Coastal Conservation Prioritization Using the Conservation Assessment and Prioritization System (CAPS) and Designing Sustainable Landscapes (DSL)

A Report to The Trustees of Reservations

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Introduction

Massachusetts has an extensive coastline with an abundance of salt marshes, dunes, natural shorelines, coastal bays and tidal creeks. These coastal ecosystems provide valuable wildlife habitat, spawning and nursery habitat for fish, buffers from coastal storms, and recreational and economic opportunities for residents and visitors. Massachusetts is also one of the most densely populated states in the country, with a majority of its population concentrated along the coast. Conserving coastal ecosystems is a challenge given the impact of current land and water use, the potential for continued coastal development, and rising sea level and other impacts of global warming.

At the request of The Trustees of Reservations (The Trustees), the Landscape Ecology Lab at UMass Amherst conducted an analysis of coastal ecosystems to identify areas of high ecological integrity, and to provide information that will aid in the prioritization of conservation action to maintain healthy coastal ecosystems well into the future. This analysis focuses on six coastal systems: salt marshes, rocky intertidal shores, coastal beaches, coastal dunes, vegetated dunes, and sea cliffs.

Overview

Many criteria can be used to prioritize coastal areas for land conservation. One of the more difficult criteria is ecological value. In this project, we used data from The Nature Conservancy's Identifying Resilient Coastal Sites analysis, the Conservation Assessment and Prioritization System (CAPS), the Designing Sustainable Landscapes (DSL) project, and other available GIS data to create a system for use by The Trustees to set priorities for coastal land conservation.

We generated "conservation units" that targeted high integrity coastal ecosystems along the Massachusetts coast and accompanying buffers to protect their value. We combined ecosystem-based conservation units into a set of merged units that spanned the targeted systems. We also calculated an extensive suite of metrics characterizing the ecological integrity, accessibility, coastal resilience, mean parcel size, percent of the conservation unit already conserved, and the likely impact of development on integrity for both system-specific and merged units. Finally, for the merged conservation units we quantified the benefit of land conservation within the unit in terms of development impacts on target systems avoided due to conservation action.

Conservation Assessment and Prioritization System

The Conservation Assessment and Prioritization System (CAPS) is a conservation planning system for Massachusetts from the Landscape Ecology Lab at UMass. CAPS is a suite of computer programs and an approach to prioritizing land for conservation based on the assessment of ecological integrity for various ecological communities (e.g. forest, salt marsh, headwater stream) within an area. Various metrics are applied to the landscape and then integrated in weighted linear combinations, creating models for predicting ecological integrity. This process results in an Index of Ecological Integrity (IEI) for each point in the landscape based on models constructed separately for each ecological community (McGarigal et al. 2018a). Because CAPS provides a quantitative assessment of ecological integrity, it can be used for comparing various scenarios. In essence, scenario analysis involves running CAPS separately for each scenario, and comparing results to determine the loss (or gain) in IEI units. See umasscaps.org for documentation and data.

Designing Sustainable Landscapes and the SPRAWL Model

Designing Sustainable Landscapes is a region-wide conservation modeling effort by the UMass Landscape Ecology Lab, funded by the U.S. Fish and Wildlife Service (USFWS). It includes CAPS-IEI, habitat for focal species, a conservation design, and SPRAWL, an urban growth model for 13 states in the Northeastern U.S. SPRAWL is a nonstationary model that gives both probability of development and stochastic instances of development by decade through 2080 (McGarigal et al., 2018b). See umassdsl.org for documentation and data.

TNC Coastal Resilience

Coastal Resilience data are from The Nature Conservancy's assessment of relative resilience or vulnerability of coastal sites, identifying those most likely to support biological diversity and ecological function in the face of climate change (Anderson and Barnett, 2017). A key component of resilient coastal sites is the amount of space available for habitat migration in response to sea level rise.

Other Data Used

Target Coastal Ecosystems – Distribution of target coastal ecosystems is from the CAPS landcover classification and largely based on MassDEP Wetlands (2005) obtained from MassGIS.

Beach Access – Massachusetts Office of Coastal Zone Management (CZM, 2017) coastal access linear features viewable on MORIS: http://maps.massgis.state.ma.us/map_ol/moris.php

Parcels – Parcel size calculated from a 30-meter raster that was derived from the Mass GIS vector parcel data aggregated across all towns that intersect the conservation units

Protected Open Space – Permanently protected open space based on MassGIS's inventory (EOEEA, 2019)

Scenic Resources – From the Scenic Landscape Inventory polygons produced by the Massachusetts Landscape Inventory Project (DCR, 1982). https://docs.digital.mass.gov/dataset/massgis-data-scenic-landscape-inventory

Target Coastal Ecosystems (Target Systems)

This analysis primarily focuses on five coastal ecosystems: salt marsh, dune (including vegetated dune and coastal dune), coastal beach, sea cliff, and rocky intertidal shore. We used the CAPS Index of Ecological Integrity (IEI) in a core building process similar to that used in the DSL project, to create conservation units that included high integrity areas for one or more of the five target ecosystems. We created system-specific conservation units for salt marsh, dune, and sea cliff, which were then merged to create multi-system conservation units. Rocky intertidal shores and coastal beaches are poorly represented in the raster format used by CAPS and thus were of limited value for creating multi-system conservation units. However, coastal beaches and rocky intertidal shores were used in the generation of salt marsh, dune and sea cliff conservation units, as well as the multi-system conservation units derived from them. Coastal beaches and rocky intertidal shores were also used in the generation of metrics for prioritizing conservation units.

Merged Coastal Ecosystem Conservation Units

We created conservation units to include: (1) areas of highest ecological integrity for each targeted system, (2) surrounding areas of high to moderately high integrity, and (3) land that serves to buffer these high and moderately high integrity areas to protect high-integrity target ecosystems. To build the units we first created a selection index from CAPS IEI for each target coastal system (except rocky intertidal shore). To convert IEI to a selection index for each target system used (Table 1) we logistically rescaled IEI within the target system such that values at the high end of the IEI range were pushed towards 1.0 and those at the low end of the range were pushed towards zero. This has the effect of lessening the differences between very good scores and the best scores within that system, while also reducing the values of lower-scored cells. As a result, scores at the high end were equalized somewhat by the logistic transformation.

Next, the IEI scores of other target coastal systems (not the current target but other target coastal systems) were multiplied by 0.9 and the IEI scores of all remaining ecosystems (e.g. forest, shrub swamps) were multiplied by 0.8. The purpose of this down-weighting process was to ensure that the selection index prioritized the target system most, other coastal systems next, and other ecosystems a little less. For dunes, the process was modified slightly in that both dune systems (coastal and vegetated) were rescaled with the logistic function, beaches were used at their original values (not logistically rescaled, nor multiplied by 0.9), while the remaining coastal systems (salt marsh, sea cliff and rocky intertidal shore) were multiplied by 0.9 and other ecosystems multiplied by 0.8.

We started the core building process by identifying potential "seeds" by selecting all cells for a given target system with a selection index score greater than 0.9. We then dropped those seeds (contiguous cells) that were below a size threshold that varied by system (Table 1). We applied a resistant kernel process to grow a core outward from the remaining seeds, spreading more through high scoring cells (low resistance) than cells with low selection index values (high resistance). The resistant kernel we used had a Gaussian decay with a bandwidth calibrated to each target system (Table 1).

The core building process resulted in four sets of cores, each targeting a particular coastal ecosystem, but also including areas of generally high value for other target coastal systems. These cores were each buffered by including land (both developed and undeveloped) within a fixed 500 m distance, resulting in system-specific conservation units for salt marshes, dunes, sea cliffs and coastal beaches. Finally, the system-specific units were merged by coalescing any touching or overlapping units, resulting in multi-system conservation units. In this last process, system-specific conservation units for coastal beach were excluded, as we felt that the linear nature of the beaches were poorly represented in the raster GIS data and subject to spurious fragmentation when represented as cells rather than polygons. Coastal beaches and rocky intertidal shores were used in the generation of salt marsh, dune and sea cliff conservation units and thereby were included in multi-system conservation units. Using this process, we created 71 conservation units based on a statewide version of CAPS IEI (Figure 1).

Data generated in our analysis of conservation units are available as CSV files (Appendix A) and shapefiles (Appendix B).

Table 1. Systems and core-building parameters: the four types of system conservation units, land cover types they targeted, minimum seed size, bandwidth (the standard deviation of the Gaussian resistant kernel used to grow the core), and whether the system-specific conservation unit was included in merged multi-system conservation units. Generally, for systems that tend to occur in larger patches, the required number of cells to retain a seed and the bandwidth were both larger.

Target System	Land Cover Types	Size Threshold (ha)	Bandwidth (m)	Included in Merged Conservation Units?
Salt marsh	Saltmarsh	3.6	2000	Yes
Dune	Vegetated dune Coastal dune	0.9	1000	Yes
Sea cliff	Sea cliff	0.45	1000	Yes
Coastal Beach	Coastal beach	0.45	1000	No

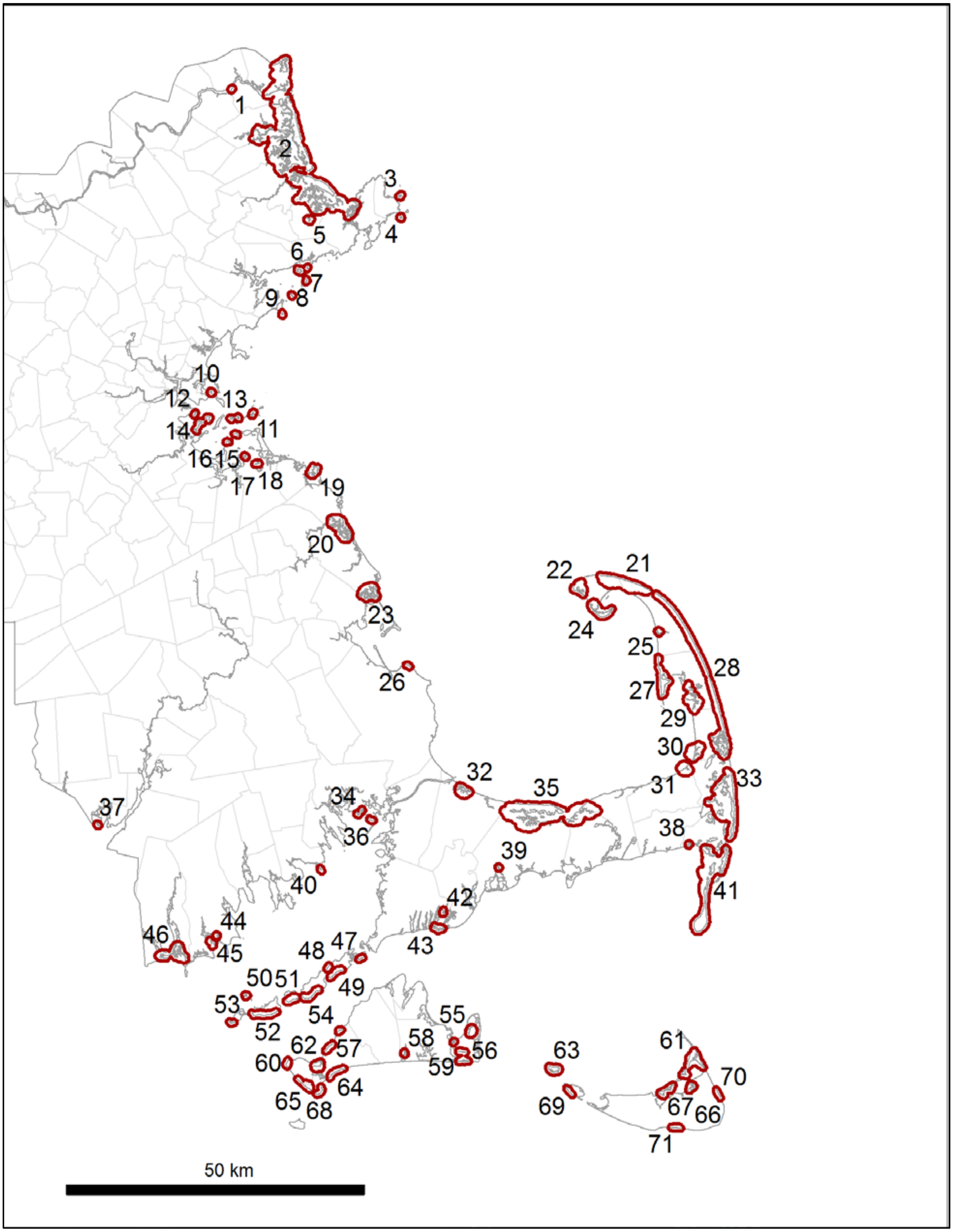

Figure 1. Merged Conservation Units created using CAPS statewide IEI numbered 1 through 71 consecutively from north to south. Their IDs are these numbers appended to the prefix "S-M-".

Identifying Priorities for Conservation

Prioritization Based on Ecological Value

One simple approach for prioritizing conservation units for conservation action is to focus on units with high IEI in the target systems or high Coastal Resilience scores (for those cells that had Coastal Resilience values). The process for creating conservation units ensures that all will contain high quality habitat for the target systems. Yet, it is still possible to rank the units relative to each other based on Ecological Integrity (IEI) or Coastal Resilience (Figure 2). In calculating Mean IEI scores for conservation units, we used squared IEI. Squaring IEI before calculating Mean IEI and other, related statistics has the effect of putting more relative weight on areas with high IEI values. Results for *Mean Squared IEI* and ranked order of conservation units based on *Mean Squared IEI* are presented in Figure 3.

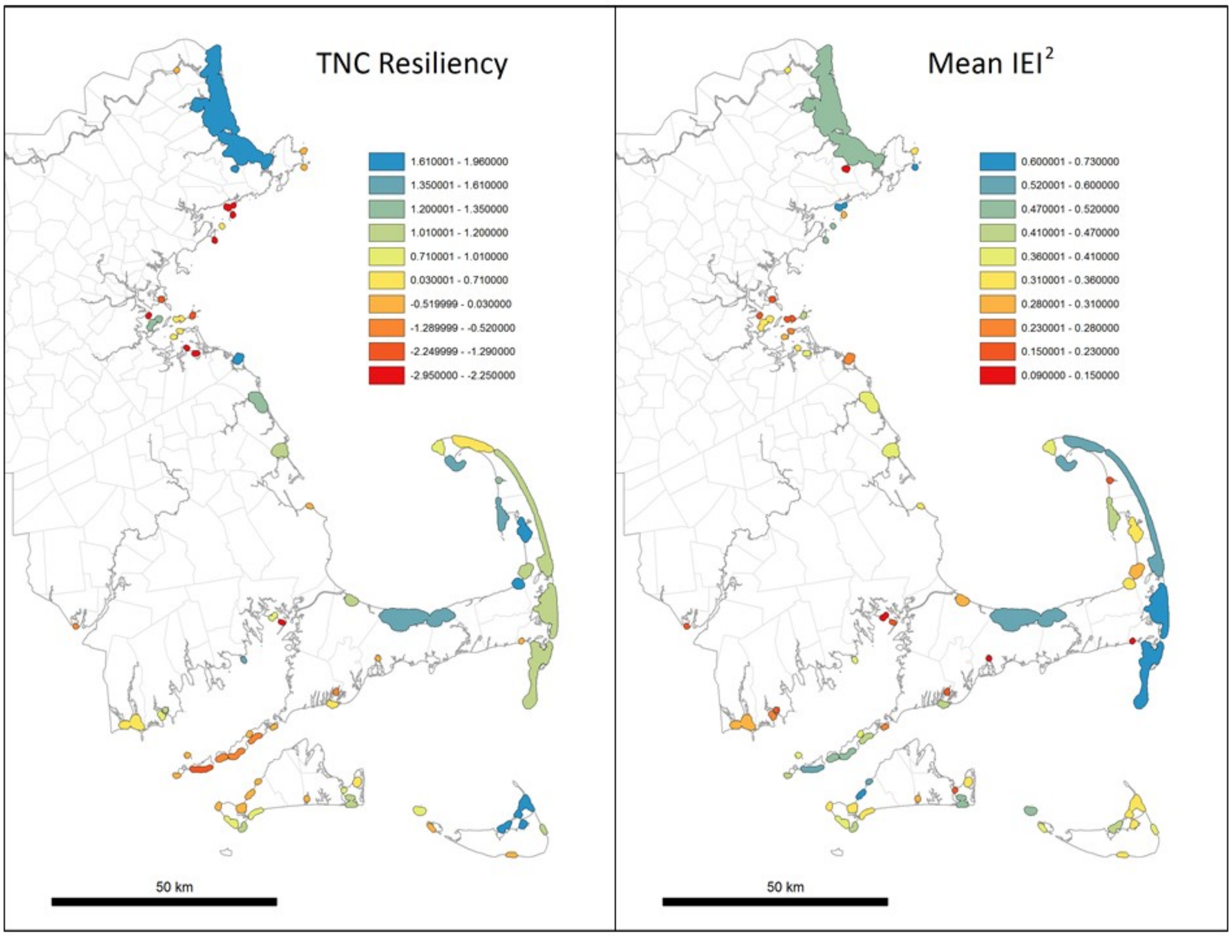

Figure 2. Mean Coastal Resilience *and* Mean Squared IEI *scores for Conservation Units. High scoring units are in blue; low scoring units are in red.*

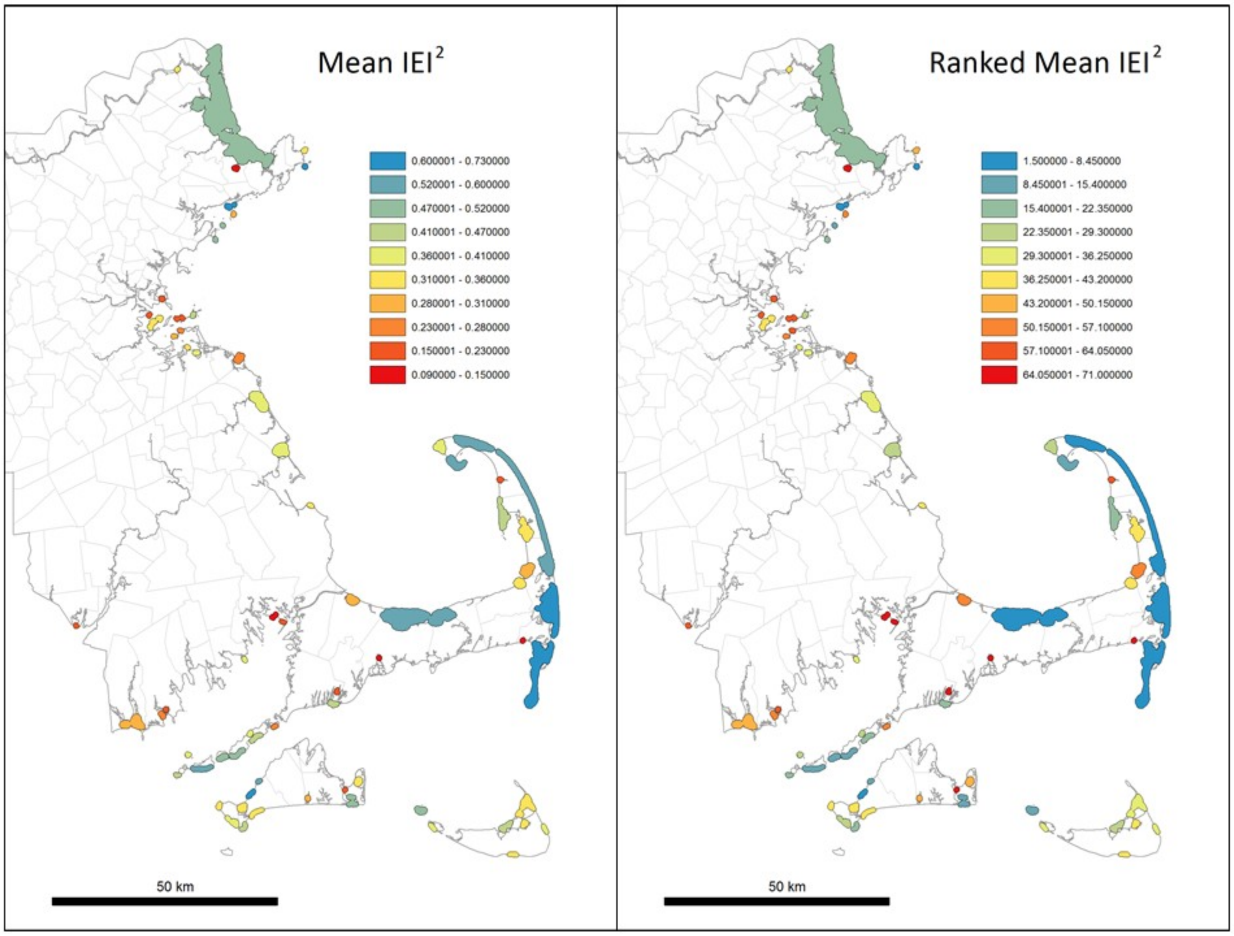

Figure 3. Conservation units scored by Mean Squared IEI *(left) and color-coded by rank order based on* Mean Squared IEI *scores (right). High scoring units are in blue; low scoring units are in red.*

One potentially undesirable effect of using *Mean Squared IEI* for entire conservation units is that those units often include adjacent areas of open water (bays, salt ponds, rivers, lakes, ponds, and open water portions of estuaries) that may be less of a priority for conservation efforts. To address this issue, we created a new metric, "*Density*," summing squared IEI for the target systems within each conservation unit and dividing by the number of non-water cells in the unit. We then rescaled *Density* to create "*Importance*." *Importance* is *Density* divided by the mean *Density* for the target systems observed across all conservation units. It has a theoretical minimum value of zero (a *Mean Squared IEI* of zero for the unit); there is no upper bound. An *Importance* value of 1 indicates that the conservation unit's *Density* equals the mean *Density* for all units; values above 1 indicate above average *Importance* (Figure 4).

