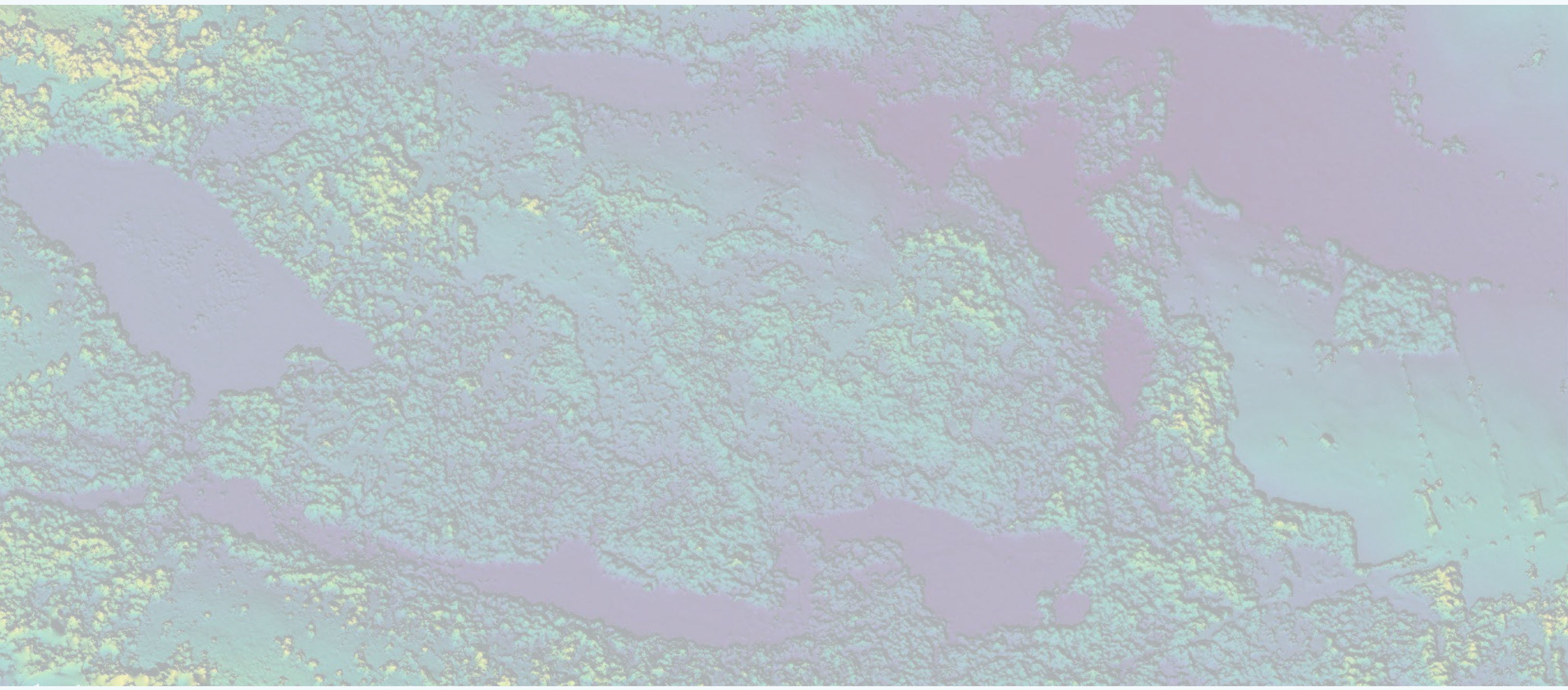
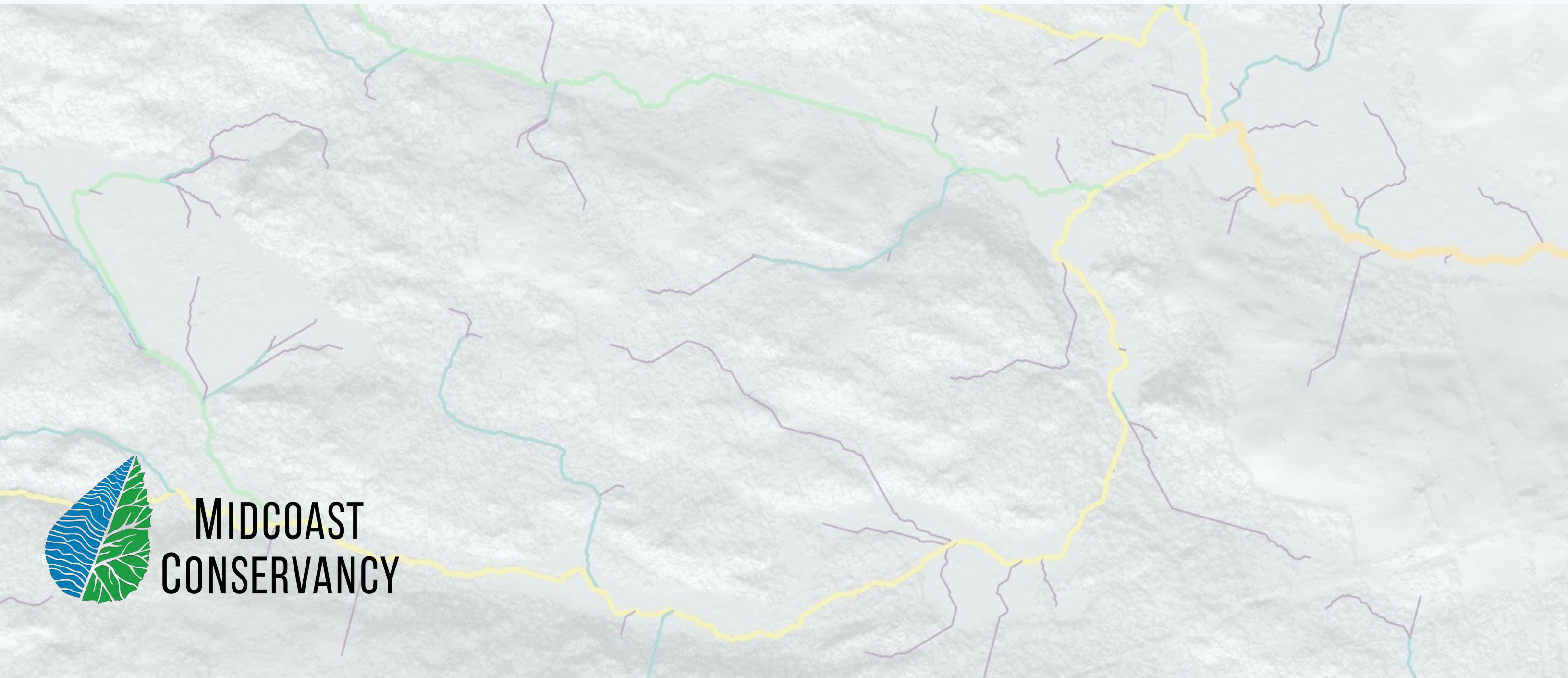
Midcoast Conservancy 30 x 30

Landscape Priority Assessment

December 2022





Midcoast Conservancy

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*Click carets (**^**) and section symbols (**§**) throughout the document to jump to pages, sections, and/or references. Click the phrase (**^ToC**) at the bottom of each section to return to this Table of Contents. Hyperlinks (<Link>) to web addresses are working as of December 1, 2022. References are listed in §5 Resources in the order that they appear. The only other annotations are in the form of figures and footnotes—these are in sequential order throughout the entire document and refer to each page alone.*

1 - Project Overview

This section gives a narrative report of the 30x30 Landscape Priority Assessment as a project. It starts with onboarding and setup, reviews the purpose and approach, gives a chronology of the effort, lists personnel and involved parties, details the scope of the work performed, and presents a brief summary of findings.

1.1 - About the Project

1.1.1 - Executive Summary

What follows is a document describing the final deliverables for a two-phase project commissioned by Midcoast Conservancy and authored by consultants at Rhumb Line Maps LLC (*also referred to variously as "Rhumbline" or "Rhumbline Consulting Team" or "RLM"*). The goal of this document is: **1)** to describe a series of geospatial data deliverables provided to Midcoast Conservancy designed to aid in their conservation planning and decision-making processes, **2)** to document our consulting firm's workflow and rationale, and **3)** to offer several substantive recommendations in support of Midcoast Conservancy's long-term goals. This document is organized in 6 sections:

1 - Project Overview — The section acts primarily as business documentation; it provides a more or less chronological account of the effort and describes the personnel, goals, and other items of interest regarding the work.

2 - GIS User's Guide — The data deliverables are principally designed for a GIS professional to use in a rural planning environment. This section orients users to the database deliverables and assumes that readers are likely already somewhat familiar with geospatial technology and data science.

3 - Assessments — This section describes all of the critical decisions made in producing the product. This might normally be considered a "methods" section in a scientific report; the process we've undertaken, however, aims to provide a dispassionate assessment of priorities based on scientific data, not to advance a scientific hypothesis through experimentation or observational study. Because this report is a planning document with a predetermined agenda, this section is entitled "assessments."

4 - Recommendations — Here we offer a short discussion of the implications of the results, several insights into the process itself, and the reflections and opinions of the two lead consultants.

5 - Resources — In lieu of a bibliography, this section aims to provide readers and users with a quick reference guide to further reading material, links to useful industry tools, and context for where we sourced the literature and databases that anchored our assessments.

6 - Appendix — This section provides a basic landscape reference map, an array of Grid Score maps that display the results of the overall analyses, and the workflow diagram.

1.1.2 - Background

First Meeting

In the spring of 2022 Midcoast Conservancy approached **Ben Meader** (*Director, Rhumb Line Maps LLC*) at the suggestion of Janet McMahon to help develop guidelines for Midcoast's 30 x 30 planning goals. Ben met with **Pete Nichols** (*Executive Director, Midcoast Conservancy*) and **Chris Schorn** (*Director of Land Conservation and Ecology, Midcoast Conservancy*) on March 28th to talk about a proposal for a five-phase plan totaling approximately $50,000. Phase One would inventory existing conditions, Phase Two would analyze ecological assets of the study region, Phase 3 would assess development risk, Phase Four would integrate the previous topics into a Multiple Criteria Evaluation (*MCE*), and Phase 5 would produce communication products and project closeout materials.

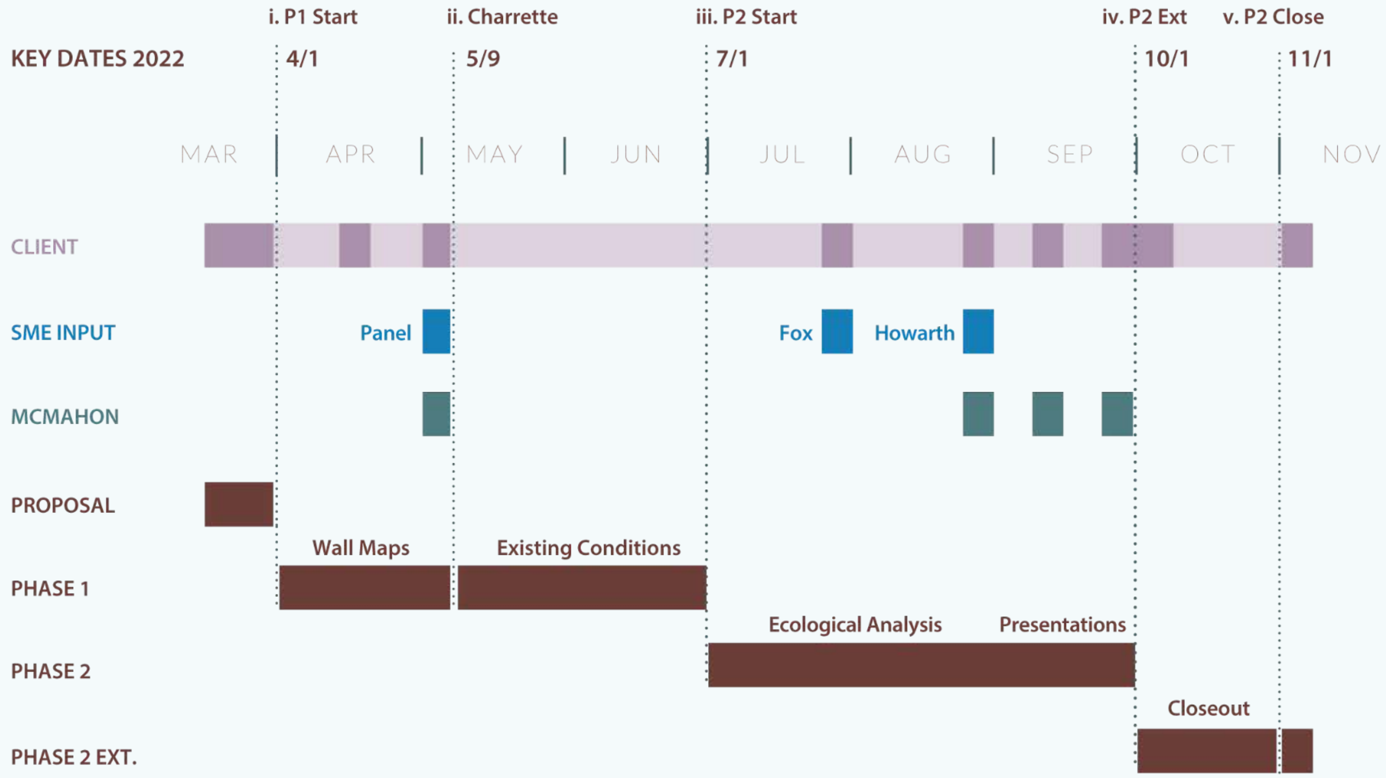
Chris emphasized the immediate need for parcel evaluation tools based on ecological parameters, especially to create metrics that were more robust and founded in recent advances in conservation thinking. Pete emphasized the need for simple, effective, and persuasive communication visuals to supplement their organization's publications and donor outreach. Ben emphasized his company's background in planning, Rhumbline's intentionally iterative creative process, and the need to bring in Subject Matter Experts (*SMEs*) as needed.

Consulting Schedule

The parties agreed to begin with Phase One (*April-June*) and planned to proceed to Phase Two (*June-September*) for a project closeout in the fall. This report represents the completion of those first **two phases**. Phases Three through Five have not been greenlit. For more detail on each completed phase, please see the project reports (§1.2). Phase One was completed on time and under budget. Phase Two met presentation deadlines but was extended for an additional month (*through October*) with additional funds to finish project closeout and communication deliverables.

The main **project development events** included intermittent as well as biweekly meetings between Midcoast Conservancy staff and the Rhumbline Team, an existing conditions charrette, a meeting with Christian Fox at The Nature Conservancy's office in Brunswick Maine, several meetings with Janet McMahon, and a meeting with Jeff Howarth, a professor of geography with experience in ecological conservation from Vermont. The main **project presentation events** included an in-person Midcoast Conservancy Board meeting and a subsequent staff meeting using Zoom.

Figure 1 — Timeline



1.1.3 - Purpose

The 30 x 30 Initiative

The 30 x 30 initiative began when President Joe Biden issued the “America the Beautiful Initiative” in December of 2021. The national goal is to conserve 30 percent of U.S. lands and freshwater as well as 30 percent of the United States ocean areas by the year 2030. Through this conservation it is hoped that the negative impacts caused by the decline in biodiversity can be reversed. In addition, more communities will be able to have access to nature.

The America the Beautiful Campaign aims to unite Americans in a common cause through locally led campaigns following eight principles:

- Pursue a Collaborative and Inclusive Approach to Conservation
- Conserve America's Lands and Waters for the Benefit of All People
- Support Locally Led and Locally Designed Conservation Efforts
- Honor Tribal Sovereignty and Support the Priorities of Tribal Nations
- Pursue Approaches that Create Jobs and Support Healthy Communities
- Honor Private Property Rights and Voluntary Stewardship Efforts
- Use Science as a Guide
- Build on Existing Tools and Strategies with Flexibility and Adaptive Approaches

Actionable Goals

Midcoast Conservancy and its parent organizations have conserved 14,211 acres of land—7,842 in fee and 6,369 through conservation easements. To reach their goal of conserving 30,000 acres in the Midcoast by 2030, they aim to conserve another 16,000 acres of land in the next eight years. However, their aim is not just to conserve another 16,000 acres—it's to conserve the most important 16,000 acres possible. Because the best practices and goals of conservation and ecology are continuing to transform, the Rhumbline Team was hired to help unpack this general question: *Which places ought to be targeted for conservation?*

Although this question can often be answered by individuals and experts using local knowledge (*ecological, political, financial, etc.*), we believe these implications should be investigated with a systems-based approach founded in empirical methodology. Our aim, therefore, is to demonstrate an integrated system anchored in existing research, geospatial technology, and enduring parameters that ensure the visioning process fosters long-term institutional knowledge and replicability.

This means that our final data products are intended to be used by industry GIS professionals; they should not require advanced knowledge in data development, but they should address the complex issues facing the local region. The difficulty here is that complex issues often require solutions to be developed with similarly complex workflows and/or sophisticated tools. This report aims to help GIS users employ the data products we've created (§2) and help communicate the decision-making process used to arrive at those products (§3).

Our firm is not composed of professional ecologists or conservationists, but we have hazarded a brief set of recommendations based on the work we completed. We hope that our outside perspective will not be taken as prescription but instead provide fodder for future discussion.

1.1.4 - Approach

Knowledge-Building Philosophy

We see that the job of geospatial communication is to illuminate unseen patterns while not obscuring reality—that is, it is our job to turn raw data into information, analyze information to foster knowledge, and leverage knowledge to help our clients make responsible actions. No map or geovisualization is completely infallible; all forms of communication use abstraction. We have the responsibility to present data in a way that is truthful, engaging, and insightful. To do this, we believe in developing systems that are **replicable**, **defensible**, and **augmentable**. "Replicable" means that an analyst should be able to hand over the inputs, parameters, tools, and outputs to another entity of similar capabilities and they should be able to reproduce the analysis. "Defensible" means that key analysis decisions should be related to existing research, studies, reports, or other peer-reviewed methods. "Augmentable" means that the model's inputs and parameters should be able to be adjusted to respond to future conditions.

In an ideal world, an analyst might perhaps employ one programming language to write the entire analysis as a series of commands. In reality there are many hundreds if not thousands of unique parameter decisions that go into an analysis of this type, certain data processes that cannot be automated, and many dozens of tools that operate best in disparate environments. Reproducing our exact study would require a similar level of effort from a firm or entity of similar analytical and programming capability; though this document has been written in such a way that we would expect a firm attempting to do so would end up with very similar scores if our parameters were followed closely. We do, however, expect that visualizing and summarizing the final scores of this analysis will be accessible to an industry GIS professional; we expect that our products will prove useful at the parcel level. See the section on "Summarization" (§2.2.4) regarding weighting methods.

Design Thinking

Although communication tools should include analytical, empirically rigorous, and streamlined components, professional planning and design work will always require an intentionally iterative process. Good products, ideas, and plans are developed, not discovered. This is why we separate our work into three broad categories: *creation, analysis,* and *synthesis*.

The **creation** phase involves generating as many good concepts as possible from all applicable stakeholders and resources—as incongruous as these may sometimes be. We often employ subject matter experts (SMEs) to ensure ideation covers all useful areas of inquiry. A useful metaphor here is to encourage broad concept "growth" at this stage regardless of outcome.

The **analysis** phase should anchor and integrate the best of these ideas into real, actionable plans. This means using the best data and empirical methods to investigate the implications of our designs. We may develop some of these, abandon others, or even decide to return to the creation phase as needed. A useful metaphor here is that there comes a time to "weed out, nurture, and/or strengthen" ideas to move toward results.

The **synthesis** phase acts to communicate our efforts to an audience. This requires that we identify that audience, design our messaging to access that audience, and earnestly portray our creation and analysis phases in a way that is clear of jargon and understandable to non-experts. Although this phase may seem obvious, it is often overlooked; it is the *reason* that we undertook this process to begin with. A useful metaphor here is that our efforts must not only "bear fruit," but that fruit must also be useful to those it is meant to serve. It is tempting to think that these phases should always happen one after the other, but the process is holistic and recursive. Synthesis naturally brings about more creation and analysis. We endorse the mindset that not only is this process expected, but it is crucial to quality outcomes.

Intentionally Subjective

This assessment is first and foremost designed to be used as a **planning tool**. The authors are not professional ecologists or biologists; this report is not a professional academic study, nor should it be. Just as no single expert should advise an organization's interests alone, no single body of knowledge can advise all decision making. Therefore the expertise here should be understood to be **novel communication of existing conditions**. Data, information, and existing knowledge are digested to answer the question: *where should we devote energy and resources for land conservation?* This is an inherently subjective question requiring a subjective answer.

Subjectivity does not mean that assessments should be based in individual or fringe opinions. The point of subjectivity is to order and prioritize competing interests; these prioritizations should of course be anchored in objective and empirical research using a scientific rationale, but they must provide an **opinion** about which places matter most. A series of values with very little variation would not provide for good planning.

Throughout this report you will see a series of scores assigned for each set of input variables. These products are called **ordinal values**. In general, we have based these scores off of our interpretation of the literature, expert input, and the need to create a compelling distribution of final ranked values. To do this we principally use manual classification for discrete values and we use fuzzy membership or min-max normalization for real values. In all cases we attempt to assign meaningful class breaks and membership thresholds that follow natural patterns in the data—geometric intervals, gaussian standard deviations, bimodal and multimodal classes, etc.—our reasoning is described below in the assessment section. For more information on ordinal data and the pitfalls of Multiple-Criteria Evaluations (*MCEs*), please see the section on "MCEs and Ordinal Data" (§2.2.2).

1.1.5 - Personnel

The personnel listed below all contributed their opinions to the output, but it should be noted that this report was principally authored by the Project Manager and Lead Analyst. Any opinions stated herein are the work of these two alone.

Rhumbline Consulting Team

Ben Meader | *Project Manager* — Ben is the Director of Rhumb Line Maps, LLC and the lead consultant of the Rhumbline Team. He has worked in the geospatial industry for over a decade and collaborated on numerous ecological and environmental assessments. Ben was the principal liaison and coordinated all of the visioning, concepts, and effort.

Emily French | *Watershed Analyst* — Emily started the project as the Rhumbline Team's lead analyst and performed the watershed analysis. She left the project in June to attend graduate school.

Vincent Falardeau | *Lead Analyst* — Vincent is the Rhumbline Team's Geospatial Data Analyst; he joined the project in May of 2022. Vincent was responsible for implementing all of the data analysis and tool building. He assumed the role of lead analyst in July of 2022.

Emily Meader | *Assistant Cartographer* — Emily acted as the team's designer. She created the large format "Overview Wall Maps" as well as many of the other publications.

Forrest Meader | *GIS Technician* — Forrest acted as the team's core GIS technician. He was instrumental in organizing the data at the outset of the existing conditions analysis in Phase One.

Midcoast Conservancy

Pete Nichols | *Executive Director* — Pete authorized the project and was present at all key meetings. He offered big-picture visioning as well as design ideas at each step of the project.

Chris Schorn | *Director of Land Conservation and Ecology* — Chris was the main client contact and co-managed the project with Rhumbline's Director. He provided specific guidance for which data outputs would be most valuable.

Subject Matter Experts

Janet McMahon | *Independent Ecologist* — Janet is an independent ecologist with many decades of experience in both fieldwork and regional landscape analysis. She attended many of the planning meetings and discussions throughout the project, bringing expert ecological knowledge and offering helpful brainstorming, advice, and critique.

Christian Fox | *Watershed Restoration Specialist* — Christian is an ecologist with The Nature Conservancy who focuses on restoring river and stream connectivity. Christian played an important advisory role in discussing the inputs for assessing the aquatic habitat quality and connectivity analyses.

Jeff Howarth | *Professor of Geography* — Jeff is an Associate Professor of Geography at Middlebury College and a GIS and GIScience expert. His experience in landform description and analysis, biogeographical modeling, and problem-space definition proved crucial for developing our team's direction. He offered innovative, academic perspectives for framing the terrestrial quality and connectivity methods.

1.1.6 - Scope

Level of Effort

This project was given a budget of roughly $4,000 to $5,000 per month for 6 months. The effort was estimated to take approximately 500-600 hours; however, with the contract extension the total actual amount of hourly effort was approximately 700-800 hours. While some of this effort overage is attributable to extra time on the analysis, there were also extra deliverables created throughout the process.

While all members of the Rhumbline consulting team assisted with this project, well over two-thirds of the funded effort was accomplished by Rhumbline's Geospatial Data Analyst, Vincent Falardeau. Many hours of volunteer effort were given by Midcoast Conservancy's staff, board, and an array of experts.

Service Area vs. Study Areas

Midcoast Conservancy's "service area" represents the union of several designations by its previous constituent land trusts: Sheepscot Valley Conservation Association, the Sheepscot Wellspring Land Alliance, Hidden Valley Nature Center, Damariscotta Lake Watershed Association, and Medomak Valley Land Trust. This shape is broad and stretches across much of Midcoast Maine, but it does not encapsulate a self-contained ecoregion; rather, this shape participates in a larger ecoregion. So, our team based the terrestrial and aquatic analyses on broader natural boundaries with regards to each meso-scale phenomenon instead of limiting the work to the organization's service area.

Terrestrial study area. Because our connectivity studies were largely based on habitat blocks and block connections, we sought to limit our study to an area with relatively homogeneous patterns of interruption and linkage. For natural terrestrial habitat boundaries, we used **1)** the Kennebec River (*very* *wide and tidal up to Augusta with few bridges*), **2)** Interstate 95 stretching to the Bangor region and the Penobscot River (*most disruptive terrestrial feature in southern Maine*), and **3)** the ocean (*nearby islands included, distant islands excluded*).

Aquatic study area. Our assessment of high-quality fish habitat depended in large part on upslope areas delineated above stream junctions in the midcoast service region. We defined our study region using the broader watersheds that include all of these junctions and their upslope areas. The study region extends from the Sheepscot watershed in the west to the Medomak watershed in the east, southward to the Boothbay and Pemaquid peninsulas and Westport Island, and seaward to include coastal flowages draining into Sheepscot Bay and Muscongus Bay.

Scale

For our landscape analysis, we started with 10-meter resolution landcover and elevation data, creating core habitat blocks and a cost surface at that resolution. Currently, 10-meter landcover data is the finest resolution we have statewide in Maine, with the exception of 5-meter MeLCD, which dates back to 2004 and is too outdated to be useful. Soon the State of Maine will publish a new 1-meter landcover dataset (^5.1.2.a). For our iterative connectivity scripts, we resampled our outputs to a coarser 30-meter grain to achieve runtimes on the order of a few hours. This allowed us to map corridors and pathways connecting core habitat blocks in an area as large as the whole Midcoast ecoregion we defined above.

For our aquatic analysis, we opted for a 4-meter resolution. This was a compromise between allowing for the finest level of detail while still allowing for computational efficiency. At a finer scale than this and with a study region of this size, the risk of time loss and tool performance had to be balanced with the need to work iteratively. More discussion of these issues available in a later section (§1.3.2).

