegetation on mountaintops); calculated based on the mean sustained wind speeds at 30 m above ground level using a 200 m resolution model developed for wind energy purposes. *Units & range*: meters per second *Source*: MassGIS wind speed data
	Wave exposure (waves)	Wave exposure measures direct exposure to ocean waves, which can influence physical substrate stability and hence plant community development. *Units & range*: index from none (no wave exposure) to maximum wave exposure (e.g., open ocean) *Source*: derived from custom GIS model that measures the average distance to land from a set of radial vectors emanating outward from the focal cell, scaled by the MassGIS wind power grid
	Steep slopes (slope)	Steep slopes measures the propensity for gravity-induced physical disturbance (e.g., talus slopes). *Units & range*: percent slope (0-infinite) *Source*: derived from DEM
Moisture	Wetness (wetness)	Soil moisture (in a gradient from xeric to hydric). *Units & range*: arbitrary *Source*: Topographic wetness index, using FD8 algorithm, from DEM

Biophysical attribute	Biophysical variable (grid name)	Description
Hydrology	Flow gradient (gradient)	Gradient (percent slope) of a stream determines water velocity, often approximated by categories such as pool, riffle, run, cascade. *Units & range*: % slope, unbounded; 0 = flat *Source*: from DEM and MassGIS stream centerlines
	Flow volume (volume)	Flow volume (watershed size) measures the absolute size of a stream or river. This value is often approximated by stream order. *Units & range*: arbitrary; 0 for non-flowing systems *Source*: log-scaled FD8 flow accumulation, from DEM
	Tidal regime (tides)	In coastal areas, degree of tidal influence. *Units & range*: ranges from 0 for upland/inland areas beyond the reach of storm surges to 1 for areas with daily tides. *Source*: modeled from 5 m DEM, NOAA tide range data, and DEP wetlands
Vegetation	Vegetative structure (structure)	Coarse vegetative structure, from unvegetated through shrubland to closed canopy forest. *Units & range*: 1 to 10, ordinal *Source*: land use
Development	Developed (developed)	Indicator of development. *Units & range*: 0 = undeveloped; 1 = developed *Source*: land use
	Hard development (hard)	Indicator of mostly impervious development. *Units & range*: 0 = undeveloped or mostly pervious development (e.g. orchards, cemeteries); 1 = developed *Source*: land use

Biophysical attribute	Biophysical variable (grid name)	Description
	Traffic rate (traffic)	Traffic is based on a model of the probability of an animal crossing a road being hit given the traffic rate (see Gibbs and Shriver 2002, Conservation Biology 16:1647-1652). *Units & range*: 0-1 *Source*: MassDOT roads layer and custom statistical modeling.
	Impervious (impervious)	Percent impervious surface. *Units & ranges*: 0-100% *Source*: MassGIS impervious layer, upscaled to 30 m
	Terrestrial barriers (tbarriers)	Barriers to terrestrial organisms. *Units & ranges*: 0 to 5, expert-assigned *Source*: MassDOT roads, MassGIS trains
	Aquatic barriers (abarriers)	Barriers to aquatic organisms. *Units & ranges*: 0-1, values for dams, culverts, and bridges *Source*: MassDOT roads, MassGIS trains, MassGIS stream centerlines, NACC road-stream crossing surveys

Appendix F: Community Descriptions

This appendix lists the developed land and natural communities mapped and used in this version of CAPS. An index of ecological integrity is estimated for each of the natural communities (except bare land and ocean). Remember that IEI is scaled by comparing each cell in a community to other cells in the same community, thus IEI must be interpreted in terms of communities. Descriptions of classes from NOAA's C-CAP are paraphrased from their land cover classification scheme (https://coast.noaa.gov/data/digitalcoast/pdf/ccap-class-scheme-highres.pdf). See Appendix I for the grid codes used for each of these classes in CAPSland.

Developed land

Buildings (MassGIS roofprints, MassGIS 2016 land use) – we combined roofprints with land use to map five classes of buildings: commercial, industrial, agricultural, residential, recreational, and public buildings.

Pavement (Impervious in C-CAP) – typically parking lots or other extensive paved areas. We map buildings and roads separately.

Developed open space (C-CAP) – areas with a mixture of some constructed material, but mostly managed grasses or low-lying vegetation, maintained by human activity. Constructed surfaces account for 20% or less. Developed open space usually represents managed semi-natural space such as lawns, parks, and cemeteries.

