

The Northern Appalachian/Acadian Ecoregion
Priority Locations for Conservation Action



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Correct citation for this report: Trombulak, S.C., M.G. Anderson, R.F. Baldwin, K. Beazley, J.C. Ray, C. Reining, G. Woolmer, C. Bettigole, G. Forbes, and L. Gratton. 2008. The Northern Appalachian/Acadian Ecoregion: Priority Locations for Conservation Action. Two Countries, One Forest Special Report No. 1.



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is a major Canadian-U.S. collaborative of conservation organizations, researchers, foundations, and conservation-minded individuals. Our international community is focused on protection, conservation, and restoration of forests and natural heritage from New York to Nova Scotia, across the Northern Appalachian/Acadian ecoregion.

This ecoregion encompasses over 330,000 km² in the northeastern U.S. and southeastern Canada, including all or a part of northern New York, Vermont, New Hampshire, Maine, southern Québec, New Brunswick, Nova Scotia, and Prince Edward Island. It is ecologically diverse, dominated by spruce-fir and northern hardwood forests, extensive coastlines, inland mountain ranges, and glacially carved landscapes. It is an ecological transition zone between northern boreal and southern temperate forests, and will come increasingly to serve as a north-south biological corridor for species as their ranges shift in response to climate change.

This report describes the results of a research initiative launched by 2C1Forest to identify irreplaceable and vulnerable locations in the Northern Appalachian/Acadian ecoregion for the purpose of identifying priority locations for conservation action. Our methodology is data driven, comprehensive across the entire ecoregion, and spatially explicit at a high resolution, which allows our results to be replicated and applied at numerous spatial scales. Our approach to identifying priority locations involved three interlocking lines of analysis.

First, we characterized vulnerability through analysis of the ecoregion's Human Footprint, a relative measure of the degree of landscape transformation from its completely natural condition. We assessed both the Current Human Footprint—based

on the best and most recently available data on human population, transportation and energy distribution networks, and changes in land cover—and projections of Future Human Footprints under alternative scenarios of future population growth rates and settlement patterns.

Second, we characterized irreplaceability through a process of systematic conservation planning, identifying sets of locations that together satisfy targets established for protection of threatened and endangered species and ecosystems, source habitat for focal carnivores, and abiotic landscape features. Because many different sets of locations can equally satisfy the targets, locations are characterized by the percentage of sets in which they are included, ranging from always being included in a set (and thus the location is completely irreplaceable) to never being included (and thus is completely replaceable). In addition, we assessed irreplaceability under three different levels of targets: low (a small number of replicates required for each ecological feature to consider the goals satisfied), medium, and high.

Third, we subdivided the entire ecoregion into subregions and assessed the irreplaceability and vulnerability scores for each subregion to identify those with (a) high irreplaceability and high vulnerability (signifying a high priority for conservation action), (b) high irreplaceability but low vulnerability, and high vulnerability but low irreplaceability (moderate priority), and (c) low irreplaceability and low vulnerability (low priority). We used three different methods for subdividing the ecoregion: a regularly distributed network of 10-km² hexagons, hydrologic units (related to watershed boundaries), and biophysical units (related to ecological and geological characteristics).

For conservation practitioners, the key points revealed in these analyses are the following:

- ~ The Northern Appalachian/Acadian ecoregion still retains large areas of wild, relatively untransformed land. In particular, these include the Adirondack Mountains and Tug Hill Plateau of New York, northern Maine, the Gaspé Peninsula of Québec, and both the northern and southern tips of Nova Scotia.
- ~ While the Northern Appalachian/Acadian ecoregion is still one of the most forested and “wild” ecoregions in eastern North America, it may be one of the most vulnerable simply because so much undeveloped land is unprotected and within reach of densely populated areas. Threats to the Northern Appalachian/Acadian ecoregion’s land area are currently concentrated in settled landscapes but may rapidly expand outwards given changes in social or ecological conditions that would encourage rapid human population growth and settlement (e.g., climate, location of large industries, and availability of land with high amenity value).
- ~ We assume that all lands that are currently permanently protected against conversion to development will continue to be a part of the ecoregion’s system of conserved lands. Given this assumption, at low target levels for conservation of threatened and endangered species and ecosystems, source habitat for focal carnivores, and abiotic landscape features, approximately 27% of the landscape is irreplaceable for achieving these goals.
- ~ As target levels for conservation increase, the amount of land needed to meet overall conservation goals necessarily increases. However, there is a great deal of replaceability for those additional lands. Thus, achieving higher target levels requires greater replication of protected lands for ecological features, which can be achieved with many different configurations of lands apart from the limited amount of land identified as completely irreplaceable.
- ~ When target levels are low, broad areas of the ecoregion (almost 50%) never contribute to achieving the specified conservation goals. However, as target levels increase, the potential contribution of much of these areas also increases, indicating that virtually all areas in the ecoregion have the capacity to contribute to achieving conservation goals if the desired level of ecological replication is high enough.
- ~ Some locations consistently emerge with the same priority ranking for conservation action regardless of the scenarios used to measure irreplaceability and vulnerability, or how the ecoregion is subdivided. In contrast, the priority rankings for other locations vary and are highly sensitive to both the assessment method used and how subdivision is achieved. The fact that there is not one unique objective measurement of priority for all locations does not undercut this approach to assessing priority locations for conservation action. Rather, it highlights the importance of assessing the robustness of all spatially explicit conservation initiatives and selecting the appropriate spatial scale on which to base planning decisions.
- ~ These analyses do not include a comprehensive assessment of priorities to achieve functional connectivity across the ecoregion, either for ecological needs in the present time (e.g., movement of wide-ranging species) or in the future (e.g., ecosystem response to climate change). However, major locations important for structural connectivity, linking large regions with low degrees of transformation, are revealed and include areas connecting the Tug Hill Plateau and Adirondack Mountains in New York; the Adirondack Mountains and the Green Mountains in Vermont; the Green Mountains and Sutton Mountains in Québec; from northern Maine to the Gaspé Peninsula in Québec across northern New Brunswick; and between New Brunswick and Nova Scotia across the Chignecto Isthmus.

Two Countries, One Forest/ Deux Pays, Une Forêt (2P1Forêt)

est une initiative canado-américaine d'envergure regroupant des organisations, des chercheurs et des fondations œuvrant en conservation ainsi que des individus intéressés par ce domaine. Les activités de cette organisation internationale portent avant tout sur la protection, la conservation et la restauration des forêts et du patrimoine naturel de l'écorégion des Appalaches nordiques et de l'Acadie, qui s'étend de l'État de New York à la Nouvelle-Écosse.

Cette écorégion couvre plus de 330 000 km² dans le nord-est des États-Unis et le sud-est du Canada et englobe en totalité ou en partie le nord de l'État de New York, le Vermont, le New Hampshire, le Maine, le sud du Québec, le Nouveau-Brunswick, la Nouvelle-Écosse et l'Île-du-Prince-Édouard. Très diversifiée sur le plan écologique, la région est dominée par des forêts de sapin, d'épinette et de bois francs nordiques, d'importantes zones côtières, des chaînes de montagnes et des paysages forgés par le retrait des glaciers. Elle constitue une zone de transition écologique entre la forêt boréale, au nord, et les forêts tempérées, au sud, et sera de plus en plus appelée à servir de corridor biologique nord-sud pour les espèces dont l'aire de répartition se modifie en raison des changements climatiques.

Le présent rapport décrit les résultats d'une recherche entreprise par 2P1Forêt dans le but de déterminer quels sont les endroits irremplaçables et les plus vulnérables de l'écorégion des Appalaches nordiques et de l'Acadie et d'établir des priorités en matière de conservation. Notre méthodologie, qui se base sur des données portant sur l'ensemble de l'écorégion, est spatialement explicite à haute résolution, ce qui permet à nos résultats d'être reproduits et appliqués à de nombreuses échelles spatiales. L'approche que nous avons adoptée pour déterminer les endroits prioritaires a fait appel à trois méthodes d'analyse étroitement reliées.