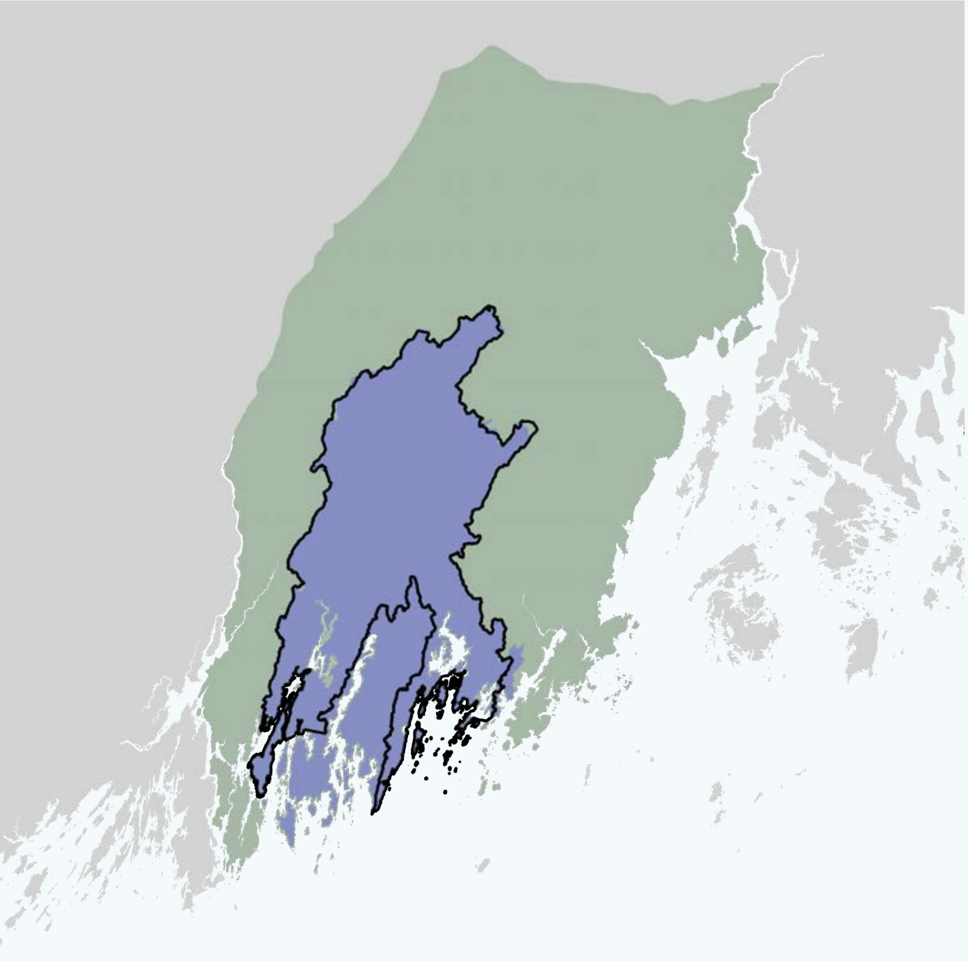


Figure 2 — Map Sketch: Study Areas vs Service Area

Green Fill = Terrestrial Study Area.
Blue Fill = Aquatic Study Area.
Black Outline = MC Service Area.

Each study area was chosen to reflect the natural boundaries associated with each phenomenon. Aquatic analysis follows watershed demarcation whereas terrestrial analysis follows large natural ecosystem disruptions in habitat blocks.

(^ToC)

1.2 - Project Reports

1.2.1 - Phase One Summary | Existing Conditions

What follows is a summary of the activities for Phase One, in which we carried out an exploration of existing conditions and knowledge, performed a high-resolution watershed analysis, created large-scale wall maps for display and discussion, hosted a planning charrette that brought together a wide variety of stakeholders, and compiled conservation reports and geospatial datasets for use as reference and background material in the start of Phase Two.

Geospatial Data Inventory

This project required an exhaustive inventory of ecological data. We looked at everything available from USGS, MEGIS, Beginning with Habitat, The Nature Conservancy, NOAA, the USDA, and many others. At the charrette we received helpful feedback about how to focus on the most important elements, as well as additional attributes to append to existing geometries.

Watershed Analysis

We started the project with a region-wide analysis of drainage patterns using LiDAR-derived digital elevation models (*DEMs*).[1] Hydrology was modeled to generate Strahler classes, streams, junctions, and sub-basins. Maine's Elevation GeoLibrary had full coverage of our study area for preprocessed, LiDAR-derived rasters which removed the need for point cloud processing. Upwards of 2,800 raw tiles were acquired for full coverage of the region. Innovating from previous experience using SAGA tools on a project in the Allagash region, our analyst for this section (*Emily French*) opted to use Whitebox tools to economize the workflow. After the data were mosaicked, projected, and resampled to 2-meters, we performed the following analysis at both 2- and 4-meter grains.

Working in Python, we employed Whitebox tools to run the traditional drainage workflow. This involved creating a NoData category for "ocean" (*outflow locations*), filling sinks using an extremely shallow artificial slope on waterbodies, and several other preprocessing commands to create a single, cohesive, hydrologically-consistent elevation model. The resulting flow accumulation file was then categorized using a "stream order" command in which each cell was assigned its Strahler order.[2] We included all coastal flowages, which means there were no gaps from missing upslope elements. Only hydrological features that were processed circumstantially outside the study area may have inconsistent class ranks. The flowlines derived from the Strahler cells were then vectorized and symbolized on top of watershed basin information.

Planning Charrette

A charrette was planned in Brunswick to provide the opportunity to sound the opinions of experts and to brainstorm ideas about conservation priorities in Midcoast Maine. While the discussion was varied and took many turns, some key themes emerged. Participants discussed aquatic habitat, connectivity, undeveloped land, rare vs. commonplace ecological features, the realities of conservation and land acquisition, pressures on the Midcoast region, substantive assessment of habitat quality—among other topics.

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[1] A note that later in the report we often use the term DTM in addition to the term DEM. DEM is a general category of data—elevation data—whereas a DTM refers specifically to DEMs that attempt to model the"bare-earth" terrain.

[2] There are many novel and useful ways to computationally categorize streams, all of which have various uses (^5.1.2.b). Strahler is one of the most common; it is useful for many reasons. You can read more about this in the AC section (§3.3).

Conversation revolved around large maps pinned to the walls, but it also occasionally departed from the maps when visuals were not needed. Our team was offered constructive critique, sometimes pushing back against our initial proposed directions. For instance, participants at the charrette described the shortcomings of mapping ecological features based on the state's limited polygons (*e.g. wader habitat, deer wintering areas, rare plants/species instances, etc.*). The wildlife ecologists asserted that the data density was heterogeneous, in that there are many qualities of the landscape in which data are inconsistent, incomplete, or have yet to be mapped. At the same time, many participants suggested that we take a close look at existing knowledge and datasets, and that there might be, perhaps, a way to improve upon existing research. In fact, some of the most helpful products from the charrette took the form of direct annotations to our maps, advising us where to look for more studies and data.

The ecologists at the charrette placed considerable emphasis on the **state of aquatic habitats**, focusing on coldwater streams for brook trout and connectivity for migrating Atlantic salmon. Stream dry-ups were also mentioned, along with questions of sufficient groundwater input and nitrogen pollution concerns near the ocean and the Sheepscot farm belt. At the junctions where coldwater streams meet warmer rivers, thermal refugia were identified as important for many fish species; it was clear, quite quickly, that this topic demanded attention. The watershed map we presented at the charrette helped to further the discussion around aquatic habitats and how conservation might target riverine and diadromous fish species. The hydrological analyses we performed enabled us to visualize and delineate streams and basins at a higher resolution than had been previously mapped for the Midcoast region. This sharpened discussion of where water was flowing from and to. We discussed the possibility of using this model to assess what sub-watersheds and drainages run into any given point on the stream network, perhaps a useful tool for understanding the potential impacts of agricultural runoff. We also discussed modeling places where coldwater streams meet warmer waters, providing likely high value locations for coldwater refugia.

Figure 3 — Charrette at Curtis Library, Brunswick, ME

Participants discuss each of the three themed Overview Wall Maps. The meeting went from 10 a.m. to 1:30 p.m and was held on May 9, 2022.

Connectivity and fragmentation were other key issues discussed at the charrette. Dan Coker brought a map showing large undeveloped blocks and the wildlife corridors between them, and the private survey carried out at the charrette illuminated a widespread interest in connectivity. Janet McMahon also described how connectivity between peninsulas and the inland is highly threatened by development along the major east-west highways that block the movement of particular species. Connectivity relates also to the ongoing and future movement of organisms in response to a changing climate, as species will continue to carry out range shifts and adopt adaptive behaviors. However, we were advised against recreating a landform analysis of resiliency (*like the TNC's regional model*), since doing so may not provide new actionable information. Most participants agreed that connectivity was amorphous but critical. It could take many forms: relationships between tracts of land, a watershed's stream network, existing parcels of conserved lands, or many other concepts. Exploring connectivity further seemed to be both an agreed upon next step, but also the subject with the most room for interpretation.

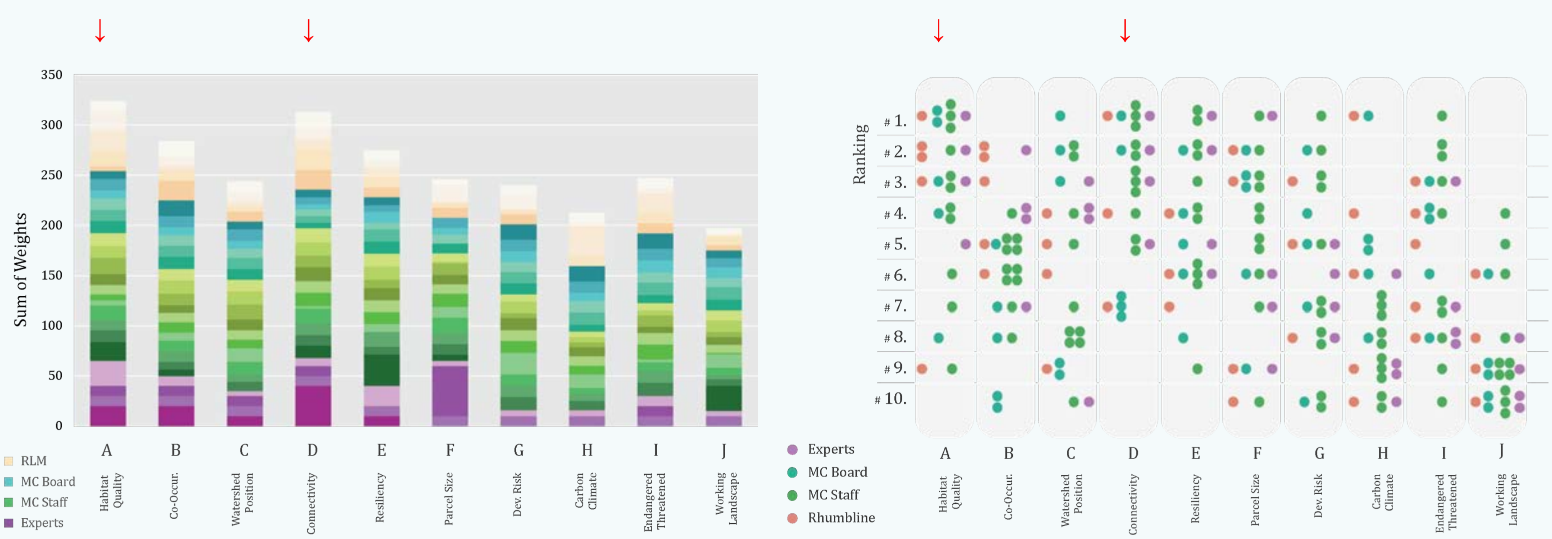
Participants were also interested in the real-world **circumstances tied to land acquisition** and conservation. Parcel size, water frontage, development threat, easement/fee status, recreation potential, land value, and other parameters were raised as interests. We discussed the possibility of adding value to Midcoast Conservancy's acquisition process. While these considerations may have to be approached on a case-by-case basis, a private database and/or queryable system could foster institutional knowledge.

Toward the end of the charrette, we discussed "triage spending," and the ways funding and time get divided between projects in the service region. We also discussed how regional connectivity may sometimes need to be prioritized—meaning it could be important to protect diverse types of land, not just large tracts of an optimal acreage. It was also stated that we needed to consider coastal parcels with recreational value, particular beauty, agricultural value, or ecological importance. Discussion then moved toward preserving a balance between rare instances of species and natural communities, but also valuing 'commonplace' habitat that nevertheless holds value in forming a matrix of protected land.

After the charrette we created charts from participant surveys, read our notes, and compiled a list of map annotations. The main takeaways we gleaned, broadly, were: **1)** add to/incorporate existing knowledge, **2)** focus on connectivity and habitat quality, and **3)** keep efforts tied to digestible, communicable goals.

Figure 4 — Survey Results

Participants privately evaluated suggested conservation considerations.
High clusters were found in both A and D for both scoring systems (weighted sum vs. ranking frequency).



Literature Review

We carried out a literature review focused on Maine state resources, available geographic datasets, and topics mentioned at the charrette. The MDIFW, DACF, MDMR, and MDEP host links to many web maps, datasets, and reports. We also looked to the *Maine State Wildlife Action Plan* (MESWAP) which emphasized the importance of preserving habitat of high quality for the state's species of greatest conservation need (^5.1.1.a). For broader perspectives on conservation planning, we consulted the Nature Conservancy's *Resilient Sites for Terrestrial Conservation*, which proved to be a great source of inspiration and a foundational framework (^5.1.1.b). For comparison with the efforts of neighboring states, we looked to *Vermont Conservation Design* (^5.1.1.c)—a program that prioritizes ecological land value at a statewide level in nearby Vermont. We then downloaded novel geographic data (*where linked and available*) and analyzed the metadata for replicability. In some cases, it made sense to refine geographic information to a finer spatial scale for the Midcoast region. In other cases, the data were used as they were, or were requested from the relevant agencies.

Figure 5 — Review of Literature

Lead analyst's partial list of key literature (this inventory was appended and expanded throughout Phase Two).

	SOURCE	YEAR	SUBJECT	ITEM	GEODATA
catalogs		2015	Endangered Species	State List of Endangered and Threatened Species	
catalogs		2021	Geology	Maine Geological Survey - Maps, Publications, and Data	*
catalogs		2022	Marine Environment	Department of Marine Resources - Maps and Data	*
catalogs		2022	Natural Communities	Maine Natural Areas Program	
catalogs		2022	Salmon Habitat	Salmon Monitoring Habitat Program	*
data	The Nature Conservancy	2014	Lakes and Ponds	Northeast Lakes and Ponds Classification System	*
data	SHARP	2017	Saltmarsh Habitat	Saltmarsh Habitat and Avian Research Program - Maps and Spatial Data	*
data		2022	Water Quality	Maine DEP - GIS Maps and Other Data Files	*
data	USGS	2022	Stream Baseflow	Estimated Baseflow for Streams with Atlantic Salmon	*
data	USGS	2022	Stream Temperature	ECO-SHEDS Stream Temperature Database	*
data	USGS	**2022**	**Coldwater Refugia**	**Refugia Research Coalition - Coldwater Refugia Model**	*
plans		2014	Local Conservation	12 Rivers Initiative	
plans		**2015**	**State Wildlife Plan**	**Maine State Wildlife Action Plan, 2015-2025**	
plans	NOAA	2018	Salmon Recovery	Recovery Plan for the Gulf of Maine Population of Atlantic Salmon	
reports	Beginning with Habitat	2006	Road Effects	Conserving Wildlife On and Around Maine's Roads	
reports	The Nature Conservancy	**2013**	**Habitat Conditions**	**Conditions of the Northeast Terrestrial and Aquatic Habitats**	
reports		**2014**	**Habitat Connectivity**	**Vermont Habitat Blocks and Habitat Connectivity**	
reports	The Nature Conservancy	**2016**	**Landscape Resilience**	**Resilient and Connected Landscapes for Terrestrial Conservation**	
reports		2017	Stream Connectivity	Stream Connectivity Working Group Initial Sustainability Planning	
reports	Maine Audubon	2017	Stream Crossings	Stream Smart Road Crossing Pocket Guide	
reports	GOMSWG	2019	Island Seabirds	Gulf of Maine Seabird Census	
web maps		2016	Tidal Marshes	Potential Tidal Marsh Migration Map	*
web maps	Maine Audubon	2022	Road Effects	Wildlife Road Watch	
web maps	Beginning with Habitat	**2022**	**Habitat Areas**	**Beginning with Habitat - Map Viewer**	*
web maps		2022	Stream Habitat	Stream Habitat Viewer	*

1.2.2 - Phase Two Summary | Assessments

What follows is a summary of the activities for Phase Two, in which we carried out a series of analyses and assessments based on the input of a select group of stakeholders and experts. We also produced a wide array of deliverables in this time and participated in a handful of meetings and presentations.

Defining the Analysis: Categorical & Hierarchical Prioritization

Because our process showed that there are many competing priorities for this organization and its conservation efforts, we opted to create a set of categories for the scores (*instead of a single priority score*) and a hierarchy of contributing parameters. We settled on four broad themes: terrestrial connectivity (**TC**), terrestrial habitat quality (**TQ**), aquatic connectivity (**AC**), and aquatic habitat quality (**AQ**). As you'll see in our assessments section, all of the scores are organized into these categories and then broken down into their component pieces. We largely consider these four broad scores to be part of separate analyses, even though the data processing for each has informed the others.

We would not recommend creating plans based on an "overarching" ecological value score, though this attribute is listed in the resulting Grid Scores.[3] We don't recommend planning solely based on these overarching scores because: **1)** all valuable ecological parameters are obviously **not** included here, only the two most important as identified by our charrette, **2)** parcel acquisition must take in many other competing considerations (*i.e. parcel size, social capital, availability, etc.*), and **3)** many of these scores are already an abstract impression of a concept or phenomenon—further abstracting them may muddy the prioritization strategy in each.

TC | *Priority habitat connections* — Even though our participants and experts were nearly unanimous in agreeing that "connectivity between blocks" was of critical importance, it was also admitted that this was the most abstract area to develop meaningful parameters. Does the size of the block affect the importance of the connection? What about AADT for each road? Should different kinds of wetlands be included or excluded from block analysis? We began by looking at block connections mapped by Beginning with Habitat, met with Jeff Howarth and Janet McMahon to discuss methods, revamped these ideas with Chris Schorn, and eventually settled on mapping connectivity using least-cost paths and corridors among core blocks. This involved developing Python scripts to implement connectivity analyses of our own, modeled after LinkageMapper. These scripts should allow for replicability in future analysis, both here in Midcoast Maine and elsewhere.

TQ | *Priority land habitat* — While many experts asserted a wide variety of natural communities and habitat qualities of high importance, nearly all agreed that there was great value to the size and cohesiveness of terrestrial uninterrupted blocks, and that there was a great risk of future fragmentation. Therefore, we undertook the process of delineating and scoring "uninterrupted blocks" with more restrictive detail[4] so these objects could be more effectively prioritized. We built on and augmented the patch-shape metrics Dan Coker described, looking further at measures of compactness and cohesiveness. This helped identify which uninterrupted blocks were of most critical importance. We also decided to not create our own nominal land quality classes, but instead to incorporate the work done by TNC for this component.

AC | *Priority watershed connections* — The "watershed" is one of the most basic geospatial concepts in ecology and an important building block in conservation. The problem with defining a watershed's "connectivity" is that it is only useful in relation to specific problems. Anecdotally, most experts

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[3] "Grid Score" is the operative name we use for "ordinal data values" provided in our project deliverables. These scores can be found in 1) raster outputs, 2) 10-acre HexValue summaries, and 3) ParcelMesh summaries.

[4] We created a new definition, called "Core Blocks."

agreed that a watershed basin's "position" was of great importance, but only in specific case-by-case scenarios, and not necessarily as an overarching subject. Because this concept, however, ties in to so many other issues, our team believes that understanding watershed connectivity is of utmost importance. For this score, we considered stream positions between ocean outlet and headwater source, on the 'global' level (study region) and 'zonal' level (position within each watershed). We also interpreted connectivity with specific reference to fish species—how much habitat was available upstream, and how open or impeded were these riverine networks.

AQ | *Priority stream habitat* — The first thing identified at the charrette was the importance of cold water refuges for fish populations. Maine waters are unique not only regionally, but it was suggested that there was, perhaps, a global significance to the restorative potential of Maine waters for endangered fish species. In that light, we see this as one of the four flagship issues. Using our drainage data, we created a model to prioritize micro-level streams of high importance for our study area. We approached this score from the dual considerations of **1)** where water is likely cold, and **2)** where small viable streams are likely to form a junction with larger streams. We also built a workflow that allows for quick upslope summaries for the study region at a fine resolution. This model may act as a planning tool for land stewards, managers, or even those in the parcel acquisition process. From a mapped stream junction drop-point, a user can learn: basin acreage/square miles, landcover composition, habitat accessibility, stream steepness, and other upslope attributes.

Watershed Analysis Meeting | Christian Fox

At the end of July, the Rhumbline Team met with Pete Nichols, Chris Schorn, and Christian Fox at the Nature Conservancy office in Brunswick to discuss what geographic variables are most predictive of cold water refugia, and how to conserve land in such a way as to also protect critical stream habitat. Conversation on the topic was wide-ranging, and it touched on questions of groundwater, sand and gravel aquifers, baseflow and stream temperature, stream slope and elevation, soils, cool vs. warm wetlands, shaded water, existing fish habitat data, the strengths and weaknesses of the Strahler stream model, and ultimately how these elements could be related back to a parcel-oriented conservation paradigm.

We came away from this meeting intending to focus on higher-elevation streams, steeper reaches, forested headwaters, and riparian places with little sunlight exposure. The ideas from this meeting carried forward directly into our scoring schema and provided a starting point for how to execute a geographic priority analysis for places with *likely* cold streams. We also discussed the ways that stream networks could be quantified to better understand the relationships between junctions and watershed topology. This helped us develop a language for describing these relationships.

Landscape Analysis Meeting | Jeff Howarth & Janet McMahon

In parallel to the watershed analysis meeting, another meeting was convened with Jeff Howarth and Janet McMahon at the end of August to discuss the best approaches for modeling habitat quality and terrestrial connectivity. Some time was dedicated to assessing the strengths and limitations of the block connector data provided by Beginning with Habitat. Other considerations included employing novel methodologies, for instance: **1)** space syntax, a way to model the importance of connections in a defined set of "open" and "closed" areas, **2)** geomorphons, a way to map riparian areas, ridgelines, peaks, valleys, and other landforms that encourage or inhibit the movement of terrestrial fauna, **3)** using raster tools instead of vector tools to evaluate block connectivity, priority corridors, and landscape morphology, and **4)** keeping conceptualizations streamlined and not convoluted. This meeting provided fodder for our terrestrial connectivity analysis from late August into September.

The main takeaways for this meeting were that: **1)** we should not try to replicate work that had already been performed by The Nature Conservancy, Beginning with Habitat, the Maine Natural Areas Program, etc. **2)** although we are attempting to describe complex processes which likely require using complex tools or algorithms, our parameterization and description of these analyses should be communicable to a lay audience, and **3)** we should acknowledge the limitations of modeling corridors and connectivity patterns for biota that are exclusively bound by terrestrial locomotion, especially where models may express bias for large mammals.

Presentations

Ben Meader presented at the Midcoast Conservancy board meeting in late September, providing an update on where Phase Two had brought the 30x30 project up to that point. This presentation walked the board through an outline of the geographic knowledge building process, from raw data, to generated information, to analytical knowledge built on that information, and finally to action: *Where do we aim to conserve land once we know more about all of the options in front of us?* The presentation ran in sequence from a "parcel-level" example of the recent EarthSong acquisition to an overarching description of the Phase Two process, then to the example of our terrestrial connectivity analysis. This was then used to discuss the differences between "proactive conservation" and "reactive conservation" by Chris Schorn; that is, targeting specific land for acquisition versus making decisions ad hoc in response to arising opportunities.

The feedback from the presentation was mostly positive, though there were several questions raised about the need to consider conservation issues at different scales and levels of importance. Climate change, endangered species, and several other concerns were discussed—these were not directly addressed by the approach of this Landscape Priority Assessment.

A follow-up meeting was held on Zoom for Midcoast Conservancy's staff. The presentation was largely the same, though the questions asked had much more to do with how to employ these ideas as an organization. Some questions about land ethics and land economics were raised, for instance: **1)** How should we interact with municipalities in our service region? **2)** How should we communicate these priorities to audiences that may have other non ecological concerns (*i.e. economic, agricultural, amenity accessibility, social equity, etc.*)? and **3)** How should we prioritize where to spend our financial resources (*i.e. more land vs. higher quality land, etc.*)?

1-Month Extension, Final Model

The analytical process took most of the months of August and September. Besides the above-mentioned presentations, our team did not meet our goals for creating finished communication products by the end of September. We requested a 1-month extension in October to allow for more time to conclude our work. This included: **1)** the final elements of the analysis, especially the aquatic prioritization from earlier in the summer, **2)** data packaging and closeout, and **3)** basic cartographic outputs to communicate the work performed. The extra month also provided time to draft this document.

After finalizing the data deliverables we created a summary model to help describe the process we used to arrive at our Grid Scores. Please see the Appendix for a diagram of the model developed (§6.1.1). This diagram represents the broad workings of our assessment: inputs, processes, outputs, and valuations. The workflow moves from publicly available data through a series of generalized operations to ordinal scores.

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1.3 - Results

1.3.1 - Preliminary Findings

Big Idea: Terrestrial Connectivity (TC):
Interior Connections Actionable, Peninsular Corridors Vulnerable

After inspecting connectivity grid scores, there are several major themes that emerged: **1)** the most optimal connectivity corridors run northeast to southwest; **2)** although the landscape is greatly fragmented by farmland, open water, and other small-town developments, many natural corridors are created by the highly riverine and glaciated nature of the landscape's geomorphology; **3)** interior connections are often in places that seem less desirable for development and therefore actionable areas for conservation; and **4)** the coast's peninsular regions are highly isolated with vulnerable connections that cross major human thoroughfares.

After digesting these patterns, we suggest considering a plan that secures a **high volume of land in actionable places** in the interior of the service region; this will provide the most progress toward creating a cohesive whole. However, we also suggest that any conservation plan should reserve substantial resources to secure a **small handful of key habitat connections** for coastal regions. This may mean that these small coastal corridors will require much more effort per acre, but the composition of much of the coastal habitat is unique and diverse (*see* "TQ" *below*) and should be integrated as much as possible.