Roads (MassDOT) – we map five classes of roads: expressway, primary highway, secondary highway, light-duty road, and unpaved road.

Railroads (MassGIS) – active railroads, abandoned railbeds, and rail trails, mapped separately.

Bridge or culvert – road-stream crossings from North Atlantic Aquatic Connectivity Collaborative (NAACC) represent bridges or culverts.

Dam – dams from Northeast Aquatic Connectivity Assessment Project (NACAP) version 2 were (carefully) moved a short distance to our stream centerlines.

Natural communities

Forest (Deciduous, Mixed, or Evergreen forest in C-CAP) – areas dominated by trees generally greater than 5 m tall and greater than 20% vegetative cover, with any combination of deciduous and coniferous species.

Shrubland (Scrub/shrub in C-CAP) – areas dominated by shrubs less than 5 m tall, with canopy typically greater than 20% of total vegetation, including shrubs, early successional trees, and trees stunted by environmental conditions.

Cropland (Cultivated crops in C-CAP) – areas intensely managed for the production of annual crops, which account for greater than 20% of total vegetation, as well as actively tilled land.

Pasture (Pasture/hay in C-CAP) – areas of grasses, legumes, or a mixture planted for grazing or the production of hay or seed crops, typically perennial and not tilled. Such vegetation accounts for greater than 20% of total vegetation.

Grassland (Grassland/herbaceous in C-CAP) – areas dominated by graminoid or herbaceous vegetation, generally greater than 80% of total vegetation, not subject to intensive management but can be utilized for grazing. Areas mapped as grasslands are usually some form of developed open space. As natural grasslands are rare in mainland Massachusetts, we remapped grasslands to developed open space except on the Cape and Islands.

Bare land (Barren land in C-CAP) – areas of bedrock, scarps, talus, slides, glacial debris, gravel pits, with vegetation generally covering less than 10%. Typically includes anthropogenic edges and beaches. We remapped barren land that falls on or adjacent to coastal beach, sea cliff, or ocean in 2005 DEP wetlands as beach or mudflat. **We do not treat bare land as a natural community, as it is most often of anthropogenic origin in Massachusetts.**

Forested wetland (Palustrine forested wetland in C-CAP) – freshwater-tidal and nontidal wetlands dominated by woody vegetation greater than 5 m tall, with vegetation coverage greater than 20%.

Shrub swamp (Palustrine scrub/shrub wetland in C-CAP) – freshwater tidal and nontidal wetlands dominated by woody vegetation less than 5 m tall, with vegetation coverage greater than 20%, including shrubs, early successional trees, and trees stunted by environmental conditions.

Marsh (Palustrine emergent wetland [persistent] in C-CAP) – freshwater tidal and nontidal wetlands dominated by persistent emergent vascular plants or mosses, with vegetation coverage greater than 80%. Plants generally remain standing until the next growing season.

Vernal pool – Small seasonal pools from the Natural Heritage and Endangered Species Programs Potential Vernal Pools layer. We used this layer to capture small wetlands that were not mapped by 2005 DEP wetlands. We placed a one cell (30 × 30 m) vernal pool on any upland where a potential vernal pool fell, after moving potential vernal pool points out from under road cells for roadside vernal pools. Thus, our vernal pool community primarily represents small upland vernal pools. This data layer has many errors of omission (especially pools under conifer cover) and errors of commission (small permanent ponds and sometimes shadows in aerial photos), but it's the only comprehensive source for this important ecological community.

Pond – Ponds are nonflowing unvegetated waterbodies < 8 ha.

Lake – Lakes are nonflowing unvegetated waterbodies > 8 ha.

Streams, by order and gradient – Streams are mapped by approximate order (first through fifth and higher) and gradient (low vs. high). Streams are derived from open water in 2016 MassGIS land cover, which we split between lentic and lotic. Approximate orders are defined by selecting cutpoints of watershed area based on a series of logistic regressions to Strahler stream order from centerline data. All streams with watershed areas larger than the 5th order cutpoint were lumped. Gradient was split between low (flatwater, pool-riffle, plane-bed) and high (step-pool and cascade) at 3% gradient.

Salt marsh (Estuarine emergent wetland in C-CAP) – tidal wetlands dominated by erect, rooted, herbaceous hydrophytes (excluding mosses and lichens) in tidal areas with salinity of at least 0.5%. Total vegetation coverage is at least 80%, dominated by perennial plants.