Premièrement, nous avons caractérisé la vulnérabilité à partir d'une analyse de l'empreinte humaine dans l'écorégion, laquelle constitue une mesure relative du degré de transformation du paysage par rapport à son état

naturel. Nous avons évalué l'empreinte humaine actuelle – à partir des données les plus fiables et les plus récentes sur les populations humaines et les réseaux de transport et de distribution d'énergie, ainsi que les changements dans l'occupation du sol – et fait des projections de l'empreinte humaine future selon différents scénarios relatifs aux taux de croissance démographique appréhendés et aux modèles d'occupation du territoire.

Deuxièmement, nous avons caractérisé l'irremplaçabilité par un processus de planification systématique en matière de conservation et obtenu différents ensembles d'endroits qui correspondent aux objectifs établis pour la protection des espèces et des écosystèmes menacés et en voie de disparition, des habitats critiques pour les espèces focales de carnivores et des caractéristiques physiques des paysages. Étant donné que plusieurs ensembles d'endroits peuvent correspondre à ces objectifs, nous avons indiqué, pour chacun des endroits, le pourcentage d'ensembles dont ils font partie. Ces pourcentages peuvent varier, allant des endroits toujours compris dans un ensemble donné (complètement irremplaçables) aux endroits jamais compris dans un seul ensemble (complètement remplaçables). De plus, nous avons évalué l'irremplaçabilité selon trois niveaux différents de cibles : faible (un nombre restreint de réplification de chaque caractéristique écologique requis pour considérer l'objectif comme atteint), moyen et élevé.

Troisièmement, nous avons subdivisé l'écorégion en sous-régions et établi une valeur en terme d'irremplaçabilité et de vulnérabilité pour chacune d'entre elles dans le but d'indiquer celles qui sont (a) très irremplaçables et très vulnérables (donc hautement prioritaires en matière de conservation), (b) très irremplaçables, mais peu vulnérables (moyennement prioritaires), et (c) peu irremplaçables et peu vulnérables (faiblement prioritaires). Nous avons fait appel à trois méthodes différentes pour subdiviser l'écorégion : une grille uniforme d'hexagones de 10 km², des unités hydrologiques (établies en fonction des limites des bassins versants) et des unités biophysiques (établies en fonction des caractéristiques écologiques et géologiques).

Pour les praticiens de la conservation, les points essentiels qui sont ressortis de ces analyses sont les suivants :