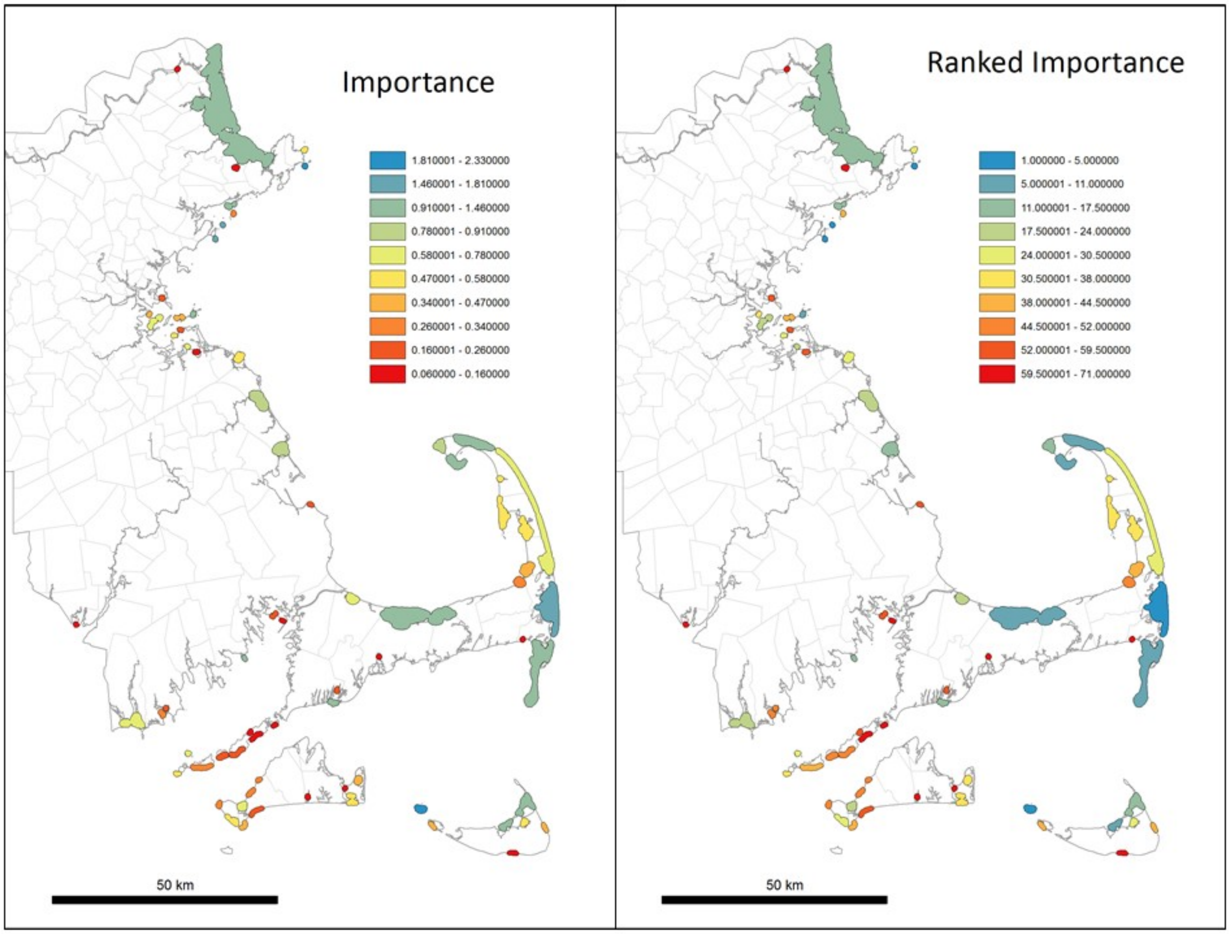

Figure 4. Conservation units scored by Importance *scores (left) and color-coded by rank order based on* Importance *scores (right). High scoring units are in blue; low scoring units are in red.*

Conservation units ranked by *Mean Squared IEI* and *Importance* are quite similar, but with some notable differences, for example Old Harbor (Sandwich), Great Island (Wellfleet), and Outer Cape-Nauset Harbor units, and units on the Elizabeth Islands, Martha's Vineyard, and Nantucket. (Figure 5). Because we are dividing by the number of non-water cells, the value of small islands are elevated as their buffers are mostly ocean and consequently, have few non-target, non-water cells within the conservation units. This is however, a real advantage of islands - you don't have to protect as much buffer to protect the target coastal ecosystems they contain.

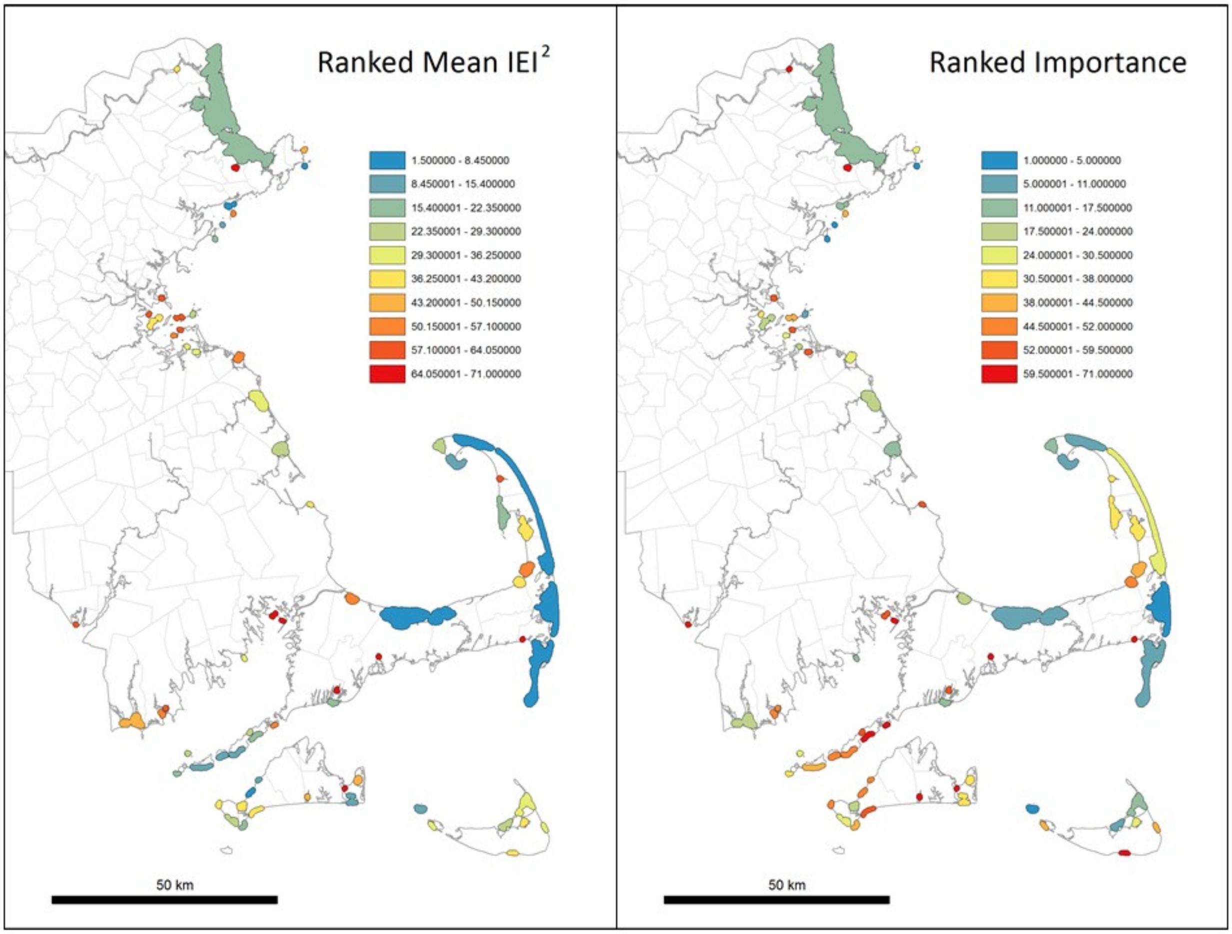

Figure 5. Conservation units color-coded by rank order based on Mean Squared IEI *(left) and* Importance *scores (right). High scoring units are in blue; low scoring units are in red.*

Prioritization Based on Ecological Value and Impact of Future Development

Another way to prioritize conservation units for land conservation is to consider how vulnerable those conservation units are to development. Development within conservation units would result in indirect effects that degrade adjacent target coastal systems. Focusing conservation activities on conservation units with a high percentage of at-risk buffer may be a more effective strategy than targeting conservation units with a low risk of being developed.

We used the DSL SPRAWL model to predict future coastal development over a 60-year period (through 2080) and used this to estimate the degradation of coastal ecosystems (reduction in ecological integrity) that would result from that development. The resulting metric, "*Impact*," quantifies the change in target system IEI scores resulting from future development, assuming that no additional land within conservation units is protected. We did not allow development in any of the target coastal systems as they were deemed to be undevelopable. Similarly, we excluded development in legally protected open space based on Mass GIS's inventory (EOEEA, 2019). *Impact* quantifies the effect of expected development over a 60-year period on IEI, but does not include sea level rise or climate change.

A second metric, "*Conservation Effect*" quantifies the degree to which adverse impacts of future development can be avoided by protecting all undeveloped land within conservation units. It is the absolute reduction in *Impact* across the six coastal classes in the conservation unit observed when we conserve the conservation unit. We calculated *Impact* for the projected landscape relative to the current condition (*Full Impact*) and we calculated impact for future landscapes in which each conservation unit was in turn protected from development (*Alternate Impact)*. *Conservation Effect* is the calculated reduction in *Impact* to target coastal systems resulting from the protection of buffering land within conservation units (*Full Impact – Alternate Impact*). Conservation units can be prioritized by either *Conservation Effect* or the rank order of conservation units based on *Conservation Effect* (Figure 6). Units with a high *Conservation Effect* score are more likely to suffer greater loss of ecological integrity due to future development within the units (but outside of target systems).

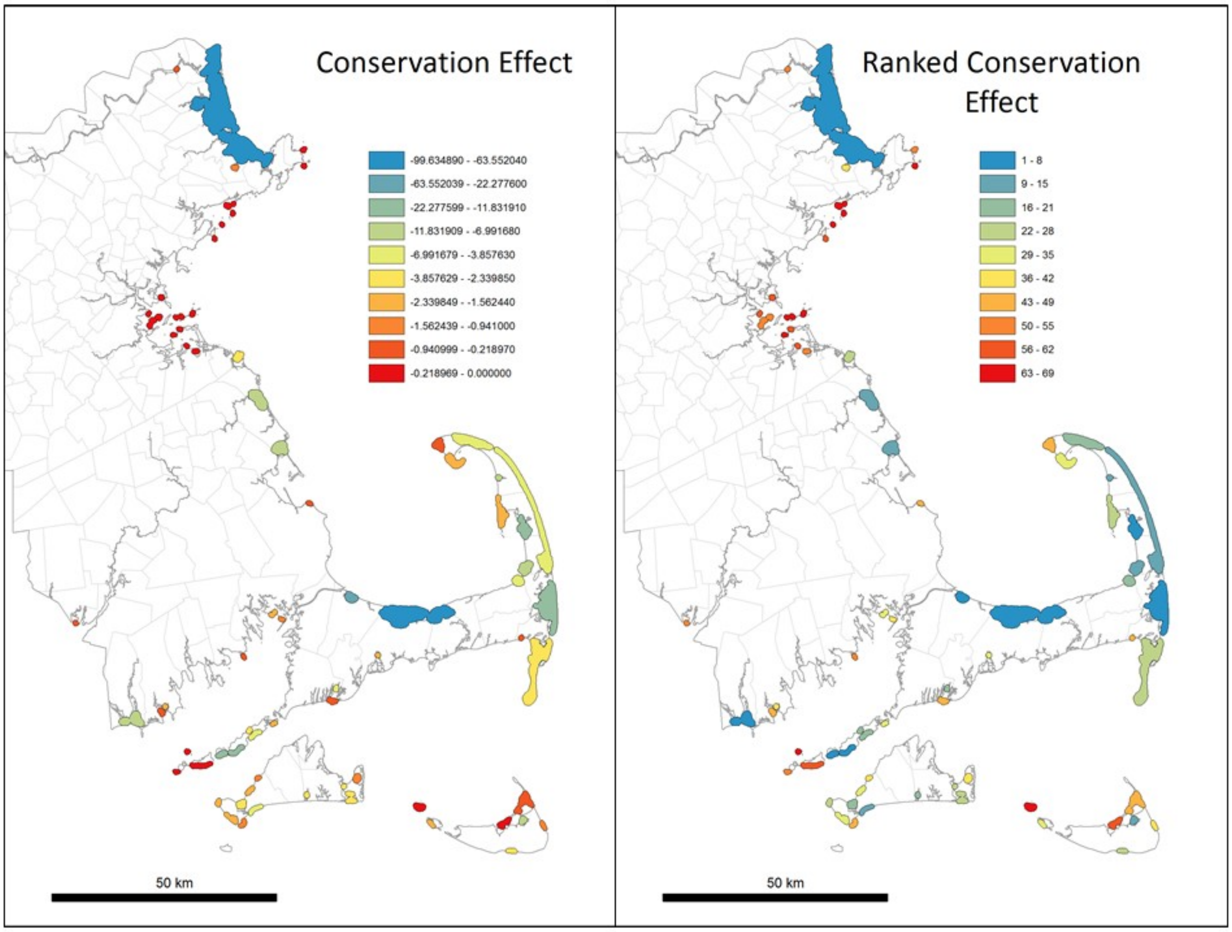

Figure 6. Conservation units scored by Conservation Effect *scores (left) and color-coded by rank order based on* Conservation Effect *scores (right). High scoring units are in blue; low scoring units are in red.*

When *Conservation Effect* is used, two areas (the PIE Great Marsh and the Barnstable Great Marsh) stand out and other conservation units pale by comparison. Ranked *Conservation Effect* highlights additional conservation units that ranked high for this metric. *Conservation Effect* generally favors large conservation units at the expense of small islands, because target coastal systems on small islands are buffered to a large extent by ocean, which is considered undevelopable.

When comparing ranked *Conservation Effect* with ranked *Importance* (Figure 7), the most notable difference is that a number of small islands that are highlighted by *Importance* are ranked much lower by *Conservation Effect*. Both Race Point and Monomoy Island are ranked lower by *Conservation Effect* because there is little developable land within these conservation units. A number of other units ranked higher when using *Conservation Effect* (in comparison with *Importance*), including: PIE Great Marsh, North River-South River, Black River (Duxbury), Old Harbor (Sandwich), Outer Cape-Nauset Harbor, Wellfleet Bay Wildlife Sanctuary, Herring River-Rock Harbor Beach, Namskaket Marsh, Horseneck Beach (Westport), Naushon Point-Pasque Island, and Wequabaque Cliffs (Chilmark).

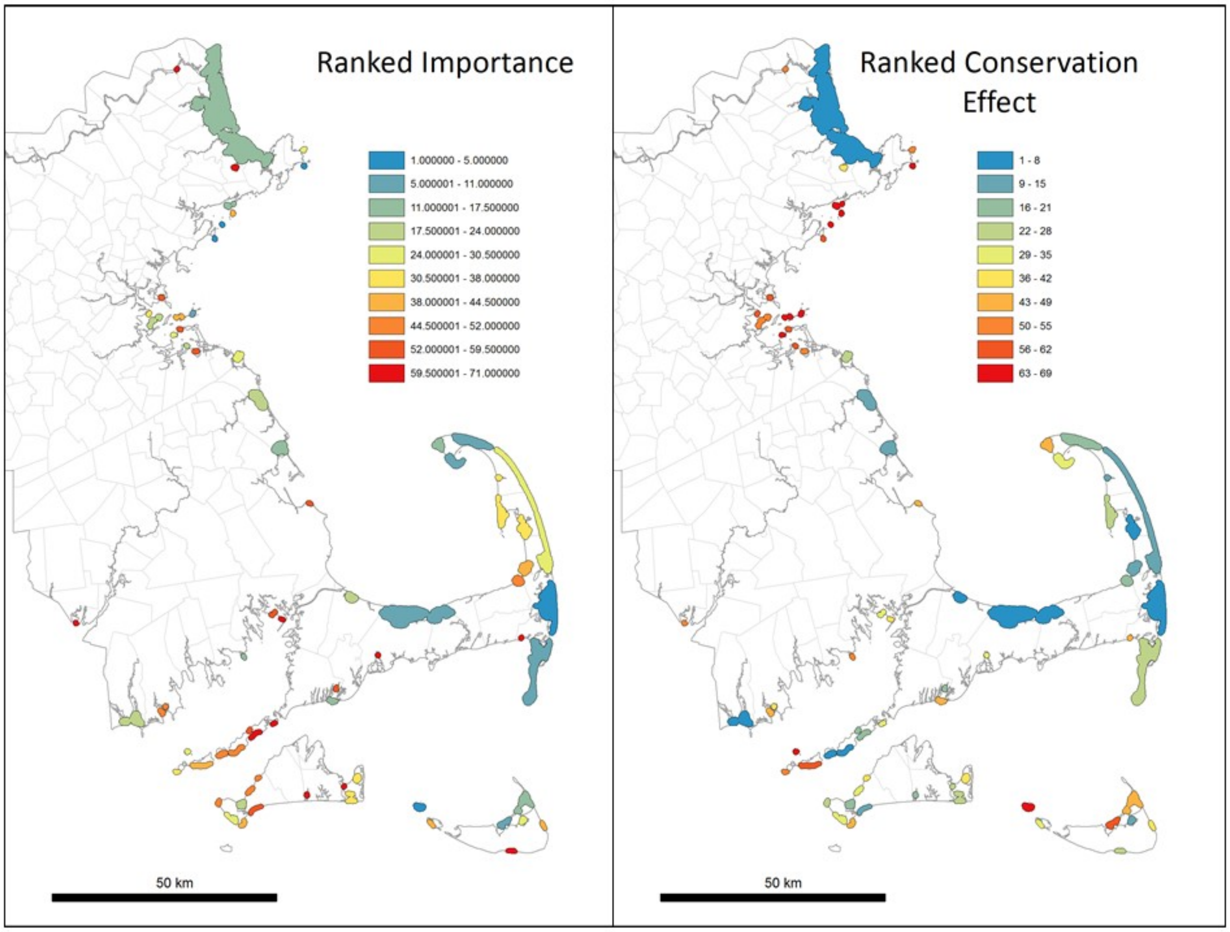

Figure 7. Conservation units color-coded by rank order based on Importance *(left) and* Conservation Effect *scores (right). High scoring units are in blue; low scoring units are in red.*

One final analysis that can be useful for prioritizing conservation action to protect ecological value of target coastal systems, considers *Conservation Effect* relative to the amount of unprotected, non-water land that would have to be protected to achieve the *Conservation Effect*. We call this "*Conservation Efficiency*," and it is *Conservation Effect* divided by the unprotected, non-water area within each conservation unit (Figure 8).