Beach or mudflat (Unconsolidated shore in C-CAP) – silt, sand, or gravel subject to inundation and redistribution due to action of water.

Coastal dune (coastal dune, barrier beach-coastal dune, or barrier beach system in 2005 DEP wetlands and bare land or developed open space in C-CAP) – coastal dunes are generally sandy or lightly vegetated, identified as dunes in aerial photographs by DEP wetlands. Vegetated areas in dunes are mapped as grasslands.

Estuarine forested wetland (Estuarine forested wetland in C-CAP) – tidal wetlands with salinity of at least 0.5% dominated by woody vegetation greater than 5 m tall, with vegetation coverage greater than 20%.

Estuarine shrub swamp (Estuarine scrub/shrub wetland in C-CAP) – tidal wetlands with salinity of at least 0.5% dominated by woody vegetation less than 5 m tall, with vegetation coverage greater than 20%, including shrubs, early successional trees, and trees stunted by environmental conditions.

Salt pond/bay – Lentic waterbodies that coincide with “brackish” in the salinity settings variable.

Estuaries, by order – Estuaries are mapped by order (but not gradient) using the same process we used for streams. Estuaries are derived from lotic open water that corresponds to “brackish” in the salinity settings variable.

Ocean – 2005 DEP wetlands “open water ocean” (poly_code = 10), adjusted to include adjacent open water in MassGIS 2016 land use. Note that although ocean is a natural community, **CAPS does not run metrics or build an IEI for ocean.**

Appendix G: Community Model Parameters

This table gives the community integrity models. The IEI for each community is a weighted combination of metrics selected by expert teams. Weights shown here are the percent contribution of each metric to each community (rounded to whole percent), thus rows sum to 100.

	Development & roads					Pollution				Biotic alterations				Hydrologic alterations			Resiliency			Coastal					
	habloss	whabloss	traffic	mowplow	edges	salt	sediment	nitrogen	phosphorus	cats	edgepred	badplants	worms	hydroalt	imperv	damint	sim	connect	aqconnect	ditches	jetties	beachpeds	beach ORVs	boats	TR
Forest	10	0	10	0	5	0	0	0	0	0	5	10	10	10	0	0	15	25	0	0	0	0	0	0	0
Shrubland	20	0	10	0	0	0	0	0	0	0	5	10	10	5	0	0	15	25	0	0	0	0	0	0	0
Grassland	20	0	10	0	0	0	0	0	0	0	5	10	10	5	0	0	15	25	0	0	0	0	0	0	0
Forested wetland	9	5	9	5	5	5	5	0	0	0	0	5	9	5	0	0	9	19	2	0	0	0	0	0	9
Estuarine forested wetland	9	5	9	5	5	5	5	0	0	0	0	5	9	5	0	0	9	19	2	0	0	0	0	0	9
Shrub swamp	11	11	11	5	0	5	5	0	0	0	0	5	0	0	5	0	11	19	3	0	0	0	0	0	11
Estuarine shrub swamp	11	11	11	5	0	5	5	0	0	0	0	5	0	0	5	0	11	19	3	0	0	0	0	0	11
Marsh	10	15	10	5	0	5	5	0	0	0	0	5	0	0	5	0	10	15	5	0	0	0	0	0	10
Vernal pool	13	0	13	6	0	13	6	0	0	0	0	6	0	0	6	0	13	25	0	0	0	0	0	0	0
Lake	11	22	6	6	0	6	6	0	0	0	0	6	0	0	6	0	11	11	11	0	0	0	0	0	0
Pond	11	21	11	5	0	5	5	0	0	0	0	5	0	0	5	0	11	21	0	0	0	0	0	0	0
Stream (1st)	9	5	5	5	5	0	5	9	2	3	0	5	0	0	9	5	0	9	18	0	0	0	0	0	9
Stream (2nd)	9	5	5	5	5	0	5	9	2	3	0	5	0	0	9	5	0	9	18	0	0	0	0	0	9
Stream (3rd)	9	9	4	4	4	0	4	9	1	3	0	4	0	0	9	4	0	4	22	0	0	0	0	0	9
Stream (4th)	9	9	4	4	0	0	4	9	1	3	0	4	0	0	9	9	0	4	22	0	0	0	0	0	9
Stream (5th)	8	12	4	4	0	0	4	9	1	3	0	4	0	0	8	8	0	4	21	0	0	0	0	0	8
Estuary (1st)	7	7	3	2	3	4	6	6	7	0	2	1	2	0	7	5	5	10	9	2	3	1	0	3	6
Estuary (2nd)	6	6	3	2	4	4	6	6	7	0	1	1	2	0	7	4	5	10	9	2	3	1	0	3	7
Estuary (3rd)	5	6	3	1	3	3	5	6	7	0	1	1	2	0	7	4	6	10	13	2	3	1	0	4	7
Estuary (4th)	6	5	3	1	3	3	5	6	7	0	1	1	2	0	6	5	5	11	14	2	3	0	0	5	7
Estuary (5th)	5	5	3	2	2	3	5	6	7	0	1	1	1	0	6	6	7	12	14	2	3	0	0	6	6
Coastal dune	9	1	5	0	3	1	1	0	0	0	5	3	4	0	4	0	13	14	0	1	13	11	12	1	0
Beach or mudflat	7	2	4	0	3	0	1	0	0	0	4	6	2	0	3	0	9	11	0	0	14	12	15	7	1
Salt marsh	7	4	3	2	3	2	4	0	0	0	3	3	6	0	5	5	8	11	0	9	7	2	1	5	11
Salt pond or bay	9	8	2	0	4	3	7	0	0	0	0	1	0	0	6	5	13	13	0	3	5	0	1	15	6