Big Idea: Terrestrial Quality (TQ):
Inland Blocks Larger and Less Fragmented, Southern Coast Geophysically Diverse

By integrating the Nature Conservancy's "diversity" scores with our core block metrics, we get an interesting picture of the long-term potential for different habitat patches. Here we see several ideas emerge: **1) medium-quality patches are highly regular** and relatively interspersed with each other, especially in the interior; **2)** the **peninsulas score very highly** between the Kennebec, Sheepscot, Damariscotta, and Medomak rivers on the TNC's diversity scale **but the blocks are smaller** and more fragmented in general; **3)** there are a **handful of standout examples** of prime quality, namely: the area surrounding the lower part of Deer Meadow Brook in the Town of Newcastle, and the area surrounding Fox Pond and nearby wetlands and uplands in the Town of Windsor.

Similar to the issues raised earlier, the competition for conservation resources will come down to a decision to invest some resources in quality and some in quantity. The interior provides ample opportunities for conserving a decent, minimally disturbed landscape, whereas the coast holds some of the most important landscape features while promising to be a more challenging arena for acquisition.

Big Idea: Aquatic Connectivity (AC):
Upper Sheepscot Best Position and Most Connected, Clary Lake Isolated

While the headwaters of each watershed are clearly valuable, the Sheepscot River north of Long Pond presents the most compelling aquatic habitat in terms of overall connectivity. These regions are important because they **1)** have **many acres of upslope wetland and open water** for fish habitat, **2)** are **relatively unimpeded** for diadromous species that migrate to and from the ocean, and **3)** have a relatively **high watershed position** (*which means there is less land upstream that can affect these waters by disturbance or human activity*).

Conversely, it appears that Clary Lake is one of the least connected places in the entire coastal watershed region. These metrics may prove odd upon first glance. Although its scores decently in terms of available habitat and watershed position, there are two fish barriers that render this sub-basin inaccessible to migratory fish. This low score means "unsuitable" in our model; however, a different interpretation might easily be drawn that there is instead a "critical need" in this case. This would require the two barriers (*Clary Lake Mill and Dam*) to be removed or circumvented.

Big Idea: Aquatic Quality (AQ):
Refugia Junctions Estimated, Fieldwork Must Follow

Although we are not professional limnologists or fluvial geomorphologists, our team has executed many hydrological tools in past projects; these tools have proved useful for aiding our colleagues in their ecological assessments and natural resource inventories throughout Maine. Using LiDAR data allows for estimating the location of novel and/or interesting drainage patterns at a high resolution. On a project for the Allagash Wilderness Waterway Foundation, for instance, we used LiDAR-derived DEMs to model the drainage patterns of small streams (*or* "seeps"), and we found that the models were remarkably accurate for predicting the locations of these seeps when field verified. We measured the temperature of these streams for that project and found that they were cool enough to suggest modeling of this kind might prove valuable for fish conservation advocates.

In the case of the Midcoast region, we were encouraged to attempt a similar strategy for identifying high-quality, coldwater intrusions into the area's rivers. The difficulty here is that predicting stream water temperature is an extremely complex process; it is still an area being researched heavily with no simple set of "Best Practices" for non-experts to follow. Our interpretation of the literature led us to create two separate models that estimate **1)** "likely cold water," and **2)** "likely refugia junctions." The former uses upslope estimates from each major hydrological junction, the latter looks for "likelihood of water presence" factored with a "difference of estimated magnitude" metric (*i.e. the most suitable stream junctions should occur where the smallest flowing viable streams enter directly into the largest order streams*). The two of these treatments are then factored together to provide for a very sparse series of guesses where cold water junctions may occur.

While we have **no way of providing an estimate for accuracy** beyond simple intuition—we expect fieldworkers will find **high-scoring areas likely have unmapped**[5] **stream junctions** present at a minimum. We cannot, however, offer a confidence-level for how well our model predicts viable coldwater refugia habitat for fish species. For robust sensitivity models, the normal scientific method would then call upon us to field verify our outputs and then rework the input parameters in an iterative fashion to better predict the expression of the particular phenomenon. This planning process does not afford those luxuries. We hope future plans look to this model, intervening fieldwork, and further scientific advances to improve upon its estimates. Only actual stream temperature measurements will acquire the critical knowledge needed for making these coldwater conservation decisions. At best, we expect our estimates may provide field ecologists with several good places to commence their work.

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[5] By this term we use a definition loosely based on municipal zoning language. Many codes consider the USGS 24k topo quads to be a definition for "mapped" hydrography. These reflect the USGS's National Hydrography Dataset (high resolution) for their flowlines. By "unmapped," we mean that we've identified a "flowline" that likely has no name and likely has no formal geographic representation on government issued topographic maps.

1.3.2 - Limitations

Some High Value Datasets Not Included

The nature of the datasets we have available to us determine what we are able to investigate within the scope of this meta-analysis, and therefore they determine the kind of approaches we can pursue. In this assessment we decided to look for datasets with relatively homogeneous data coverage; we believe this meant that while commission error is possible, errors due to omission would be minimized. In other words, while a dataset we use may occasionally misattribute qualities or quantities, these should be manageable and somewhat regular or predictable; whereas there should be very few instances in which results are confounded by an incomplete set of information.

Because of this decision, there are a number of valuable species/natural community datasets that are not used in this analysis. The fieldwork observations that created these high-value attributes are indeed very useful for documentation within each particular site; but because these data have not been uniformly recorded or investigated across the greater region, there is an incompleteness and data paucity issue that confounds larger landscape inferences and/or analysis. This means we can't know if there are other high-value occurrences that may exist but are being omitted because they have simply not been publicly recorded. Because our study area boundaries exceed the scope of these data's coverage, fieldwork data of this type would likely have a high level of *omission* error if it were integrated into our wider meta-analysis.

For these reasons, we largely rely on remotely sensed data to provide a uniform treatment of data coverage. The Coastal Change Analysis Program (CCAP) and LiDAR-derived tiles are by far the two most important data sources we used (§5.2.1). For the C-CAP—a 2015 landcover dataset with a 10 meter resolution—the coverage is particular to coastal regions of the United States. Although offered as a "beta" product, we found it to be Maine's most serviceable landcover dataset for our purposes.[6] The LiDAR data—though patched together from many hundreds of tiles (*which are themselves derived from numerous point clouds from various flight acquisitions*)—represent a very well-established and well-documented method of data processing with nearly uniform coverage. Error in both of these cases is likely to be distributed evenly across the landscape.

Reliance on Two Datasets

Although providing regional consistency, our analysis is somewhat limited by relying heavily on the two above-mentioned sources of data. The LiDAR data come from various acquisitions and often contain measurement artifacts in heavily forested areas, and the 2015 C-CAP landcover dataset is also created from various sources using experimental methods. Combining these two, also, presents the analyst with the normal suite of issues inherent with raster work: setting grain size environments, resampling, reprojection, interpolation, etc. But for our holistic approach of region-level prioritization, we believe these inputs are adequate for the meso-scale landscape metrics we have proposed.

Beyond revisiting and bolstering this process with future data—like Maine's forthcoming landcover dataset (^5.1.2.a)—we hope Maine will follow other states and provinces in developing region-wide, full-coverage natural communities and/or detailed ecosystems databases, systematized core block databases, and other environmental datasets. These resources would prove invaluable for this type of conservation planning.

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[6] We explored using both the NLCD (30m grain) as well as Maine's dated MELCD (5m grain, 2004), but found these to be less accurate than the C-CAP from NOAA when compared with contemporary aerial imagery.

Grain and Scale of Analysis Affects Outputs

The expression of the patterns that we model are dependent upon the scale and grain of the input data for each algorithm. This is true for both terrestrial and aquatic analyses. In terms of aquatic modeling and terrain morphology, for instance, we have had great success using LiDAR-derived DEMs at a 1- to 2-meter grain at the parcel-level[7] with previous clients in various fields. While we have attempted regional hydrological models at a 2-meter resolution—and did so at an early stage of this project—we find this level of detail proves computationally cost-prohibitive and does not greatly increase value or specificity. This level of detail can also create "noise" or processing artifacts when the focal operations do not match the dimensions of the modeled phenomenon. If LiDAR-derived DEMs are sampled much more than 5- or 6-meters, then the accuracy is on par with the ⅓ arcsec National Elevation Dataset and therefore also not worth the extra processing effort. For this reason, we opted for a 4-meter grain. Even with this compromise, many discrepancies or other errors can be found upon close review, particularly in areas where flowlines are not obviously channeled, slopes are non-distinct or flat, or areas are stippled with measurement artifacts. NOAA's C-CAP landcover data, for contrast, has a 10-meter pixel. This is acceptable for our broad, regional landscape analysis but could prove limiting at the parcel level. Delineating core habitat areas at the local scale would be greatly improved with a finer resolution.

Another limitation, in addition to the grain of input data, is that the scale and classes of our analysis parameters are decided subjectively; these can influence the results and outputs. For example, in our terrestrial connectivity analysis, we ran the same code multiple times with different core habitat block size thresholds, once at >100, >250, >500, and >1000 acres. We did this in part to test variability with different levels of habitat block inclusion. The outputs from each have a similar general appearance, but they vary at a local level. In part, such thresholds are driven by what is feasible. Carrying out our analyses for >10, >25, or >50 acre blocks would be achievable on a local scale, but this proved too computationally expensive for our entire study area.

1.3.3 - Deliverables

Maps

Overview Wall Maps — *3 versions @ 87" x 114" landscape* — These were our first maps for the project, developed specifically for the in-person charrette. There were three themes: ecological features, watersheds, and conserved lands. Each established existing conditions for each theme to aid discussion.

Ecological Features Maps — *5+ versions @ 48.7" x 55" landscape* — These maps were created for a variety of purposes. The first version was a general map summarizing the landscape's ecological features; it was mounted on poster board for the Wellspring Circle event. Other versions of this same publishing dimension were generated for meetings and discussions in August and September: TNC landscape diversity and resiliency data, other ecological features maps, habitat blocks, and Beginning with Habitat's block connectors.

Outreach Maps — *4 versions @ 8.5" x 11" landscape* — These maps were developed for donor outreach for Pete Nichols. These included in-process analyses and basic overviews: midcoast habitats, core habitats, watersheds, and distance to outlet. These were delivered digitally and not printed.

Board Meeting Presentation — *60 slides @ 8.5" x 11" landscape* — These slides were developed as part of a narrative geovisualization, describing our process for the terrestrial connectivity analysis. Maps

[7] We consider "parcel-level" or "site-level" scales to generally be between 1:2,400 (1"=200') to 1:12,000 (1"=1,000') for planning purposes.

included a demonstration of study area definitions, core habitat block definitions, global connectivity, and potential summarization techniques.

Outreach Publication Maps — *9+ versions @ 11" x 17" portrait* —These maps were developed as part of the final deliverable package, to be used in Midcoast's internal publication process. The themes were: service area and conserved lands, watersheds and basins, watershed position, aquatic habitat priority, watershed access, core habitat blocks, terrestrial habitat quality, corridor potential, and regional matrix formation among several other iterations.

Landscape Priorities Maps — *4 versions @ 8.5" x 11" portrait* —These maps were generated as raw Grid Score symbology maps for use in the appendix of this document.

Documents

Technical Proposal, Midcoast Priority Analysis — This document was delivered on March 28, 2022. It describes a proposed five-phase plan for approximately $50,000.

Ecological Value Survey — This document was delivered on May 4, 2022. It was used to query the participants of the charrette to gauge opinions regarding ecological value.

Phase One Report — This document was delivered on July 7, 2022. It detailed the content and progress of Phase One.

Midcoast 30 x 30 Landscape Priority Assessment — This document was delivered on December 15, 2022. It details the project as a whole, gives an explanation of methods, a short description of results, and provides a series of recommendations.

Technical Proposal, Development Risk Assessment — This document was delivered on December 31st, 2022. It will detail a proposal for investigating landscape fragmentation and development risk in the midcoast region using parcel data, suitable land assessment, zoning, market trends, and landscape economic indicators.

ArcGIS Hubsite

See hubsite live. <https://30x30-midcoastconserv.hub.arcgis.com/> This website is the main public-facing repository for the results of this assessment. This site is a live working document and likely to change and update beyond the publication date of this document.

Embedded here are also included several Google Earth Engine "slippy maps" with interactive and queryable content.

Geospatial Data Inventory

Please see the GIS users guide (§2) for an enumeration of data assets. In general, these assets include: **1)** high-resolution elevation and hydrological data, **2)** other key source ecologically relevant data, **3)** intermediary analysis data (*i.e. cost surfaces, geomorphons, core blocks, etc.*), **4)** topical multiple criteria evaluation (MCE) rasters by type (*i.e.* AC, AQ, TC, *and* TQ), and **5)** final prioritization meshes.

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2 - GIS User's Guide

This section gives GIS professionals a quick reference for the data products produced and organized by this assessment. Each primary data asset is listed, sourced, and given a short description. Beyond these are several methodological guidelines for other cartographers and GIS users.

2.1 - Quick Reference Guide

2.1.1 - Geospatial Data Assets

Below are listed the folders in the final data deliverable to Midcoast Conservancy. For the assessments folders (TC, TQ, AC, AQ), data are only described and included the first time they occur. Each subsequent assessment often includes data located in a previous folder. Many intermediary files are omitted. For instance, the C-CAP landcover data was used first to create the "Core Block" definitions, but then it was also used in several instances for work in TQ and AQ.

Of most interest will likely be the grid scores found in the *Results* folder for each assessment. These grid scores are single-band raster datasets, each is named according to its relevant descriptive section. Datasets in these *Results* are offered with a normalized maximum value of 10.[8] The aquatic assessment was performed at a 4-meter grain and the terrestrial assessment was performed at a 10-meter grain. For an overall summary of grid scores, see the "HexValues" files in the *05_Summaries* folder. These data summarize all grid scores within uniform 10-acre units for the entire union of study regions. These may be useful when comparing competing assessments, evaluating a location's context, or creating regional prioritizations.

00 Base Data

—> Beginning with Habitat

EXTENT_SERVICEAREA > BWH_Datasets.gdb________ *All subjects, Apr. 2022. **Subject to use policy.***

EXTENT_STUDYAREA-T > BwH_Datasets.gdb *Focus on terrestrial subject, Sep. 2022. **Subject to use policy.***

—> Midcoast Conservancy

FocusAreas_2022.shp________ *Areas delineating current focus areas for MC.*

ProtectedProperties.shp________ *Specified parcels currently protected by MC.*

ServiceArea_line.shp________ *Area of operation and service for MC. Polyline file.*

ServiceArea_poly.shp________ *Area of operation and service for MC. Polygon file.*

—> Rhumbline

StudyArea_Aquatic.shp________ *Bounds: Sheepscot, Medomak, Damariscotta basins.*

StudyArea_Terrestrial.shp________ *Bounds: mainland east of Kennebec, south of I-95.*

01 TC | Terrestrial Connectivity

—> Inputs

AADT.tif________ *Annual average daily traffic estimates.*

CCAP.tif________ *10-meter landcover data, 2015.*

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[8] Ordinal comparisons often produce values below 10—especially at higher levels of conceptualization and aggregation—so a fixed maximum for each scored raster was set to allow for more consistent symbology and comparison. In the *Results* folder, these numbers are rescaled using a min-max transformation to ensure the maximum is 10. For raw combinations of grid score rasters, look in the *Methods* folder of each section. Refer to workflow diagram for more guidance. Grid Scores further summarized in the HexValues and ParcelMesh datasets are **not** rescaled to 10.

dtm_10m.tif — *10-meter digital terrain model (bare earth elevation).*
UndevelopedBlocks.shp — *Locations deemed to be undeveloped.*

—> Methods

CoreBlocks.tif — *Binary raster of "Core Blocks" (CB).*
CostSurface.tif — *Cost surface raster used for impedance in LCP/CMTC models.*
Geomorphons.tif — *Landscape morphology classification.*
TC-Locl-100- [250;500;1000|filled].tif — *CMTC models by min. acre threshold, CB w/ and w/o NoData fill.*
TC_Raw.tif — *Terrestrial connectivity scores before being rescaled to 0-10.*
*%Type%*Connectivity.py — *Python scripts for reproducing iterative LCP/CMTC steps.*

—> Results

TC.tif — ***Grid score**. "Overall" - priorities for terrestrial connectivity.*
TC-Glbl.tif — ***Grid score**. "Global" - priorities for matrix-formation.*
TC-Zonl.tif — ***Grid score**. "Zonal" - priorities for connecting isolates.*
TC-Locl.tif — ***Grid score**. "Local" - priorities for connecting neighboring blocks.*

02 TQ | Terrestrial Quality

—> Inputs

CoreBlocks.shp — *"Core Blocks" (CB) with IDs alone.*
TNC-DvtyRaw.tif — *TNC's geophysical diversity data, unstratified.*
TNC-DvtyRaw_StudyArea.tif — *TNC's geophysical diversity data, unstratified, trimmed.*

—> Methods

CoreBlocks_ConvexHull.shp — *Convex hulls for compactness definitions.*
CoreBlocks_MinCircumCircle.shp — *Minimum circumscribing circle for compactness definitions.*
CoreBlocks_MinOrientBoundBox.shp — *Minimum oriented bounding box for compactness definitions.*
TQ-Blck_raw.tif — *Block compactness and size scores averaged for entire block.*
TQ_raw.tif — *Terrestrial quality scores before being rescaled to 0-10.*

—> Results

CoreBlocks_wAttributes.shp — *"Core Blocks" with compactness metrics, rescaled to 0-10.*
TQ.tif — ***Grid score**. "Overall" - priorities for terrestrial quality.*
TQ-Blck.tif — ***Grid score**. "Blocks" - priorities for conserving large cohesive blocks.*
TQ-Dvty.tif — ***Grid score**. "Diversity" - priorities for conserving diversity.*

03 AC | Aquatic Connectivity

—> Inputs

dtm_2m_mosaic.tif — *2m elev. (m) interpolated and mosaicked from source tiles.*
dtm_4m.tif — *4m elev. (m) resampled from 2m LiDAR mosaic.*
Dams.shp, Crossings.shp, NaturalBarriers.shp — *Barrier data used in the passage assessment.*
MEGIS-WetChar.shp — *Wetland habitat data used in the range assessment.*
NHD-Waterbodies.shp, NHD-Areas.shp — *Open water data used in the range assessment.*
TNC-Lakes.shp — *Open water data used in the range assessment.*

—> Methods

4mDtm_DistOutlet.tif, 4mDtm_DistSource.tif — *Distance (m) to outlet/farthest channel head for each pixel.*
4mDtm_Filled.tif — *Force drainage fill of elevation depressions to model flow.*
4mDtm_FlowAcc.tif — *Accumulated sum of cells at each location.*
4mDtm_FlowPointD8.tif — *Indicated direction of flow based on the D8 definition.*
4mDtm_Strahler.tif — *Strahler flowline where every cell is a possible channel source.*

4mStreams_5acreBinary.tif	*Streams defined as flow accumulation of 5 acres or more.*
4mStreams_Isobasins.tif	*Local drainage basins between established stream junctions.*
4mStreams_OutputConstraint.tif	*Binary that can be used to restrict scores to a riparian buffer.*
4mStreams_SegIds.tif	*Junction to junction unique IDs for established streams.*
4mStreams_Strahler.tif	*Strahler flowline where only stream cells count as sources.*
AC_P-Glbl.tif	*Watershed position 0-10 based on entire study region.*
AC_P-Zonl.tif	*Watershed position 0-10 based on each watershed's outflow.*
AC_raw.tif	*Aquatic connectivity scores before being rescaled to 0-10.*
Barriers_HydrologicalSnapping.shp	*Barrier points snapped to hydrological network.*
Barriers_MergedInputs-Reference.shp	*Merge of barrier points into one reference file.*
Barriers_UpslopeAddition.tif	*Sum of barrier scores via iterative addition.*
Range_HabitatScore.tif	*Assigned 0, 0.5 (wetland), 1 (water) for habitat range.*
Range_HabiatSum.tif	*Sum of habitat scores for upslope areas at each drop point.*
Streams_DropPoints.shp	*Points marking lowest position point in each isobasin.*

—> Results

AC	***Grid score**. "Overall" - priorities for aquatic connectivity.*
AC-Pstn.tif	***Grid score**. "Position" - priorities for conserving headwaters.*
AC-Acss.tif	***Grid score**. "Access" - priorities for securing unobstructed habitat.*
AC-Rnge.tif	***Grid score**. "Range" - priorities for linking to upstream habitat.*
AC-Rnge_StreamsAlone.tif	***Grid score**. "Range" - same as above, but limited to streams.*

04 AQ | Aquatic Quality

—> Inputs

LandsatSurfaceTemperature.tif(s)	*Surface temperature measurements via Landsat satellites.*

—> Methods

STREAMS > DtmStrahler_JxnEstimates.xlsx	*Frequency sheet for water probability and junction priority scores.*
STREAMS > TempByHeadwaterPosition.xlsx	*Graph of relationship between source distance and temp.*
AQ-C-Avge.tif	*Ave. "cold" scores from upslope summaries, by isobasin.*
AQ-C-Fctr.tif	*Stream position factor. Fuzzy power memb. (0.25) of "DistSrc" ratio.*
AQ-Cold_raw.tif	*Final "cold" score after "DistSrc" factor applied.*
AQ-J-Fctr.tif	*Refugia location estim. as 0 to 1 factor, apply to AQ-Cold for AQ.*
Basins-Upslope_1- [2;3] .shp	*Unique upslope overlapping watersheds for each DropPoint.*
DropPoints_wAttributes.shp	*Junctions as listed in AC but with summary scores included.*
IsoBasins_wAttributes.shp	*Isobasins vectorized with summary scores included.*
Station-SHEDS.shp	*Locations of stream gauges for TempByHeadwaterPosition.*
Streams_wAttributes.shp	*Streams vectorized with summary scores included.*
StrahlerUpslopeAreas.py	*Script for running upslope areas algorithms more efficiently.*

—> Results

AQ	***Grid score**. "Overall" - priorities for aquatic quality.*
AQ_StreamsAlone	***Grid score**. "Overall" - same as above, but limited to streams.*
AQ-Cold.tif	***Grid score**. "Coldwater" - priorities for locating likely cold water.*
AQ-JxSc.tif	***Grid score**. "Refugia" - priorities for locating likely refugia areas.*
AQ-JxSc_StreamsAlone.tif	***Grid score**. "Refugia" - same as above, but limited to streams.*

05 Summaries

HexValues.shp	***Grid score**. Summary of all Grid Scores by 10 acre unit.*
ParcelMesh.shp	***Grid score**. Summary of all Grid Scores by limited parcel data.*
Windsor_TaxMapMosaic.tif	*Mosaicked and georeferenced tax maps for parcel outlines.*

2.1.2 - Attribute Guide

There are hundreds of attributes and/or potential attributes that were or could have been generated. The ones included here are for the Grid Scores found in the HexValue and ParcelMesh summary files, as well as several key attributes of interest in the hydrological datasets and core habitat blocks file.

Summary Strategy

The "Grid Scores" could also have had many dozens of possible summary strategies. What you see below is a shorthand description for the method used, and the method suggested for other zonal statistics. In general, a zonal MAX is used when a scoring criterion is linear or location based, usually these have fewer, "object-based" pixels in each source raster. Using other summary types will greatly diminish their legibility. A zonal MEAN is used when a scoring criterion is largely "area-based," or, if linear, the meaning of the statistic is largely dependent on analytics derived from an areal feature (*like upslope areas*). MAJORITY is only used in one case, for "core block" scores. These have distinct edge boundaries, and the HexValues are meant to represent their membership in each object by either being included or excluded depending on where each hex contains a majority of cells. MEDIAN is also only used once, for AC-Acss, it serves a similar kind of membership function as "majority" with the exception that because it interpolates an interval scale for overlapping zones, an intermediary value is acceptable in some cases. Meaning: areas should normally be assigned specific numbers based on a majority membership, but HexValues will certainly cross multiple access areas. These access values are based on an interval scale—interpolating between these zones is acceptable in the rare cases that a hex is exactly split between zones.

In the cases of "Range" and "Junction Score," these are queried with a MAX from rasters constrained by riparian buffers. This is because the isobasin geometries—although generally useful for visualization—are poor areal units to be used for extracting values. They represent land beyond the modeled flowline. A stream-restricted object is more appropriate for extracting values for comparison.

Lastly, we occasionally use the field calculator to compute a MEAN between values that have already been summarized. This is used when values have already been greatly abstracted from their source geographies. In these cases, a user may notice scores that deviate from the Grid Score rasters. These summaries should be used with the most caution; they are the most abstract.

<u>Grid Scores</u> —> *For "HexValues10acres.shp" and "ParcelMesh.shp"*

TC	Terrestrial Connectivity	*Zonal MAX*
TC-Locl	Local Connections Between Blocks	*Zonal MEAN*
TC-Zonl	Vulnerable Corridors	*Zonal MAX*
TC-Glbl	Key Connections for Matrix Formation	*Zonal MAX*
TQ	Terrestrial Habitat Quality	*Zonal MEAN*
TQ-Dvty	TNC Landscape Diversity	*Zonal MEAN*
TQ-Blck	Block Size and Compactness	*Zonal MAJORITY*
AC	Aquatic Connectivity	*Zonal MEAN*
AC-Acss	Unimpeded/Passable to the Ocean	*Zonal MEDIAN*
AC-Pstn	Watershed Position	*Zonal MEAN*
AC-Rnge	Upstream Habitat Range	*Zonal MAX from* *AC-Rnge_StreamsAlone*
AQ	Aquatic Habitat Quality	*MEAN from Fields ("AQ-Cold"+"AQ-JxSc")/2*
AQ-Cold	Local Water Likely Cold	*Zonal MEAN*
AQ-JxSc	Likely Refugia Junction Area	*Zonal MAX from* *AQ-JxSc_StreamsAlone*
T	Terrestrial Overall	*MEAN from Fields: ("TC" + "TQ")/2*
A	Aquatic Overall	*MEAN from Fields ("AC" + "AQ")/2*
O	Overall Score	*MEAN from Fields ("T" + "Q")/2*

Hydrological Attributes —> *For "DropPoints_/IsoBasins_/Streams_wAttributes.shp"*

join	Unique text ID to allow for data joins	*Assigned north to south "ID".*
_DistOut	Distance from cell to ocean outlet	*Count "meters"*
_DistSrc	Distance to farthest channel head	*Count "meters"*
_StrhlDtm	Strahler score, all pixels are sources	*Ordinal "strahler"*
_StrhlStr	Strahler score, 5-acre FlowAcc sources	*Ordinal "strahler"*
_JxnType	StrhlDtm x StrhlDtm junctions named	*Nominal/ordinal "strahler"*
_FlowAcc	Flow accumulation for upslope basin	*Count "total pixels"*
_Ctchmnt	Catchment area for upslope basin	*Count "acres"*
AQ	Priorities for aquatic quality	*Ordinal "grid score"*
AQ-Cold	Priorities for locating likely cold water	*Ordinal "grid score"*
AQ-C-Fctr	Cold as a factor of downstream distance	*Ordinal "grid factor"*
AQ-C-Avrg	Average from upslope summaries	*Ordinal "grid score"*
AQ-C-Elev	Drop point is higher vs lower	*Ordinal "grid score"*
AQ-C-Slpe	Upslope stream is steeper vs shallower	*Ordinal "grid score"*
AQ-C-Cnpy	Upslope stream is treed vs open	*Ordinal "grid score"*
AQ-C-Sunl	Upslope stream is shaded vs exposed	*Ordinal "grid score"*
AQ-C-Temp	Upslope stream has warm vs cool banks	*Ordinal "grid score"*
AQ-JxSc	Priorities for locating likely refugia areas	*Ordinal "grid score"*
AQ-J-Fctr	Junction as a factor of likely viable	*Ordinal "grid factor"*
AQ-J-WtPr	Stream scored as a factor of likely viable	*Ordinal "grid factor"*

Core Block Attributes —> *For "CoreBlocks_wAttributes.shp"*

TQ-Blck	Block patch/shape score	*Ordinal "grid score"*
TQ-B-Size	Size	*Ordinal "grid score"*
TQ-B-CvxH	Convex hull ratio	*Ordinal "grid score"*
TQ-B-CcmC	Circumscribed circle ratio	*Ordinal "grid score"*
TQ-B-OmBB	Oriented min. bounding box Wd/Ht	*Ordinal "grid score"*
Area_m	Area	*Count "square meters"*
Area_Ac	Area	*Count "acres"*

(^ToC)

2.2 - Methodology Considerations

2.2.1 - Recommended Tools

QGIS: Access to Robust Open Source Tools

There are now many options for managing geospatial information on personal computers. Besides the industry-standard GIS software (*like that offered by ESRI, Hexagon, Blue Marble Geographics, Clark Labs, and others*), there have arisen a multitude of open source solutions for GIS analysts in the past two decades. Although our team runs ArcGIS Pro and several other proprietary platforms, we highly recommend leveraging QGIS and its associated tools.