- ~ L'écorégion des Appalaches nordiques et de l'Acadie comporte encore de vastes étendues de terres à l'état naturel et relativement vierge. Il s'agit particulièrement du massif montagneux des Adirondacks, du plateau de Tug Hill dans l'État de New York, de la partie nord du Maine, de la péninsule gaspésienne au Québec et des extrémités nord et sud de la Nouvelle-Écosse.
- ~ Si l'écorégion des Appalaches nordiques et de l'Acadie figure encore parmi les écorégions les plus boisées et les plus « sauvages » de la partie est de l'Amérique du Nord, elle est peut-être aussi l'une des plus vulnérables, simplement parce qu'elle comporte de grandes étendues de terres non développées qui ne sont pas protégées et qui se trouvent à proximité de zones densément peuplées. Les menaces au territoire de l'écorégion des Appalaches nordiques et de l'Acadie résident présentement surtout dans les régions les plus habitées, mais pourraient s'étendre rapidement s'il survient des changements dans les conditions sociales ou écologiques ayant pour effet d'encourager une croissance accélérée de la population et du peuplement humain (p. ex. le climat, la présence d'importantes industries et la disponibilité de terres possédant des d'attraits élevés).
- ~ Nous supposons que toutes les terres qui sont présentement protégées de manière permanente contre la conversion au développement continueront de faire partie du système de terres en conservation de l'écorégion. Partant de cette hypothèse et considérant un niveau faible de réplifications requis pour la conservation des espèces et des écosystèmes menacés et en voie de disparition, des habitats critiques aux espèces focales de carnivores et des caractéristiques physiques des paysages, approximativement 27 % de l'écorégion est jugé irremplaçable pour atteindre ces objectifs.
- ~ Au fur et à mesure qu'augmentent les cibles, l'étendue de terres requise pour atteindre les objectifs globaux de conservation augmente nécessairement. Toutefois, ces territoires additionnels présentent une valeur élevée de remplaçabilité. Ainsi, l'atteinte de niveaux plus élevés nécessite une plus grande réplification d'aires protégées pour représenter les caractéristiques écologiques, ce qui peut être réalisé à partir de nombreuses configurations différentes de territoires autres que les étendues plus restreintes de terres jugées complètement irremplaçables.
- ~ Lorsque les niveaux sont peu élevés, de vastes portions de l'écorégion (presque 50 %) ne contribuent jamais à l'atteinte des cibles de conservations fixées. Toutefois, à mesure que le niveau augmente, la contribution potentielle d'une bonne partie de ces régions augmente aussi, ce qui indique que pratiquement toute la surface de l'écorégion a la capacité de contribuer à l'atteinte des objectifs de conservation si le degré souhaité de réplification des caractéristiques écologiques est suffisamment élevé.
- ~ Certains endroits se voient attribuer systématiquement le même degré de priorité en matière de conservation, indépendamment des scénarios employés pour mesurer l'irremplaçabilité et la vulnérabilité, ou de la façon dont l'écorégion est subdivisée. En revanche, les degrés de priorité d'autres endroits varient et sont hautement sensibles à la méthode d'évaluation employée et à la façon dont est effectuée le découpage du territoire. Le fait qu'il n'existe pas de mesure objective unique pour identifier la priorité pour l'ensemble des endroits n'atténue pas la valeur de cette méthode de détermination des endroits prioritaires pour la conservation. Cela fait plutôt ressortir l'importance d'évaluer la solidité de toutes les initiatives de conservation spatialement explicites et de choisir l'échelle spatiale appropriée sur laquelle fonder les décisions en matière de planification.
- ~ Ces analyses ne comportent pas d'évaluation détaillée des priorités quant à l'atteinte d'une connectivité fonctionnelle dans toute l'écorégion, que ce soit pour des besoins d'ordre écologique présents (p. ex. les déplacements des espèces à grand domaine vital) ou futurs (p. ex. la réponse de l'écosystème aux changements climatiques). Toutefois, les analyses révèlent des endroits qui sont importants pour la connectivité structurelle et qui relient de vastes régions peu transformées. Il s'agit entre autres des régions reliant le plateau de Tug Hill et le massif montagneux des Adirondacks à New York, les Adirondacks et les montagnes Vertes du Vermont, les montagnes Vertes et les monts Sutton, au Québec, ainsi que le nord du Nouveau-Brunswick, qui relie la partie nord du Maine et la péninsule gaspésienne au Québec, et l'isthme de Chignecto, qui relie le Nouveau-Brunswick et la Nouvelle-Écosse.

1. Introduction

Throughout the 20th century, significant advances in conservation in North America were achieved. The rise of the science of ecology highlighted the complex interconnections and processes in ecosystems, moving beyond the ideas of food chains and static climax communities to those of food webs and the dynamics of ecological change. Theories in island biogeography, landscape ecology, and conservation biology accentuated broader scales in space and time, the importance of considering larger landscapes and regions, and threats to biodiversity from the fragmentation of forests, wetlands, and other habitats by human land-use changes. New approaches to reserve network design prompted scientists, practitioners, and governments to adopt more ambitious and systematic conservation planning goals and practices, such as representative systems of parks and protected areas, and consideration of the habitat needs of rare, wide-ranging, and threatened species. Advances in computerized geographic information systems, digital information on species and ecosystems, and modeling software have allowed more sophisticated and data-intensive analyses. Increasingly, the complexity and dynamism inherent in natural and human systems is incorporated into conservation planning.