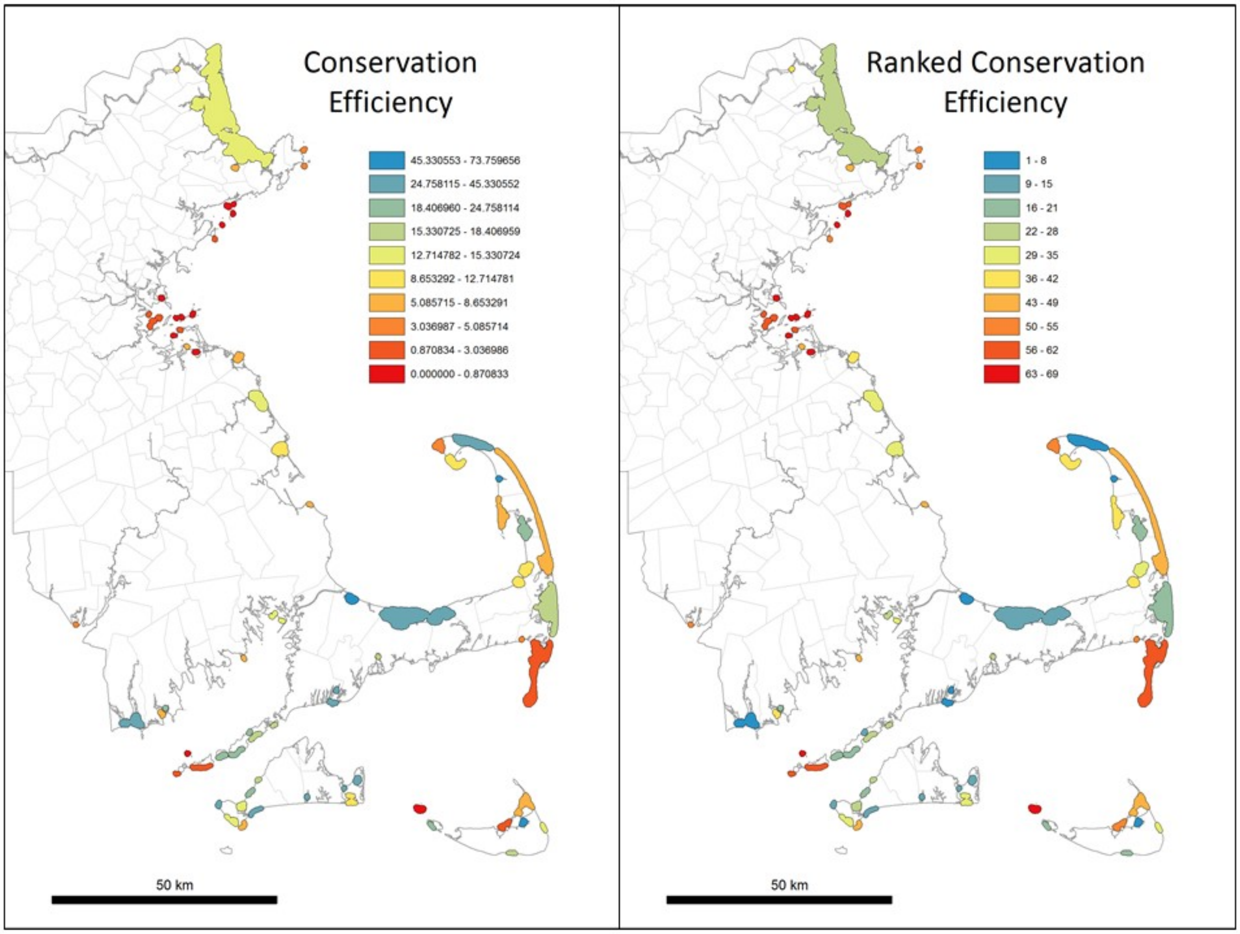

Figure 8. Conservation units scored by Conservation Efficiency *scores (left) and color-coded by rank order based on* Conservation Efficiency *scores (right). High scoring units are in blue; low scoring units are in red.*

Compared to the ranking by *Conservation Effect*, the ranking of conservation units by *Conservation Efficiency* elevates some units while deemphasizing others (Figure 9). Some large conservation units, such as PIE Great Marsh, Outer Cape-Nauset Harbor, and Monomoy received lower rankings. A few small and mid-sized units improve in the rankings: North River-South River, Black River (Duxbury), Provincelands, Meadow Neck (Falmouth), Waquoit Bay, North Neck (Edgartown), and Caleb Pond-Chappaquiddick. This is because conservation action is more efficient when you can achieve a large amount of *Conservation Effect* by protecting a relatively small amount of undeveloped buffer around high-value coastal ecosystems. Large conservation units generally include large amounts of unprotected buffer, and require a great deal of conservation effort to realize the full *Conservation Effect*.

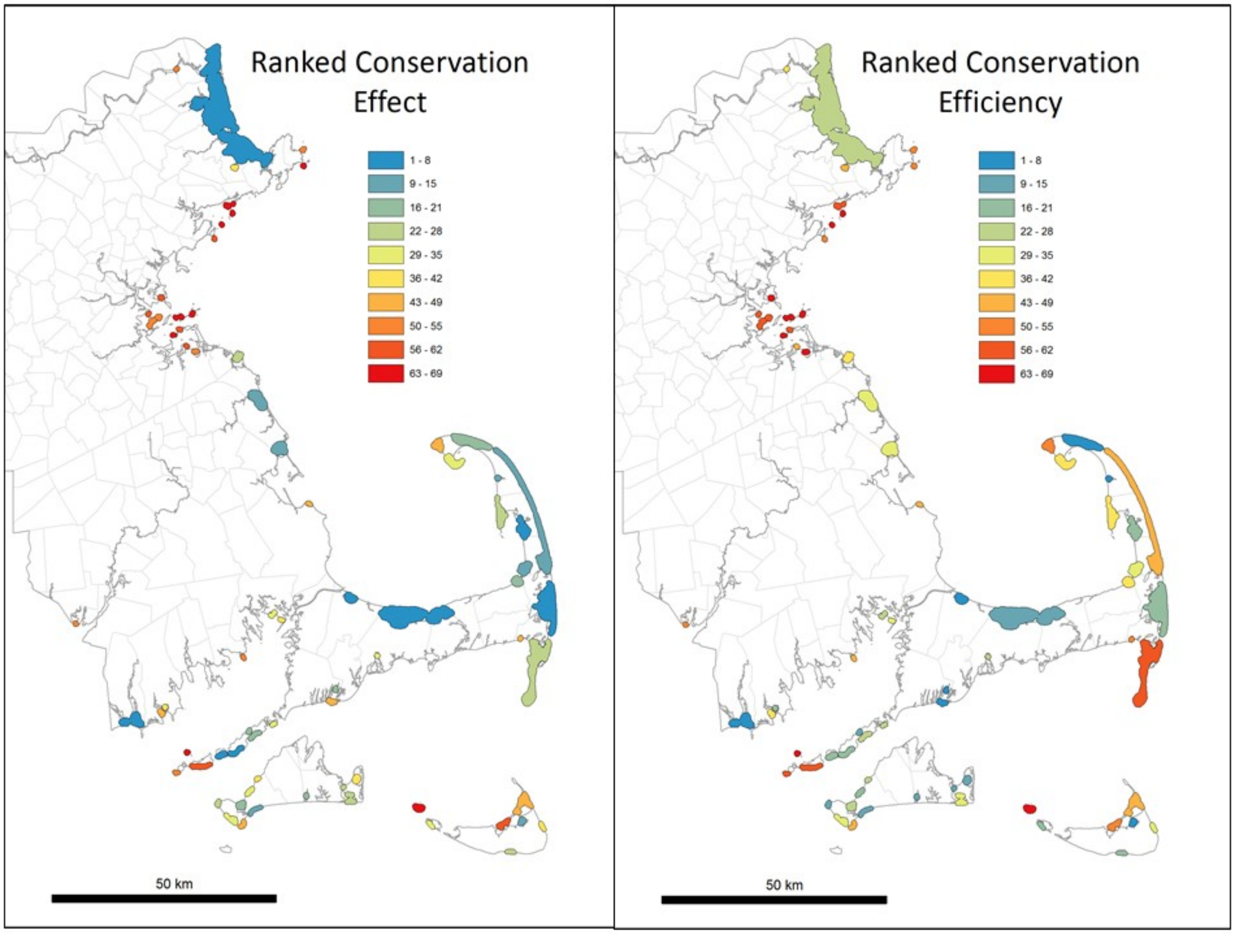

Figure 9. Conservation units color-coded by rank order based on Conservation Effect *(left) and* Conservation Efficiency *scores (right). High scoring units are in blue; low scoring units are in red.*

We believe that any of the four prioritization metrics shown in Figure 10 are valid approaches for protecting the ecological value of target coastal ecosystems. *Mean Squared IEI* and *Importance* focus exclusively on ecological integrity, whereas *Conservation Effect* and *Conservation Efficiency* also take into account the impact of future development on target systems within conservation units. Alternatively, one could use an average of rank scores from these four metrics (Figure 11). Tables containing the 71 merged conservation units with their ranks for these five metrics are provided in Appendices C and D.

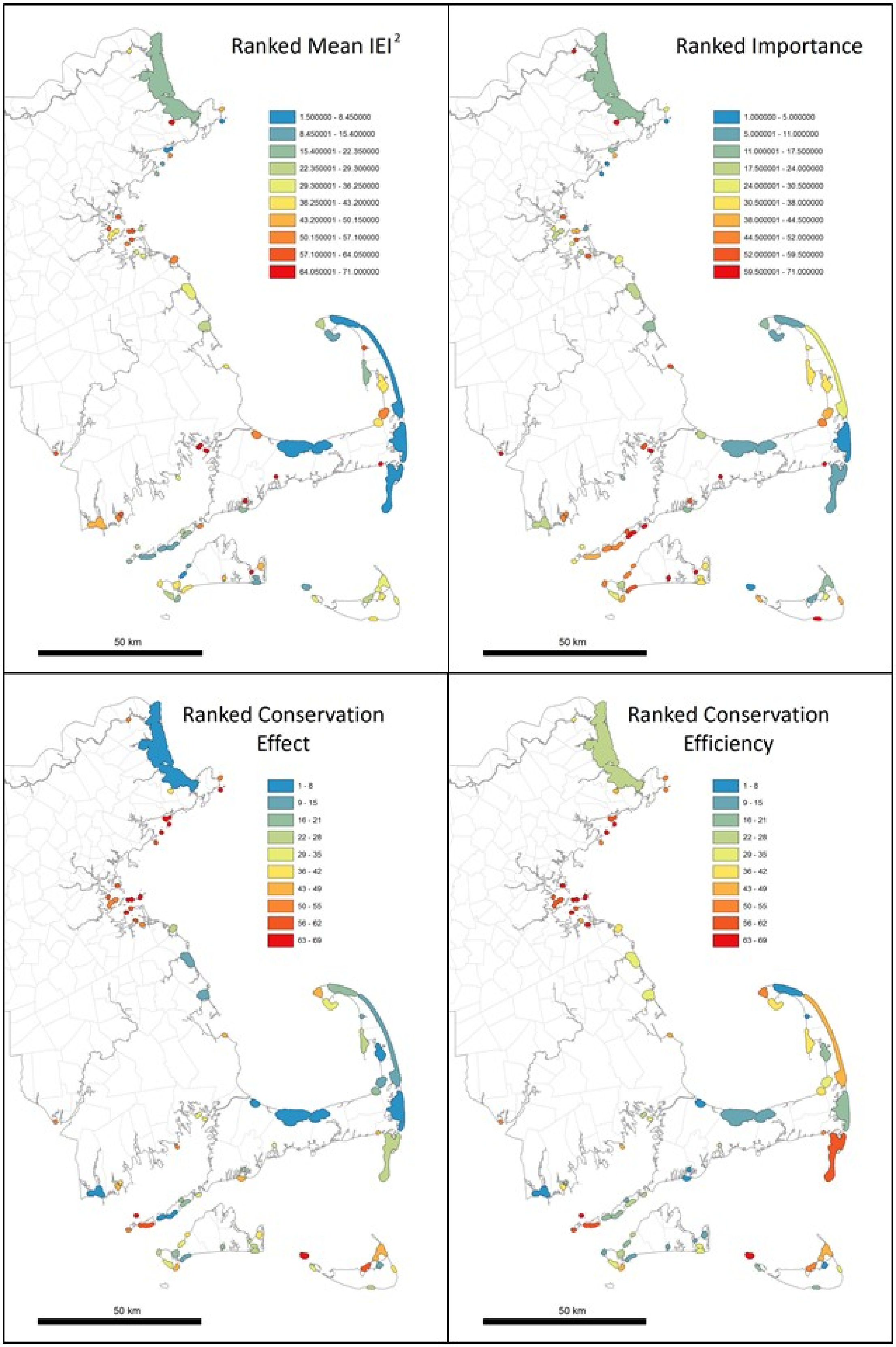

Figure 10. Prioritization of Conservation Units ranked by Mean Squared IEI*,* Importance*,* Conservation Effect*, and* Conservation Efficiency*. High scoring units are in blue; low scoring units are in red.*

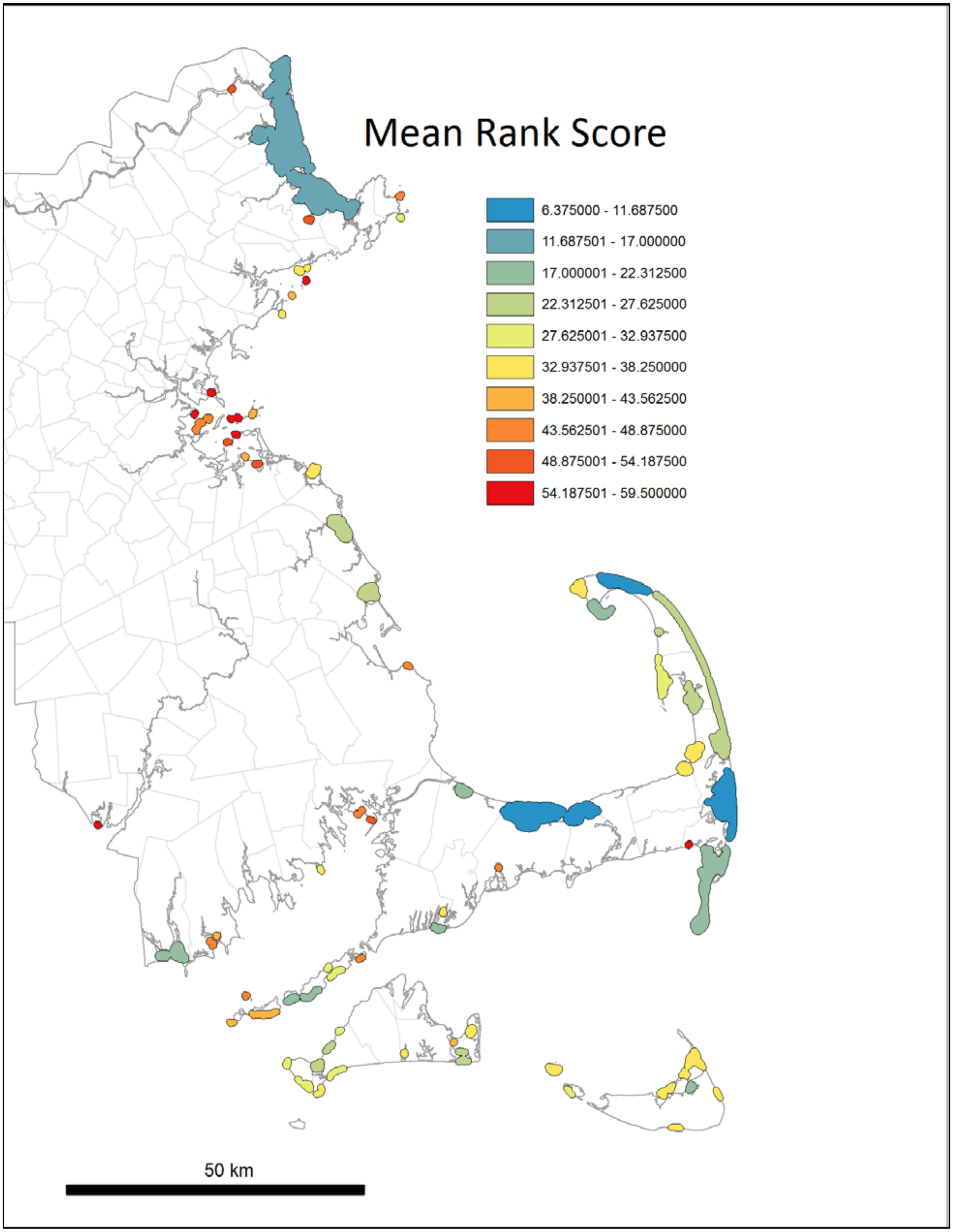

Figure 11. Average rank order for Mean Squared IEI*,* Importance*,* Conservation Effect*, and* Conservation Efficiency*. High scoring units are in blue; low scoring units are in red.*

Potential for Salt Marsh Migration

Other organizations have been or are in the process of evaluating the potential for landward migration of salt marshes and other coastal ecosystems in response to climate change. A key component of The Nature Conservancy's assessment of relative resilience or vulnerability of coastal sites is the amount of space available for habitat migration in response to sea level rise. The MA Office of Coastal Zone Management (CZM) is in the process of applying the Sea Level Affecting Marshes Model (SLAMM) to salt marshes in MA. In addition to these other efforts, one element of CAPS modeling, the tidal restrictions metric, may be useful for identifying opportunities for salt marsh restoration or up-gradient migration.

The tidal restrictions metric uses elevation and tidal range data to predict areas along the coast that, under natural conditions, would be subject to tidal flooding sufficient to support salt marshes. Potential tidal restrictions at road-stream crossings are identified, and their severity is estimated based on the amount of salt marsh mapped up-gradient of a potential restriction relative to the potential area of salt marsh based on modelling of tidal inundation. Those areas that have high scores for the tidal restrictions metric are likely to be areas where salt marshes might expand landward if those restrictions are removed. To evaluate the potential for salt marsh restoration or migration, we assume that the higher the tidal restrictions metric value, the higher the restoration/migration potential. (Note that the tidal restrictions metric is based on current sea level.)

Figure 12 depicts salt marsh restoration/migration potential as estimated by our tidal restrictions metric. *Mean Salt Marsh Restoration Potential* (*mean_tr*) is the mean of the CAPS tidal restriction metric across all salt marsh cells in the conservation unit. *Total Salt Marsh Restoration Potential* is the total tidal restriction metric value summed across all salt marsh cells in the conservation unit (*tot_tr*). There are 12 conservation units affected by tidal restrictions, according to our analysis. Table 2 is a list of those conservation units, and their total and mean tidal restriction values.

Table 2. Total *and* Mean Salt Marsh Restoration Potential *based on the CAPS tidal restrictions metric for 12 conservation units, sorted largest to smallest by* Total Salt Marsh Restoration Potential.