QGIS is free to download (^5.1.2.c). QGIS's user interface, stability, and functionality have all improved markedly since its inception. Although more complex analyses occasionally require troubleshooting, it has wide-ranging functionality and can compete head-to-head with its competitors in all routine geospatial tasks as well as occasionally providing novel/unique implementation strategies. In particular, the ability to employ user-made plug-ins, GRASS and SAGA algorithms, and cross-platform scripts and data formats renders QGIS one of the most flexible GUI systems for geospatial experimentation. QGIS's user experience is very "data tactile." This means that interaction with the data is very direct—there are very few prefabricated or automatic settings. As with any open source program, users will need to know how to troubleshoot, but the program does little to impede direct editing, customization, and manipulation.

Scripting

Writing workflow scripts greatly aids implementation and experimentation. In this project, as one example, we generated upslope areas for thousands of pour points—a process that creates many numerous outputs. Because hydrological analysis is normally performed in the raster data model, only one watershed "object" can be stored per pixel. Overlapping upslope areas have to be placed into separate files and these upslope areas must then be vectorized, merged to create topologically overlapping polygons, and then related back to their flow points.

Using a script greatly helps with this kind of iterative work, especially when it requires numerous interrelated input and output operations. Batch processing, automatically starting subsequent steps, deleting intermediary data, leveraging tools to perform concurrent tasks, etc.—these are all made easier with a script. While traditional graphical user interfaces (GUIs) and GIS canvases are still crucial for inspecting the results, many of these processes would not be possible if methods relied on manipulating data and operations manually.

Scripting can be done using a GUI-based model builder, but it is easiest in a programming environment. Although it is now being decommissioned, this project was mostly developed using the text editor Atom (^5.1.2.d). Though there are many programming languages suitable for data processing, Python is the best match for geospatial work because many tools and algorithms are also employable in this language, both in proprietary and open source software.

Whitebox Tools

We highly recommend using WhiteboxTools (^5.1.2.e), a geospatial analysis package developed by Professor John Lindsay and the University of Guelph's Department of Geography. These algorithms are particularly powerful for answering hydrological, geomorphological, and ecological queries in a raster data environment. At the suggestion of Jeff Howarth, we used these tools to power much of our analysis, including: the creation of hydrological definitions and summaries, upslope areas, cost pathways, corridor models, and patch shape metrics. This toolbox was indispensable for both the terrestrial and aquatic connectivity analyses.

A user can now download Whitebox tools as a direct extension for QGIS, but this will need to be mapped to the downloaded package (*we've included the package in our deliverables, the folder called* WBT). Once installed, the user will need to link the tools to the relevant executable file stored locally. Once you'd installed the plu-in, this can be done by **1)** navigating to QGIS's processing window to select "Options," **2)** opening the "Providers" dropdown menu, **3)** opening the "Whitebox" dropdown menu, **4)** selecting the ellipsis to navigate to the "WBT" folder included in the "Midcoast30x30_Geospatial" folder, and then **5)** selecting the file "whitebox_tools.exe." If there are issues in executing particular algorithms, it may be helpful to select actual file locations directly so that the UNC path appears instead of the layer name. Occasionally a layer may be stored in overburdened temp directories which may cause a failure. In terms of general troubleshooting and figuring out how to use the package, Whitebox has extensive documentation which is well written and useful.

Linkage Mapper

LinkageMapper is a set of tools for modeling connectivity among habitat areas (^5.1.2.f). For our local connectivity analysis, we wrote a script to carry out similar processes derived from the concepts of LinkageMapper. For general purposes, using LinkageMapper itself should prove very useful to work with as well—it runs on ESRI's ArcGIS platform.

Google Earth Engine

Google Earth Engine harnesses the power of Google's servers to allow for display and manipulation of large amounts of data in an interactive online environment (^5.1.2.g). Backed with a Javascript-style code interface, it is also possible to carry out detailed analyses within Google Earth Engine itself. We used Earth Engine to display a slippy map of streams and junctions, with clickable points which would display the corresponding upslope area and its attributes (*size, C-CAP landcover, etc.*). Earth Engine also allows for the creation of public-facing displays with many layers and different visualization schematics. We found these tools to be helpful for communicating with non-experts.

2.2.2 - MCEs and Ordinal Data

Multiple Criteria Evaluation (MCE)

There are many methods for comparing disparate variables in order to look for spatial hierarchy or other priorities. First, it is important to distinguish between the semantics of similar processes: the difference between using the scientific method to develop a "sensitivity model" and the subjective, group-decisionmaking methods commonly used for planning purposes.[9] Multiple-Criteria Evaluations (MCEs), as defined in this work, are subjective assessments of this latter variety. We take raw data, assess that data to produce information, rank that information to produce insightful ordinal data, then we use that ordinal data to generate persuasive information to be used in an argument or action plan. This means we are intentionally ranking criteria and imposing an order so decisions can be made; we base these decisions on what is better and higher scoring (*more relevant*) over what is worse and lower scoring (*less relevant*).

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[9] For an in-depth discussion of MCEs and sensitivity analysis in the spatial domain, see (^5.1.4.a).

The main difference that should be observed between a "sensitivity analysis" and an "MCE" for our working definition, is that **1)** the former attempts to predict occurrences of a naturally occurring phenomenon which requires a self-improving, recursive process to improve inputs and algorithms; and **2)** the latter attempts to present an audience with a set of informed opinions. In our case, the models we've developed have no recursive process—although some pieces of our model attempt to mimic a simple sensitivity analysis (*as in the case of* AQ, *coldwater refugia*), we do not as of yet have the ability to field verify whether the phenomenon matches our model. Our scoring method aims to create well-distributed,[10] interval values to direct attention and aid assessment. To achieve this we reclassify disparate values to create one coherent score on a 10-point scale. There are three principal ways our model ranks criteria, and two principal ways we establish comparisons between variables.

For ranking criteria, we use **1)** manual classification, **2)** fuzzy membership, and **3)** min-max normalization. For manual classifications we favor quantile breaks for distributions that are unimodal and fairly evenly distributed, geometric breaks for distributions that are unimodal but heavily skewed, symmetrical deviations for distributions that are nearly normal or gaussian, and either inferred manual breaks or Jenks (*i.e. the "natural breaks" algorithm*) for distributions that are multimodal. For fuzzy membership, we use both linear and power membership functions when we wish to adjust the histogram to reduce skew or match a relationship. For min-max normalization, we divide by the maximum value in a vector[11] and multiply by ten to achieve the desired 10-point score.

For comparing criteria, we use methods that are roughly analogous to both a Weighted Product model (WP) and a Weighted Sum (WS) model (^5.1.4.b).[12] The former method looks to create products from *factors* to maximize a differentiation, whereas the latter looks to create normalized sums from *addends* to look for averages or additive relationships. These methods are considered "dimensionless" because they abandon conventional units of measure. We found both WP and WS helpful in creating compelling ordinal values. Broadly, we consider WP effective when one of the factors may act as an explanatory variable, meaning "y" is most likely a function of "x" (*e.g. downstream distance may relate to temperature warming in streams*). We consider WS effective when both addends likely have no causal relationship, but their correlation is a matter of interest for the sake of co-occurrence and prioritization.

Ordinal Data Type

Here we think it may be helpful to have a brief description of the kinds of data values. Even though all "data" are forms of human observation and conceptualization, certain record types have more intuitive relationships to natural phenomena than others. **Raw count data**, for instance, will be the most familiar. Values are usually stored as integers or real numbers, where the number represents a quantity that can be summed, counted, or measured, and "0" represents the absence of a quantity, or rather "none/nothing." There are usually no negative numbers in this data type. **Interval data** are also familiar though often mistaken as raw count data. Values have fixed, standardized widths, except that "0" represents a location on a scale instead of "none/nothing" and negative numbers rationally describe observations below zero—as in

[10] We endeavor to match distributions to common statistical schemas. Early in the process it was suggested we simply use a percentile score, z-score, standard deviation transformation, or other sample-specific metric. We avoided this because variable distributions create widely different ordinal products which can muddle the WS comparison method. It was important to us that our scale should consistently represent a "0=least favorable," "5=neutral," and "10=most favorable" strategy.

[11] "Vector" refers to a set of related observations in an array, not a geographic data type.

[12] It should be noted that we give all criteria equal weight throughout. We have also seen this method described as "Simple Additive Weighting" (SAW), but we continue to describe it as WS throughout this document. For a discussion on weighting parameters, see following section (§2.2.4).

the case of elevation or temperature. **Ratio data** is also familiar as the relationship between two or more raw count or interval values. **Nominal** data (*a.k.a. Categorical*) usually leaves the quantitative realm to account for qualitative assignments. These data "name" the observation, and even when numbers are used, these digits do not normally carry a quantitative value (*e.g. as in the case of zip codes*).

Ordinal data are most closely related to nominal values; they are named features, with the exception that a ranking is imposed or implied as well—as in the case of "heatmaps" or "stream order" or "preference." Some of the issues here are that ordinal data often do not adhere to a fixed-width scale (*as is the case with interval data*). For instance, in a *ranking* system that places 1^{st} as the best, 2^{nd} as the second-best, and so on—this system cannot quantify these numbers with any value except to distinguish their order. This means that even if "1" is twice the value of "2," for example, "2" may very well have a different ratio value with relation to "3." To combat this, it is possible to use a *weighted score*; this introduces an interval scale to the ordinal system. This is the approach that we selected here. In concept, if the units are all of similar comparable significance, "10" would be twice as important as "5" and similarly five times as important as "2" would be. When dimensionless, this method is most easy to defend when the scores directly relate to a consistent measurement unit (*i.e. dollars, acres, etc.*). One limitation of our assessment, however, is that our variables have disparate source measurement units and normalization techniques. These scores should therefore be taken very generally, where 10 is simply "better" and 0 is simply "worse."

2.2.3 - Complications with MCEs

Misattribution of Value in "Co-Occurrence" Models

In preparing for the analysis in Phase One, our team encountered many approaches to conservation prioritization. A frequent method we encountered, not without merit, is the "co-occurrence" model of prioritization. This model stacks layers of spatial data in a WS model to look for repeat instances across locations; it then assigns values to items that overlap with a higher and lower frequency. These resulting layers can be ranked and scored in many ways. If a GIS analyst employs a "co-occurrence" method, it is very easy to inadvertently "propagate" and/or self-magnify valuations. Specificity and clarity is needed for each occurrence. Repeated instances of similar geographic delineations are common in geographic data. These *can* be helpful when the repetition is intentional, or rather, when the same representation carries a separate, distinct meaning of similar value. But these should be regarded with care.

For instance: a particular bird species may have a polygon associated with its habitat, *and* that habitat may be delineated for another item deserving conservation value (*like a wetland*). If these shapes have identical geographies, then the definitions that give rise to these identical geometric representations should be defensible and their *meanings* should not be nested—care should be taken with attribution. It is not consistent to include coincident places as "co-occurrences" if they simply represent nested attributes; however it *may be* consistent and compelling to include coincident places as "co-occurrences" if they represent values of equal definition. The key here is to remember to scrutinize the source data—were the geometries created specifically for the express purpose of the feature being described, or is the data incidentally being used for multiple purposes? See the following figure as an example.

Figure 6 — Example Poor vs. Strong Comparison of Occurrences

NO	**Wetland**	→ *Many species*	→ Valuable geometry because it describes valuable natural communities and species groups.
NO	**Wader**	→ *Single species*	→ Valuable geometry because it incidentally describes one of many valuable species.
YES	**Wetland**	→ *Landform*	→ Valuable geometry because it delineates a unique landform.
YES	**Wader**	→ *Rare species*	→ Valuable geometry because it delineates species habitat of equal value to other addends.

Pattern Distinctness, Hierarchies, and Spatial Relationships

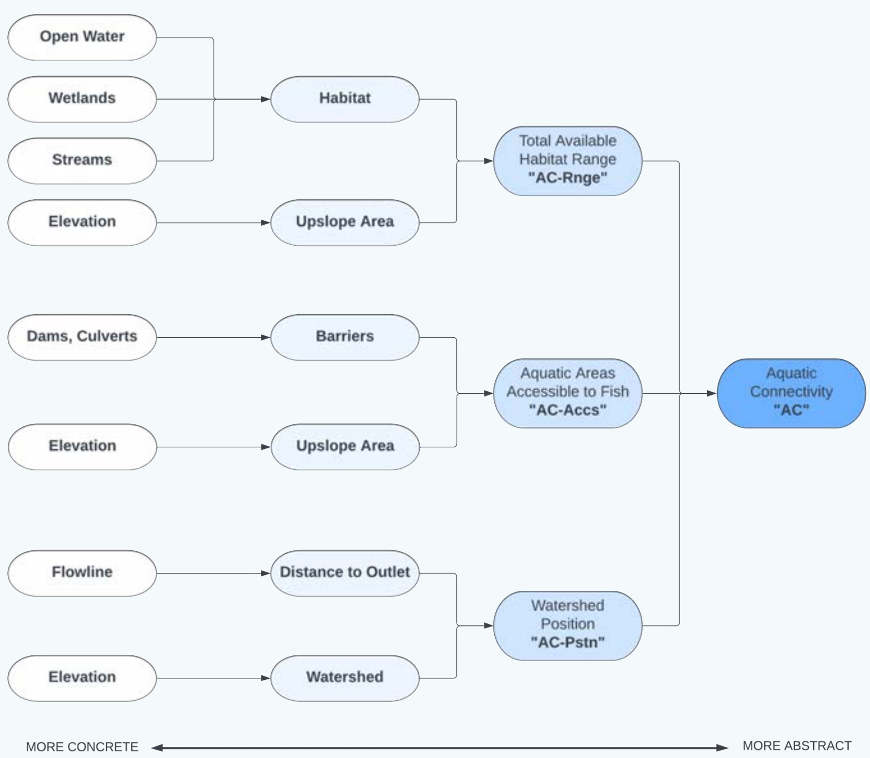
It may seem unnecessary to state that "things that are close are more related than things that are not close," but this is actually a topic of study in spatial analysis (^5.1.4.c). The misunderstandings that arise from popular conceptions of "heatmaps" are mired in the assumptions surrounding what is called "spatial autocorrelation" (*a.k.a. Tobler's Law*). These misunderstandings greatly handicap successful spatial visualization. For geographic variables we endeavor to discover whether or not spatial clustering is the product of: **1)** causal relationships, **2)** correlative relationships, **3)** coincident spatial relationships of interest, **4)** random chance, or **5)** data artifacts, processing noise, or other technical failures. While a great part of geospatial data development is concerned with assessing these differences, "Tobler's Law" does provide a useful general reference point for discussion. Namely, as we compare more and more variables (*as in our* WP *and* WS *comparative models*), it would naturally follow that spatial occurrences will become less convincingly related to each other.

See our workflow diagram for reference while exploring the provided data to see examples of this (§6.1.1). The concept to be aware of for our assessment is that ordinal valuations tend to be more coherent and communicable with less manipulation and/or fewer aggregated comparisons (*the further left on the diagram*). For instance, "fish habitat" is quite clear: *Where are there places of open water, wetlands, or streams?* "Total upstream habitat range," is also relatively straightforward, but a decidedly higher level concept: *At each isobasin, how much area of upstream habitat is available?* "Aquatic connectivity" is even more abstract: *Where are areas highly connected to habitat, well-positioned in the watershed, and unimpeded by fish barriers?* Each of these ideas therefore move from very discrete geographic expressions to less and less distinct patterns.

This means that users should expect geographic expressions and values to be more pointed/convincing at lower positions on the hierarchy and less decisive at higher levels. This is because the phenomena we compare are not causally linked (*#1 above*) but are being observed for the value of their circumstantial co-occurrence (*#3 above*). The following figure acts as a guide for how to conceptualize these ordinal values.

Figure 7 — Example Concept Hierarchy

This diagram is not meant to be comprehensive, but to show how each concept participates in a hierarchy. The higher level concepts must be understood as composed of their component pieces.



Subjectivity and Normalization

While we've already made note that the majority of this process is subjective, this is particularly evident when an analyst chooses to normalize and/or rescale data for ordinal valuation. We've already taken time to describe our classification and normalization strategy (§2.2.2), but it is worth further noting that scaling data should not be considered a practice for experts alone. All practitioners may wish to experiment with this concept given certain caveats.

The purpose of rescaling data is to assign meaningful values for communication. In the same way that the Fahrenheit system uses 100° to mean "hot" in 0° to mean "cold," and Celsius uses these same markers to mean "boiling" and "freezing" points for water, neither is an incorrect system. Our 0 to 10 scores are usually based on maxima with regard to the overarching study areas for each component. The goal here is to provide interesting and focused prioritization. If, however, an analyst were to use our data and look at a focus region or other subset—perhaps a place with relatively little variation without the region-wide context—it would not be unreasonable to re-scale or re-symbolize the data using different local maxima to look for variation.

Thoughtful consideration should be given, of course, to what type of variation the data display when the analyst sets these new parameters and scales. To restate the above, when illuminating the desired patterns of the data, are the arising variations the product of: **1)** causal relationships, **2)** correlative relationships, **3)** coincident spatial relationships of interest, **4)** random chance, or **5)** data artifacts, processing noise, or other technical failures? If the analyst can confidently answer this question, then rescaling the ordinal values will not confound the usefulness of this exercise.

2.2.4 - Summarization & Weighting

Areal Units and Geographic Summaries

All spatial analysts should develop a familiarity with the modifiable areal unit problem or "MAUP" (^5.1.4.d), but otherwise the main consideration here for GIS analysts is to make sure that units of area match the summary strategy both statistically and semantically. For instance, if you were to look at our "HexValues" file, you'll note each hexagon represents 10 acres. It does **not** consistently follow in every case, though, that because one hex has a score of "10," then half of this 10-acre hexagon would relate to a score of "5" in each half, or that there is a normalized score of "1" point per acre. This means that we are generalizing these ordinal/interval scores across space in a geographic summarization not consistently tied to areal units. You can see our summarization strategy for zonal statistics in an earlier section (§2.1.2).

A caveat for working with ordinal data is that the GIS user should be conscious of the fact that no matter how these values are represented across geographic space, they will not be considered "count" data. Although this may seem self-evident, it is important to remember that relating these scores to areal summarization will always be approximate and occasionally fraught.

How to Weight Scores for Custom Assessments

There are dozens of strategies for weighting scores to emphasize or de-emphasize particular attributes of interest, some of which are demonstrated here (*weighted scores, ranking frequency, percentage thresholds, WP, WS, etc.*). Here we offer a simple way to take our Grid Scores and assign further weights for comparison. Using the raster or field calculator with our raw Grid Scores (blue), employ the WS model where the integers (red) are altered to represent multiplicative weights, and the normalization integer (purple) always equals the sum of weights (*i.e. 2 = twice as important as one, 0.5 = half as important, etc.*):

((TQ * **1**) + (TC * **3**)) / **4** = Weighted Score "**T**" (*where TC is three times as important as TQ*)

2.2.5 - Glossary

Geospatial Data and Concepts

binary (raster) – this is a raster of zeros and ones in which zeros represent a "false" value for the occurrence of an object and ones represent a "true" value for the occurrence of the same object

buffer – the process of expanding a feature's shape by a uniform distance

centroid – there are many ways to compute, but this broadly means: the point that represents the "average" geometric center of an object

classification – any system that assigns new values based on previous values

connectivity – as in TC or AC: landscape locations on which pathway values or relationships between objects can be enumerated/described through computation, measures of connection usually use networks, origin and destination matrices, least cost path frequency, or conditional minimum transit cost

data/information – broadly, data represent raw observations of a subject/phenomenon, while information consists of assessments based on those observations; for instance, elevation values represent data, whereas "slopes too steep for construction" might be information derived from that data

data type – strategy or method for recording kinds of values for observations, several types include: raw count, interval, ratio, nominal, and ordinal

discrete/continuous – broadly, discrete indicates object representations (identifiable, usually qualitative) and continuous indicates field representations (measurable, usually quantitative)

fuzzy membership – a method of classifying continuous data uniquely in each case (instead of step-wise) so that the lower boundary is assigned a value of 0 and the upper boundary of signs of value of 1

geovisualization – the process of symbolizing raw data to explore patterns and seek understanding of different geographic expressions and/or phenomena

intersect – a method for selecting locations that coincide between all included datasets, i.e. only where features mutually overlap—considered here to be the same as a logical "AND" operator

LiDAR – Light Detection And Ranging is a remote sensing method in which high precision elevation information can be acquired using a series of pings to measure returns from aerial vehicles

MCE – a Multiple-Criteria Evaluation enables value assessment across otherwise disparate variables; in this case, we are performing an MCE of conservation value using a variety of scores for aquatic and terrestrial quality and connectivity

null value – a value not included in an operation or analysis, the omission indicates "NoData," that the value is outside of the study region, or that the value is not pertinent to the operation

ordinal data – ranked numbers, or assigned scores based on a classification of data

quality – as in TQ or AQ: attributes and scores that relate to a valuable conditions, the purpose of which is to evaluate the worth of that object or area for conservation purposes

raster – a geographic data format in which observations are presented as a grid of pixels, each pixel contains a data value in a particular location; especially useful for representing field phenomena

union – a method for selecting all locations that partake in multiple datasets of interest, definitions unite to encompass the largest common area—considered here to be the same as a logical "OR" operator

vector – a geographic format in which observations are presented as points, lines, and polygons, each feature comprises a geometric figure linked to a table of attributes

Hydrology

barrier – an impedance to the movement of fish species; usually a physical object, prohibitive passage, or an insurmountable drop in elevation rendering upstream areas inaccessible

basin/sub-basin – a unit of area in which all flowing water drains to a single drop point; this word usually implies that the area partakes in a larger system

distance from outlet – at any location on a stream network, this is defined total distance to the outlet from that location via the network

drop point/pour point – any location on a topographic surface from which hydrological definitions can be made with regard to basins, watersheds, and/or upslope areas

flowline – a line representing the flow of water across topography

farthest channel head – at any location on a stream network, this is defined as the farthest stream-head/source from that location upstream via the network; compare as conceptual complement to "distance from outlet"

flow accumulation/catchment – the total number of pixels that flow to any drop point, and/or the total quantifiable area that's flows to any drop point

isobasin – a basin that includes only the immediate upslope area around a given stream junction, these basins exclude all areas upstream of the next highest junction

junction – a meeting place (*point or pixel*) of two or more flowlines

outlet – the terminus of any flowline; in our region we take this to mean the junction point where a stream or flowline meets the ocean

river – flowlines with larger volumes than streams; in our region these are places we expect to find water year-round

source – the highest point on any flowline; in a raster setting this would mean any pixel with "0" flow accumulation, in attributes we use this definition interchangeably with farthest channel head

Strahler – a system for scoring a stream's topological position with regards to other flowlines that precede it in the network; the score is increased when a stream is met by another of the same magnitude

stream – a flowline where one can expect to find flowing water for part or all of the year

stream order – a measure of the branching complexity of streams, where streams are assigned numerical values based on their topological relationships in a network

tributary/branch – we call a stream or river a "tributary" when it flows into a larger stream or river, as defined by Strahler order; we call a stream or river is a "branch" when it meets another stream of identical Strahler order to create a new stream or river one order higher

upslope area – an upslope basin represents the entire catchment area that flows to a given junction or any location on a topographic surface

watershed – the all-encompassing area of a contained flowing-water system, including all headwaters, basins, and one or more outlets

Landscape Morphology

conditional minimum transit cost (CMTC) – a method for defining likely corridors as field phenomena instead of discrete pathways; cost distances between origin and destination objects are added and normalized to generate a continuous surface of LCPs unique to each pairing

core block – in our analysis, an area of land buffered 200 meters from "disturbed land" (*developed land, grassland/agriculture, and cleared/forested land*), clipped within Beginning With Habitat's undeveloped blocks; areas we can reasonably believe to represent 'interior' habitat conditions

corridor – a swath of land connecting two or more core habitat blocks; though we usually use this term to describe either a high value CMTC or many overlapping LCPs

cost distance – a measurement of distance where euclidean space is augmented by a “cost surface” whose score affects the measured distance; in our analysis this is modeled in a raster environment

cost surface – a raster where pixel values represent “costs” and denote the ease or difficulty of agent mobility; in our analysis this was developed as impedance/conductance for terrestrial locomotion

fragmentation/cohesiveness – this relates to the shape attributes of patch objects; in our analysis we quantified “core blocks” using area relationships between each patch object’s circumscribed circles, convex hulls, width to height ratio, and relative size threshold

geomorphon – landform types derived from an elevation dataset, based on the high and low elevation angles in each direction from a pixel; in our analysis, geomorphons help us describe valleys, slopes, peaks, ridges, etc. for the purpose of describing wildlife movement

landcover – a categorical class for what can be found on the ground; distinct from landuse in that landcover tends to describe literal coverage without human abstraction (*i.e. “grass” instead of “pasture”*)

least cost pathway (LCP) – a path between two places with the lowest accumulated cost over a cost surface raster, typically a line between any origin-destination pair

local, zonal, global – levels of analysis which help to distinguish processes by scale; local refers to feature-level interactions among units, zonal refers to area-level interactions, and global refers to region-wide interactions

undeveloped block – an area of natural or grassland landcover at least a minimum distance from developed land or impervious surfaces, as mapped by Beginning With Habitat

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2.3 - Suggested Applications

2.3.1 - Creating Visuals and Figures

Reference Cartography

Although the majority of our time was spent creating assessments, summaries, and other ordinal data, we have also created a handful of source data files that may be useful for general mapping purposes: core habitat blocks, a high resolution flowline network, LiDAR-derived elevation mosaics, upslope basins, junctions, and iso-basins.