Yet, despite some notable conservation successes during the past century, nature is more threatened today with a larger number of species and ecosystems at risk of permanent loss than ever before. Threats to biodiversity have continued, and in many cases intensified, and new global threats such as climate change have emerged. Existing approaches to conservation and their implementation on the ground have clearly been insufficient to address the current context in which we find ourselves.

Three main themes need to be better integrated into conservation approaches. First, specific locations must be considered within the larger landscape context in which they are embedded. Conservation efforts targeted to specific wetlands, specific valleys, and specific parcels are fundamentally dependent upon the condition of the sur-

rounding landscape. The borders of conservation areas need to be defined in ecologically-meaningful ways, incorporating the movement of animals and the flow of air and water. The design of conservation areas should include buffers from what is happening around them and acknowledge that their ability to support populations of native species is dependent upon addressing the stresses faced by those populations elsewhere. In short, conservationists need to comprehend the rate, extent, or influence of fragmentation across the broader landscape.

Second, conservation efforts should address the dynamism inherent in species, places, and time frames, recognizing that nature changes over both short and long periods of time, and that the places important for conservation in the present may not be important in the future. Ecological change, both natural and human-induced, needs to be considered in conservation planning. Third, conservation action must respond to longer-term considerations as well as immediate needs. Since conservation problems are immensely more difficult to solve once they reach the level of a crisis, conservation goals can more readily be reached if they are thought to be priorities before time is of the essence and the stakes are high, and while opportunities to negotiate solutions that are agreeable and cost-effective remain available.

Clearly, the transformational advances in conservation theory and practice over the past century, combined with current stresses such as climate change, require and support a reinvention of conservation. If conservation in the 21st century is to be successful in slowing down and turning around the rate of biological impoverishment, we need a proactive and dynamic landscape view of nature, where the contribution of one location to achieving conservation goals can only be understood in a regional context, where the importance of a conservation initiative in the present can only be understood in context with the future, and where workable solutions are consistently found by addressing problems before they become crises.

It is in light of these observations that Two Countries, One Forest/Deux Pays, Une Forêt initiated a research program to identify priority areas for conservation in the Northern Appalachian/Acadian ecoregion based on the principles that:

- ~ A conservation strategy for any portion of the ecoregion ultimately depends on a comprehensive strategy that addresses the need for conservation everywhere in the ecoregion; and
- ~ Priority locations for conservation effort need to be assessed both in terms of their ecological importance and their threat of transformation both now and in the future.

Two Countries, One Forest/Deux Pays, Une Forêt (2C1Forest) is a major Canadian-U.S. collaborative of conservation organizations, researchers, foundations, and conservation-minded individuals. Our international community is focused on protection, conservation, and restoration of forests and natural heritage from New York to Nova Scotia, across the Northern Appalachian/Acadian ecoregion. Although our professional affiliations are varied, including academia and conservation organizations, we share a commitment to science-based planning tools and data-driven interpretations of patterns and processes related to achieving conservation goals on a landscape scale.