Conservation Unit ID	Conservation Unit Name	*Total Salt Marsh Restoration Potential*	*Mean Salt Marsh Restoration Potential*
S-M-2	PIE-Great Marsh	303.22	0.00478
S-M-46	Horseneck Beach-Westport	57.23	0.02489
S-M-20	North River-South River	28.94	0.00564
S-M-39	Baxter Neck-Prince Cove-Barnstable	13.78	0.06499
S-M-44	Lloyd Woods-Little River-Dartmouth	12.26	0.03616
S-M-25	Pamet River-Truro	5.79	0.01032
S-M-5	Alewife Brook - Essex River	5.37	0.00906
S-M-35	Barnstable Harbor-Great Marsh	2.81	0.00014
S-M-42	Meadow Neck-Falmouth	2.61	0.02075
S-M-10	Snake Island	0.42	0.00296
S-M-62	Menemsha Pond-Aquinnah	0.28	0.00167
S-M-32	Old Harbor-Sandwich	0.03	0.00001

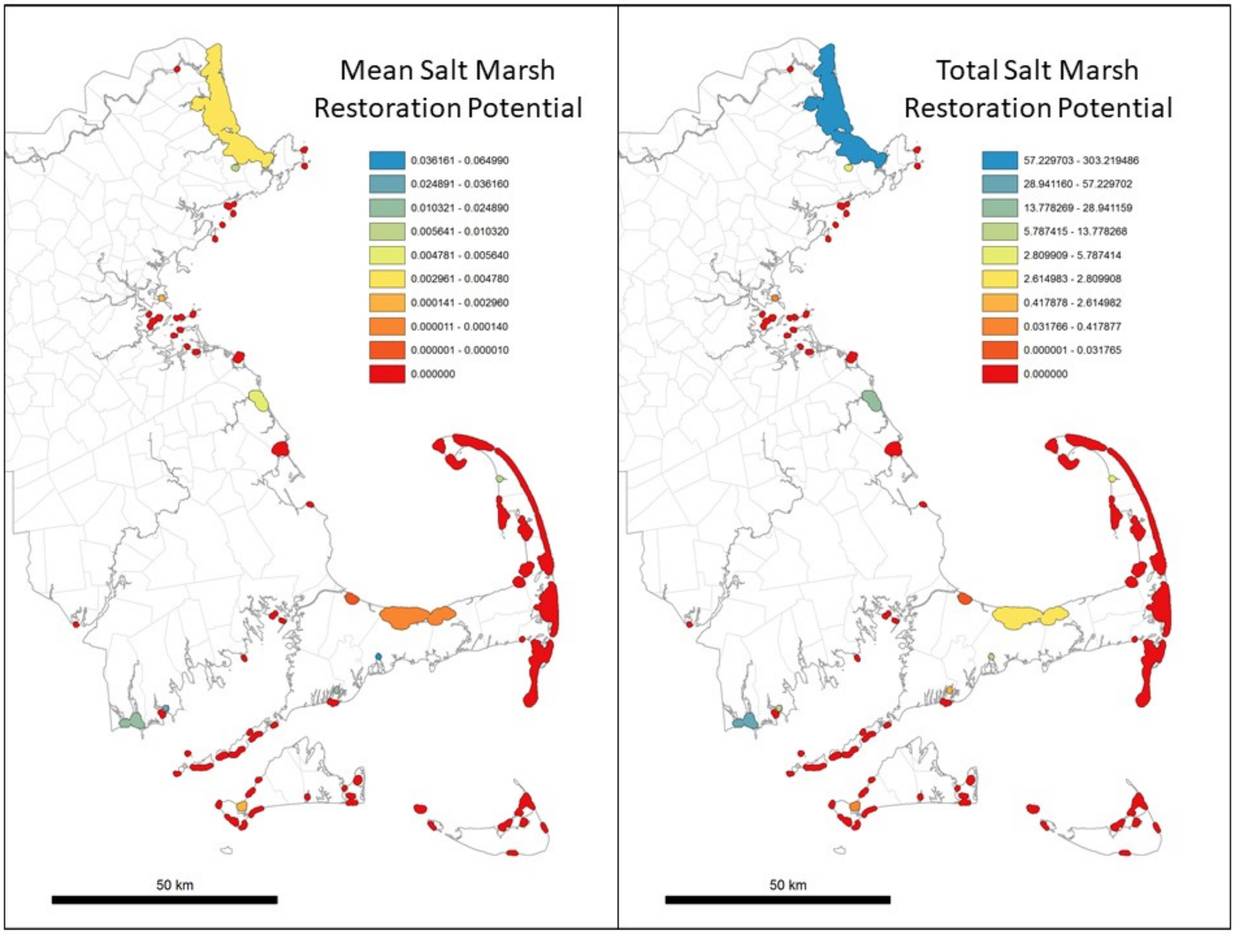

Figure 12. Conservation Units scored by Mean Salt Marsh Restoration Potential *(left) and* Total Salt Marsh Restoration Potential *(right) based on the CAPS tidal restriction metric. Conservation Units in blue are most highly impacted by tidal restrictions and thus, have the best potential for salt marsh restoration or up-gradient migration via removal of tidal restrictions. Conservation Units in red are relatively unaffected by tidal restrictions (or contain little or no salt marsh).*

Figure 13 shows conservation units scored by *Total Salt Marsh Restoration Potential* from this analysis along with *Coastal Resiliency* scores from the TNC analysis. The three highest scoring conservation units based on *Total Salt Marsh Restoration Potential* are among the top ten conservation units scored by TNC *Coastal Resiliency*.

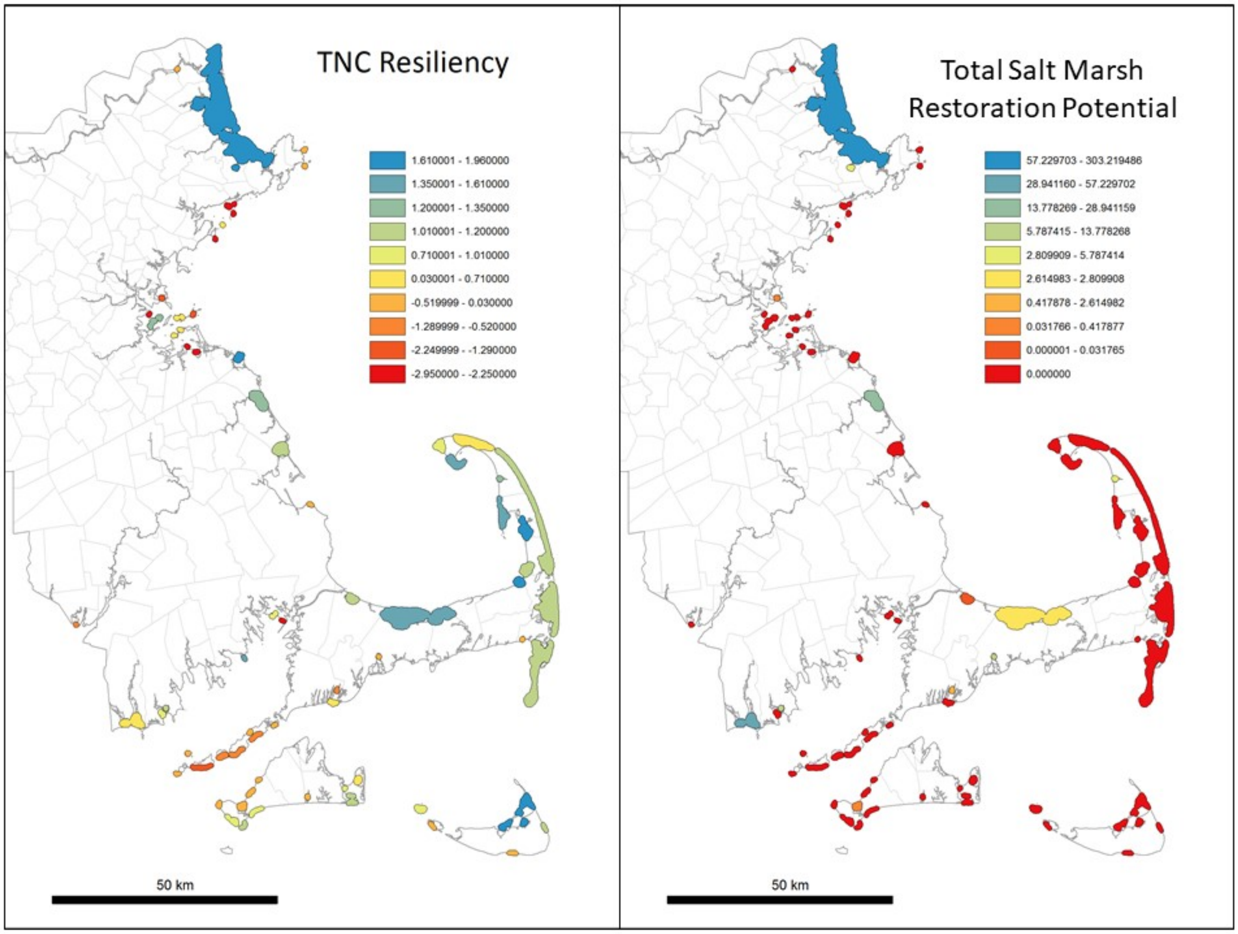

Figure 13. Conservation Units scored by mean TNC Coastal Resiliency *scores (left) and the* Total Salt Marsh Restoration Potential *based on the CAPS tidal restriction metric (right). For both images, Conservation Units in blue offer the greatest potential for salt marsh restoration and/or up-gradient salt marsh migration. Conservation Units in red have relatively little potential for salt marsh restoration or migration (or contain little or no salt marsh).*

Prioritization by Ecosystem-specific Conservation Unit.

One can also prioritize coastal areas for conservation by focusing on particular coastal ecosystems; for example, systems of high vulnerability to sea level rise (e.g., salt marsh) or systems with lower proportions of high value sites that occur in permanently protected open space (e.g., rocky intertidal shore). Table 3 contains summary statistics for the six target coastal ecosystems, based on their representation in protected land and in merged conservation units created by our analysis. This table is available for all sets of conservation units ([units]_system_stats.csv) but only the last two columns will vary with the configuration of the conservation units. Generally, the percentage of IEI either protected or in the conservation units is higher than the corresponding percentage of the area protected or in conservation units. This means both protected areas and the conservation units tend to contain areas with higher than average IEI.

Large proportions of coastal dune (80.7%) and vegetated dune (76.2%) occur within protected land. Protected lands include 87 percent and 80.1 percent of coastal dune and vegetative dune IEI, respectively. A large proportion of salt marsh IEI (79.8%) occurs within conservation land, even though only 60.7 percent of salt marsh area falls within protected land. In contrast, only 7.4 percent of Rocky Intertidal Shore area, and 9.1 percent of its IEI, is protected within conservation land. Rocky Intertidal Shore was not directly targeted by any of the units, and coastal beach units were not included in the merged units. As a result, only 20.8 percent of Rocky Intertidal Shore and 37.7 percent of coastal beach are contained within merged conservation units.

Table 3. Statistics on the six coastal systems: percent of the system area protected, percent of the IEI in the system protected, percent of the system area in the merged (state-scaled) conservation units, and percent of the system IEI in the conservation units.

Coastal Ecosystem	Area (ha)	Area Protected (ha)	Percent protected	Percent IEI protected	Percent in Conservation Units	% IEI in Conservation Units
Salt marsh	17840	9313	52.2	60.7	60.7	79.8
Sea cliff	1351	339	25.1	34.7	35.8	55.3
Vegetated dune	1351	799	59.1	76.2	61.4	80.1
Coastal dune	4329	3017	69.7	80.7	69.3	87
Coastal beach	5327	1454	27.3	33.7	37.7	53.4
Rocky intertidal	664	49	7.4	9.1	20.8	30

System-specific conservation units were created as part of the process of constructing merged conservation units. These system-specific conservation units can be used to focus conservation attention on specific coastal ecosystems (except for Rocky Intertidal Shore; system-specific conservation units were not created for this system). Figures 14-18 depict metric scores (*Mean Squared IEI* and *Importance*) for system-specific conservation units for salt marsh, coastal beach, coastal dune, vegetated dune, and sea cliff. Note that the number and configuation of conservation units differ from one coastal ecosystem to another.

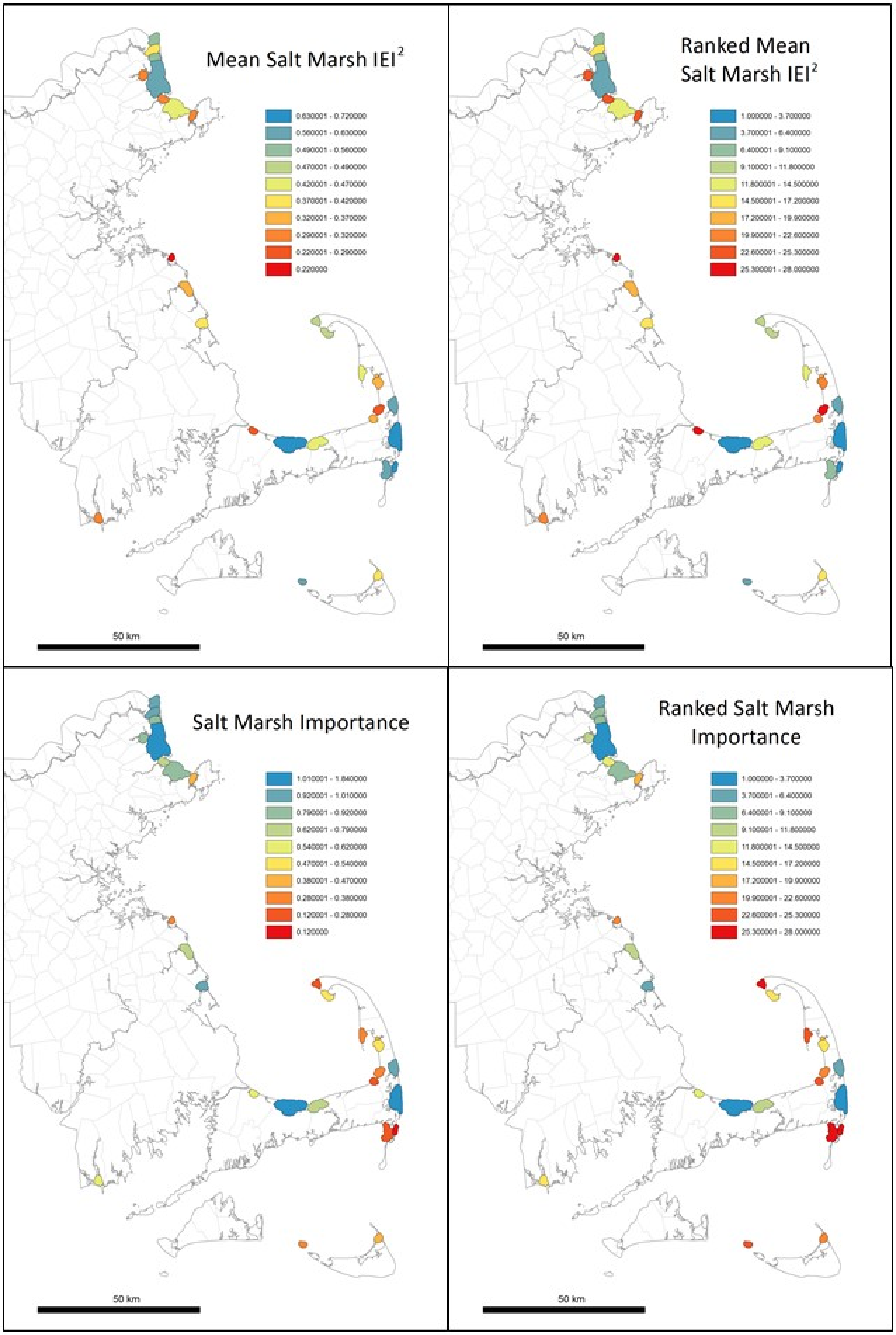

Figure 14. Metric scores for Salt Marsh-specific Conservation Units. High scoring units are in blue; low scoring units are in red.

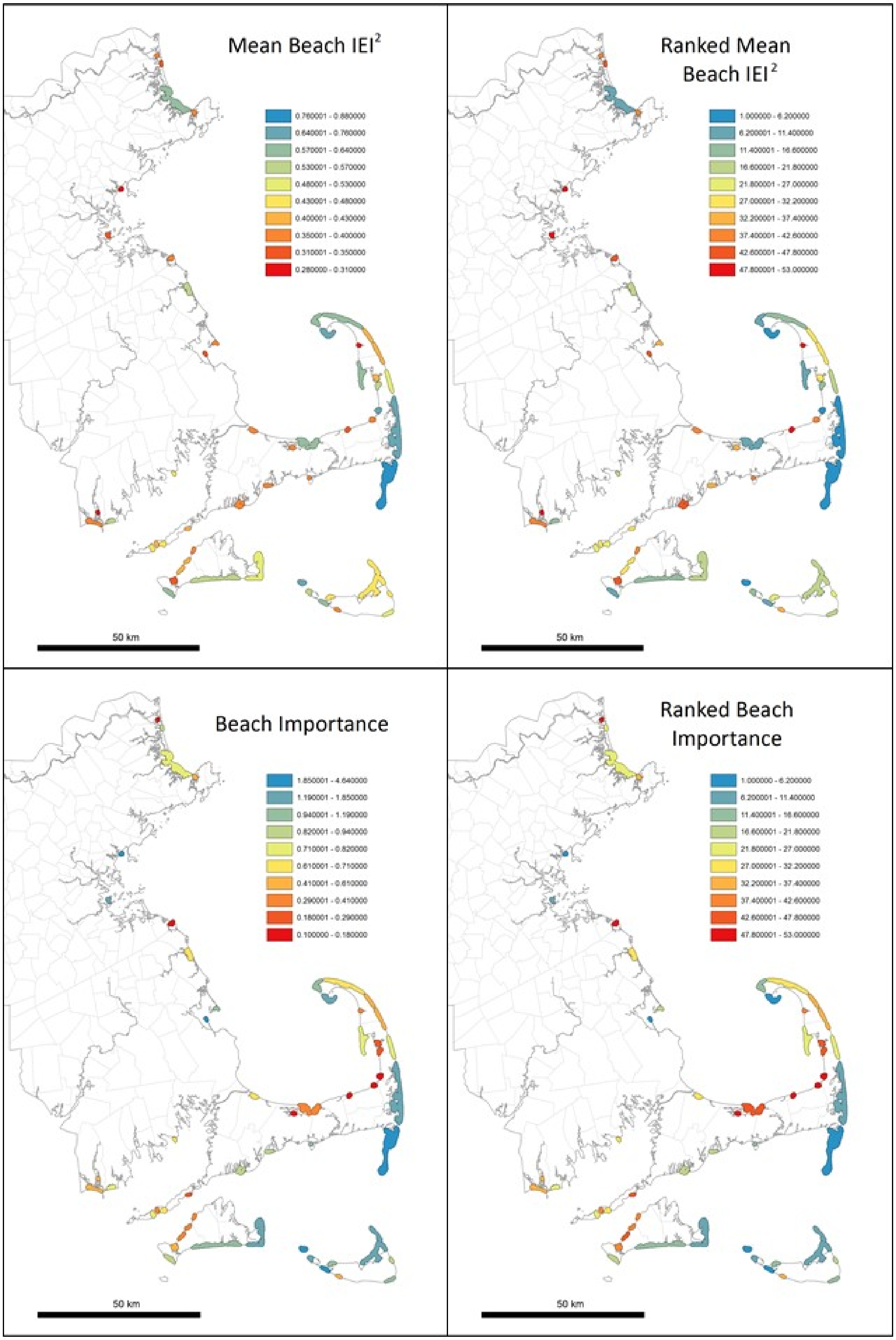

Figure 15. Metric scores for Coastal Beach-specific Conservation Units. High scoring units are in blue; low scoring units are in red.