Appendix H: Settings Variable Parameters

This appendix lists ecological settings variables (described in Appendix D) with their GIS grid names and information on how they are used in the CAPS model. Ecological settings variables are used to determine resistance in Connectedness and Aquatic connectedness, and to determine ecological distance in Connectedness, Aquatic Connectedness, and Similarity. Settings variables are combined using the weights listed below for resistance and distance.

Settings variable	Grid name	Mixing[1]	Resistance	Distance
Temperature				
Growing season degree-days	degdays		0.3	1
Minimum winter temperature	mintemp		0.1	1
Solar energy				
Incident solar radiation	sun		0.1	1
Chemical & physical substrate				
Soil pH	soilph		0.05	0.5
Soil depth	soildepth		0.05	0.5
Soil texture	soiltex		0.05	0.5
Water salinity	salinity	inflows	4	3
Substrate mobility	substrate		2	2
CaCO3 content	calcium	inflows	0.1	1
Physical disturbance				
Wind exposure	wind		0.1	1
Wave exposure	waves		0.5	1
Steep slopes	slope		1	1
Moisture				
Wetness	wetness	inflows	4	8
Hydrology				
Flow gradient	gradient	pond	1	2
Flow volume	volume	sumlogs	5	5
Tidal regime	tides		2	2
Vegetation				
Vegetative structure	structure		3	8
Development				
Developed	developed		1	20
Hard development	hard		2	1000
Traffic rate	traffic		40	
Impervious	imperv		5	
Terrestrial barriers	tbarriers		15	
Aquatic barriers	abarriers		100	

[1] Settings variables may be mixed for water bodies and wetlands in several different ways:

inflows: all cells in a water body or wetland get the sum of inflowing values

sumlogs: the same as inflows for log-scaled variables

pond: all cells in a water body or wetland get the mean of all non-missing values

Appendix I: Land cover Grid Classification

The following are land cover classes used in the CAPSland land cover grid. See Appendix F for detailed descriptions.

11 Commercial building
12 Industrial building
13 Agricultural building
14 Residential building
15 Recreational building
16 Public building
20 Pavement
30 Developed open space

41 Expressway
42 Primary highway
43 Secondary highway
44 Light duty road
45 Unpaved road
51 Railroad

52 Abandoned railbed
53 Rail trail
60 Bridge or culvert
61 Dam

100 Forest
110 Shrubland
120 Cropland
121 Pasture
122 Grassland
130 Bare land

141 Forested wetland
142 Shrub swamp
143 Marsh
144 Vernal pool
145 Pond
146 Lake

151 Stream (1st) low
152 Stream (1st) high
161 Stream (2nd) low
162 Stream (2nd) high
171 Stream (3rd) low
172 Stream (3rd) high
181 Stream (4th) low
182 Stream (4th) high
191 Stream (5th) low
192 Stream (5th) high

201 Salt marsh
202 Beach or mudflat
203 Coastal dune
204 Estuarine forested wetland
205 Estuarine shrub swamp
206 Salt pond or bay
211 Estuary (1st)
212 Estuary (2nd)
213 Estuary (3rd)
214 Estuary (4th)
215 Estuary (5th)

220 Ocean

Appendix J: GIS Data Directory

Data organization. All CAPS results and many intermediate results are available for download. This section provides links to the various versions of IEI, the CAPS land cover, results of individual metrics, and settings variables. Data are available in grouped .zip files, listed below.