The core habitat blocks shapefile could be used with Beginning with Habitat's uninterrupted blocks file to create interesting maps that illustrate habitat fragmentation and cohesiveness. The flowline network and high-resolution elevation model provide decent drainage information usable at the parcel level, enabling quality topographic mapping for most sites across the study area. The upslope areas show a multiplicity of different drainage basins based on thousands of flowline junctions throughout the study region. This could prove useful for making quick zonal summaries or drainage maps that are relevant to individual flow points.

Thematic Cartography

This is distinct from reference cartography in that *thematic* cartography communicates spatial or statistical patterns related to a theme; the map usually attempts to do more than directly depict the physical landscape. This means the pattern of the depicted attributes would not be seen if they were not visualized with some type of abstraction. Landcover classification, surface temperature, flowline stream order, habitat block size, and proximity to outlet are all examples of such "themes"—these all have interesting, insightful, and/or novel spatial patterns with real-world applications. You can see examples of thematic cartography in the appendix of this document.

The data we've provided here—inputs, methods, and outputs—will be very useful in creating thematic maps for the region. These could be used for donor outreach, board presentations, newsletters, or other publications by in-house GIS professionals.

Geovisualization

Where **cartography** aims to communicate a coherent spatial idea to an audience, **geovisualization** is the creative and analytical process of developing nascent spatial ideas or developing new approaches. Most GIS analysts and geospatial data professionals will be familiar with data exploration. For instance, an analyst may look at our Grid Scores data and see a hotspot of interest. It may be necessary to query this sub-region of interest and visualize the scores on a different scale or with a different classification symbology to see what meaningful patterns emerge. This guides the analyst to asking better questions that either help reveal or refute conceptual theories about the causal mechanisms underpinning geographic expressions. With time, a geospatial data scientist develops an understanding of how to infer which patterns have meaning: which patterns are the results of circumstantial correlation, dependent variable correlation, causation, or which patterns are simply "noise"—i.e. data collection/manipulation artifacts, data misinterpretation, or confirmation bias. This intuition leads to more effective inquiry.

More simply, geovisualization can also mean it is necessary to look at ancillary data along with the subject of interest—e.g. aerial imagery, elevation models, parcel boundaries, etc. This may help an analyst to see how a score may or may not be applied to a conservation goal. Geovisualization may appear messy and non-discrete to non-experts, but it is an essential process for geospatial experts before focusing in on an analysis and/or cartographic design workflow.

2.3.2 - Landscape Evaluation

By Parcel

One of the most desirable ways to use these data will be to assess the value of individual parcels, either in reaction to an acquisition that has already happened or to determine which parcel should be targeted for conservation. There are several ways to approach this: zonal statistics, parcel metrics, and case-by-case inference.

"Zonal statistics" provide perhaps the most quick and engaging way to use our data for immediate evaluation. All of the source rasters can be used as a background image from which values may be extracted for each parcel. The problem with this is that the values we've provided are "ordinal," they represent a rough interval scale and not count data. This means that they cannot be easily summed. See the section on geographic summarization for more explanation (§2.2.4). We believe that with the right type of geographic summarization technique, fairly substantive evaluations can be made on a parcel level, though these should always be contextualized and investigated on a case-by-case basis.

By "parcel metrics," we mean that the shape of each parcel can be quantified and/or compared to other novel data to create useful statistics. For example, a user could produce acreage or distance measurements for each parcel with relation to the core blocks, watersheds, upslope basins, flowlines, or any of the hydrology rasters. With our data, it would be easy to find out: how many acres of core habitat or landcover types each parcel contains or joins to, how far each parcel is from headwater or outlet, how many acres of upstream land or habitat there are, etc.

In terms of "inference," it is important to understand that the scores we've created are contingent to very specific geographic ideas. As is mentioned in the preliminary results section, inferences can be made by identifying patterns in the ordinal data or by viewing ancillary data, not just by identifying "hotspots" or high value areas alone. As a case in point, the inference made by identifying the low scoring water barriers to Clary Lake: this area may be a great place to invest in future migratory fish infrastructure.

Focus Area Evaluation

For long-range planning, Midcoast Conservancy and other organizations use "Focus Areas" to help guide and communicate their conservation goals. While these have often been intuitively drawn with the aid of expert ecologists and biologists, it might be possible to incorporate the grid scores we've created into this process. Because planning of this kind relies upon generalization, we suggest using the "HexValues" shapefile, which aggregates our scores to 10-acre spatial units. Because our analysis only takes two major concepts and applies a valuation for these across two domains, we don't recommend using our data alone to inform this planning process.

By way of example: looking at the HexValues, a user may note that there are several Focus Areas that already encapsulate high value TQ areas suggested by our model. In order to seek out new ideas for potential Focus Areas we suggest the following geovisualization technique: **1)** overlay Focus Areas, Conserved Lands, and Midcoast's properties on top of one set of HexValues at a time with adequate transparency, **2)** look for areas that have relatively high Grid Scores, perhaps masking values outside the Service Area, and **3)** compare with existing Conserved Land and Midcoast's properties to identify lacunas.

It may also be helpful to compare multiple grid scores at a time. As is noted in our earlier summarization sections, great care should be taken in understanding how these combinations will either reveal or muddy results. The higher up in the hierarchical scoring system you visualize, spatial relationships will appear much less sharply. The further down in the system you visualize, the more simple the semantic language gets. For instance, explaining “Block Size” or “Convex Hull Ratio” is more concise and communicable than “Block Fragmentation;” this, in turn, is more clear than “Terrestrial Quality,” which is more clear than an overall “Terrestrial” priority score.

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3 - Assessments

3.1 - Terrestrial *Connectivity* (TC)

3.1.1 - Goal: Find Best Corridors for Developing Core Blocks Matrix

Connectivity amongst core habitat areas was named as a key priority at the charrette in May, so we focused much of our energy on mapping these corridors and pathways across the Midcoast service region. As climate change intensifies, connectivity becomes ever more important: animals and other wildlife need to be able to carry out range shifts in response to changing conditions (^5.1.1.b). Ecologists, geographers, and conservation biologists have taken many different approaches to modeling the connections between areas of core habitat—one literature review describes 35 different metrics that have been used to "quantify connectivity of focal patches or of networks and monitor changes over time in an ecoscape" (^5.1.3.a). We focused on a movement-cost-based method, where corridors are mapped in a similar fashion to the LinkageMapper tool using Conditional Minimum Transit Costs (CMTCs), and scoring Least-Cost Pathways (LCPs) between blocks. The LCPs use a graph-theory approach that prioritizes repeated uses of a given connection to describe the entire network of core habitat areas. We use these methods **not to find likely corridors of existing high-traffic**, but to **identify optimal places for linking blocks** to create regional cohesion. The components of the final average TC score are: TC-Locl, TC-Zonl, and TC-Glbl.

3.1.2 - Data Creation: Cost Surface Raster

For our terrestrial connectivity analyses, we generated a cost surface from a series of inputs: C-CAP landcover, undeveloped blocks, and core blocks, elevation-derived riparian areas and ridgelines, and MaineDOT average annual daily traffic (^5.2.1).

Vermont Conservation Design applies different movement costs to landcover types in the state, with lower costs for wetlands and forests, higher costs for scrub and barren land, and so on (^5.1.1.c). Our approach was closely adapted from this plan, with modifications to account for differences in the landscape type (*i.e. lack of information on development intensity, estuarine aquatic beds not found in Vermont, etc.*). We also simplified the rationale behind the cost for each landcover class. In brief, since mixed forest is the dominant landcover type in the Midcoast region, we used this as our base value and then made impedance and/or conductance decisions for other landcover classes in a decision tree.[13]

To lower movement costs for undeveloped blocks and core areas, we reduced the cost by 20% in undeveloped blocks, and a further 20% in core areas. Next, from elevation data, we generated "geomorphons," as described in Jasiewicz and Stepinski, 2013 (^5.1.4.e), using the Whitebox Geomorphons tool (^5.1.2.h). These represent the basic types of landforms most common across all topographies and are generated by searching a large group of neighboring pixels for each location in an elevation raster. With a series of definitions, the algorithm evaluates how a given pixel relates to its environment. At our meeting regarding terrestrial parameters in August, our expert participants cited the key role of riparian areas, valley bottoms, and ridgelines for facilitating the movement of terrestrial species. So, we used 10-meter elevation data from the USGS and isolated peaks, ridges, valleys, and pits (*the first two were considered ridgeline corridors, the latter two were considered riparian corridors*). These distinctions were made with a lookup

[13] Forested wetland was given 50% lower cost than mixed forest, scrub wetland 25% lower cost, emergent wetland 12.5% higher cost, scrubland 50% higher cost, open water 125% higher cost, grassland and barren land 200% higher cost, and developed land 800% higher cost. These numbers resemble those of the Vermont Conservation Design somewhat closely.

distance of 30 grid cells and a flatness threshold of 1 degree. To denoise the output of Whitebox's Geomorphons tool, we selected only areas of at least 100 contiguous cells in the four classes of interest. Subsequently, the cost surface was reduced by 50% in these places, but only if they were also contained within the undeveloped blocks.

To address the increased movement cost introduced by busy roads, we took average annual daily traffic (AADT) data and categorized roads by the amount of traffic, then burned[14] these lines into our cost surface. Roads with less than 500 cars a day were omitted; roads with 500-1000 were burned in with a cost of 25% less than generic developed landcover; roads with 1000-2000 were burned in as equal to developed landcover; roads with 2000-5000 were burned in as 25% more costly than developed landcover; and roads with 5000+ cars/day were burned into the cost surface as 50% more costly than generic developed landcover. It should be noted that there are several cases where our AADT values do not appear because the threshold is low enough to omit it, but a CCAP value along a road does assign pixels as "developed" land. This may cause some impedance scores along roadways to appear dappled in rural areas. The effect on LCPs was not noticeable. For the regional model, we believe this level of detail is quite adequate. Seeing as a new, high resolution landcover dataset will be published for Maine in the near future, this product may be useful to create with a smaller grain for local analyses.

3.1.3 - TC-Locl | *Local Neighborhood Connections*

The root question in our analysis of local connectivity between core habitat blocks was to ask where animals and other wildlife are likely to move most easily between neighboring habitat areas. To get at this question, we wrote a script modeled after LinkageMapper's Linkage Pathways tool (^5.1.2.i), which computes a Conditional Minimum Transit Cost (CMTC) between any two neighboring blocks, where neighboring blocks are paired based on adjacency in a cost-weighted distance allocation step (*see Figure 9*). Landscape ecologists have described CMTC as a graph-theoretic approach to mapping connections between habitat blocks, particularly good for revealing multiple redundant similarly low-cost pathways, rather than only isolating one of several origin-destination Least-Cost Pathways (^5.1.3.b). The output is a set of braided corridors across the landscape. Scored values range from 10 in the most direct, least-cost path between neighboring blocks, down to lower scores as the accumulated cost gets much greater than the least-cost path. We can therefore ascribe high scores as high likelihood of block-to-block wildlife movement based on the lowest resistance encountered between the patchwork of blocks.

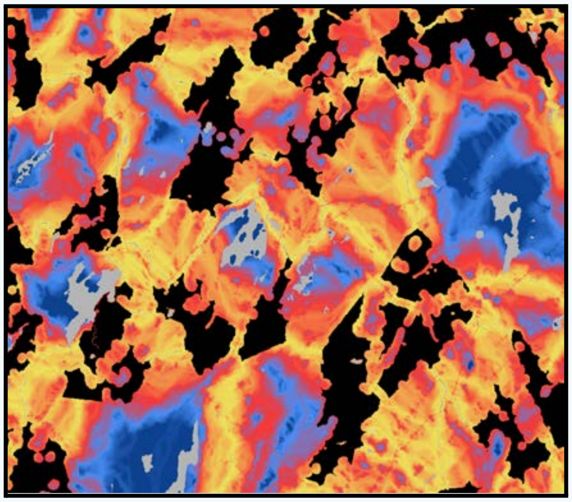


Figure 8 — Example CMTC Product

Local connection corridors between adjacent core habitat areas. Brighter yellow indicates low-cost / high-probability corridors for movement. Orange to red indicate medium cost, and darker blue indicates the highest-cost local routes. To explore the results most effectively, load the TC-Locl rasters with the *CoreBlocks.shp* layered on top, similar to the strategy at left. Make all files semi-transparent and view on an aerial or shaded-relief LiDAR base. Of most interest may be viewing the results of different block size thresholds. The overall average between these is stored in the *Results* folder for TC. Because these CMTCs are edge dependent, they also have null values in their source rasters. Under the *Methods* folder there are several versions that include void filled for averaging, but we suggest always viewing with the core blocks file overlaid.

[14] In this case, "burn" means to overwrite a raster with another assigned value.

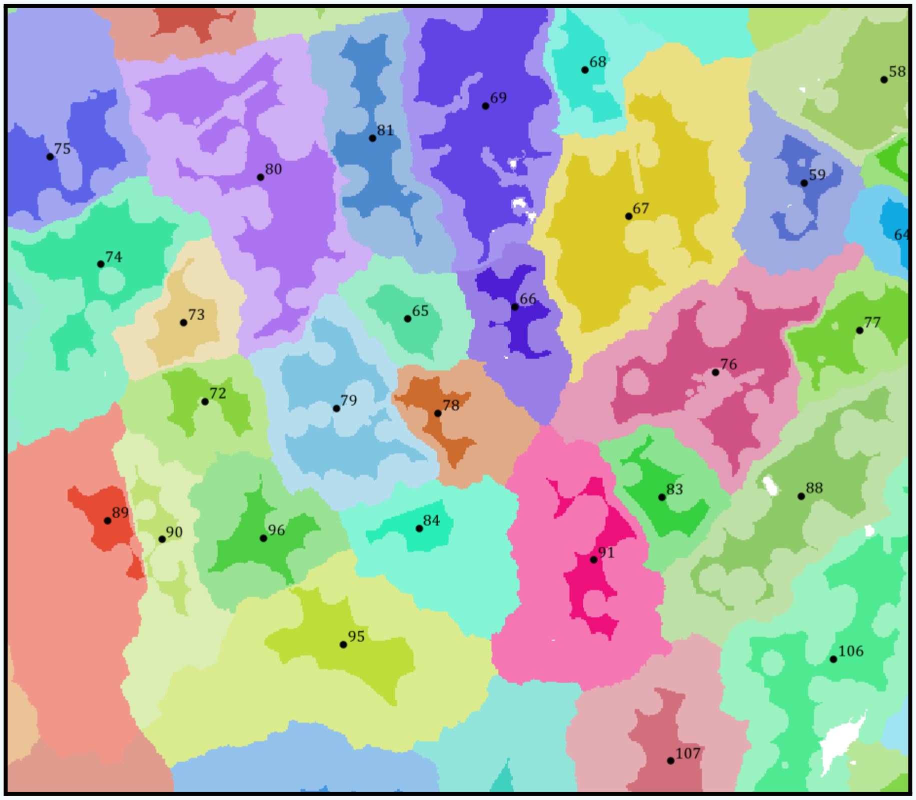
Our script operates by first creating a cost accumulation raster for each core habitat block. Then, for each core habitat block, we identify the neighboring blocks by buffering a cost allocation zone around a subject block and list the unique IDs of neighbors abutting via that buffer. For each of these neighbors, we sum the cost accumulation of subject and neighbor to generate a CMTC raster for the unique pairs. Then we take the "minimum" between this pair's CMTC and an iterating[15] region-wide minimum CMTC raster. This region-wide raster starts as a constant raster of a very high maximum value, and as each pair's CMTC is compared to the region-wide raster for "minimums," the values gradually decrease by each allocation area, converging on the final raster of local neighborhood minimum connections.

We carried out the same local connections analysis for core habitat blocks thresholded by different sizes: first for all blocks of at least 100 acres, then for all blocks of 250+ acres, for all blocks of 500+ acres, and finally for blocks of 1000+ acres. Using a lower threshold results in much shorter and more direct connections, and is more comprehensive in mapping connections to local-scale habitat areas. Meanwhile, taking a higher size threshold generates cross-landscape connections that can be more circuitous but also more revealing of how large habitat areas may best connect together to form a matrix of connected pieces. Raster values were converted from raw values (*cost-above-least-cost*) to a scale of 0-10 using the PercentageContrastStretch tool in Whitebox (^5.1.2.j) to normalize the values by percentiles. For each scale, this step was performed with a 5% clip on the upper tail of the distribution of values, and 100 classes ('tones'), one for each possible decimal score between 0.0 and 10.0.

Figure 9 — Example CMTC Process, Allocation Areas

This illustrates an important step in mapping corridors for local connectivity: to create CMTCs, the analyst must identify which patches are adjacent to one another. This is done by generating a cost backlink file from the full set of core areas, then allocating to the nearest clump of core habitat. At right, clumps are shown in darker categorical/random colors, while the allocation is shown in lighter matching hues.

For each clump of core habitat, the allocation area is converted into a binary raster, buffered outward by one grid cell, and the unique values in that buffer represent the other core areas for which a local connectivity corridor should be generated.



[15] This means that there is one large raster file for the region that is being continuously updated as the algorithm runs.

3.1.4 - TC-Zonl | *Critical Corridors for Each Zone*

A key tension in the idea of regional connectivity is that some patches and corridors are demonstrably more critical to overall connectivity *because* they are central, whereas fringe blocks pathways are more vulnerable and distal. The semantics boil down to the following question: *for regional connectivity, is it more important to **ensure** that every major block and/or critical zone is connected, or is it more important to **facilitate** the largest number of connections most easily?* We address the first part of this question by scoring which corridors are most crucial for ensuring each block will be connected in our "zonal" treatment; we address the second part of the question in the following "global" section.

For this "zonal" connectivity consideration, we drew a raster of Least-Cost Pathways from each core habitat block's centroid to all other block centroids as a single binary web of raster cells. This process is then repeated for every other core habitat block. At the end, the result is summed to yield a raster where the pixel values represent **how many core habitat blocks <u>require</u> that pathway** to connect to all other blocks. As such, the maximum value of the output raster is the total number of core habitat blocks: in places where only **one** corridor can connect a block to all the others (*as is the case with Owl's Head*), these areas receive the maximum score. Peninsular and fringe connections tend to be highlighted in this method, since patches at the end of peninsulas can only connect to the rest of the network through specific pinch points. For the zonal connectivity analysis, we used core blocks of at least 100 acres, and rescaled the raw output from 1 to 10, while places with no pathway whatsoever were assigned a score of 0.

3.1.5 - TC-Glbl | *Ecoregion Matrix-Formation*

Global connectivity as we've defined it represents how frequently a location is used for connecting pairs of blocks using Least-Cost Pathways (LCPs) in the study region where all core blocks must connect once to all the other core blocks. We see this frequency measure as a decent **indicator for which corridors will be most helpful in facilitating the formation of a regional matrix** of connected habitat patches across the ecoregion.

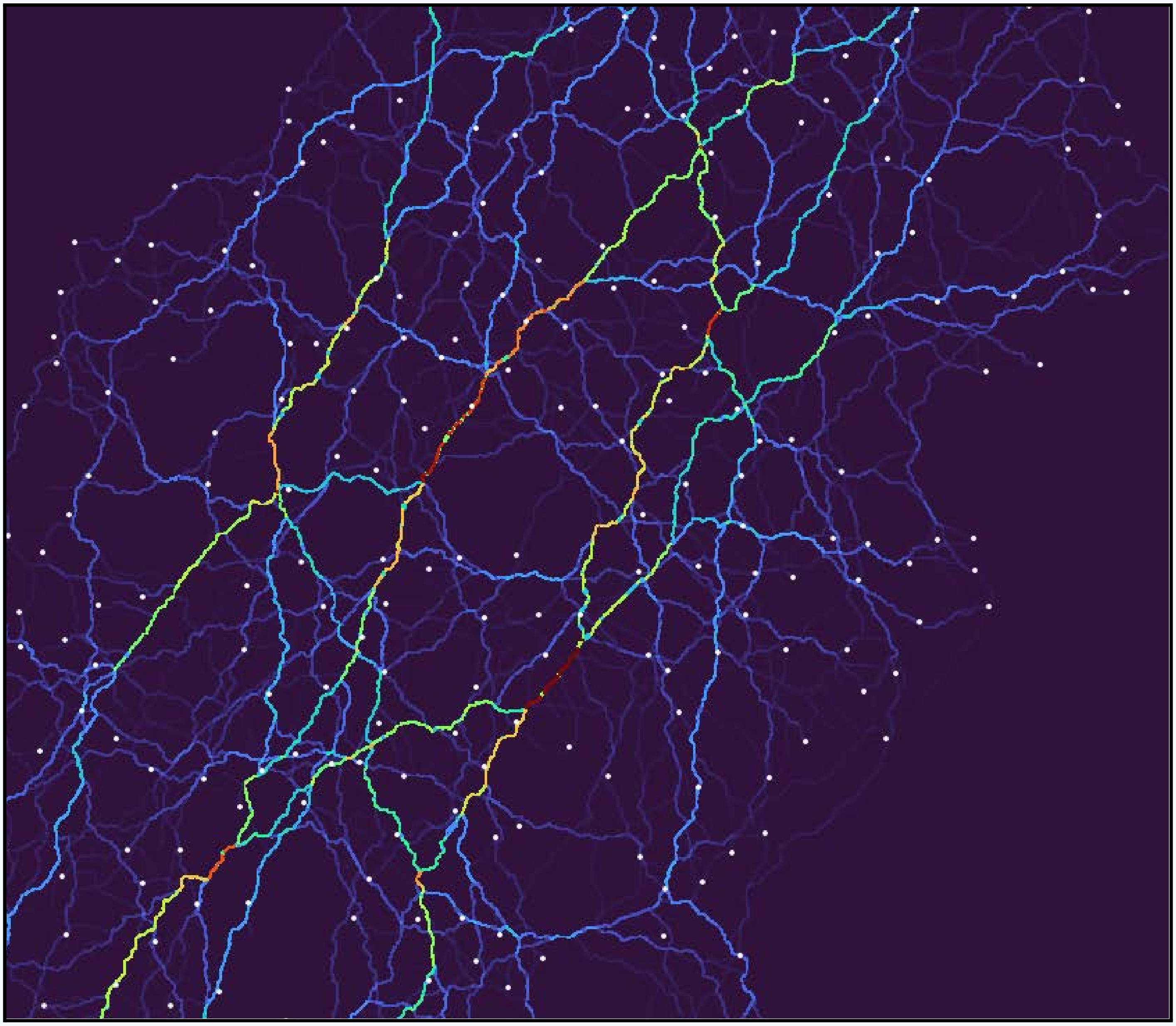
Some conservation biologists have described this metric as the "betweenness centrality," which acts as a proxy for a pathway's influence or role in maintaining the connections between all pairs of core habitat blocks (^5.1.3.c). Typically this is assessed using a vector network of nodes and edges; our innovation was to take a circuit-based approach over a raster surface, calculating the "betweenness centrality" for every pixel using block centroids as origins and destinations. Circuit theory is increasingly used in ecological modeling to assess connectivity across landscapes (^5.1.3.d). Our approach was to take all the core habitat blocks and convert them to single centroid raster cells. Then, for each core habitat block, we connect it to the "ground" and send it a single unit of "current" from each other block's centroid cell by generating an LCP binary. At the end, we take a sum of these iterative rasters to yield a single raster where each pixel counts the number of centroid-to-block pairs that pass through that pixel in an accumulation raster. This methodology is similar to the Circuitscape iterative all-to-one approach; for an applied example, see Dickson et al., 2016 (^5.1.3.e).

For our global connectivity approach, we used core habitat blocks of 100 or more acres, since these provide a fine level of detail while remaining computationally manageable. As might be expected, the most globally critical places for forming a coherent matrix are pathways along the interior of the study region, through which many pairs of habitat areas are connected. Scores were rescaled from 1 to 10, while any places without a pathway were scored as 0. The greater the "betweenness centrality" of a pathway, the greater its overall connectivity score.

Figure 10 — Example Iterative LCPs

In the blocks-to-blocks method, we draw a Least-Cost Pathway (LCP) from every core block's centroid to every other block's centroid. With 622 core areas over 100 acres, there are 193,131 block-to-block (*or centroid-to-centroid*) pathways. The number of such pathways overlapping on any pixel (*then rescaled where 10 is the max and 1 is the minimum with 0 as none*) is our proxy for how important that place is for global connectivity in the study region.

Below, high frequency pathways for global connectivity are shown in an early stage of processing in red/yellow/green. Tertiary pathways are in darker blue, and white dots represent core area centroids connected via the network.



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3.2 - Terrestrial *Habitat Quality* (TQ)

3.2.1 - Goal: Large, Unfragmented, Diverse

While all participants of this process acknowledged that "core habitat blocks" or "uninterrupted habitats" were critically important, it was also agreed that not all blocks have equal ecological value. Larger, more compact blocks generally provide better habitat, as do those with less internal fragmentation and more landscape diversity.

The "diversity" score we use here is taken directly from the TNC's resiliency work. We don't use their "resiliency" data, however, because these scores are a combination of "diversity" with a different set of independent "connectivity" parameters. Because we created our own connectivity parameters, we opted to select the diversity data alone for a purely landform quality assessment. Furthermore, the idea of "geophysical diversity" as described in the report convinced us that these diverse areas will provide fertile future settings on which vibrant natural communities and biota are likely to develop and thrive long term. In the spirit of conserving landscapes instead of features (§4.1.1), we felt the "diversity" score was the closest measure we could find for assessing the landscape "quality" as a goal. As the TNC had already rigorously developed these data, we decided to employ an unstratified version of their existing diversity data[16] instead of recreating or attempting to replicate their methods, especially given our limited scope.

To enhance this landscape valuation, we decided to overlay this with our core blocks; these blocks were rated based on their size and compactness. We believe this combination provides for a useful comparison: **1)** places where **cohesive, undisturbed habitat is incumbent and available** for conservation (*patch shape scores high*), but also **2)** places that are **likely to be resilient** long term (*TNC diversity scores high*). This also provides the entire study area with a score on the ground, both inside and outside of core blocks.

3.2.2 - Data Creation: Core Habitat Blocks

For the purposes of delineating core habitat areas, we used the C-CAP landcover data (^5.2.1). "Disturbed land" was defined by identifying fragmenting landcover types—these were estimated using proxies. The guiding principles here for definition derive from the natural communities descriptions in *Natural Landscapes of Maine* (^5.1.1.d). We took the C-CAP and isolated all non-forest land, comparing with aerials and the NLCD to distinguish "naturally barren" versus "disturbed areas." This means we preprocessed classes to ensure that coastal and interior "naturally barren" land was treated as acceptable and non-fragmenting. Barren land within a 30-meter buffer of water was identified as natural, as were small clusters of grassland/barren pixels within forests or wetlands which clearly appeared to be outcrops or misclassified uplands or wetlands (*<40 pixels of grassland or <20 pixels of barren land*). This helped us avoid putting erroneous pockmarks in our core habitat areas where outlier patches of natural barren land occur.