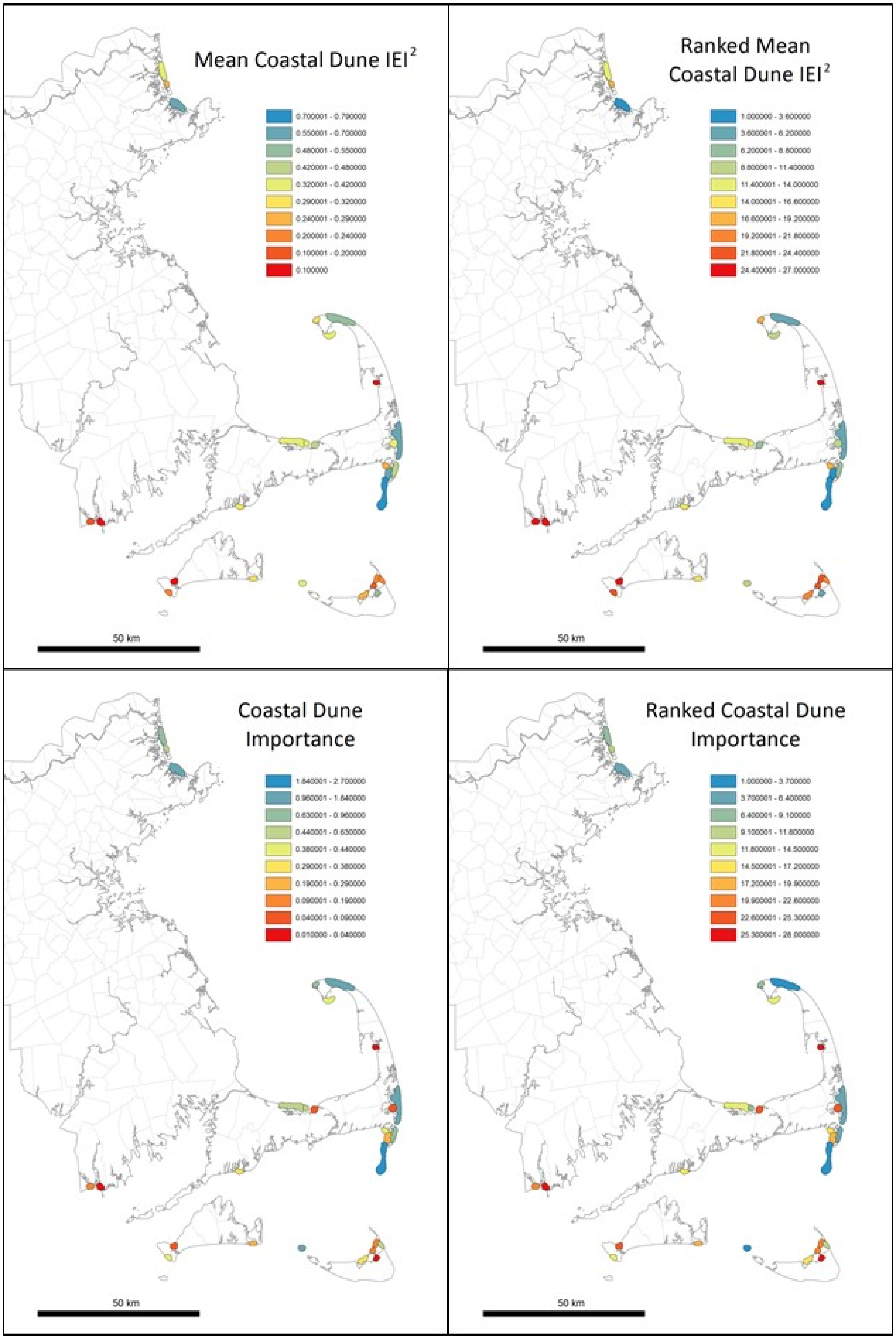

Figure 16. Metric scores for Coastal Dune-specific Conservation Units. High scoring units are in blue; low scoring units are in red.

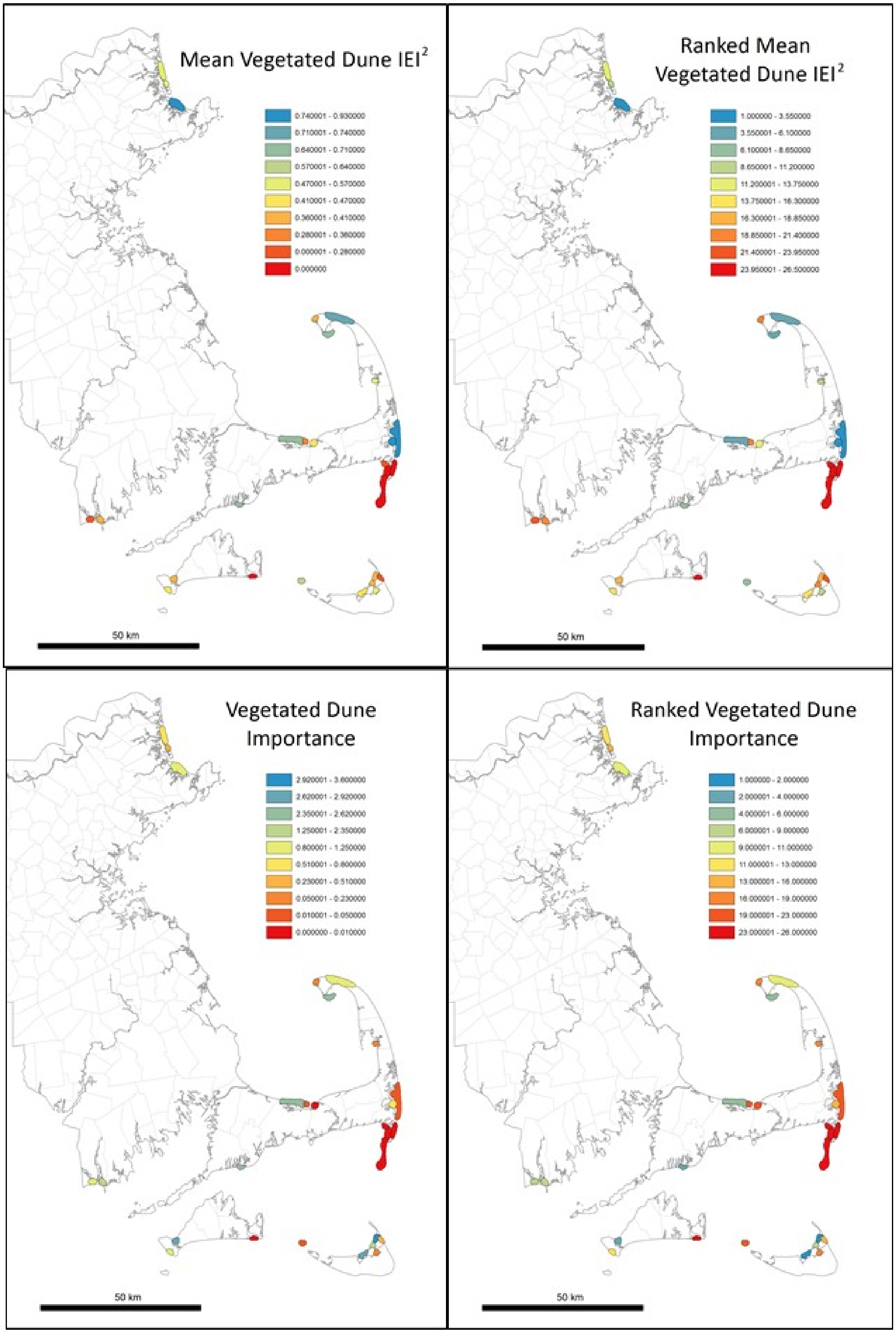

Figure 17. Metric scores for Vegetated Dune-specific Conservation Units. High scoring units are in blue; low scoring units are in red.

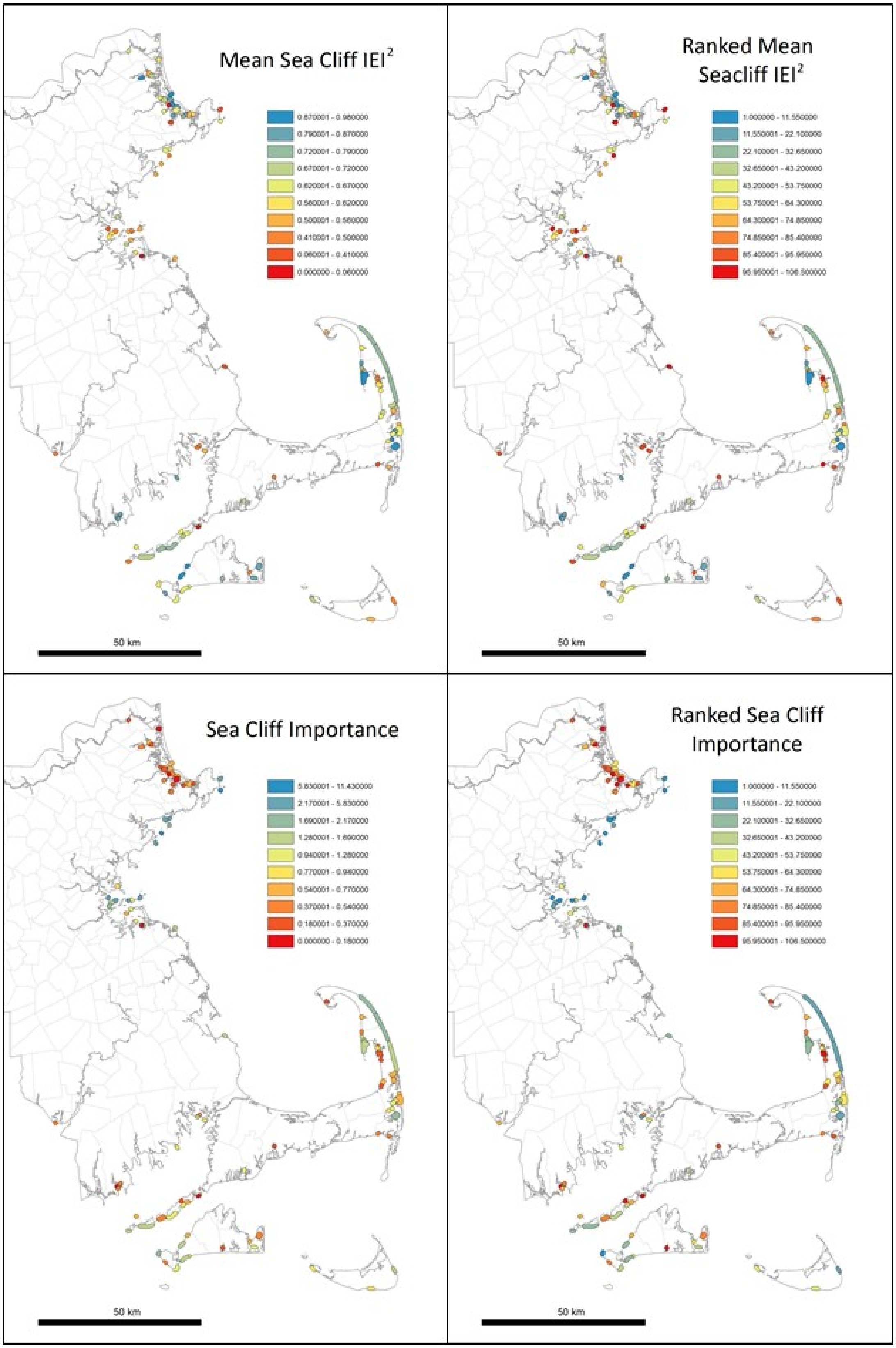

Figure 18. Metric scores for Sea Cliff-specific Conservation Units. High scoring units are in blue; low scoring units are in red.

Additional Analyses – Ecoregionally-Generated Conservation Units

Our primary analyses described above were based on conservation units identified using our statewide rescaled version of IEI. However, we also used an ecoregionally-rescaled version of IEI to create an alternative set of conservation units that might prove useful for areas of the Massachusetts coastline where few conservation units were identified by the statewide approach. IEI rescaled by ecoregion gives, for each cell, the percentile of that cell's IEI compared to other cells of the same community within that cell's ecoregion. Many of the same metrics are available for ecoregionally-rescaled conservation units. Although the identification of these units was based on ecoregionally-rescaled IEI, the metrics using IEI and IEI^2 were based on the statewide version of IEI. The effects of future development were modeled, but the benefits of conservation (*Conservation Effect* and *Conservation Efficiency*) were not modeled for these units. Ecoregional conservation units are shown in Figure 19 for merged units, Figure 20 for salt marsh units, Figure 21 for dune units, and Figure 22 for sea cliff units.

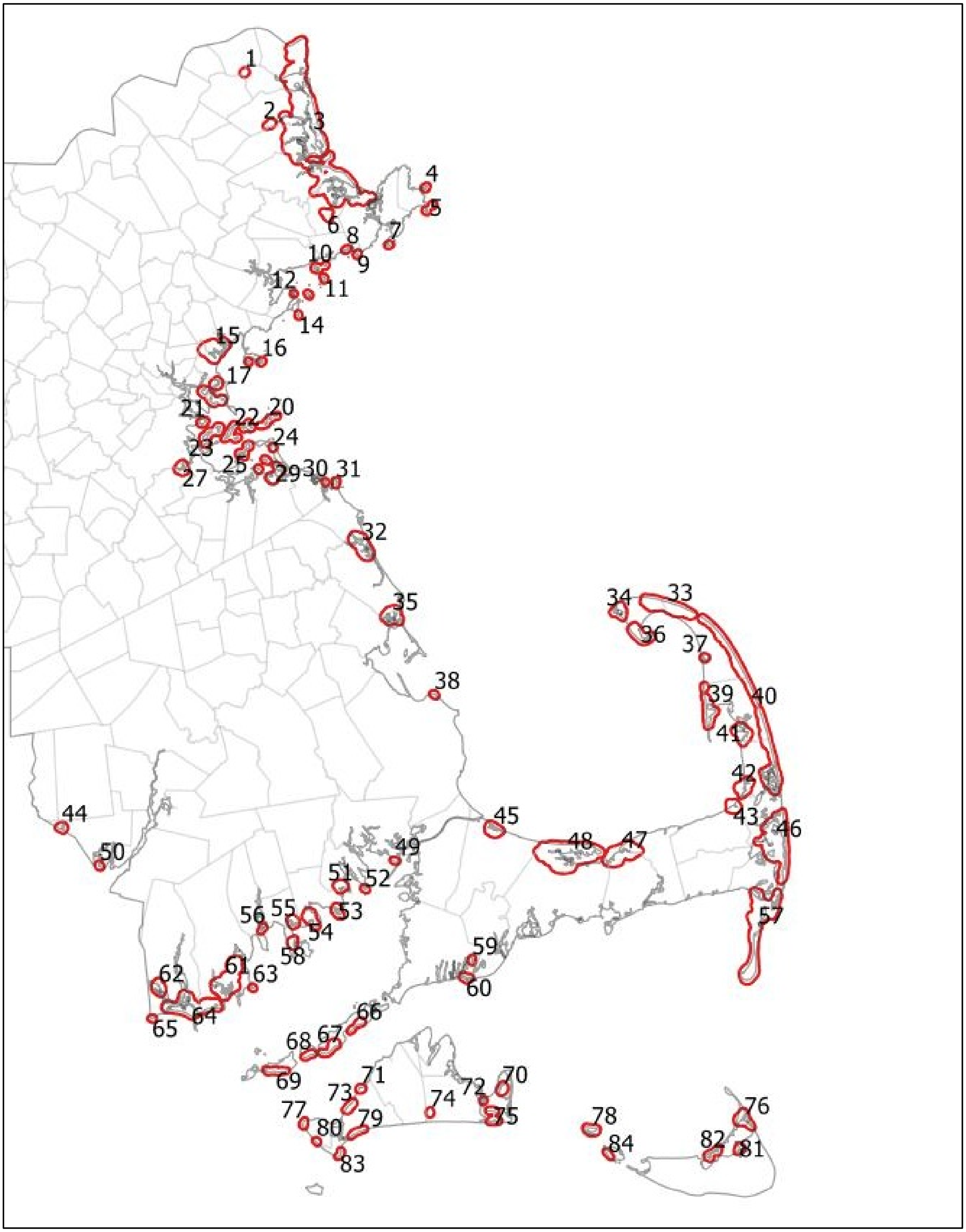

Figure 19. Merged Conservation Units created using CAPS ecoregional IEI numbered consecutively from north to south. Their IDs are these numbers appended to the prefix "E-M-".

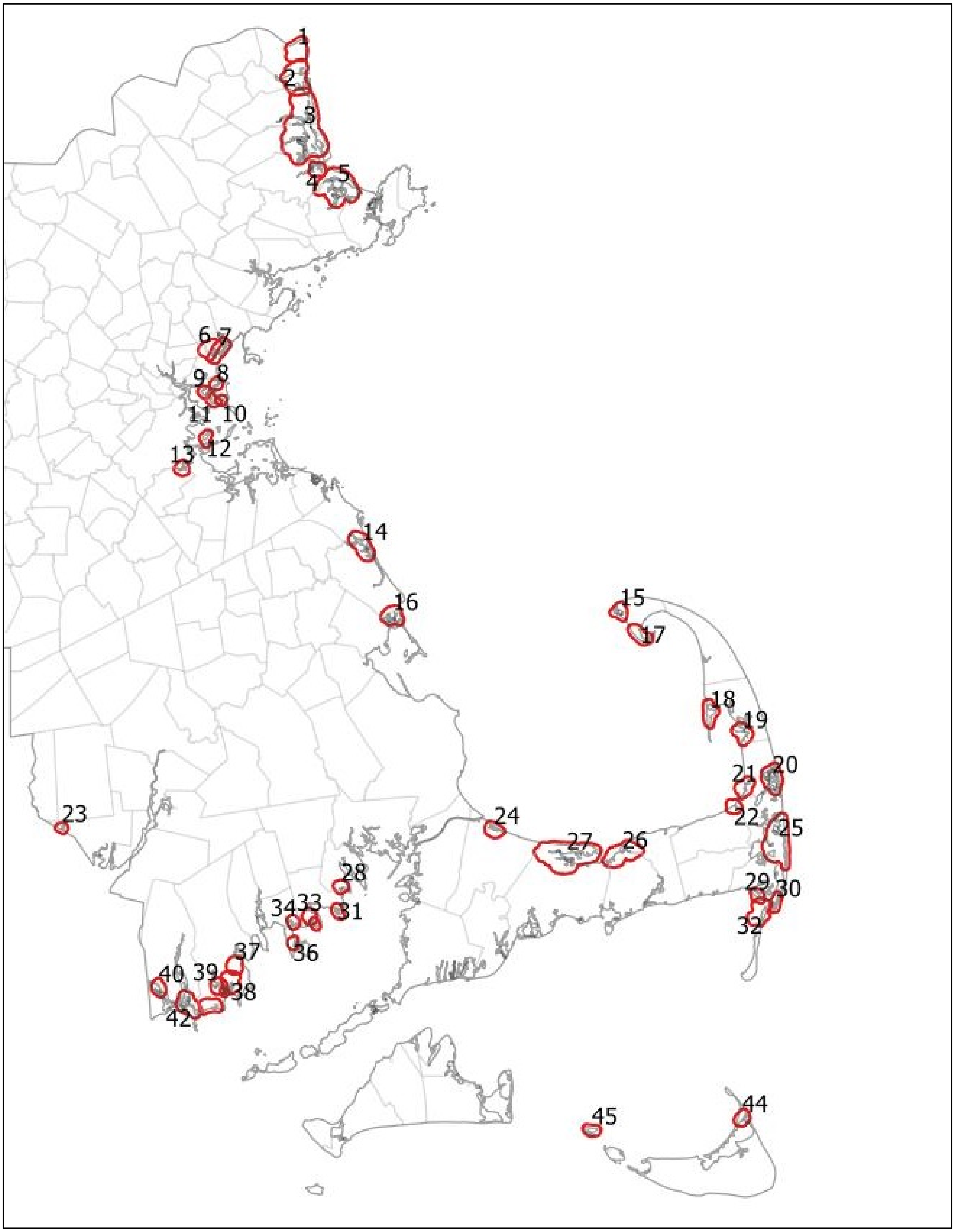

Figure 20. Salt Marsh-specific Conservation Units created using CAPS ecoregional IEI numbered consecutively from north to south. Their IDs are these numbers appended to the prefix "E-SM-".