Data formats. With this release, we're supplying all raster files as geoTIFFs. GeoTIFFs have several advantages over Arc grids: they are typically more space-efficient, they can be viewed in most image viewers and browsers as well as with GIS software, they can contain display formats intrinsically rather than requiring a separate application-specific legend, and most importantly, geoTIFF is a public domain format, as opposed to ESRI's proprietary format. As open-source GIS software (such as QGIS) becomes more sophisticated and stable, we anticipate many users will migrate to open source GIS. To support this migration, we are now making our data available in public domain formats such as geoTIFF.

Scaling. IEI is scaled by percentile for each community, represented by an index that runs from 0 (low integrity) to 1 (high integrity). Metrics and settings grids are scaled in original units, unique to each grid. The CAPS final land cover, capsland, represents land cover classes using integer classes (see Appendix H); it has an interpretable color pallette.

The coordinate reference system for all data is Massachusetts mainland State Plane, NAD83, matching the projection used by most data on MassGIS.

Basic results

These are the most basic results, for those who want immediate gratification. This .zip file consists of two files in geoTIFF format:

iei_i	CAPS Integrated IEI (scaled 0-1)
capsland	CAPS land cover grid

http://jamba.provost.ads.umass.edu/web/masscaps/basic.zip (48 MB)

Standard results

These results contain all four versions of the IEI, as well as land cover. IEI is scaled from 0 (low integrity) to 1 (high integrity).

iei	CAPS statewide IEI
iei_e	CAPS ecoregion IEI
iei_w	CAPS watershed IEI

iei_i	CAPS Integrated IEI
capsland	CAPS land cover grid

http://jamba.provost.ads.umass.edu/web/masscaps/standard.zip (126 MB)

Five color integrated IEI

The grid used to produce the IEI town maps ("areas of potential high ecological integrity") are available in a geoTIFF. This grid is the top 50% integrated IEI, displayed in five color gradients (green for forests, orange for nonforested uplands, yellow-brown for coastal uplands, blue for freshwater wetland and aquatic, and cyan for coastal wetlands). The values in this grid encode the color; they are not meaningful otherwise.

http://jamba.provost.ads.umass.edu/web/masscaps/fivecolor.zip (7 MB)

DEP Habitat of Potential Regional or Statewide Importance

The DEP Massachusetts Habitat of Potential Regional and Statewide Importance data are available is simply the top 40% of integrated IEI (iei_i > 0.6); cells with a value of 1 are within DEP Habitat of Potential Regional and Statewide Importance.

http://jamba.provost.ads.umass.edu/web/masscaps/depiei.zip (1 MB)

Raw metrics

These .zip files contain all raw metrics results. See Appendix C for a list of metrics, grid names, and brief descriptions, and Appendix F for the contribution of each metric to each community's IEI. Raw metrics are scaled in original units, unique to each metric. Integrity increases with decreasing values of stressor metrics, and increasing values of resiliency metrics. See Appendix D for grid names used for metrics.

http://jamba.provost.ads.umass.edu/web/masscaps/metrics.zip (1.1 GBB)

Settings variables

These .zip files contain mixed (unscaled) settings variables. See Appendix D for a list and brief description of settings variables, and Appendix G for grid names and weights. Settings variables are scaled in original units, unique to each variable. See Appendix E for grid names used for settings variables.

http://jamba.provost.ads.umass.edu/web/masscaps/settings.zip (823 MB)

Additional data

A large collection of additional GIS data for Massachusetts are available from MassGIS (https://www.mass.gov/orgs/massgis-bureau-of-geographic-information). Many of these data layers, such as town boundaries, ecoregions, watersheds, aerial photos, and USGS topographic maps are extremely helpful for viewing and interpreting CAPS results.

Running CAPS for Massachusetts requires a large number of additional intermediate data sources not linked above. These data are available on request.