The Northern Appalachian/Acadian ecoregion is an ecologically diverse area, dominated by spruce-fir and northern hardwood forests, extensive coastlines, inland mountain ranges, and glacially carved landscapes. It is an ecological transition zone between northern boreal and southern temperate forests, and will come increasingly to serve as a north-south biological corridor for species as their ranges shift northward in response to climate change. It is also culturally diverse, with a long history of human occupancy, proximity to large urban areas, an economy strongly dependent on both natural resource extraction and nature-based recreation, and a diversity of political traditions. It is also a region with tremendous opportunities for achieving large conservation goals. Despite a long history of widespread forest clearing, much of the region has experienced impressive levels of recovery of forest cover since the end of the 19th century. As a result of sustained public support for conservation,

numerous protected areas have been established throughout the region with management plans strongly oriented toward conservation of biological diversity. Furthermore, land ownership patterns in the region are currently in flux, where lands traditionally owned by forest-products companies are being put up for sale. Those transitions in ownership that occur in the near future—either to owners with conservation goals, natural resource harvesting goals, or land speculation and development goals—will have a major influence on the ecological health of this region for decades to come. Clearly, both the challenges and opportunities for conservation in this ecoregion are noteworthy.

This report describes our work to date to identify priority locations for conservation action in the Northern Appalachian/Acadian ecoregion. It both provides the results for a small series of independently-conceived analyses that collectively articulate a picture of the ecological status and future trends that characterize this landscape and brings the highlights together for a synthesized conservation-based plan for the ecoregion. These analyses are already informing conservation efforts so that the collective actions of all conservation agencies, organizations, and practitioners in the ecoregion will eventually result in a comprehensive system of conservation strategies. It is our hope that these will ultimately serve to promote long-term ecological integrity even in the face of uncertain environmental changes and that are embedded within a social framework that can promote both healthy natural landscapes and healthy human communities.

Our work involved the development and synthesis of several separate analyses of ecological and social patterns across the ecoregion. In this report, we will first describe the ecoregion in more detail (Section 2), describing why it is considered to be a coherent ecological region, how it differs from neighboring regions, and why conservation efforts here will ultimately benefit from considering the region as a whole rather than as isolated and disconnected parts.

In Section 3 we describe the work conducted by two organizations that participate with Two Countries, One Forest/Deux Pays, Une Forêt, work that provided the basic data that allowed the identification of ecologically important locations in the ecoregion. The first of these, The Eastern Resource

Office of The Nature Conservancy (in cooperation with the state and provincial offices of both The Nature Conservancy and Nature Conservancy of Canada/Conservation de la Nature Canada), developed a comprehensive survey of ecological land units, unique ecosystems, and priority forest blocks. The second, the Wildlands Project, developed detailed population models that identified critical locations for the focal carnivore species marten, lynx, and wolf. Taken together, these data sets provide an unparalleled picture of how diverse critical ecological features are distributed across the entire landscape.

Section 4 describes our work to identify threats to the landscape, both now and in the future. We adopted the approach of modeling the region's Human Footprint, a spatially-explicit technique pioneered by the Wildlife Conservation Society that measures the relative magnitude of direct human impact on the landscape. Rather than simply choosing one or two measures of impact as an index of threat, we map several different factors—from human population density to the access provided by road networks to changes in land cover—to create a composite index of the degree of impact that is evident across the region.

Furthermore, we mapped the Human Footprint both in the present, as a measure of current conservation threat, and in the future, as potential measures of conservation threat in the years to come. It is, of course, impossible to know exactly how cultural factors like population size and road density will change across the landscape. Thus, we took the approach of modeling the future under a series of hypothetical but plausible scenarios, each based on trends seen in this ecoregion or in other comparable areas in the recent past. Our assessment of future threats is therefore based on a series of Future Human Footprints, based on plausible future scenarios.

In Section 5 we then describe how these data sets were used to identify those areas in the ecoregion that are important, or irreplaceable, for protecting these ecological features. Our approach to measuring irreplaceability was through an analysis that assessed how critical an area is to protecting ecological features when considered along with all other areas in the ecoregion. Thus, areas that are important no matter what other areas are also pro-

tected are identified as being highly irreplaceable; areas that can contribute to protecting ecological features but that can be substituted for other such areas are only moderately irreplaceable; and areas that do not make a contribution no matter what other areas are protected are highly replaceable. Thus, an interpretation of the ecological importance of a site is intimately associated with a consideration of the larger landscape.