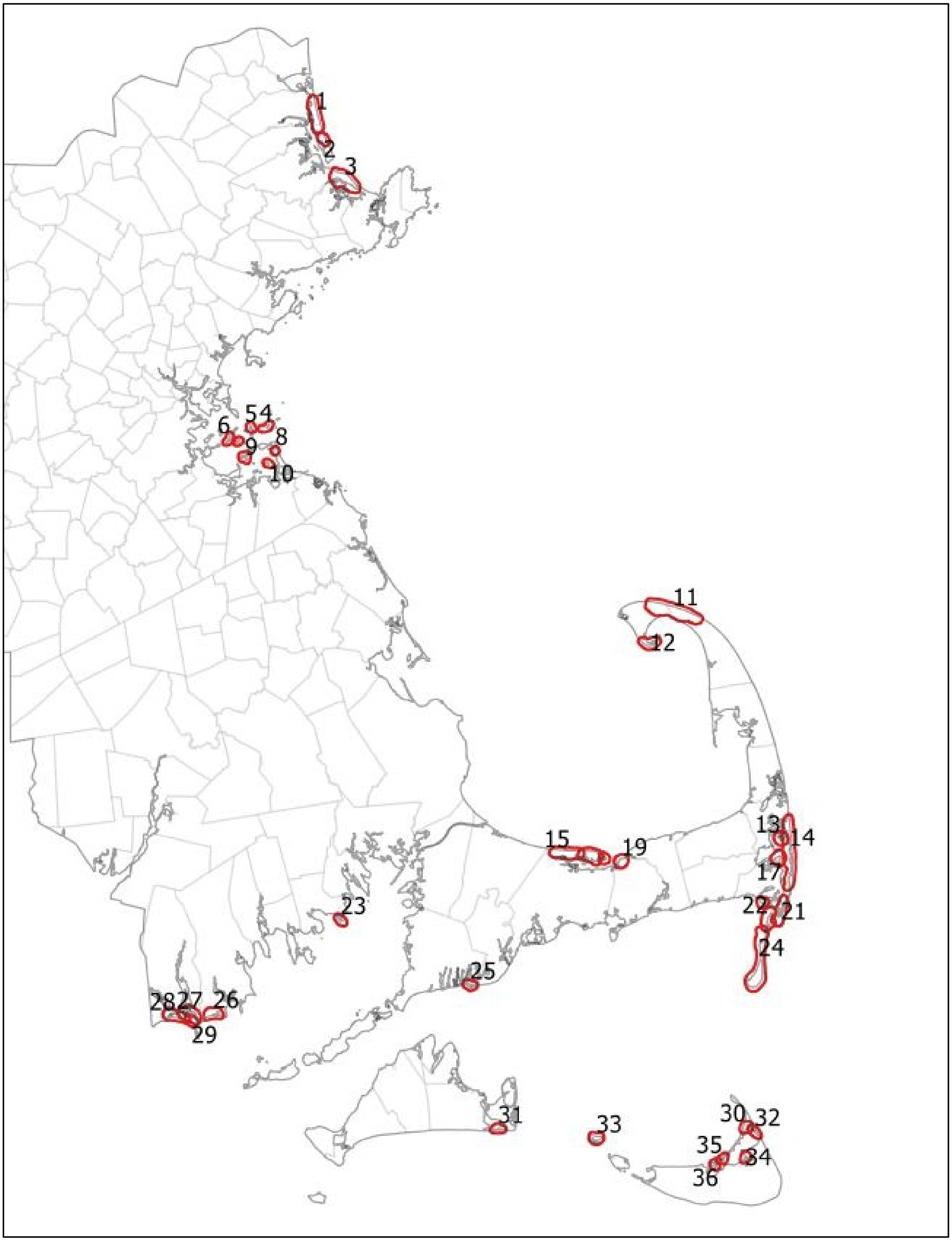

Figure 21. Dune-specific Conservation Units created using CAPS ecoregional IEI numbered consecutively from north to south. Their IDs are these numbers appended to the prefix "E-DU-".

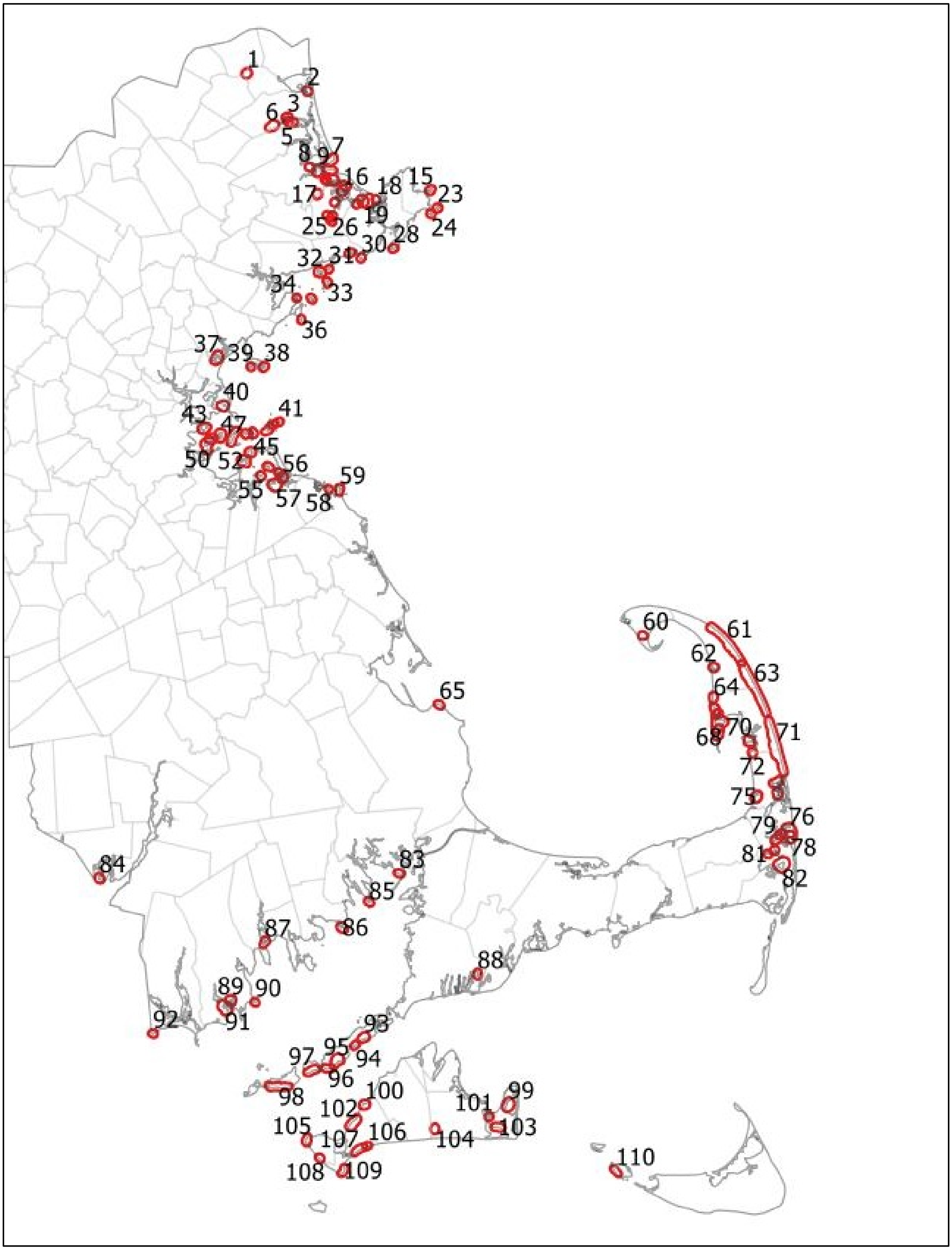

Figure 22. Sea Cliff Conservation Units created using CAPS ecoregional IEI numbered consecutively from north to south. Their IDs are these numbers appended to the prefix "E-SC-".

Other Considerations for Ranking Conservation Units

In addition to ecological value and impacts of future development, other metrics can be used to prioritize conservation units based on values other than ecological ones.

Parcel Size

Parcel size was calculated from a 30-meter raster that was derived from the Mass GIS vector parcel data aggregated across all towns that intersect the conservation units. *Parcel Size* is the area-weighted mean parcel size of the conservation unit, in hectares. This is not the mean of all parcel sizes within the unit, but is the mean parcel size we would expect to find if we sampled a bunch of random points within the conservation unit. *Unprotected Parcel Size* is the area-weighted mean parcel size for unprotected land in each conservation unit (Figure 23).

Beach Access

Beach Access is based on the CZM (2017) coastal access linear features viewable on MORIS: http://maps.massgis.state.ma.us/map_ol/moris.php. The CZM dataset contains both a linear layer that represents public and semi-public beaches and a point layer that includes, among other features, access points classified as public or semi-public. Figure 24 depicts conservation units scored by the total length of public and semi-public beach within each conservation unit.

Scenic Value

Scenic Value was scored based on the Scenic Landscape Inventory Polygons produced by the Massachusetts Landscape Inventory Project (DCR, 1982). It is the proportion of the non-water area of the conservation unit that fell within Scenic Landscape Inventory polygons (Figure 25).

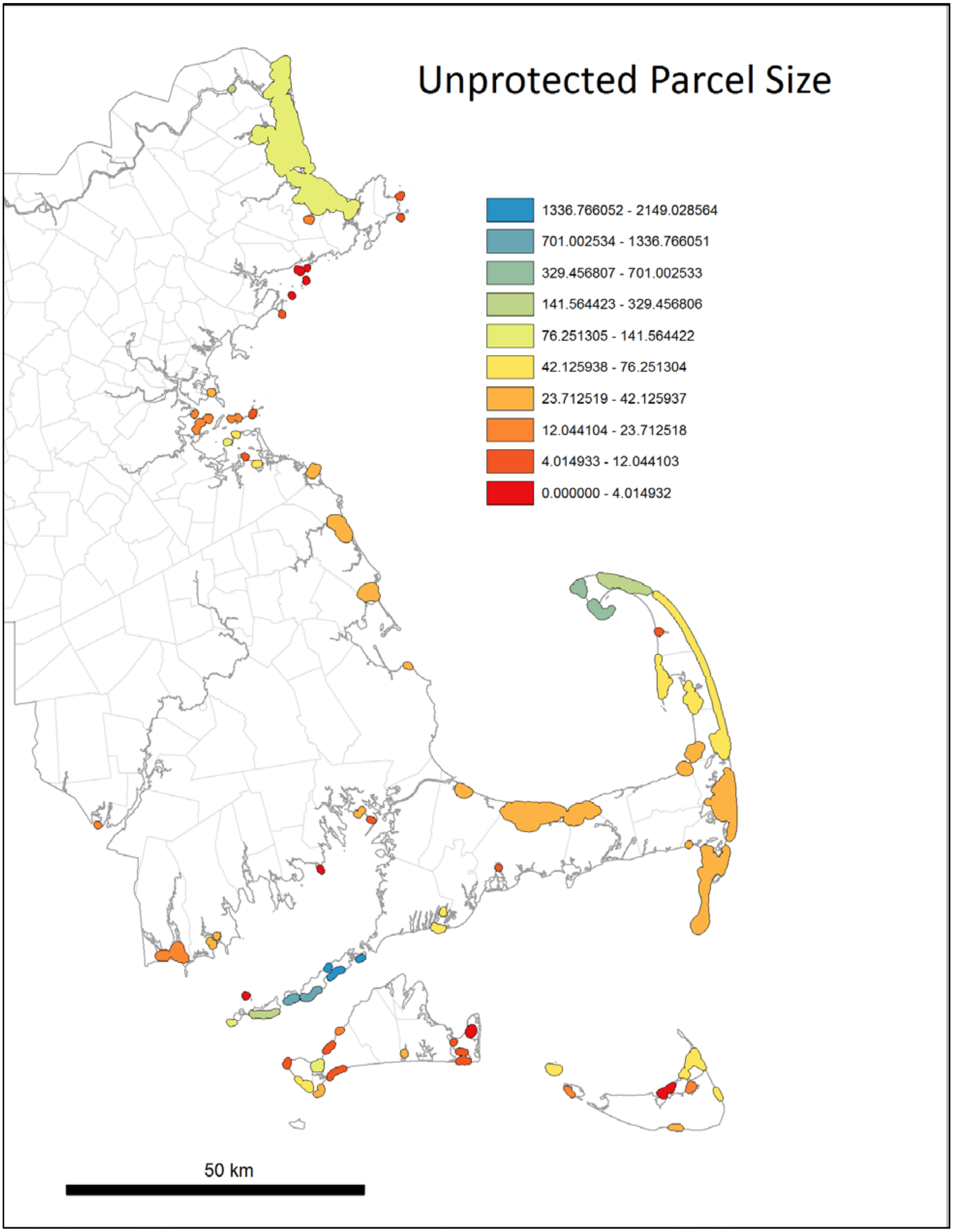

Figure 23. Conservation units color-coded by Unprotected Parcel Size*. High scoring units are in blue; low scoring units are in red.*

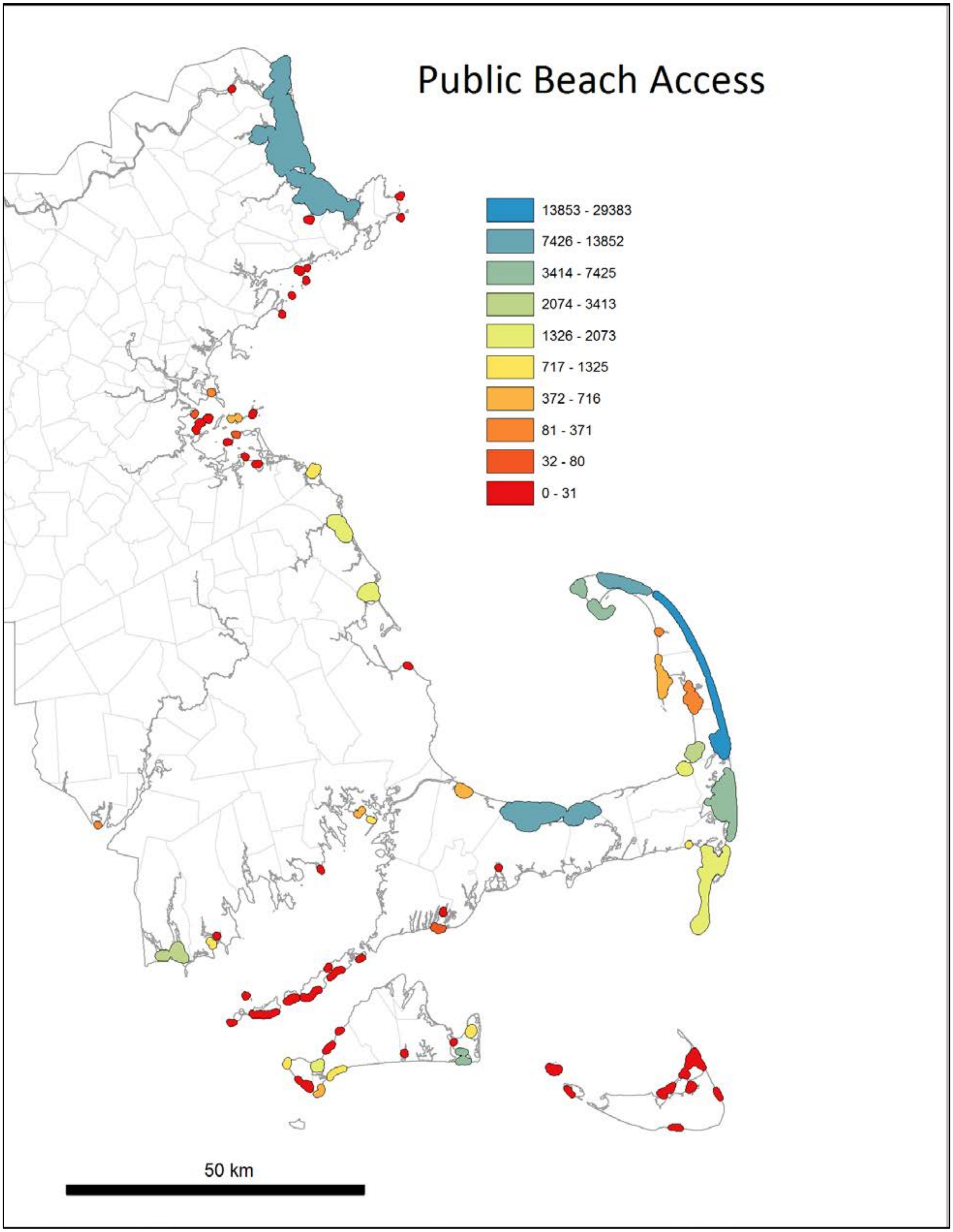

Figure 24. Conservation units scored by total length of public and semi-public beach within each unit. High scoring units are in blue; low scoring units are in red.

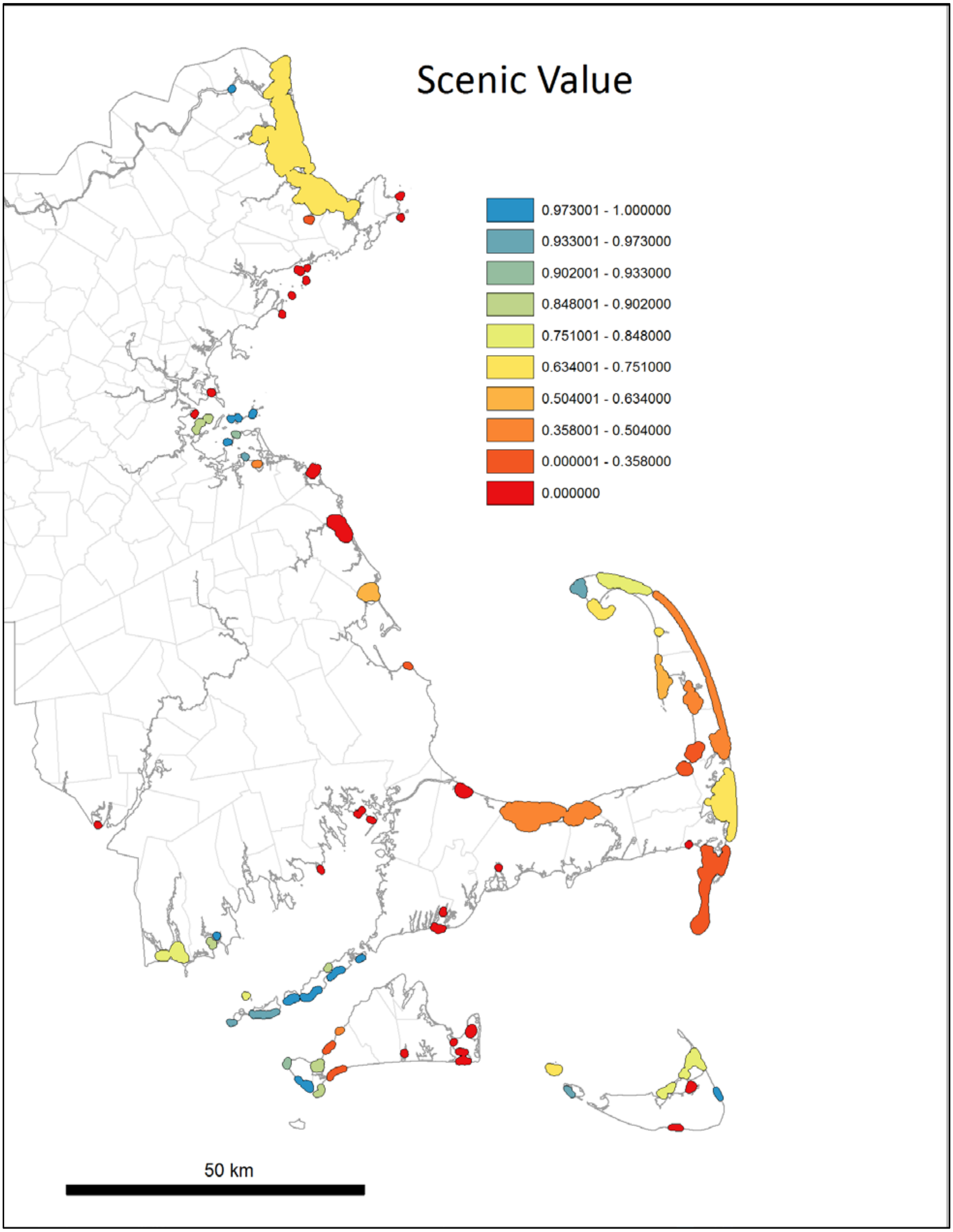

Figure 25. Conservation units scored by Scenic Value*. High scoring units are in blue; low scoring units are in red.*

Discussion

There are many ways to prioritize land for conservation and many considerations that affect whether particular parcels should be targeted for protection. Although we provide data on beach access, parcel size and scenic value, the primary focus of our analysis is ecological value. As part of this analysis, we created system-specific conservation units that were then merged into multisystem conservation units. We calculated a suite of metrics for conservation units and then selected four of them (*Mean Squared IEI*, *Importance*, *Conservation Effect* and *Conservation Efficiency*), plus a fifth based on the mean rank order of the four other metrics, that we recommend for setting conservation priorities.