Based on the methods of *Vermont Conservation Design* (^5.1.1.c) and the Virginia Transportation Research Council (^5.1.1.e), and considering the research of Harper et al., 2005 (^5.1.3.f) on edge effects in fragmented forest landscapes, we chose to buffer this "disturbed" land (*developed, agricultural, cleared, and mowed grassland*) by 200 meters. Natural landcover outside of that buffer was considered to be core habitat. We also clipped our results by the Beginning with Habitat "undeveloped blocks" because we felt that these objects consistently included some regions our treatment missed, most usually information including roads, buildings, or other vector-based data.

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[16] Provided by Dan Coker of TNC Maine upon request.

3.2.3 - TQ-Blck | *Size Thresholding & Measures of Compactness*

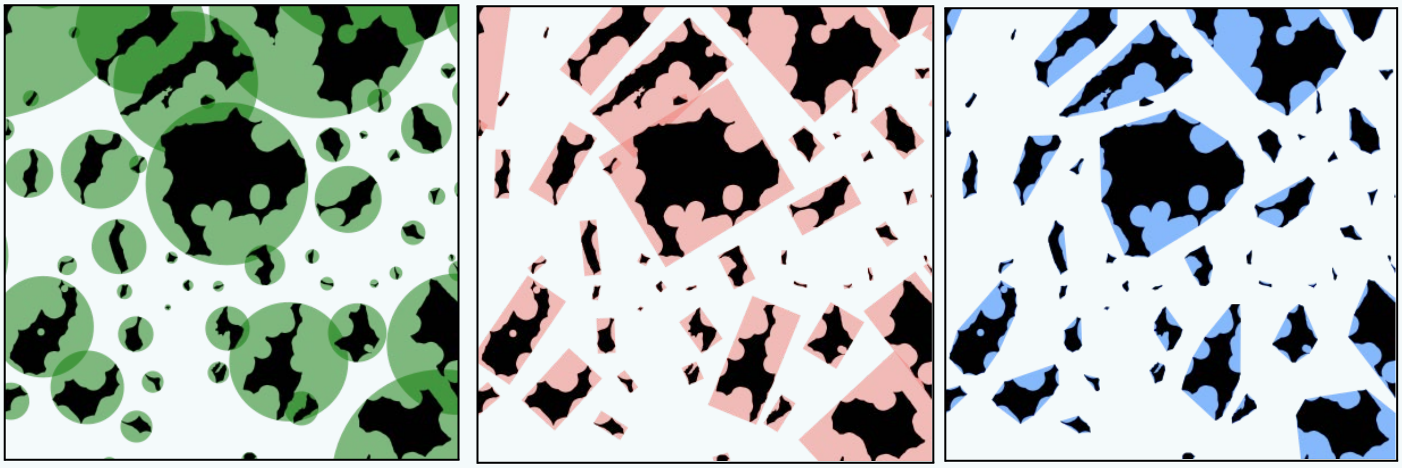
Large core blocks are critical in providing many different species with healthy, uninterrupted habitat. Since we did not carry out any species-specific analysis in our terrestrial quality assessment, we used this "patch quality" of core habitat blocks to help us identify larger blocks as suitable for the biological needs of the greatest number of species. First, we scored blocks by size thresholds in a roughly geometric schema.[17] In this way, we prioritize large intact habitat areas, while giving lower scores to core habitat areas that are small and isolated.

Next, the more compact a core habitat area, the greater we expect its ecological integrity to be. To assess the compactness of core habitat blocks, we explored several metrics inspired and adapted from a conversation with Dan Coker at the charrette in May. We calculated three measures of compactness: **1)** each block's circumscribed circle area ratio, **2)** the width-to-height ratio deviance of minimum oriented bounding boxes, and **3)** the area of the block as a fraction of its convex hull area. Perimeter to area ratio was abandoned because of well-documented size dependency issues which cause this metric to be a poor indicator. While we were intrigued by many ideas (*maximum inscribed circles, iterative inscribed object summaries, Voronoi skeleton metrics, etc.*), these seemed easily confounded by occasional artifacts and pockmarks in the internal geometries of the patches. We opted for simple area ratios and geometric measures; these appear to be somewhat complementary to each other and fairly robust to small patch irregularities that do not warrant a significantly lower score.

Raw values for these ratios range from 0 to 1, where values closer to 1 indicate greater compactness—or rather, shapes that are closer to a perfect circle, a square, or a smooth hull. All of these raw scores were normalized between their minimum and maximum values (*each geometry ratio relates to the source patch with varying distributions*) and cast to rounded values from 0 to 10. Finally, we took an average of the size score along with these three compactness scores to arrive at the overall TQ-Blck score.

Figure 11 — Example Measures of Compactness

The following shapes are compared to their source objects.



Circumscribed Circle *Min-Max Norm (Area1 / Area2)* | **Minimum Oriented Bounding Box** *Min-Max Norm (ShortSide / LongSide)* | **Convex Hull** *Min-Max Norm (Area1 / Area2)*

[17] Blocks over 1000 acres score 10, blocks 500-1000 acres score 9, blocks 250-500 acres score 8, blocks 100-250 acres score 7, blocks 50-100 acres score 6, blocks 25-50 acres score 5, blocks 10-25 acres score 4, blocks 5-10 acres score 3, blocks 2-5 acres score 2, and blocks 1-2 acres score 1.

3.2.4 - TQ-Dvty | *Diversity (TNC)*

The Nature Conservancy calculates an index of landscape diversity, "based on landform variety, elevation range, wetland density and configuration, and soil diversity" (^5.1.2.k). This value is then normally standardized and stratified by ecoregion. Landscape diversity reveals landforms that are especially suitable for fostering ecosystem adaptation in the face of climate change and other environmental shifts. Whether by local biotic movement to higher slopes, or by natural community augmentations to fit impending changes in microtopographies, "diversity" is our primary indicator for landscape quality (^5.1.1.b).

The TNC data is a raster of integer values—for our purposes we kept this raster as it was, simply clipping it to our study region and rescaling the values from 0.0 to 10.0.[18] More information on these scores from the TNC:

> *"A climate-resilient conservation portfolio includes sites representative of all geophysical settings selected for their landscape diversity and local connectedness. We developed methods to identify such a portfolio. First, we mapped geophysical settings across the entire study area. Second, within each geophysical setting we located sites with diverse topography that were highly connected by natural cover. Third, we compared the identified sites with the current network of conservation lands and with The Nature Conservancy's (TNC's) portfolio of important biodiversity sites identified based on rare species and natural community locations. Using this information we noted geophysical settings that were underrepresented in current conservation and identified places for each setting that could serve as strongholds for diversity both now and into the future. The variety of microclimates present in a landscape, what we term the site's landscape diversity, can be used to estimate the* ***capacity of the site to maintain species and functions*** [emphasis added]*. We measured landscape diversity as a function of topography, elevation range, the density and configuration of wetlands, and soil diversity. Topography describes the natural surface features of an area, and forms local landforms such as cliffs, summits, coves, basins, and valleys. Landforms are a primary edaphic controller of species distributions, due to the variation they create in rates of erosion and deposition, in soil depth and texture, in nutrient availability, and in the distribution of moisture and temperature. Because each landform represents a local expression of solar radiation and moisture availability, a variety of landforms results in a variety of meso and micro climates. When climate change is considered, landform variation increases the persistence of species by providing many combinations of temperature and moisture within a local neighborhood, and these options buffer the resident species from the direct effects of the changing regional climate. We hypothesized that sites with a large variety of landforms and long elevation gradients will retain more species throughout a changing climate by offering ample microclimates and thus more options for rearrangement. However, we found that in areas with very little topographic diversity, we needed a finer-scale indicator of subtle micro topographic features, to distinguish between otherwise similar landscapes. We chose wetland density as a surrogate for micro-topography in flat landscapes after experimenting with several rugosity measures. Our final measure of landscape diversity was based on landform variety, elevation range, wetland density and configuration, and soil diversity."*
>
> *—Landscape Diversity Stratified by Geophysical Setting and Ecoregion with Regional Override, 2016 Eastern U.S. and Canada*

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[18] GIS users may note that the Cape Small, Boothbay, and Pemaquid peninsulas rank very highly on this scale. In scrutinizing other associated datasets from TNC, you may find versions in which there is a sub-ecoregion demarcation isolating these peninsulas from the rest of the study region. The file we've used is non-stratified, meaning values are raw for the entire eastern region as a whole so as not to incorrectly compare dissimilar values from separate regions. Even with this consideration, it is notable how high these peninsular regions still mark for geophysical diversity.

3.3 - Aquatic *Connectivity* (AC)

3.3.1 - Goal: Protect Key Locations in the Hydrological Network

Stream topology and hydrological connectivity represent the literal lifeblood of the aquatic system. The unit of the "watershed" has long been one of the most common tools and geographic descriptors for conservation advocates. At the charrette we discussed how the idea of watershed or aquatic "connectivity" was very vague and difficult to describe. After several key meetings with stakeholders, we developed the following metrics to help create geographic priorities. We identified places that prioritize: **1)** locations that clearly have **ample upstream habitat**, **2)** hydrography that is **not inhibited by physical mobility barriers** to migratory fish species, and **3)** places that have a **high position in the watershed**, unlikely to be affected by upstream disturbance. We see these places as critical both individually and collectively for fish habitat—migratory fish were considered to be the biota of most concern in the aquatic sphere for the study region. In particular, we see that the key is not only to protect forests and palustrine forested wetlands far upstream to promote clean water, but also to protect key linkages in the topological network that provide the greatest access to the entire hydrological system.

3.3.2 - Data Creation: Upslope Basin, Isobasin

To perform hydrological connectivity parameters, we used the 4-meter elevation model and its derivatives (§3.4.2). We modeled "streams" as flowlines with a minimum flow accumulation of five acres catchment area, then extracted the "drop points" as vertices derived from pixels that were one pixel higher than flowline junctions. We categorized the topological relationships of these stream junctions and drop points by the relationship of pairs of Strahler scores using a neighborhood function. For clarity, we discuss these junctions as being part of one of four classes: sources, tributaries, branches, and outlets. "Sources" are the beginning points of each vectorized stream; "tributaries" are where a lower-order stream flows into a recipient stream of higher order; "branches" occur where two equally-ordered streams meet, creating a new stream of a higher order; and "outlets"[19] are where the stream exits the freshwater system to the ocean or brackish estuary system.

Instead of using large watersheds as the primary unit of analysis, we use nested "upslope areas" for our summaries and "isobasins" for data visualization. Watershedding[20] a set of points in a stream network generates the boundaries of the catchment area that flows to each point. However, using this Whitebox algorithm, if point A is within the upslope area of point B, then the watershed generated for B excludes A's watershed, resulting in an incomplete upslope area. Using Whitebox's UnnestBasins tool instead of the watershed tool creates a stack of overlapping upslope areas, this provides the entire upslope area from each junction (^5.1.2.l). After processing the network drop points, we made overlapping/nested upslope area polygons for all points. To do so, we ran UnnestBasins to generate many output rasters, converted these rasters to vector polygons, and finally merged them into one shapefile of upslope areas. Running Whitebox's watershed tool on the entire set of drop points (^5.1.2.m) gave us a set of exclusive isobasins; these were useful for visualization.

[19] Occasionally we use the word "sink" for this object. "Sinks" can also mean small depressions in an elevation model, but because all of our analyses use a sink-filled elevation model, we consider "sinks" to be the places where an actual hydrological terminus exists.

[20] Term used in some technical documentation for Whitebox, this refers to the tool that delineates non-overlapping basins from one or several drop points. This tool is one of many watershed and/or basin algorithms.

3.3.3 - AC-Rnge | *Ample Upstream Habitat Range*

Just as we gave higher scores to corridors that enable access to the highest number of core blocks, we prioritized higher scores for stream reaches that connect downstream water to the highest amount of upstream habitat range. Fish benefit from unfragmented upstream habitat in which to feed and live. One study suggests that fish mobility and "home range" are related to or dependent on habitat size; this is in contrast to earlier arguments that stated "home range" was related principally to the physical size of the fish and other biological constraints (^5.1.3.g).

For this score, "habitat" pixels in a raster of the aquatic study region were derived by querying and performing a union between TNC's Lake and Pond Classification data, the National Hydrography Dataset, and the Maine Wetlands Characteristics file. These were classified as non-water (0), wetlands supporting finfish (0.5), and open water (1). Carrying out a zonal sum, we add the values of all pixels in any given upslope area to get a total raw score of probable upslope aquatic habitat range. These raw values are then rescaled from 0 (*no upstream water or wetlands*) to 10 (*the most upstream water and wetlands*). This score offers somewhat of a counterpoint to "watershed position."

3.3.4 - AC-Acss | *Accessible to Diadromous Fish*

The fish passage score for aquatic connectivity reflects how accessible any place in the study region is for migratory fish based on the potential obstruction of: **1)** dams, **2)** road and railroad crossings, and **3)** natural barriers (*mostly falls, some long-term debris jams*). To achieve this we gathered data from the Maine Department of Marine Resources's Stream Habitat Viewer (^5.2.1), specifically: the Dams, Crossings, and Natural Barriers files. Then, we carefully assessed the level of obstruction posed by different types of barriers, designating barriers as either high, medium, low, or unlikely passable.[21] To assess barrier types, we read about stream road crossings (^5.1.1.f), verified the locations of dams (*accounting for some recent dam removals*), and studied a representative sample of photos of culverts, dams, and falls in the barrier data. We scored the study region based on how many barriers impede the stream network between the ocean and all upstream habitat, with more severely obstructive barriers leading to a lower score for fish passability.

In our raw scoring of accessibility to the ocean, a score of 0 indicates that a place is entirely unbarred with open access to the ocean. From there, we added 1 for every intervening upstream barrier of "high passability," 2 for each barrier of "medium passability," 4 for every barrier of "low passability," and 8 for every barrier "unlikely to be passable." To determine what areas are blocked from the ocean by particular barriers, we snapped barrier points to match the stream network before creating watershed delineations above each barrier. Creating a sum of all overlapping upslope areas from these barriers yields a value where high values represent highly obstructed places. This high score is then inverted and rescaled so that a score of 10 indicates a place that is entirely open to the ocean, and a score of 0 marks the place with the least modeled accessibility to the ocean.

3.3.4 - AC-Pstn | *Good Watershed Position*

To represent a high value watershed position, we calculated the "distance to outlet" at every location along the flowline network. Then we created two sets of scores from 0 to 1: **1)** the ratio of the distance to outlet of each pixel divided by the maximum distance to outlet for the entire regional watershed, thus

[21] In the crossing data, 'Potential Barrier' points were scored as high passability if "Physical_1" was not severe, and medium passability if severe; meanwhile 'Barrier' points were deemed low passability if not severe, and unlikely to be passable if severe. In the natural barriers, 'Potential Barrier' points were deemed to be highly passable, and 'Barrier' points low passability. Lastly, dams were deemed highly passable if they had fishways or full breaches, medium if they had partial breaches, and unlikely if 'Barrier' type with no known fishway or breach.

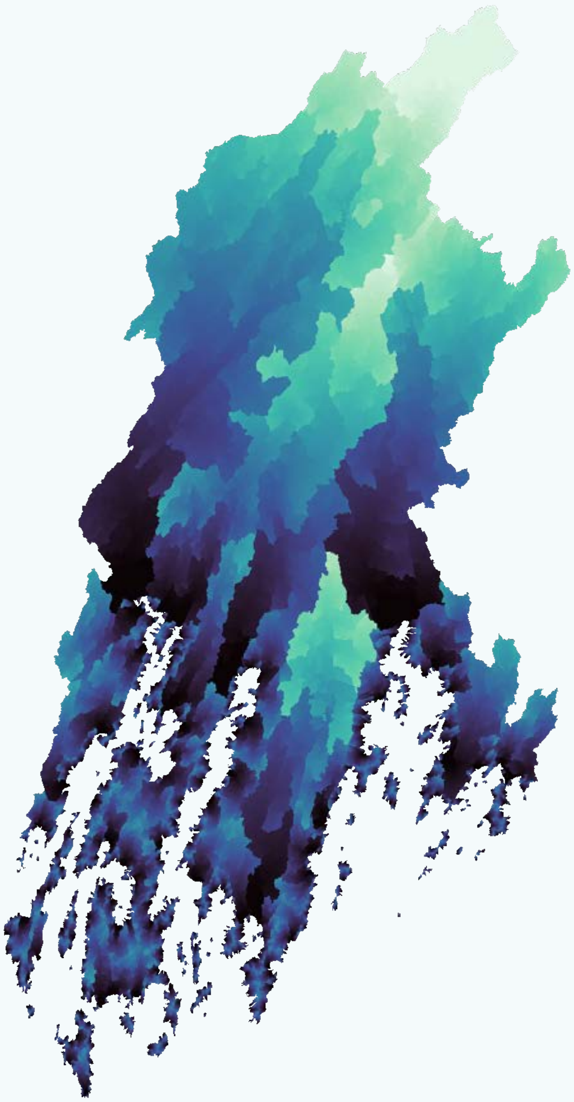
creating a "global" position score, and **2)** the ratio of the distance to outlet divided by the maximum distance to outlet for each sink's sub-watershed/basin, creating a "zonal" position score. These two scores were averaged and scaled to a 10-point scale to generate an overall "position" score.

The output is a continuous raster where watershed position values are from 0 to 10, and rounded to one decimal. This method highlights the headwater reaches of every watershed, especially where smaller coastal watersheds do not extend far from the ocean, but still have watershed boundaries and stream sources worthy of notice. Averaging these two scores also allows for the farthest reaches at the head of the Sheepscot, Pemaquid, and Medomak rivers to stand at the top of the list of priorities.

Figure 12 — Example Watershed Position

Shown at right is a raw symbology for the "AC-Pstn" raster. In **black** are locations considered low priority for watershed position because they are highly affected by upstream land. Priority increases through **dark blue**, **teal** and finally **light green** for higher priority places at the head of each watershed and/or sub-watershed.

To view the constituent pieces used to create this raster, please see the "AC-P-Zonl" and "AC-P-Glbl" files, these are found in the: 03_AC > Methods folders.



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3.4 - Aquatic *Habitat Quality* (AQ)

3.4.1 - Goal: Identify Likely Coldwater Refugia

Although there are many possible definitions for “high quality” aquatic habitat, the advice we received at the charrette in May was to focus on isolating coldwater refugia locations. These would be key to the species of concern amid the coming environmental transitions and warming climate. The participating ecologists and conservationists expressed great interest in finding and protecting not only the coldest waters for salmon and brook trout, but particularly where these small coldwater streams seep into larger, warmer streams. These coldwater intrusions are of great interest.

To this end, we separately modeled where we expect cold water streams might be found (AQ-Cold), and where we might expect small viable stream junctions to meet larger streams (AQ-JxSc). These scores were then combined using several WP comparisons to generate an overall assessment of aquatic habitat quality, where quality is defined as: **1)** a stream is likely colder, *and* **2)** it is also where the smallest viable streams enter larger ones. A great variety of data inputs were applied in this section. All scores are available in numerous ways: as attributes in the three vector datasets, as rasters defined by isobasins, and as rasters defined by isobasins but restricted by a stream buffer. Viewing these scores as related to the actual flowlines they pertain to may be most helpful (*see* AQ_StreamsAlone.tif). The isobasins are helpful for visualization on a regional scale, but can prove confounding at the local level.

3.4.2 - Data Creation: 4-Meter Drainage Study

We acquired tiles of LiDAR elevation data at 1-meter resolution and combined them to create seamless mosaics of elevation, resampled to 2 and 4 meters. Important steps included feathering the tiles to avoid seams, filling no data gaps, finding no-flow cells, and filling depressions in the elevation raster so that all grid cells flowed to the ocean. From the region-wide elevation mosaic, we then generated rasters typical of hydrological workflows: flow accumulation, flow direction, etc. Using these outputs, we made a set of streams defined where the flow accumulation was greater than 5-acres. We then scored these streams and their junctions using a variety of other tools (§3.3.2).

Of particular note are the two “Strahler” classes included. The Strahler method serves as a relatively accurate shorthand for classifying streams to visualize their relative size and importance in the network. We’ve found that running this algorithm at different thresholds can help to even further understand the system. We run Strahler both for where “established” streams run together (*catchments are >5 acres*), but then we also run it using every pixel as a potential stream source. This latter method creates a very dendritic set of flowlines with a wider distribution of classes; these are helpful for interpreting the overall construction of the watershed’s flowline structures (*called* _StrhlDtm *in the deliverable attributes*).

3.4.3 - AQ-C-Avrg | *Streamwater Likely Cold*

To predict where the coldest waters in the Midcoast service region are likely to be found, we began by investigating five characteristics of each junction’s upslope area: **1)** minimum elevation, **2)** slope of stream/flowline, **3)** estimated riparian land temperature, **4)** solar illumination based on local topography, and **5)** riparian tree canopy coverage. We expect future fieldworkers will most likely find cold water in places with high, steep headwater streams in which the surrounding riparian land of contributing branches and tributaries are shaded and cool. The further downstream, the larger the contributing upslope averages will likely be warmed by variable factors.

Minimum elevation is correlated with cold water streams, as shown by Monk et al (^5.1.3.h). We sampled the elevation of each upslope area at its corresponding junction (*its lowest point*). Then we scaled the results of all scores from 0 (*lowest elevation*) to 10 (*highest elevation*). While elevation may not be a direct causal mechanism for coldwater in our particular case (*elevation ranges in the Midcoast region likely do not have enough climatic variance to be a major source for cooling*), our reading suggests that this elevation is still a decent proxy for other related variables.

Stream slope in watersheds was the second variable used to assess how cold certain waters of the Midcoast study region might be. The authors of the same study in New Brunswick (*Monk et al.*) used high-resolution thermal infrared imagery and regression with potential predictor variables to show that "median temperatures of tributary catchments are driven by their position within the landscape including slope in addition to the density of wetlands and mixed forest within the upstream catchment" (^5.1.3.h). The authors of that study calculated the average slope for upstream catchments as a whole. We hypothesized that instead we should limit our slope calculations to linear stream features within catchments. This should provide a more standardized description of the places where water flows quickly and will likely be less confounded by neighboring topographic relief. To implement this, we calculated the rise over run for each stream segment, then rescaled values between the minimum and maximum segment slopes: the flattest streams score 0 and the steepest 10. These were summarized by upslope area using the "mean" zonal static.

We also estimated surface temperature for the land immediately surrounding streams in a 50-meter riparian buffer. Streams moving through cool forests, for instance, are likely to be cooler than streams that have passed through hotter agricultural fields and/or impervious areas. The USGS creates 30-meter resolution surface temperature products in degrees Kelvin.[22] To understand the temperature differentiations in the land for the Midcoast region, we downloaded a set of surface temperature images from the USGS EarthExplorer (^5.1.2.o), filtering to collect images with less than 1% cloud cover, between the months of May and September, from 2017-2022. We took the average of the surface temperature products and removed some of the local anomalistic temperatures that were present in single images; this showed us patterns of temperature over time. Rockland, for example, is consistently hotter relative to other places in the study region; meanwhile, the Boothbay and Pemaquid peninsulas are consistently cooler. Kelvin temperatures were rescaled 0-10 (hot-to-cool) using a Gaussian contrast stretch (^5.1.2.p) and limited to the riparian zone and averaged with a zonal "mean" by upslope area.

We then incorporated a model of solar illumination based on bare-earth topography, using Whitebox's TimeInDaylight tool (^5.1.2.q). For every day of the year, this tool models how long the sun is above the horizon and what proportion of that time any place spends in light versus shadow. Valleys spend more time shadowed by the surrounding topography, and are likely cooler; northern slopes of hills get less year-round sun than southern ones; and large flat areas get maximum possible sun exposure. Output values were again rescaled 0-10, from sunny to shady, summarized by upslope area using a zonal "mean."

Lastly, we created a binary raster of canopy using the mixed forest and forested wetland classes in NOAA's C-CAP landcover dataset. Since forest canopy is crucial for keeping waters cool (^5.1.3.i), we calculated the proportion of all 50-meter riparian buffers in the upslope area occupied by forest.[23] At the end, the final ratio value was rescaled from 0 (no forest canopy) to 10 (all forest canopy).

[22] This uses Landsat thermal infrared bands and a refinement process that includes supplementary observations of emissivity, a vegetation index, and atmospheric profiles (^5.1.2.n).

[23] "Protecting riparian forest covers at local scales has been sufficient for limiting summer temperature increases that adversely affect cold-water trout species" (Kirk et al., 2022).

3.4.4 - AQ-JxSc | *Creating Junction Scores*

Advective thermal mixing between cold tributaries and warm mainstem rivers has been identified as a factor in providing local temperature refugia for fish (^5.1.3.j). We aimed to map stream junctions where lower-order, viable streams meet larger rivers. In this section, we simply try to identify whether or not a junction is a likely topological location (*water temperature is addressed in the previous section*). We try to isolate streams and junctions where: **1)** small flowlines appear to be viable streams, and **2)** stream junctions likely mimic the small-into-large stream pattern common in the "refugia" phenomenon.

First we performed a simple frequency test to see whether or not flowlines were likely viable streams based on their Strahler order (*using* StrhlDtm *not* StrhlStr). This was done by randomizing 15 points for each Starhler class and comparing these to modeled flowline with aerial imagery and LiDAR topography to see if stream morphology was present.[24] Presence/absence scores were averaged into one "viability" score for unique Strahler classes (**iv** *below*). We then developed a score to rank junction viability based on a product of these frequency scores (**ii** *below*). We also created a simple stepwise array based on desirable Strahler junction types (**i** *below*) where "small order into large" is preferred. These two arrays are then factored and rescaled to arrive at a final set of scores (**iii** *below*). This final array of values was joined back to the spatial data to provide junctions with values that estimate where smallest viable streams enter large streams.

Figure 13 — AQ-JxSc | Junction Score Strategy

The following arrays rate junctions for desirable topology and water viability.