Finally in Section 6 we look at the intersection of these two analyses—threats and irreplaceability—to create a simple classification of conservation priority: areas that are highly threatened and highly irreplaceable are viewed as immediate conservation priorities; areas that are either highly irreplaceable and unthreatened, or highly threatened and replaceable, are less immediate priorities; and areas that are unthreatened and replaceable are low priorities. Thus, areas in the ecoregion can be assessed in terms of their importance across a diverse array of ecological features, their threat from transformation in the present, and their threat from transformation under different scenarios of future change, all of which allow a meaningful ranking of priority for action. By following this path we take advantage both of the experience of other conservation planning initiatives around the world that have employed similar frameworks in spatial prioritization of conservation action, while at the same time taking a significant step further by incorporating objectively-derived data layers at all stages.

We firmly believe that this approach will move conservation efforts in this ecoregion toward the conservation agenda of the 21st century: landscape-scale planning that recognizes both that ecological and cultural conditions may change and that conservation works best when it casts a critical eye into the future. In this context, however, it is important to note that the real work of conservation is not done simply by generating these analyses; it is done by the thousands of conservation practitioners in this ecoregion who will use these analyses as tools for making their work more effective. It is this group of people for whom this report has been written. To make the transfer of these tools and analyses as easy as possible, we end the report (Sections 7 and 8) with a summary of our conclusions, a description of how to get access to the data and associated maps on which our conclusions are based, and cita-

tions for additional resources to aid ecoregional-scale conservation planning.

We also write this report for our children. Fundamentally, we chose to carry out these analyses in the Northern Appalachian/Acadian ecoregion simply because it is where we live or work. All of us involved in this project spend a considerable portion of our time thinking about how to promote the ecological health of this region, through land pro-

tection, restoration, and management of development. We also spend at least an equal amount of time thinking about the future. Our greatest desire is to be able to pass on to our children a landscape that is richer in native wildlife and natural communities and that is more resilient to environmental stress than it was when we were children. We believe the scientific work described in this report is an important part of achieving this goal.

2. Ecological Description of the Northern Appalachian/Acadian Ecoregion¹

The Northern Appalachian/Acadian ecoregion extends from the Tug Hill and Adirondack Mountains of New York, across the Green Mountains of Vermont and the White Mountains of New Hampshire, then into Maine and Maritime Canada (Figure 2.1).

It includes all the provinces of New Brunswick, Nova Scotia, and Prince Edward Island, as well as Îles-de-la-Madeleine (Magdalene Islands) and the part of Québec extending from the Gaspé Peninsula, southwesterly through the Appalachian complex of eastern Québec to the United States border, south of Sherbrooke.

It is considered a transitional zone between regions characterized by more temperate influences to the south and boreal conditions to the north. These changes in latitude are modified by the inland continental climate to the west and maritime influ-

ences to the east. Especially in the eastern Acadian portion of the ecoregion, the proximity to the Atlantic Ocean, the interplay of the Gulf Stream and the Labrador Current, and the long and ragged coast have combined to produce a cool and humid maritime climate. In general, summers are warm and winters are long and snowy.

The rugged landscape has endured extensive periods of volcanic activity, mountain building, erosion, sedimentation, and several major glaciations. The last of these, ending in the ecoregion about 10,000–12,000 years ago, was responsible for the present land forms of sculpted mountains, flat plateaus, and carved valleys. Elevation ranges from sea-level on the Maine and Maritime coast to over 5000 feet on a few isolated peaks. The extensive but ancient mountain ranges are composed of granites and metamorphic rocks overlain by a thin veneer of



Figure 2.1. The Northern Appalachian/Acadian ecoregion.

glacial till. Most of the glacially broadened valleys are plugged with deep morainal or outwash deposits giving rise to thousands of swamps, bogs, lakes, and ponds. Additionally, the region includes, in the U.S. alone, over 68,000 miles of rivers and streams and at least 8,000 lakes and ponds covering over a million acres.