Metric data for system-specific units, as well as conservation units based on ecoregion-rescaled IEI, are provided for users that are interested in conserving specific coastal ecosystems or for identifying conservation priorities in specific regions of the Massachusetts coastline (see Appendices A & B). Our primary analysis focuses on merged conservation units based on state-scaled IEI. We believe that any of the five primary metrics discussed (Figures 10 & 11, and Appendices C & D) are useful for setting conservation priorities along the Massachusetts coastline. We chose to use two of these metrics (Mean Rank and *Conservation Effect*) to make recommendations for 20 merged conservation units that we believe should be priorities for coastal conservation efforts (Table 4).

Table 4. Twenty highest-ranking merged conservation units (with Conservation Unit IDs) for Mean Rank and Conservation Effect.

Rank	Mean Rank	*Conservation Effect*
1	Barnstable Harbor-Great Marsh (S-M-35)	PIE-Great Marsh (S-M-2)
2	Pleasant Bay (S-M-33)	Barnstable Harbor-Great Marsh (S-M-35)
3	Provincelands (S-M-21)	Old Harbor-Sandwich (S-M-32)
4	PIE-Great Marsh (S-M-2)	Wellfleet Bay Wildlife Sanctuary (S-M-29)
5	Old Harbor-Sandwich (S-M-32)	Pleasant Bay (S-M-33)
6	Horseneck Beach-Westport (S-M-46)	Naushon Point - Pasque Island (S-M-51)
7	Quaise Point-Pocomo Creek-Nantucket (S-M-66)	Horseneck Beach-Westport (S-M-46)
8	Wood End-Long Point (S-M-24)	North River-South River (S-M-20)
9	Naushon Point - Pasque Island (S-M-51)	Black River-Duxbury (S-M-23)
10	Monomoy (S-M-41)	Quaise Point-Pocomo Creek-Nantucket (S-M-66)
11	Waquoit Bay (S-M-43)	Herring River-Rock Harbor Beach (S-M-30)
12	North River-South River (S-M-20)	Pamet River-Truro (S-M-25)
13	Black River-Duxbury (S-M-23)	Wequabaque Cliffs-Chilmark (S-M-64)
14	Outter Cape-Nauset Harbor (S-M-28)	Outter Cape-Nauset Harbor (S-M-28)
15	Wellfleet Bay Wildlife Sanctuary (S-M-29)	South Bluff-Witches Glen-Naushon Island (S-M-49)
16	Menemsha Hills-Chilmark (S-M-62)	Provincelands (S-M-21)
17	Pamet River-Truro (S-M-25)	Namskaket Marsh (S-M-31)
18	Norton Point Beach-Katama Bay (S-M-59)	Meadow Neck-Falmouth (S-M-42)
19	Menemsha Pond-Aquinnah (S-M-62)	Menemsha Pond-Aquinnah (S-M-62)
20	Milk Island (S-M-4)	Oyster Pond-Edgartown (S-M-58)

Fourteen conservation units ranked in the top 20 for both metrics. Therefore, we believe that these units (listed in alphabetical order) should be among the highest priority conservation units for coastal ecosystem protection.

Barnstable Harbor-Great Marsh (S-M-35)
Black River-Duxbury (S-M-23)
Horseneck Beach-Westport (S-M-46)
Menemsha Pond-Aquinnah (S-M-62)
Naushon Point - Pasque Island (S-M-51)
North River-South River (S-M-20)
Old Harbor-Sandwich (S-M-32)
Outter Cape-Nauset Harbor (S-M-28)
Pamet River-Truro (S-M-25)
PIE-Great Marsh (S-M-2)
Pleasant Bay (S-M-33)
Provincelands (S-M-21)
Quaise Point-Pocomo Creek-Nantucket (S-M-66)
Wellfleet Bay Wildlife Sanctuary (S-M-29)

Of those fourteen conservation units, three also scored high in salt marsh restoration potential: PIE-Great Marsh, Horseneck Beach-Westport, and North River-South Rive (Table 2, Figure 12).

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Executive Office of Energy and Environmental Affairs (EOEEA). 2019. Protected and Recreational OpenSpace. https://docs.digital.mass.gov/dataset/massgis-data-protected-and-recreational-openspace. Downloaded on July 9, 2019.

Department of Conservation and Recreation (DCR) Scenic Landscape Inventory Project, 1982. https://docs.digital.mass.gov/dataset/massgis-data-scenic-landscape-inventory.

Massachusetts Office of Coastal Zone Management (CZM), Massachusetts Ocean Resource Information System (MORIS). 2017. Coastal access sites. http://maps.massgis.state.ma.us/map_ol/moris.php. (Note data provided by the Trustees as the MORIS system currently does not support downloads).

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McGarigal K., Compton B.W., Plunkett E.B., DeLuca W.V., Grand J., Ene E., Jackson S.D. 2018a. A landscape index of ecological integrity to inform landscape conservation. Landscape Ecology 33:1029-1048. https://doi.org/10.1007/s10980-018-0653-9.

McGarigal K., Plunkett E.B., Willey L.L., Compton B.W., DeLuca W.V., Grand J. 2018b. Modeling non-stationary urban growth: the SPRAWL model and the ecological impacts of development. Landscape and Urban Planning 177:178-190. https://doi.org/10.1016/j.landurbplan.2018.04.018.

Appendix A

Metrics Calculated for Conservation Units Included in CSV files

Tables of data for all calculated metrics are distributed as CSV files defining the Conservation Units with the same base name as the shapefile along with "_data.csv"

"[system]" in a column name is a place holder for one of the six coastal classes: "SM" salt marsh, "SC" sea cliff, "VD" vegetated dune, "CD" coastal dune, "CB" coastal beach, or "RI" rocky intertidal.

Columns marked with an asterisk (*) depend on the alternate impact analysis which was only performed for the state-scaled merged Conservation Units and so will be absent from all other sets of Conservation Units.

Column	Description
conunit	**Conservation Unit number.** For each set of Conservation Units the numbers were assigned north to south sequentially starting with 1. This number is not unique across sets of Conservation Units (e.g. merged units versus system-specific units).
ID	**ID.** The Conservation Unit ID. This is a unique ID across all sets of Conservation Units. It consists of a single letter for the IEI scaling used to make the Conservation Units (either "S" for statewide or "E" for ecosystem); a dash; one or two letters for the type of Conservation Unit (either "M" for merged units or two letters indicating the system targeted by the system specific units); a second dash and then the Conservation Unit number. E.g. "S-M-1" is the northernmost Conservation Unit in the merged Conservation Units based on the statewide scaling of IEI.
Name	**Name.** A name assigned to each Conservation Unit based on geographic place names within each unit.
*mean_rank**	**Mean Rank.** Mean of the rank order of Conservation Units ranked by Mean Squared IEI (*R_mean_I2*), Importance (from squared IEI - *R_impor2*), Conservation Effect (*R_CEffect*), and Conservation Efficiency (*R_Effic*). These are the four metrics which we deemed most important, and thus the average of these rank scores can be interpreted as an overall score. It is only available for the state-scaled merged cores as that is the only set of Conservation Units on which we performed the alternative impact analysis. Conservation Units that scored better in each metric were given lower rank numbers so the lower the mean rank score the better the unit is. It ranges from theoretically 1 (if a unit scored first in each metric) to N if the unit scored last in each metric. In practice, the range of Mean Rank scores is reduced because no unit consistently scores either first or last.
HA	**Hectares.** The total hectares within the Conservation Unit (including water).
terr_HA	**Non-water hectares.** The total non-water hectares in the unit – includes vegetated wetlands and all terrestrial land cover.
pct_secure	**Percent secure.** Percent of the non-water area in the Conservation Unit that is protected.
res	**Mean Resilience.** Mean of TNC's Coastal Resilience (Anderson, M.G. and Barnett, A. 2017), across cells with resilience values only. Based on the SLR 6 scenario (6 ft. sea level rise) and specifically on the RESILZZBst column, which contains z-scored resilience with a bonus or penalty for the sites migration space trend. 0 represents the mean score, positive indicates above average and negative indicates below average.
res_prop	**Resilience Proportion.** Proportion of the cells in the Conservation Unit that had a Coastal Resilience value.
res_tot	**Total Resilience.** Total Coastal Resilience value across all cells in the Conservation Unit. Note the presence of negative values makes this slightly tricky to interpret, but higher values indicate greater resilience.

mean_tr	**Mean Tidal Restriction.** Mean of the CAPS Tidal Restriction metric across all salt marsh cells in the Conservation Unit. Higher values indicate that saltmarshes in the Conservation Unit are subject to greater tidal restrictions on average.
tot_tr	**Total Tidal Restrictions.** The Total Tidal Restriction metric value summed across all salt marsh cells in the Conservation Unit. This represents the total impact on saltmarshes of tidal restrictions and thus also serves as an indication of the restoration potential for salt marshes in the unit.
UP_ParcelHA	**Unprotected Parcel Size (hectares).** Unprotected area weighted mean parcel size for the Conservation Unit, calculated from all the cells in the unit that were not classified as protected. It is not a straight average, but is the average size that would be encountered in a randomly sample of points in the unprotected portion of the unit.
ParcelHA	**Parcel Size (hectares).** The area weighted mean parcel size of parcels in the Conservation Unit. This is the mean parcel size we would expect to encounter if we sampled random points within the Conservation Unit, but is not the same as the mean of all parcel sizes within the unit.
scenic	**Scenic Proportion.** Proportion of the non-water area of the Conservation Unit that fell within the Scenic Landscape Inventory polygons produced by the Massachusetts Landscape Inventory Project (DCR, 1982). https://docs.digital.mass.gov/dataset/massgis-data-scenic-landscape-inventory
Beach_P_M	**Public Beach Length.** Length in meters of public beach within the Conservation Unit based on the Massachusetts Office of Coastal Zone Management (CZM, 2017) coastal access linear features viewable on MORIS: http://maps.massgis.state.ma.us/map_ol/moris.php
Beach_SP_M	**Semi-public Beach Length.** Length in meters of CZM coastal access semi-public beach within each Conservation Unit.
Beach_Tot_M	**Accessible Beach Length.** Total length in meters of CZM public and semi-public beach with each Conservation Unit. The sum of prior two columns.
Beach_P_Pts	**Beach Public Access Points.** Count of CZM public beach access points within each Conservation Unit.
Beach_SP_Pts	**Beach Semi-Public Access Points**. Count of CZM semi-public beach access points within each Conservation Unit.
Beach_Tot_Pts	**Beach Total Access Points**. Count of CZM public and semi-public access points within each Conservation Unit.
mean_I	**Mean IEI.** Mean Index of Ecological Integrity (IEI) across all 6 coastal classes within the Conservation Unit. This uses the statewide scaling of IEI regardless of how the Conservation Units were formed (from statewide or ecoregional scaled IEI).
R_mean_I	**Rank Mean IEI.** The rank order of Conservation Units by Mean IEI from highest to lowest; 1 is best.
pct_I	**Percent IEI**. Percentage of all state-scaled IEI within the 6 coastal classes that falls in the Conservation Unit.
density	**Density**. Sum of the state-scaled IEI in the 6 coastal systems divided by the number of non-water cells in the Conservation Unit. Density will be higher if the IEI values in the target systems are high and if a larger percentage of the Conservation Unit is made up of these systems. Density indicates how much value each Conservation Unit captures per non-water hectare. Importantly, and slightly problematically, because we are dividing by the non-water area, small islands have an advantage as their buffer is ocean, which doesn't add non-target non-water cells to the Conservation Unit. This is however a real advantage of islands - you don't have to buy as much buffer to protect them.
impor	**Importance.** Density divided by the expected Density if every non-water cell in the Conservation Unit had the mean Density for the target systems observed across all Conservation Units. It has a minimum value of 0 (no IEI in the unit), a value of 1

	indicates that its Density equals the expected Density; values above 1 indicate better than expected; there is no upper bound. Importance like Density reflects the amount of IEI captured per non-water hectare but because it is expressed relative to the expected value for a system (i.e. the mean Density across all Conservation Units), it is reasonable to compare Importance but not Density across systems. Importantly, and slightly problematically, because Density is calculated by dividing the total IEI in the Conservation Unit by the Unit's non-water area, small islands have an advantage as their buffer is ocean, which doesn't add non-target non-water cells to the Conservation Unit. This is however a real advantage of islands - you don't have to buy as much buffer to protect them.
R_impor	**Rank Importance.** The rank order of Conservation Units by Importance (*impor*) from highest to lowest; 1 is best.
mean_I2 *R_mean_I2* *pct_I2* *density2* *impor2* *R_impor2*	Same as the similarly named columns above but based on squared state-scaled IEI rather than IEI directly. Squaring IEI cell by cell prior to calculating the statistics has the effect of giving more relative weight to high IEI cells and less to low IEI cells.
Impact	**Impact.** Total impact of future development on IEI across the six coastal classes for the Conservation Unit when the unit is not subject to any additional land protection. Larger numbers indicate greater total impact to coastal systems, which could be due to a large area of small impact or a smaller area of greater impact. Impact is calculated by running CAPS on a landscape with development projected to the year 2080 and with land cover and related settings variables (e.g. traffic, imperviousness) updated to account for the projected development. Impact is negative so larger negative numbers have greater absolute value and indicate greater impact of development on the IEI of the system.
mean_Imp	**Mean Impact.** Mean Impact across the 6 coastal classes for the Conservation Unit. Larger negative numbers indicate a higher Impact per unit of coastal area - a more intense impact.
pct_Imp	**Percent Impact.** Percentage of all statewide Impact to the 6 coastal classes that occurs within each Conservation Unit.
*AImpact**	**Alternate Impact.** Total Impact from future development across the six coastal classes within each Conservation Unit when land within that unit is protected from development. It represents the projected indirect impact of development outside of the unit on ecological integrity within the unit. This analysis was only performed on the state-scaled merged Conservation Units so this column will not be in the data for the other sets of Conservation Units.
*mean_AImp**	**Mean Alternate Impact.** Mean of Alternate Impact for the Conservation Unit, across all cells in the six coastal classes.
*ConEffect**	**Conservation Effect**. Difference between Impact and the Alternate Impact (*AImpact*). It is the absolute reduction in Impact across the six coastal classes in the Conservation Unit that is realized if we protect the Conservation Unit from development.
*R_CEffect**	**Rank Conservation Effect.** Rank order of Conservation Units based on Conservation Effect. Large effects result in lower rank numbers signifying better outcomes.
*PctEffect**	**Percent Conservation Effect.** Percentage of Impact (for the 6 coastal classes) eliminated due to land conservation in the Conservation Unit. Calculated as *ConEffect / Impact* x 100.
*Efficiency**	**Conservation Efficiency**. Conservation Effect divided by unprotected non-water area within the Conservation Unit. This indicates how much of a Conservation Effect is generated per unit area protected.
*R_Effic**	**Rank Conservation Efficiency.** The rank order of Conservation Units based on Conservation Efficiency. Units with higher Conservation Efficiency values have lower rank scores; 1 is best.

mean[system]_I	**Mean IEI** (system specific)**.** The Mean IEI (Index of Ecological Integrity) of cells in the [system] land cover type within the Conservation Unit. This and other system specific columns below are only included for the systems associated with a system-specific Conservation Unit file. For example, *meanCB_I* is included in the beach Conservation Unit files but not in the merged or other system-specific Unit files.
R_mn[system]_I	**Rank Mean IEI** (system specific). The prior column in rank order from highest to lowest IEI; 1 is best.
pct[system]_I	**Percent IEI** (system specific). The percentage of all [system] IEI in the state, that falls within the Conservation Unit.
[system]_dens	**Density** (system specific). Density calculated for a single system: the total IEI in that system within the Conservation Unit, divided by the number of non-water cells within the unit.
[system]_impor	**Importance** (system specific). Importance calculated for a single system.
R_[system]_impo	**Ranked Importance** (system specific). The rank of each Conservation Unit when they are ordered from highest to lowest based on Importance; 1 is best.
mean[system]_I2 *R_mn[system]_I2* *pct[system]_I2* *[system]_dens2* *[system]_impor2* *R_[system]_impo2*	Same as the similarly named columns above but based on squared state-scaled IEI rather than the IEI directly. Squaring IEI cell by cell prior to calculating the statistics has the effect of putting more relative weight on high IEI cells and less on low IEI cells.
[system]_imp	**Impact** (system specific). This is the total impact of development for all cells in the system within the Conservation Unit given projected future development without further land protection.
mean_[system]_imp	**Mean Impact** (system specific). Mean Impact across all cells in the system.
pct_[system]_imp	**Percent Impact** (system specific). Percent of the impact of future development on all cells within the system that occurs within the Conservation Unit.
[system]_AImp*	**Alternate Impact** (system specific). The impact of development for all cells in the system when land within the Conservation Unit is protected from further development.
mean_[system]_AImp*	**Mean Alternate Impact** (system specific)**.** Mean Alternate Impact for the system within the Conservation Unit.
[system]_ConEffect*	**Conservation Effect** (system specific). The system specific reduction in Impact of future development due to land conservation within the Conservation Unit.
[system]_PctEffect*	**Percent Conservation Effect** (system specific). The percent reduction in Impact of future development within the system due to land conservation in the unit.
[system]_Efficient*	**Conservation Efficiency** (system specific). The Conservation Effect (using only cells in the system) divided by the count of unprotected, non-water cells in the Conservation Unit.

Appendix B

Metrics Calculated for Conservation Units Included in Shapefiles

Selected metrics from Appendix A were included as attributes in shapefiles. For each shapefile, the metrics included are a subset of the full set of metrics available in the associated .csv file.

Columns marked with an asterisk (*) depend on the alternate impact analysis which was only performed for the state scaled merged Conservation Units and so will be absent from all other sets of Conservation Units.

Columns marked with a double asterisk (**) are system specific columns and are only included in the system-specific Conservation Units shapefiles and only for the systems that are associated with those Conservation Units. "[system]" in these column names is a place holder for one of the six coastal classes: "SM" salt marsh, "SC" sea cliff, "VD" vegetated dune, "CD" coastal dune, "CB" coastal beach, or "RI" rocky intertidal.