Step J'xn Score: **i.**

3	4	5	6	7	8	9	10	11	12	
0.50	1.11	2.22	3.33	4.44	5.56	6.67	7.78	8.89	10.00	3
	0.50	1.11	2.22	3.33	4.44	5.56	6.67	7.78	8.89	4
		0.50	1.11	2.22	3.33	4.44	5.56	6.67	7.78	5
			0.50	1.11	2.22	3.33	4.44	5.56	6.67	6
				0.50	1.11	2.22	3.33	4.44	5.56	7
					0.50	1.11	2.22	3.33	4.44	8
						0.50	1.11	2.22	3.33	9
							0.50	1.11	2.22	10
								0.50	1.11	11
									0.50	12

ii. = [**iv.**] [**iv.**] —> max := 10

iii. = [**i.**] [**ii.**] —> max := 10

Viable J'xnScore: **ii.**

3	4	5	6	7	8	9	10	11	12	
0.10	0.21	0.26	0.29	0.41	0.67	0.83	0.90	1.00	1.00	3
	0.46	0.55	0.61	0.87	1.42	1.78	1.92	2.13	2.13	4
		0.68	0.75	1.06	1.73	2.17	2.34	2.60	2.60	5
			0.82	1.17	1.91	2.39	2.58	2.87	2.87	6
				1.65	2.71	3.39	3.66	4.07	4.07	7
					4.44	5.56	6.00	6.67	6.67	8
						6.94	7.50	8.33	8.33	9
							8.10	9.00	9.00	10
								10.00	10.00	11
									10.00	12

iv. *Viable Stream Score*

1.00
2.13
2.60
2.87
4.07
6.67
8.33
9.00
10.00
10.00

AQ-JxSc *(Score):* **iii.**

3	4	5	6	7	8	9	10	11	12	
0.02	0.08	0.19	0.32	0.61	1.25	1.87	2.36	3.00	3.37	3
	0.08	0.21	0.46	0.98	2.13	3.33	4.32	5.60	6.40	4
		0.11	0.28	0.79	1.95	3.25	4.39	5.85	6.82	5
			0.14	0.44	1.43	2.69	3.87	5.37	6.45	6
				0.28	1.02	2.54	4.12	6.10	7.62	7
					0.75	2.08	4.50	7.50	10.00	8
						1.17	2.81	6.25	9.37	9
							1.37	3.37	6.75	10
								1.69	3.75	11
									1.69	12

We created these scores as both: **1)** regular 0 to 10 Grid Scores for visualization, and **2)** a variable to use as a factor 0 to 1 for a WP comparison. To create a functional, well-distributed set of values from 0 to 1 for this final comparison, we re-stretched the values using a fuzzy power membership algorithm.

[24] Each of the 15 sample points for each Strahler class was scored where 0.1 = no discernable stream morphology and very low confidence in finding water, 0.5 = some stream morphology visible on LiDAR topography relief, but open water unknown with approximately 50% confidence, and 1 = open water clearly visible or likely to be present at location with high confidence. These scores were averaged to produce an estimate of "likely viable stream."

3.4.5 - AQ-C-Fctr, AQ-J-Fctr | *Estimating Coldwater Refugia Locations*

Up to this point all ordinal comparisons have employed a weighted sums (WS) strategy in which variables are compared using addition. We believe this is effective when looking for circumstantial correlation because it generally causes a "smoothing" effect where resulting values illuminate commonality; but this method can also muddy meaningful overlapping geographic expressions if the contributing numbers do not represent salient scores. So, when we see that delicate variations are important, and that they may have more of an operative or causal significance, we then use the weighted product (WP) strategy to maximize the expression of these relationships. We call the inputs to these models "factors."

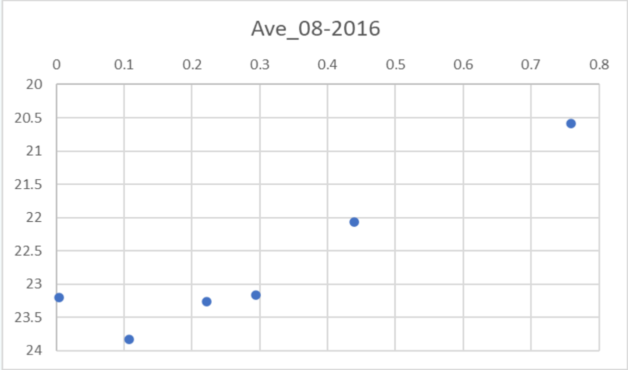
Here we would just like to note predicting stream temperature is still an area of open research. We found that even simple concepts, like: *water temperature should increase further downstream*, was difficult to substantiate in the literature. How much is water temperature likely to increase or decrease due to mass interaction at each tributary? How much does water temperature increase or decrease due to changes in the riparian areas of the watershed? Does stream temperature reliably increase "downstream" at all?[25]

After much deliberation, our team decided to explore the "downstream" factor as a possible explanatory variable because we believed our ordinal scores should reflect an integrated, interdependent system. So, to sketch a baseline for this approach, we used the EcoSheds data to investigate stream temperatures for our study region. After sampling time-controlled averages for water temperature along the Sheepscot River, we guessed that stream locations were likely warmer downstream relative to "their farthest channel heads" (DistSrc). Using the maximum DistSrc for the waterway (*the outlet of the Sheepscot*) each upstream pixel uses a ratio to describe its proximity to its DistSrc, from 0 to 1. Pixels in main channels score lower than those on side branches, because these side channels are more proximate to their DistSrc. Plotting this relationship against actual stream temperature seemed to suggest that our guesses were on the right track.[26] Stream temperature seems to decay toward the outlet based on this ratio.

Figure 14 — AQ-C-Fctr | Factor Rationale

To the right, stream temperature averages for six locations along the Sheepscot River are reported for August of 2016. Temperature is reported on the y-axis in Celsius, the "Distance-to-Source" (*farthest channel head*) ratio is reported on the x-axis. As is evident in this simple plot, stream temperature does seem to cool for locations that are proportionally closer to their farthest channel head. To create these ratios, the following operation was applied to every pixel and snapped to the stream temperature gauges:

$$\mathrm{Abs}\left(\frac{\mathrm{DistSrc} - \max(\mathrm{DistSrc})}{\max(\mathrm{DistSrc})}\right)$$



With these ideas in mind, we used this ratio (AQ-C-Fctr) as a "factor" to scale our stream temperature scores (AQ-C-Avrg); the output is our best guess at cool stream temperature (AQ-Cold). Similarly, we use the above junction score (AQ-JxSc) and convert that into a factor (AQ-J-Fctr) from 0 to 1 to maximize the visibility of likely viable junctions in another WP comparison, arriving at AQ.

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[25] One paper evaluates stream temperature-over-distance "profiles" for an entire region. It concludes that many profiles are more complex than the simple asymptotic "warmer downstream" model. (^5.1.3.k)

[26] We understand the need for more data of similar geographic and temporal spread, but this does not exist in the same region or at the comparable time intervals. This correlation is a simple sketch, we can't report a particular confidence.

4 - Recommendations

4.1 - Prioritization in Practice

4.1.1 - Conserve Landscapes, Not Features

Abstract the Goals and Communicate Land Value

Action plans for larger areas require principles that become similarly broad as the geographic scope widens. Certain species or natural communities that are considered very rare or unique in one area (*or of special concern to one stakeholder*) may be common in other locations (*or less valued by other stakeholders*). This does not mean that we should exclude these considerations—but it does mean we should acknowledge that it is more effective to focus on what is actionable within a defined scope. It is impossible to account for every piece of ecological value at every scale; thinking this way likely will inhibit progress and prevent quick action.

It is likely helpful, then, to think about creating goals that are intentionally abstract and less case-specific. "Abstract" does not mean vague. It means that there is an idea or mental model that can take the place of or represent a more complex system so it can be better understood and digested. Similar to the "hierarchy of concepts" discussion earlier (§2.2.3), it is wise to establish intentional, general goals that address the greatest number of problems for the greatest number of special interests/concerns. *What specific goals "fit under the same tent" as broader, abstracted goals?*

Like other Northeast land trusts, Midcoast Conservancy operates at a "meso" scale—meaning the service area is larger than a town but does not encompass an entire ecological region or functional natural boundary. This means that the organization's main purview is to buy land locally, establish easements, and act as a steward of the lands under its care.

We suggest that its landscape prioritization should similarly reflect a land-value approach, especially where these values can be abstracted to general, defensible concepts and then these values can be communicated to non-experts.

TNC's "Stage Not the Actors" Approach

One of the most compelling paradigm shifts in conservation is the concept promoted by The Nature Conservancy to conserve "types of landscapes" instead of particular habitats, or rather the "stage" and not the "actors." In particular, our team found the landscape diversity section (*and accompanying dataset*) published by TNC to be very compelling. We recommend heeding their publications regarding how to evaluate and preserve diverse geophysical settings to promote regional resiliency. This is because these diverse landscapes will be best suited to act as future "stages" of action, ready to receive whatever species and natural communities are likely to develop over time.

The previous statement may insinuate that because landscape change is inevitable, then it may only matter to preserve geophysical settings for whatever natural communities will arise with little or no regard to existing biota—that is not our intent. Critically important species and community types should always be a consideration and best left to professional ecologists.

But we do also suggest that this organization should look to bolstering landscapes that are currently undisturbed and unfragmented. Though natural community regeneration and land reclamation are possible (*as in the case of reforesting farmland*), this presents a myriad of issues and should not be counted upon with the current development pressure on the local landscape. As with many procedures, work will be easiest if you can make efficient use of the existing conditions.

Lastly, if the goal is to preserve the "stage and not the actors," we might further that metaphor by recommending that the theaters themselves should be connected together as efficiently as possible. Prioritization should foster the greatest interconnectedness between all elements in the greater eco-region. Our assessments included here have offered a picture of one way to do that, but this concept of interconnection should not end with acreage. This will be most effective if partner organizations, diverse social groups, and local municipalities are included in this interconnectedness as well.

4.1.2 - Situate Knowledge-Building

Distinguish Between Expertise and Meta-analysis

While it is tempting and convincing to look at our detailed scoring data as a representation of the "truth," we must remember that our work here is an abstraction, an interpretation of value. This is necessary in the planning process, but it should be understood to be an opinion and not a set of scientific facts. In particular, our data products (*see ordinal data*) are the result of what is called a **meta-analysis**, a process of digesting the work of others. We then provide an **assessment** where we take the evidence we encounter and assign subjective scores and priorities based on an informed process.

The authors of this report and its assessments have professional training in geospatial technology and communication, but only a familiarity with ecology and biology. We do our best to base our interpretations of the landscape on others' expertise, but we **1)** do not claim to represent our interpretations or the input of others as fact, and **2)** do not claim to represent the opinions of others[27] here.

At every stage of this process we attempted to be deferential domain experts. We also recommend that if the results of these data conflict with what an expert recommends, that that expert should be given deference in their area of expertise. A model can always be improved; true expertise is only arrived at through earned experience and should be valued as such. It is only through these conflicts and friction points that improvements can arise and the knowledge-building process can become more robust.

Distinguish Between Planning Uses vs. Real World Phenomena

Another difficult concept to keep in mind is that the habitat modeling we have done relates to how we think an organization *should* value it, not on whether the land is currently thriving, verdant, or particularly abundant with species on the ground. For instance, our corridor models are based on existing research, but they still represent planning concepts—that is, where *should* corridors be made or protected based on larger landscape processes.

A fieldwork trip to one of our "high value" corridor areas will likely not reveal remarkable numbers or instances of terrestrial fauna in migration. These are simply important theoretical linkages, ones that will help to create a cohesive matrix of uninterrupted land from the perspective of spatial computation. Example abstractions like these are useful for setting planning goals, but they may frustrate the field ecologist or wildlife biologist with a lack of material to subject to groundtruthing. A limitation to this type of computational abstraction is that it restricts us to considering our input data alone. Ecological phenomena, however, are often best understood on the ground. If nothing else, we hope that these abstractions may serve to guide field ecologists to areas worthy of further inspection.

[27] The opinions represented here are solely the product of work performed by the Rhumbline Consulting Team. The lead authors are Ben Meader and Vincent Falardeau.

Leverage GIS to Support Conservation

As we have noted numerous times, assessment is subjective by design. This means that your team should experiment with which methods it uses to assess parcels and focus areas; we think the aim should then be to create a system for ingesting the Grid Scores into that workflow. We offer some implementation strategies for summarizing scores in the GIS User's section (§2).

Our conversations with Chris Schorn identified the need to promote other forms of conservation activity. Historically many conservation efforts have revolved around "reacting" to potential conservation events—philanthropic interests, social network capitalization, and real estate market opportunities—as they arise. This might be considered "reactive conservation" because it is by definition opportunistic and based on naturally arising occurrences. The issue with this style of conservation is that it does not easily allow for targeted goals in particular geographic areas. While our team can't comment specifically on best practices for donor outreach or landowner relationships, we can suggest the best ways to use GIS materials to support both reactive and proactive conservation efforts.

For reactive conservation, we suggest using the Grid Scores along with parcel data to infer interesting patterns that complement local knowledge. This means that if multiple opportunities arise at the same time, a GIS user should be able to look at each parcel and get a better understanding of how each parcel might or might not integrate with the larger vision of landscape priority. Similarly, some of our novel data sets (*core blocks, drainage, etc.*) could be used to provide novel statistics.

For proactive conservation, we suggest layering the grid scores with existing conservation land to see where gaps exist. Although it would be most useful to be able to see real estate, economic, cost, or other property variables—corridors and quality areas of interest should be apparent in regional geovisualization. See the section on suggested applications for more information (§2.3).

Consider Other Systems of Value

This area we now call Maine has been home to humans, animals, plants, and other biota for millennia. The dominant culture on this landscape is now a colonial one, founded on an English land management system of private property, towns, and counties. While we cannot completely step outside the system of metes and bounds we inhabit at will, it is helpful to get diverse perspectives on the landscape. The dominant American culture has largely supplanted the indigenous cultures that preceded it, though in Maine we still have the voices of the Maliseet, Mi'kmaq, Penobscot, and Passamaquoddy peoples to listen to. These people and their cultures contain within their very language the names of the places we visit daily, and carry many hundreds of generations-worth of heritage and landscape knowledge. What ways of conserving land or understanding its value could be learned by incorporating these perspectives?

In similar fashion, the dominant forces and ideologies that now shape this landscape are ones that were born from a culture that values empiricism and bears an undoubtable "land as commodity" bias. This report's attempt to assign value is evidence of this. If we are to make decisions based on abstracting value and/or communicating in a language of common ethics, where should we find these ethics? What attempts—other than, perhaps Leopold's 73-year-old *Land Ethic*—have been made to attempt to construct a system of durable conservation principles?

None of these questions can be answered by running algorithms. Therefore, we also recommend regular consideration of the value systems that underpin your organization's mission, so that you may, as a group, always act in step.

4.1.3 - Treat Conservation as a Planning Process

Group Decision-making

As previously stated, we acknowledge that, for specific decision-making, expert opinion is irreplaceable. It is, however, important to distinguish what the role of individual expertise should be in good group decision-making for long term processes. For on-the-spot, domain-specific assessments, an expert will outperform a generalized system of knowledge creation in every specific case.

But expert knowledge is normally tied to individuals or special interest groups; these parties can not be relied upon to endure over the life of an organization that needs to regularly call upon high-level knowledge for taking action. Because these social relationships are ephemeral and time dependent, systems of group decision-making should ideally be built on a consensus interpretation of well-analyzed data. These systems should ideally be based on durable and enduring methodologies. Although many of these group decision-making methodologies have long been known and variously implemented in political institutions and large, multi-generational businesses, smaller organizations often struggle to codify and support their decision-making processes with replicable and augmentable solutions. The next several paragraphs list our firm's suggestion for fostering institutional knowledge.

Delphi Method

This has become somewhat of a catch-all term for "surveying a group of experts" or "assembling a group of scored opinions." Many of the ideas for developing good, dispassionate decisionmaking systems developed in the Cold War under the threat of catastrophe. Today these methods are largely implemented by panels of investors and other economists, though it is easy to see potential applications here. The importance of the general concept of the Delphi method is to harvest "the wisdom of the crowd" instead of reacting to the "pressures of the mob." To do this there are a few key concepts that are important. It is best to have: **1)** a great diversity of opinions that sample the group well, **2)** survey anonymity, **3)** a structured flow of information, **4)** the option to iterate for improvement, and **5)** a dispassionate facilitator to synthesize the group decision.

Anonymous surveys are used so that the greatest diversity of opinions can be sounded without social influence. Use group discussion to identify tension points and to mature opposing arguments, but allow private reflection for sounding considered opinions. The information from the surveys must be structured so it can be understood in aggregate. Our organization used both weighted and ranked scores to understand the values of the participants; the former demonstrates emotional resonance with each topic, the latter demonstrates agreement and/or disagreement between participants by showing a frequency of ranks via forced prioritization (*respondents can't weight every score the same and must create score variation*). These results can be easily aggregated and categorized to estimate "group opinion."

Live Charrettes

While not specifically part of the "Delphi Method," we've seen great success with live charrettes through the work we've done in urban and municipal planning. The novelty of digesting maps, visuals, and graphics combined with the warmth of in-person communication strategies—body language, casual conversation, etc.—all contribute to an air of collaboration. Although the subtext is that there is likely disagreement to work on, the overt message is that all participants are trying to solve a problem together.

The difference between a charrette and other stakeholder meetings is that: **1)** it is usually hosted by a dispassionate third-party, **2)** the meeting's outcomes and its goals are not explicitly defined at the outset, but instead these items are arrived at by the end, and **3)** the participants and their opinions are not beholden to any individual organization's rules, protocols, or special interests.

Structured Reviews

Similar to how New England municipalities develop 10-year comprehensive plans to address changing conditions, we suggest codifying a new type of landscape-scale visioning process as part of your organization's landscape responsibility. This can help provide a level of accountability and engagement for the organization, both to itself and its constituents. This type of repeated planning process requires several things: **1)** a schedule, **2)** an appropriate budget, and **3)** a desired product. While our firm's members are not professional planners, we can share some ideas that we've encountered with our partners in that industry.

A 10-year minimum for revisiting these variables seems reasonable—but with new data, rapid advances in geospatial technology, and a volatile real estate market, it is probably appropriate to revisit more quickly. Based on our experience preparing this document, we would suggest a minimum budget of $40,000 to cover two to three major ecological topics in an open RFP process.

In terms of a desired product, we've witnessed some organizations abandon the concept of a final document to opt for online, multimedia, or other digital products. The argument is that they are more accessible to their constituents. Documents are useful, however, because they represent the synthesis of a particular group in a time and place. Situated information is invaluable for historical processes. We recommend, at a minimum, that your organization develop a data repository with historical records of existing conditions (parcels, holdings, focus areas, etc.) as these may prove invaluable to future analysts.

Disjoint Action Plans by Design

Our results reveal different hotspots based on each criterion. As was discussed earlier, spatial correlation is usually tighter with variables that relate to each other. This is why we separated the terrestrial/aquatic and quality/connectivity subjects into different areas of inquiry. While it is possible to combine all of these scores into one "overall" score, the results are less decisive. Users will also find that each overall score for the various subject areas (A, T, or AQ, AC, TQ, TC) share a similar problem—each component of these overall assessments is sometimes more interesting or definitive when investigated alone or for case-specific applications.

We suggest crafting intentionally disjoint action plans that fulfill and address these goals separately as necessary. This means that the conservation goals for addressing terrestrial connectivity, for instance, may often compete with the resources demanded by a separate goal, like preserving aquatic habitat quality. With limited resources it may be useful to create a decision tree or other prioritization scheme for allocating funds and allotting time for simultaneously working toward these different goals.

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4.2 - Discussion of Results

4.2.1 - Lead Analyst's Report

The following reflections are offered by the project's lead analyst:

> *This project has taken what to me was previously an unfamiliar landscape and given such depth of meaning to the hills and folds of the terrain, the streams and rivers and bays, the forests and wetlands we hope to protect. In particular, there are corners of the Midcoast service region that draw my attention, that consistently suggest conservation potential. There are the hills around Hibberts Gore and in Washington, Palermo, and Liberty — just a bit steeper, shadier, and cooler than much of the service region, partly sitting atop sand and gravel aquifers, maybe a place where cold headwater streams start flowing. There are the peninsulas, with stretches of cooler land, perhaps moderated in summer by the influence of the ocean, land that is also reliant on pinch points of connection to the broader eco-region. At the outset of this project I imagined wildlife would all be headed north in a great exodus in our heating climate; now I wonder whether there might be movement toward the coast, too. The 'zonal connectivity' we describe above in such technical terms really comes down to this kind of reality on the ground: can you get there from here? And how do we prioritize land for conservation in such a way that we protect not just populations as they are, where they are, but populations as they might be, where they might go?*
>
> *With every charrette, meeting, or exchange and every new study, report, or GIS tool, I have felt honored to partake in the launch of this 30x30 project and glean an intimate knowledge of the study areas. At each step of the way, the Midcoast and Rhumbline teams, and all of our advisors and experts, have been recycling what we already think and know into what we want to know, what new knowledge we ought to seek in order to be smarter about targeted, proactive conservation for terrestrial and aquatic ecosystems. Through this process, we have generated a substantial set of scores for habitat quality and connectivity, ways of looking at the various opportunities presented by this changing landscape. At the same time, this set is far from exhaustive, more of a beginning than an end to the analysis of conservation potential. There are so many spinoff research questions I would love to have had time to pursue — saltmarsh sparrow habitat, for one, or changes in vegetation health over time using remote sensing, or shaded streams and rivers based on a digital surface model of treetops. And I wonder what a habitat quality model could look like, individualized by species of greatest conservation need, as outlined in the Maine State Wildlife Action Plan. There is such a growing volume of data out there that we must choose our goals carefully, and I think we have ultimately done so — focusing on just two subjects, quality and connectivity, for the aquatic and terrestrial domains.*
>
> *Developing scores for aquatic quality and connectivity was sometimes a challenge, but the process ultimately became especially rewarding as the different threads of the analysis were successfully woven together. For thousands of points across the Midcoast service region, we mapped upslope contributing areas with sharp accuracy, and could then use these areas to summarize potential indicators of cold water and good fish habitat. I am frequently astonished by the tools we have at our disposal to describe stream networks, whether it's measuring the distance along a continuous flowline to the ocean for every pixel in a raster, or whether it's the reverse, modeling the complexity of upslope streams.*
>
> *Along with the aquatic quality scores, the terrestrial connectivity outputs are perhaps what I am most proud of having had a hand in making. For the local connectivity analysis, I wrote a script based closely on LinkageMapper, and customized the code in such a way as to map movement corridors between all adjacent blocks, using multiple and differing block size thresholds. I think this is a powerful method for showing the diversity of possible connections across the landscape — I imagine any of these connections severed by development, and I picture how animals would have to take more circuitous routes across the terrain, or riskier ones across fragmenting roads and unsheltered areas. To my mind, conservation is a matter of showing compassion to the wildlife we share this land with, considering how any change we make to the environment is not just a change for ourselves, but for other life too.*
>
> *— Vincent*

4.2.2 - Project Manager's Report

The following reflections are offered by the project manager:

> *Anecdotally I can say that many academics I've worked with consider a multiple criteria analysis dangerous territory. But having worked with professional planners for the better part of a decade, I wonder now if that "dangerous territory" is really more akin to "terra incognita"—the idea of assigning value and ranking things opens the door for too much speculation and interacting with uncontrolled variables. Most academic researchers must therefore eschew matters of personal opinion or priority in the pursuit of facts and evidence. Planners, however, do not have the luxury of pursuing their goals with perfect knowledge, because not every condition and outcome can be known. On principle, the process of developing a plan requires that we gather input, avow opinions, establish consensus, and then take a stand for implementing collective action. The only way to do this, of course, is to evaluate many, many criteria as rigorously as possible and then make a plan.*
>
> *I've worked on dozens of projects in multiple disciplines over the years, but I think conservation planning has to be among the most interesting of intellectual and ethical dilemmas. We're forced to think about a future we can't see, wrestle problems we can't fully solve, and take action in a landscape whose rules are hard to decipher. I appreciate how such a simple question: "What land should we conserve?" has such a myriad of possibilities and competing views even among members of the same team. The outcomes will affect all members of the human-environment system.*
>
> *To me, the most interesting concepts that have arisen during this project concern time, scale, effort, and money. I believe that the greatest threat to coastal Maine's ecological landscape is natural community fragmentation. While I do think that creating sustainable environments for human habitation and activity requires growth, I believe that unfettered landscape development will probably be the most significant contributing mechanism to that fragmentation in the next 20 years. Not only is this the issue with the most proximal results (in terms of tangible time and scale), but it also presents Midcoast Conservancy with a set of problems in its most actionable arena of engagement (where it can spend appropriate effort and money).*
>
> *What of all of the other issues? Threatened species, climate change, rare or endangered natural communities, or other particular interests? Although there are a myriad of competing factors, it seems to me that preserving biodiversity and regional cohesion will have the most applicable results for this immediate 30 x 30 effort. Habitats, parcels, towns, powerlines, roads, rivers, lakes, mountains—many of these will change dramatically over the course of centuries and millennia, both naturally and anthropomorphically. We're all complicit participants and spectators. I wonder then, if the goal is to see how Midcoast Conservancy can specifically aid in the sustenance of the local environment in a tangible way, then shouldn't its goals be simple? Attempt to acquire a high volume of land that is well-positioned for long-term value?*
>
> *Perhaps I'll further venture an opinion and say that we should always look to work at the right scale for each kind of effort. We should work with partners as part of a larger community on larger issues, and we should work ardently on the local scale within our own means in the proper fields of action. For Midcoast Conservancy, I think that means securing parcels that allow natural communities, both now and in the future, to thrive. Preserve land that allows high diversity natural systems to coalesce into cohesive, matrix-forming biomes.*
>
> *Writing recommendations for a plan is no small task, and I wish I had the verbal acumen to be more concise. I'm sure prevailing wisdom will change, just like the ideas Vincent and I have put together here. May the reader therefore please feel free to contact me to discuss any part of this project, if nothing else than to poke holes in ideas and to provide for interesting conversation.*
>
> *— Ben*

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5 - Resources

5.1 - References & Citations

5.1.1 - Conservation Plans, Articles, Topical Publications

5.1.1.a A thorough Maine state conservation plan focused on protecting species of greatest conservation need:
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5.1.2 - Geospatial Methods and Reference Material

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5.1.2.b Useful description of different stream classification methods:
R.stream.order. GRASS GIS Manual; GRASS Development Team, Open Source Geospatial Foundation.
https://grass.osgeo.org/grass82/manuals/addons/r.stream.order.html

5.1.2.c QGIS, the leading open source GIS software, free to download for any platform:
QGIS: A Free and Open Source Geographic Information System. https://qgis.org/en/site/

5.1.2.d Atom, a great text editor used for this analysis, unfortunately being decommissioned:
Atom: a Hackable Text Editor for the 21st Century. https://atom.io/

5.1.2.e Whitebox Tools, very robust operations for open source use, especially in the raster environment:
Whitebox Geospatial Inc: Innovative Geospatial Software Built on Open Source.
https://www.whiteboxgeo.com/

5.1.2.f **Linkage Mapper, a novel set of tools that provide a wide variety of connectivity models for ArcGIS:**
Linkage Mapper. https://linkagemapper.org/

5.1.2.g **Google Earth Engine, powerful open tools for analysis and data display for non-profits and educational institutions:**
Google Earth Engine: A Planetary-scale Platform for Earth Science Data & Analysis. https://earthengine.google.com/

5.1.2.h **Documentation for Whitebox Geomorphons tool:**
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5.1.3 - Academic Papers in Conservation or Ecology