Column	**Description**
conunit	**Conservation Unit number.** For each set of Conservation Units the numbers were assigned north to south sequentially starting with 1. This number is not unique across sets of Conservation Units (e.g. merged units versus system-specific units).
ID	**ID.** The Conservation Unit ID. This is a unique ID across all sets of Conservation Units. It consists of a single letter for the IEI scaling used to make the Conservation Units (either "S" for statewide or "E" for ecosystem); a dash; one or two letters for the type of Conservation Unit (either "M" for merged units or two letters indicating the system targeted by the system specific units); a second dash and then the Conservation Unit number. E.g. "S-M-1" is the northernmost Conservation Unit in the merged Conservation Units based on the statewide scaling of IEI.
Name	**Name.** A name assigned to each Conservation Unit based on geographic place names within each unit.
*mean_rank**	**Mean Rank.** Mean of the rank order of Conservation Units ranked by Mean Squared IEI (*R_mean_I2*), Importance (from squared IEI - *R_impor2*), Conservation Effect (*R_CEffect*), and Conservation Efficiency (*R_Effic*). These are the four metrics which we deemed most important, and thus the average of these rank scores can be interpreted as an overall score. It is only available for the state scaled merged cores as that is the only set of Conservation Units on which we performed the alternative impact analysis. Conservation Units that scored better in each metric were given lower rank numbers so the lower the mean rank score the better the unit is. It ranges from theoretically 1 (if a unit scored first in each metric) to N if the unit scored last in each metric. In practice, the range of Mean Rank scores is reduced because no unit consistently scores either first or last.
HA	**Hectares.** The total hectares within the Conservation Unit (including water).
terr_HA	**Non-water hectares.** The total non-water hectares in the unit – includes vegetated wetlands and all terrestrial land cover.
pct_secure	**Percent secure.** Percent of the non-water area in the Conservation Unit that is protected.

res	**Mean Resilience.** Mean of TNC's Coastal Resilience (Anderson, M.G. and Barnett, A. 2017), across cells with resilience values only. Based on the SLR 6 scenario (6 ft. sea level rise) and specifically on the RESILZZBst column, which contains z-scored resilience with a bonus or penalty for the sites migration space trend. 0 represents the mean score, positive indicates above average and negative indicates below average.
mean_tr	**Mean Tidal Restriction.** Mean of the CAPS Tidal Restriction metric across all salt marsh cells in the Conservation Unit. Higher values indicate that saltmarshes in the Conservation Unit are subject to greater tidal restrictions on average.
tot_tr	**Total Tidal Restrictions.** The Total Tidal Restriction metric value summed across all salt marsh cells in the Conservation Unit. This represents the total impact on saltmarshes of tidal restrictions and thus also serves as an indication of the restoration potential for salt marshes in the unit.
UP_ParcelH	**Unprotected Parcel Size (hectares).** Unprotected area weighted mean parcel size for the Conservation Unit, calculated from all the cells in the unit that were not classified as protected. It is not a straight average, but is the average size that would be encountered in a randomly sample of points in the unprotected portion of the unit.
ParcelHA	**Parcel Size (hectares).** The area weighted mean parcel size of parcels in the Conservation Unit. This is the mean parcel size we would expect to encounter if we sampled random points within the Conservation Unit, but is not the same as the mean of all parcel sizes within the unit.
scenic	**Scenic Proportion.** Proportion of the non-water area of the Conservation Unit that fell within the Scenic Landscape Inventory polygons produced by the Massachusetts Landscape Inventory Project (DCR, 1982). https://docs.digital.mass.gov/dataset/massgis-data-scenic-landscape-inventory
Beach_TotM	**Accessible Beach Length.** Length in meters of public and semi-public beach within the Conservation Unit based on the Massachusetts Office of Coastal Zone Management (CZM, 2017) coastal access linear features viewable on MORIS: http://maps.massgis.state.ma.us/map_ol/moris.php
mean_I	**Mean IEI.** Mean Index of Ecological Integrity (IEI) across all 6 coastal classes within the Conservation Unit. This uses the statewide scaling of IEI regardless of how the Conservation Units were formed (from statewide or ecoregional scaled IEI).
mean_I2	**Mean Squared IEI.** Mean of squared IEI across all 6 coastal classes within the Conservation Unit. This uses the statewide scaling of IEI regardless of how the Conservation Units were formed (from statewide or ecoregional scaled IEI).
R_mean_I2	**Rank Mean Squared IEI.** The rank order of Conservation Units by Mean Squared IEI from highest to lowest; 1 is best.
pct_I2	**Percent IEI**. Percentage of all state-scaled squared IEI within the 6 coastal classes that falls in the Conservation Unit.
impor2	**Importance** (based on squared IEI). Density divided by the expected Density if every non-water cell in the Conservation Unit had the mean Density for the target systems observed across all Conservation Units. It has a minimum value of 0 (no IEI in the unit), a value of 1 indicates that its Density equals the expected Density; values above 1 indicate better than expected; there is no upper bound.

	Importance like Density reflects the amount of squared IEI captured per non-water hectare but because it is expressed relative to the expected value for a system (i.e. the mean Density across all Conservation Units), it is reasonable to compare Importance but not Density across systems. Importantly, and slightly problematically, because Density is calculated by dividing the total IEI in the Conservation Unit by the Unit's non-water area, small islands have an advantage as their buffer is ocean, which doesn't add non-target non-water cells to the Conservation Unit. This is however a real advantage of islands - you don't have to buy as much buffer to protect them.
R_impor2	**Rank Importance** (based on squared IEI). The rank order of Conservation Units by Importance (i*mpor2*) from highest to lowest; 1 is best.
Impact	**Impact.** Total impact of future development on IEI across the six coastal classes for the Conservation Unit when the unit is not subject to any additional land protection. Larger numbers indicate greater total impact to coastal systems, which could be due to a large area of small impact or a smaller area of greater impact. Impact is calculated by running CAPS on a landscape with development projected to the year 2080 and with land cover and related settings variables (e.g. traffic, imperviousness) updated to account for the projected development. Impact is negative so larger negative numbers have greater absolute value and indicate greater impact of development on the IEI of the system.
mean_Imp	**Mean Impact.** Mean Impact across the 6 coastal classes for the Conservation Unit. Larger negative numbers indicate a higher Impact per unit of coastal area - a more intense impact.
pct_Imp	**Percent Impact.** Percentage of all statewide Impact to the 6 coastal classes that occurs within each Conservation Unit.
*AImpact**	**Alternate Impact.** Total Impact from future development across the six coastal classes within each Conservation Unit when land within that unit is protected from development. It represents the projected indirect impact of development outside of the unit on ecological integrity within the unit. This analysis was only performed on the state-scaled merged Conservation Units so this column will not be in the data for the other sets of Conservation Units.
*mean_AImp**	**Mean Alternate Impact.** Mean of Alternate Impact for the Conservation Unit, across all cells in the six coastal classes.
*ConEffect**	**Conservation Effect**. Difference between Impact and the Alternate Impact (*AImpact*). It is the absolute reduction in Impact across the six coastal classes in the Conservation Unit that is realized if we protect the Conservation Unit from development.
*R_CEffect**	**Rank Conservation Effect.** Rank order of Conservation Units based on Conservation Effect. Large effects result in lower rank numbers signifying better outcomes.
*PctEffect**	**Percent Conservation Effect.** Percentage of Impact (for the 6 coastal classes) eliminated due to land conservation in the Conservation Unit. Calculated as *ConEffect* / *Impact* x 100.
*Efficiency**	**Conservation Efficiency**. Conservation Effect divided by unprotected non-water area within the Conservation Unit. This indicates how much of a Conservation Effect is generated per unit area protected.

*R_Effic**	**Rank Conservation Efficiency.** The rank order of Conservation Units based on Conservation Efficiency. Units with higher Conservation Efficiency values have lower rank scores; 1 is best.
*mean[system]_I2***	**Mean Squared IEI** (system specific)**.** The Mean Squared IEI (Index of Ecological Integrity) of cells in the [system] land cover type within the Conservation Unit. This and other system specific columns below are only included for the systems associated with a system-specific Conservation Unit file. For example, *meanCB_I2* is included in the beach Conservation Unit files but not in the merged or other system-specific Unit files.
*R_mn[system]_I2***	**Rank Mean Squared IEI** (system specific). The prior column in rank order from highest to lowest IEI; 1 is best.
*[system]_impor2***	**Importance** (system specific, based on squared IEI). Importance calculated for a single system from squared IEI.
*R_[system]_impo2***	**Ranked Importance** (system specific, based on squared IEI). The rank of each Conservation Unit when they are ordered from highest to lowest based on Importance (*[system]_import2*); 1 is best.

Appendix C

Prioritization of Conservation Units Based on Mean Rank of Four Ranked Metrics: *Mean Squared IEI*, *Importance*, *Conservation Effect*, and *Conservation Efficiency*

Conservation Unit ID (*ID*)	Name	Mean Rank (*mean_rank*)	Rank of *Mean IEI*^{2} (*R_mean_I2*)	Rank of *Importance* (*R_impor2*)	Rank of *Conservation Effect* (*R_CEffect*)	Rank of *Conservation Efficiency* (*R_Effic*)
S-M-35	Barnstable Harbor-Great Marsh	6.4	6	9.5	2	8
S-M-33	Pleasant Bay	8.8	5	5	5	20
S-M-21	Provincelands	9.8	7.5	9.5	16	6
S-M-2	PIE-Great Marsh	14.3	16	13	1	27
S-M-32	Old Harbor-Sandwich	20.4	53	22.5	3	3
S-M-46	Horseneck Beach-Westport	20.4	49.5	20	7	5
S-M-66	Quaise Point-Pocomo Creek-Nantucket	21.1	43	30.5	10	1
S-M-24	Wood End-Long Point	21.8	10	11	29	37
S-M-51	Naushon Point - Pasque Island	21.8	13	51	6	17
S-M-41	Monomoy	22.1	1.5	6	22	59
S-M-43	Waquoit Bay	22.1	21	14.5	46	7
S-M-20	North River-South River	22.5	34	19	8	29
S-M-23	Black River-Duxbury	22.5	28.5	17.5	9	35
S-M-28	Outter Cape-Nauset Harbor	23.1	7.5	26	14	45
S-M-29	Wellfleet Bay Wildlife Sanctuary	25.1	43	35.5	4	18
S-M-57	Menemsha Hills-Chilmark	25.6	4	48.5	34	16
S-M-25	Pamet River-Truro	26.4	59.5	32	12	2
S-M-59	Norton Point Beach-Katama Bay	26.4	15	33.5	24	33
S-M-62	Menemsha Pond-Aquinnah	27.6	43	22.5	19	26
S-M-4	Milk Island	29.3	3	1	64	49
S-M-64	Wequabaque Cliffs-Chilmark	29.3	38	56	13	10
S-M-65	Long Beach-Squibnocket Beach	29.3	26	27	33	31
S-M-49	South Bluff-Witches Glen-Naushon Island	29.9	18	62.5	15	24
S-M-69	Tuckernuck Island	30.0	32	43	30	15
S-M-48	Silver Beach- Naushon Island	30.1	26	59.5	21	14
S-M-27	Great Island-Wellfleet	30.6	19	35.5	28	40
S-M-60	Gay Head-Aquinnah	30.8	38	47	27	11
S-M-54	Cape Higgon-Chilmark	31.3	10	50	40	25
S-M-9	Tinkers Island	33.5	17	3	60	54
S-M-55	North Neck-Edgartown	33.9	47.5	38	38	12
S-M-6	Great Misery-Little Misery-House Islands	34.6	1.5	12	63	62

S-M-30	Herring River-Rock Harbor Beach	34.9	53	41.5	11	34
S-M-22	Race Point	35.4	26	17.5	45	53
S-M-67	Coatue Point-Nantucket	35.5	24	7	56	55
S-M-40	Angelica Point-Mattapoisett	35.6	32	14.5	50	46
S-M-70	Quidnet Beach-Nantucket	35.6	32	39.5	41	30
S-M-31	Namskaket Marsh	36.1	43	48.5	17	36
S-M-42	Meadow Neck-Falmouth	36.3	65	58	18	4
S-M-61	Coskata-Coatue Wildlife Refuge-Nantucket	36.3	35	16	47	47
S-M-68	Squibnocket Point-Chilmark	36.6	21	41.5	42	42
S-M-58	Oyster Pond-Edgartown	37.0	49.5	69.5	20	9
S-M-71	Nobadeer Beach-Madequecham Beach-Nantucket	37.6	38	66.5	25	21
S-M-19	Scituate Neck	38.0	56.5	30.5	26	39
S-M-63	Muskeget Island	38.3	13	2	69	69
S-M-8	Cat Island-Cormorant Rock	38.8	13	4	69	69
S-M-17	Slate Island	40.5	36	21	57	48
S-M-53	Cuttyhunk Island	40.9	21	33.5	52	57
S-M-56	Caleb Pond-Chappaquiddick	41.3	66.5	62.5	23	13
S-M-11	Great Brewster Island	42.3	23	8	69	69
S-M-44	Lloyd Woods-Little River-Dartmouth	42.4	62.5	52	36	19
S-M-52	Nashawena Island	43.4	10	44.5	59	60
S-M-14	Thompson-Spectacle Islands	44.0	43	24	53	56
S-M-47	Nonamesset Island-Gosnold	44.3	56.5	62.5	35	23
S-M-3	Straitsmouth Island	45.4	47.5	28	55	51
S-M-34	Indian Neck-Bourne Point-Wareham	45.8	68	56	31	28
S-M-26	Rocky Point-Plymouth	46.0	43	54	43	44
S-M-45	Demarest Lloyd State Park-Giles Creek	46.5	55	46	44	41
S-M-50	Penikese Island	47.9	28.5	25	69	69
S-M-39	Baxter Neck-Prince Cove-Barnstable	48.6	71	69.5	32	22
S-M-1	Merrimack River - Maudslay State Park	50.3	43	71	49	38
S-M-36	Great Neck-Tempes Knob-Wareham	51.0	66.5	66.5	39	32
S-M-18	Langlee-Ragged-Sarah Islands	51.9	30	59.5	54	64
S-M-16	West Head-Peddocks Island	52.5	51	29	65	65
S-M-5	Alewife Brook - Essex River	54.0	69.5	66.5	37	43
S-M-12	Castle-Head Islands	55.0	64	37	61	58
S-M-37	Bay Point-Gardners Neck-Swansea	55.8	59.5	62.5	51	50
S-M-13	Gallops-Lovell Islands	58.5	62.5	39.5	66	66
S-M-15	East Head-Peddocks Island	58.5	58	53	62	61
S-M-7	Bakers Island	58.9	53	44.5	69	69
S-M-38	Forest Beach-Chatham	59.0	69.5	66.5	48	52
S-M-10	Snake Island	59.5	61	56	58	63

Appendix D

Prioritization of Conservation Units Based on the Rank Order of *Conservation Effect*

Conservation Unit ID (*ID*)	Name	Mean Rank (*mean_rank*)	Rank of *Mean IEI*^{2} (*R_mean_I2*)	Rank of *Importance* (*R_impor2*)	Rank of *Conservation Effect* (*R_CEffect*)	Rank of *Conservation Efficiency* (*R_Effic*)
S-M-2	PIE-Great Marsh	14.3	16	13	1	27
S-M-35	Barnstable Harbor-Great Marsh	6.4	6	9.5	2	8
S-M-32	Old Harbor-Sandwich	20.4	53	22.5	3	3
S-M-29	Wellfleet Bay Wildlife Sanctuary	25.1	43	35.5	4	18
S-M-33	Pleasant Bay	8.8	5	5	5	20
S-M-51	Naushon Point - Pasque Island	21.8	13	51	6	17
S-M-46	Horseneck Beach-Westport	20.4	49.5	20	7	5
S-M-20	North River-South River	22.5	34	19	8	29
S-M-23	Black River-Duxbury	22.5	28.5	17.5	9	35
S-M-66	Quaise Point-Pocomo Creek-Nantucket	21.1	43	30.5	10	1
S-M-30	Herring River-Rock Harbor Beach	34.9	53	41.5	11	34
S-M-25	Pamet River-Truro	26.4	59.5	32	12	2
S-M-64	Wequabaque Cliffs-Chilmark	29.3	38	56	13	10
S-M-28	Outter Cape-Nauset Harbor	23.1	7.5	26	14	45
S-M-49	South Bluff-Witches Glen-Naushon Island	29.9	18	62.5	15	24
S-M-21	Provincelands	9.8	7.5	9.5	16	6
S-M-31	Namskaket Marsh	36.1	43	48.5	17	36
S-M-42	Meadow Neck-Falmouth	36.3	65	58	18	4
S-M-62	Menemsha Pond-Aquinnah	27.6	43	22.5	19	26
S-M-58	Oyster Pond-Edgartown	37.0	49.5	69.5	20	9
S-M-48	Silver Beach- Naushon Island	30.1	26	59.5	21	14
S-M-41	Monomoy	22.1	1.5	6	22	59
S-M-56	Caleb Pond-Chappaquiddick	41.3	66.5	62.5	23	13
S-M-59	Norton Point Beach-Katama Bay	26.4	15	33.5	24	33
S-M-71	Nobadeer Beach-Madequecham Beach-Nantucket	37.6	38	66.5	25	21
S-M-19	Scituate Neck	38.0	56.5	30.5	26	39
S-M-60	Gay Head-Aquinnah	30.8	38	47	27	11
S-M-27	Great Island-Wellfleet	30.6	19	35.5	28	40
S-M-24	Wood End-Long Point	21.8	10	11	29	37
S-M-69	Tuckernuck Island	30.0	32	43	30	15
S-M-34	Indian Neck-Bourne Point-Wareham	45.8	68	56	31	28
S-M-39	Baxter Neck-Prince Cove-Barnstable	48.6	71	69.5	32	22

S-M-65	Long Beach-Squibnocket Beach	29.3	26	27	33	31
S-M-57	Menemsha Hills-Chilmark	25.6	4	48.5	34	16
S-M-47	Nonamesset Island-Gosnold	44.3	56.5	62.5	35	23
S-M-44	Lloyd Woods-Little River-Dartmouth	42.4	62.5	52	36	19
S-M-5	Alewife Brook - Essex River	54.0	69.5	66.5	37	43
S-M-55	North Neck-Edgartown	33.9	47.5	38	38	12
S-M-36	Great Neck-Tempes Knob-Wareham	51.0	66.5	66.5	39	32
S-M-54	Cape Higgon-Chilmark	31.3	10	50	40	25
S-M-70	Quidnet Beach-Nantucket	35.6	32	39.5	41	30
S-M-68	Squibnocket Point-Chilmark	36.6	21	41.5	42	42
S-M-26	Rocky Point-Plymouth	46.0	43	54	43	44
S-M-45	Demarest Lloyd State Park-Giles Creek	46.5	55	46	44	41
S-M-22	Race Point	35.4	26	17.5	45	53
S-M-43	Waquoit Bay	22.1	21	14.5	46	7
S-M-61	Coskata-Coatue Wildlife Refuge-Nantucket	36.3	35	16	47	47
S-M-38	Forest Beach-Chatham	59.0	69.5	66.5	48	52
S-M-1	Merrimack River - Maudslay State Park	50.3	43	71	49	38
S-M-40	Angelica Point-Mattapoisett	35.6	32	14.5	50	46
S-M-37	Bay Point-Gardners Neck-Swansea	55.8	59.5	62.5	51	50
S-M-53	Cuttyhunk Island	40.9	21	33.5	52	57
S-M-14	Thompson-Spectacle Islands	44.0	43	24	53	56
S-M-18	Langlee-Ragged-Sarah Islands	51.9	30	59.5	54	64
S-M-3	Straitsmouth Island	45.4	47.5	28	55	51
S-M-67	Coatue Point-Nantucket	35.5	24	7	56	55
S-M-17	Slate Island	40.5	36	21	57	48
S-M-10	Snake Island	59.5	61	56	58	63
S-M-52	Nashawena Island	43.4	10	44.5	59	60
S-M-9	Tinkers Island	33.5	17	3	60	54
S-M-12	Castle-Head Islands	55.0	64	37	61	58
S-M-15	East Head-Peddocks Island	58.5	58	53	62	61
S-M-6	Great Misery-Little Misery-House Islands	34.6	1.5	12	63	62
S-M-4	Milk Island	29.3	3	1	64	49
S-M-16	West Head-Peddocks Island	52.5	51	29	65	65
S-M-13	Gallops-Lovell Islands	58.5	62.5	39.5	66	66
S-M-63	Muskeget Island	38.3	13	2	69	69
S-M-8	Cat Island-Cormorant Rock	38.8	13	4	69	69
S-M-11	Great Brewster Island	42.3	23	8	69	69
S-M-50	Penikese Island	47.9	28.5	25	69	69
S-M-7	Bakers Island	58.9	53	44.5	69	69