5.1.3.a A review of connectivity metrics used in geographic studies of conservation planning:
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5.1.3.b The conditional minimum transit cost (CMTC) approach to mapping multiple redundant low-cost wildlife corridors:
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Delgado, Montserrat Gómez, and Joaquín Bosque Sendra. "Sensitivity Analysis in Multicriteria Spatial Decision-Making: A Review." *Human and Ecological Risk Assessment: An International Journal*, vol. 10, no. 6, Dec. 2004, pp. 1173–87. https://doi.org/10.1080/10807030490887221

5.1.4.b A paper with good descriptions on the <u>differences between weighted sums and weighted products</u>:
Triantaphyllou, Evangelos, and Alfonso Sánchez. "A Sensitivity Analysis Approach for Some Deterministic Multi-Criteria Decision-Making Methods." Decision Sciences, vol. 28, no. 1, Jan. 1997, pp. 151–94. https://doi.org/10.1111/j.1540-5915.1997.tb01306.x

5.1.4.c Discussion of the importance of <u>spatial autocorrelation</u> and "Tobler's first law" in analysis:
Miller, Harvey J. "Tobler's First Law and Spatial Analysis." Annals of the Association of American Geographers, vol. 94, no. 2, June 2004, pp. 284–89. https://doi.org/10.1111/j.1467-8306.2004.09402005.x

5.1.4.d Description of the <u>modifiable areal unit problem</u> (MAUP), which applies to conclusions drawn from a spatial analysis:
Openshaw, S. (1983). The Modifiable Areal Unit Problem. *Concepts and Techniques in Modern Geography, No. 38. ISBN 0860941345.* https://www.uio.no/studier/emner/sv/iss/SGO9010/openshaw1983.pdf

5.1.4.e A paper describing methods for <u>classifying common landforms</u> from any digital elevation model:
Jasiewicz, J., & Stepinski, T. F. (2013). Geomorphons—A pattern recognition approach to classification and mapping of landforms. *Geomorphology, 182,* 147–156. https://doi.org/10.1016/j.geomorph.2012.11.005

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5.2 - Data and Processing

5.2.1 - Sources

- **Beginning With Habitat** | *Focus areas; wetlands characterization; rare, threatened, and endangered plants; deer wintering areas; inland wader and waterfowl habitat; salmon habitat; brook trout priority areas; undeveloped blocks. Data on all ecological subjects available via request. Undeveloped blocks and wetlands figure critically in our analysis.*
https://www.maine.gov/ifw/fish-wildlife/wildlife/beginning-with-habitat/maps/index.html

- **Midcoast Conservancy** | *Current conservancy focus areas, service region, and protected properties. Contact the Midcoast Conservancy to request data. These data shape the study regions of our terrestrial and aquatic analyses.*
https://www.midcoastconservancy.org/contact

- **NOAA Coastal Change Analysis Program** | *2015 landcover classification at 10-meter resolution; CCAP data grounds much of our terrestrial connectivity analysis, and can be downloaded state by state.*
https://coast.noaa.gov/digitalcoast/data/ccapderived.html

- **USGS National Elevation Dataset** | *Elevation data at 10-meter resolution; from NED data, we generate geomorphons, identifying ridge and valley landforms, and we assess time-in-daylight based on topography. Download 1 degree x 1 degree tiles from The National Map Download Application.*
https://apps.nationalmap.gov/downloader/#/?z=9&y=44.1&x=-69.2&basemap=usgs_topo&datasets=elevation-products-three-dep&layerIds=

- **Maine GeoLibrary LiDAR** | *2015 elevation data at 1-meter resolution; for the sake of regional analysis, we downsample to 4-meter resolution. This data is used throughout our aquatic connectivity and quality analyses. Download by tile via the Maine GeoLibrary Discovery and Download Application.*
https://www.maine.gov/geolib/ediscovery/site/index.html

- **Maine GeoLibrary AADT** | *Public roads dataset with the average annual daily traffic (AADT). High-traffic roads impede wildlife movement in our connectivity analysis. Download from the Maine GeoLibrary.*
https://maine.hub.arcgis.com/datasets/1a3a6436cc054eb3947d8cb36b039daa/explore

- **TNC Landscape Diversity** | *Raw landscape diversity scores across the Northeast US region, which we use in our analysis of terrestrial quality. Provided by The Nature Conservancy.*
https://tnc.app.box.com/s/hhfmvxomlyal6kbnmflulczt884ypvr5

- **MDMR Stream Habitat Viewer** | *Barrier data – dams, crossings, and natural barriers – are the basis of our AC-Acss analysis. Download from the Maine Stream Viewer web app.*
https://webapps2.cgis-solutions.com/MaineStreamViewer/

- **USGS Landsat Surface Temperature** | *The USGS processes Landsat satellite imagery into 30-meter resolution surface temperature products, which we average over a year of cloud-free images in our coldwater analysis. Download from the USGS Earth Explorer.*
https://www.usgs.gov/landsat-missions/landsat-collection-2-surface-temperature

- **SHEDS Stream Temperature Database** | *Data from active and inactive stream temperature logs throughout the Northeast. We plot this data against distance-to-source to determine how to scale AQ-C scores. Find data through the Public Data Viewer.*
http://db.ecosheds.org/viewer

- **Maine GeoLibrary Parcels** | *Parcel data for organized towns and unorganized territories, which we supplement with parcel data requested directly from towns. Download cadastral data from the Maine GeoLibrary.*
https://www.maine.gov/geolib/catalog.html#planning

5.2.2 - Generated by RLM

- **Terrestrial Study Region** | *A region demarcated by the Kennebec River in the west, Route 95 in the north, and the Penobscot River in the east. One broadly cohesive region to analyze for habitat connectivity across the landscape and beyond the Midcoast service region.*

- **Aquatic Study Region** | *The watersheds between the Sheepscot River watershed in the west and the Medomak River watershed to the east, and southward, including coastal flowages not partaking of major river watersheds. This study region was determined from a watershedding operation using LiDAR data.*

- **Core Blocks** | *Core habitat areas generated by removing 200-meter buffers of "disturbed" land and clipping by Beginning With Habitat undeveloped blocks. This dataset was generated from CCAP landcover, and exists in raster and shapefile format. These become the basic units for terrestrial quality analysis, and the areas of habitat to connect in connectivity modeling.*

- **Cost Surface** | *A raster developed from a reclassification of CCAP data, augmented with geomorphons, core and undeveloped blocks, and traffic data. This piece of data represents the resistance in all terrestrial connectivity analyses.*

- **Geomorphons** | *A layer representing ridgeline and riparian landforms serving as movement corridors, generated from NED 10-meter elevation data. Selected landform types are used in the cost surface to highlight higher potential for movement along natural features.*

- **Strahler Streams** | *A shapefile with lines for each stream reach, generated from the 4-meter resampled LiDAR data through the intermediate processes of hydrological DEM correction, flow direction, and flow accumulation. Attributed with aquatic results and outputs.*

- **Upslope Areas** | *Upslope areas generated from stream junctions of a minimum size or larger, used in zonal statistics steps to analyze the qualities of the watershed above any given point in the aquatic service region. An item used in many analytical processes, but not used as a reporting unit.*

- **Isobasins** | *Unique, non-overlapping, sub- or micro-watershed polygons generated using the Whitebox Isobasins tool and the 4-meter resampled LiDAR data. These correspond one-to-one-to-one with associated stream network junctions and upslope areas.*

5.2.3 - Environments

The GIS work for this project was carried out in a mixed software environment, predominantly using QGIS version 3.22.9, 'Białowieża,' for visualization and to run some tools, and using Atom (version 1.63) to run Python scripts adapting Whitebox tools (version 2.1.0). The typical workflow involved pre-processing data in QGIS, then running analyses in Atom, visualizing the new data outputs in QGIS, and returning to Atom to refine the parameters of the analysis. Some other data, programming, and cartography tasks were conducted using Microsoft Excel, Jupyter Notebooks, Google Earth Engine, Adobe Illustrator, and a suite of other programs.

All data were projected to EPSG: 26919 (UTM 19N, NAD 83).

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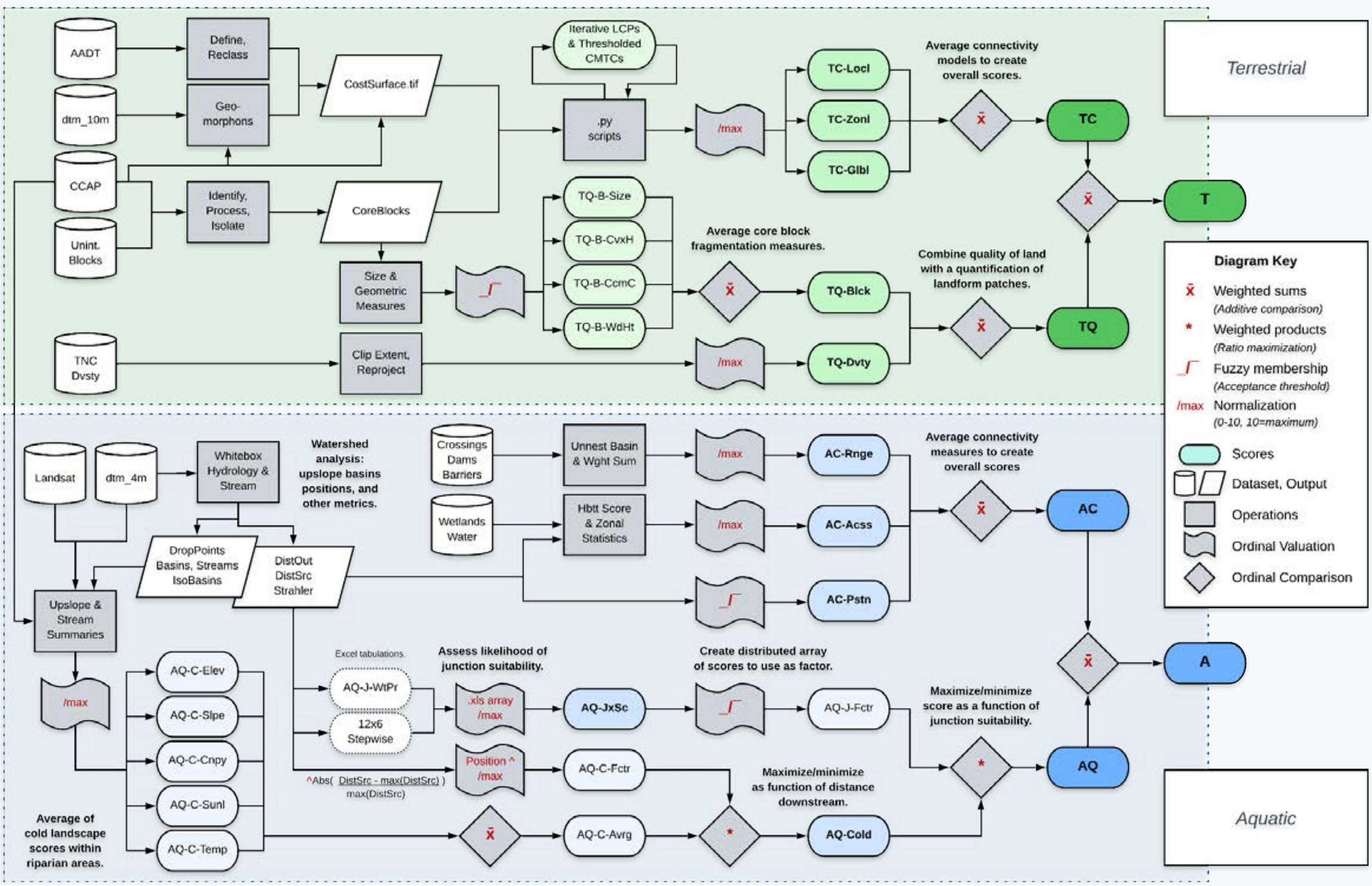
6 - Appendix

The following pages include basic maps and exports of the results of this assessment. For more information, please see the data deliverables provided to Midcoast Conservancy.

6.1 - Diagrams

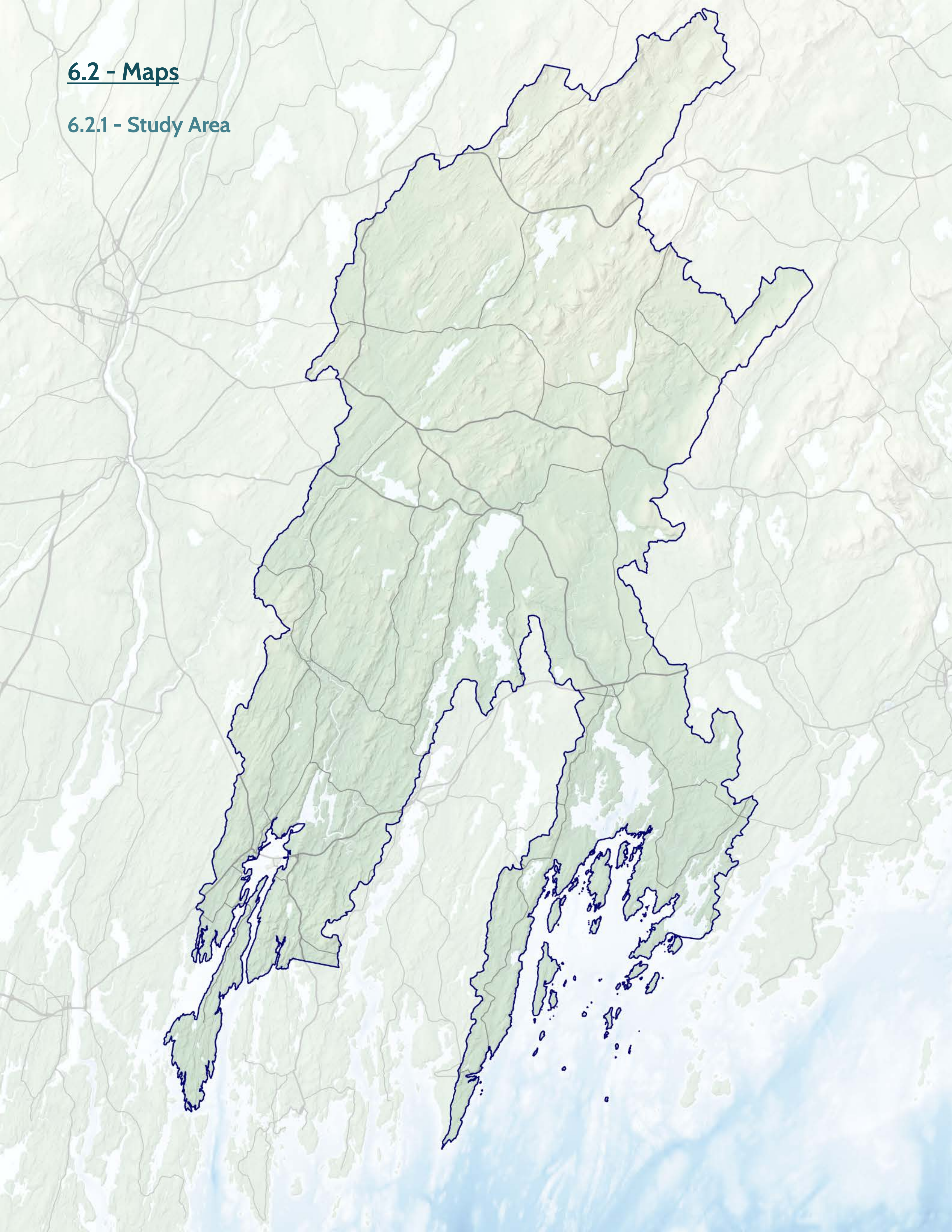
6.1.1 - Workflow Diagram

Below is a summary of the basic workflow for the analysis. See key for the categories of elements. All processes, shown in gray, are comprised of intermediary steps, too numerous to concisely list here. The purpose of this diagram is mainly to demonstrate context for how the scores were created, it is not meant to be taken as a literal input-output schematic for workflow replication.

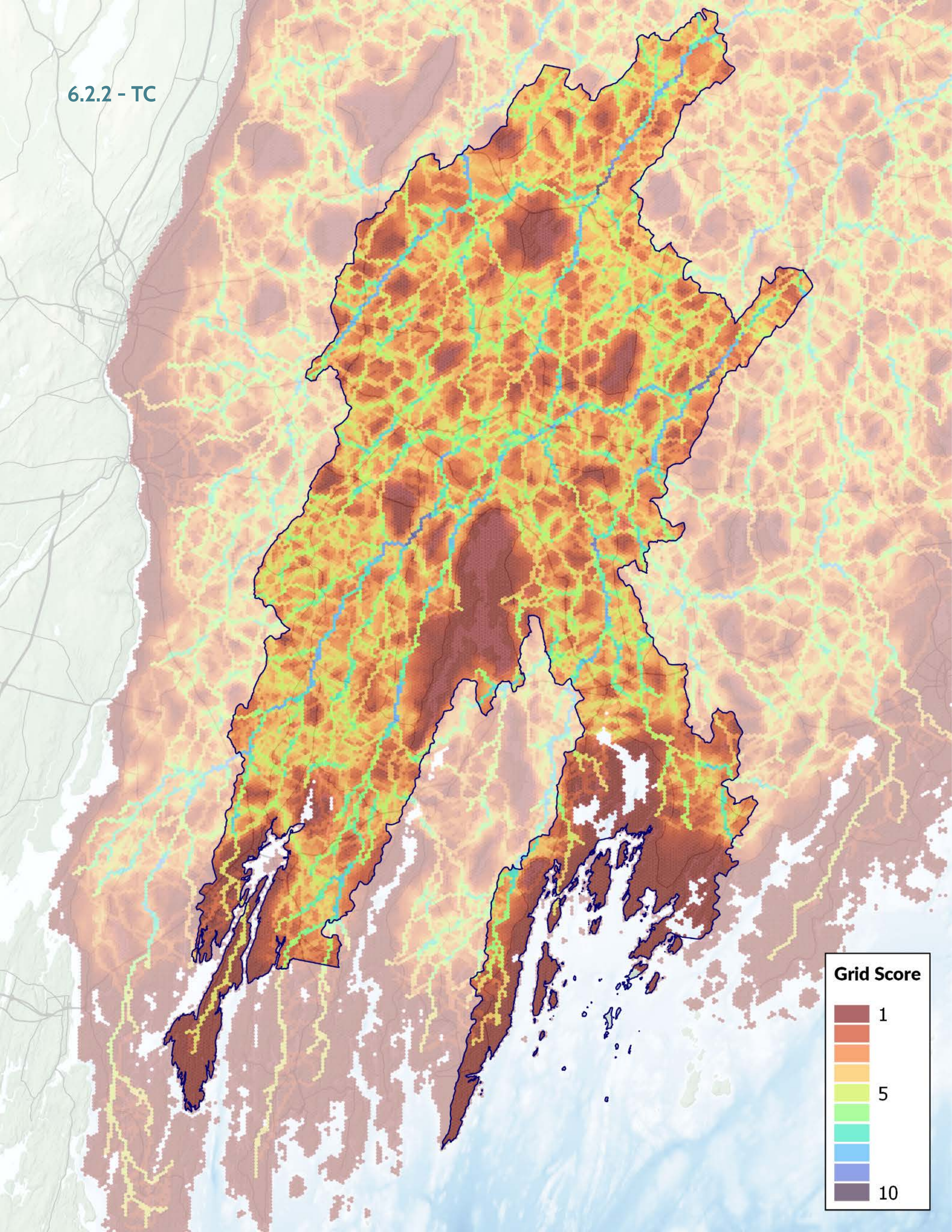


6.2 - Maps

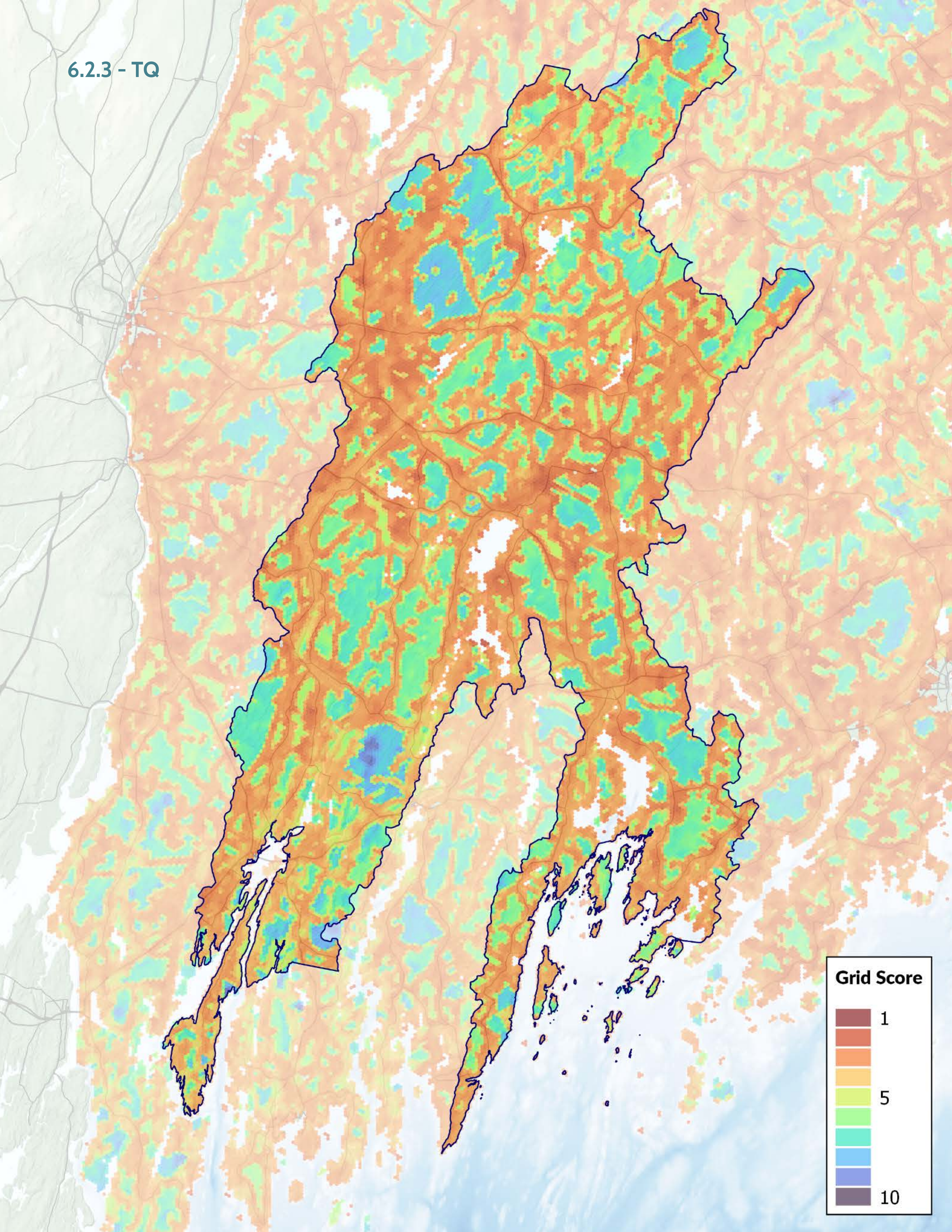
6.2.1 - Study Area



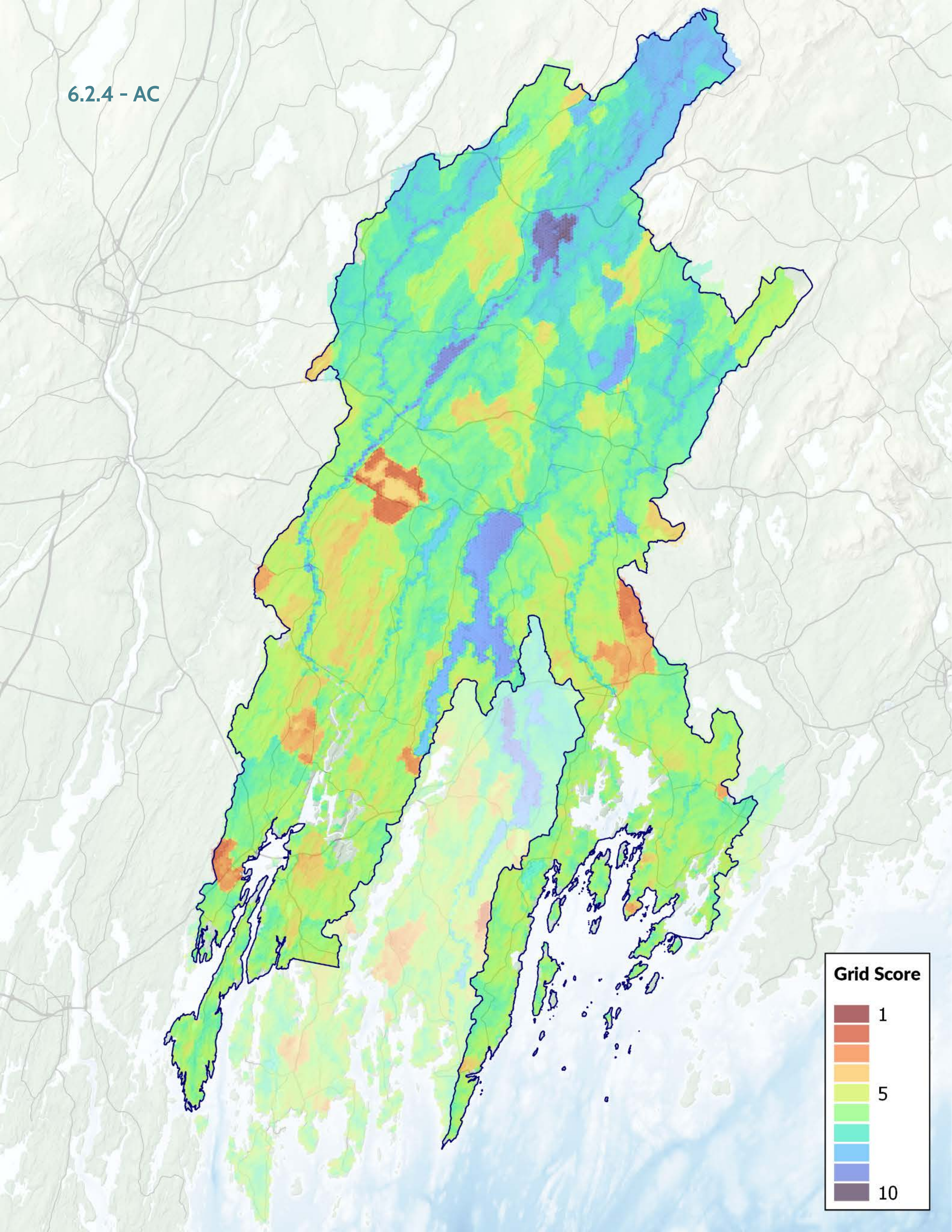
6.2.2 - TC



6.2.3 - TQ



6.2.4 – AC



6.2.5 - AQ