The Northern Appalachian/Acadian ecoregion extends over large ecological gradients from the boreal forest to the north and the deciduous forest to the south. The Gaspé Peninsula and higher elevations support species and communities that are characteristic of the more northern taiga. At lower elevations and latitudes, there is a gradual shift toward higher proportions of northern hardwood and softwood species (particularly red spruce, balsam fir, yellow birch, sugar maple, red oak, red maple, American beech, red and eastern white pine, and eastern hemlock), which marks the transition into the Acadian forest. It also supports local endemic species, as well as rare, disjunct, and peripheral populations of arctic, alpine, southern, and coastal plain species that are more common elsewhere.

There has been a historical shift away from the uneven-aged and multi-generational “old-growth” forest toward even-aged and early successional forest types due to human activities. This mirrors the historical trends toward mechanization and industrialization within the forest resource sector over the past century and a shift from harvesting large dimension lumber to smaller dimension pulpwood.

In total, the Northern Appalachian/Acadian ecoregion encompasses an estimated 3,844 species

of flora and macrofauna, including 148 rare endemics. For vertebrate diversity, it is among the 20 richest ecoregions in the continental United States and Canada and the second-richest ecoregion within the temperate broadleaf and mixed forest types. The forests also contain 14 species of conifers, among the most for any ecoregion within this major habitat type.

Characteristic mammals include moose, black bear, red fox, snowshoe hare, porcupine, fisher, beaver, bobcat, Canada lynx, American marten, muskrat, and raccoon, although some of these species become less common in the southern parts of the ecoregion. White-tailed deer have expanded northward and displaced the woodland caribou from the northern parts of the ecoregion. Coyotes have recently replaced wolves, which were eradicated here in historical times, along with the eastern cougar, woodland caribou, and elk.

A diversity of aquatic, wetland, riparian, and coastal ecosystems are interspersed between forest and woodland habitats. These include floodplains; marshes; estuaries; bogs; fens; peatlands; vast stretches of cobble, sand, and barrier beaches; coastal marshes and tidal mudflats; and rocky headlands, ravines, and coastal forests. Bald Eagles reach their highest breeding density in eastern North America (Nova Scotia), and the Upper Bay of Fundy is a globally significant flyway for as many as 2.5 million Semipalmated Sandpipers that feed in the tidal mudflats. The ecoregion has many fast-flowing, cold water rocky rivers with highly fluctuating water levels that support rare species and multi-species assemblages.

3. Critical Ecological Features

Three organizations engaged in 2C1Forest’s efforts provided the basic data that allowed the identification of ecologically important locations in the ecoregion. The first two of these, The Nature Conservancy and Nature Conservancy of Canada, developed a comprehensive survey of ecological land units, unique ecosystems, and priority forest blocks. The third, the Wildlands Project, developed detailed population models to predict potential source habitats (where births exceed deaths) for three focal carnivore species—marten, lynx, and wolf. The contributions of each to 2C1Forest’s analyses are described in this section. Taken together, these data sets provide a comprehensive picture of how diverse critical ecological features are distributed across the entire landscape.

THE NATURE CONSERVANCY/NATURE CONSERVANCY OF CANADA ANALYSIS²

In 1999, The Nature Conservancy (TNC) prepared the first iteration of an ecoregional assessment for the U.S. portion of the Northern Appalachian/Acadian ecoregion. An ecoregional assessment is a rigorous, repeatable identification of the most critical ecological features of a given ecoregion, and a consistent, transparent rendering of trends. Ecoregional assessments are carried out by a team of scientists representing many different institutions and areas of expertise. The first iteration identified several key deficiencies that would need to be addressed in a subsequent iteration. In 2001, The Nature Conservancy and The Nature Conservancy of Canada (NCC) began preparation for a second iteration of an ecoregional assessment that would better address these deficiencies and incorporate a significant amount of new inventory data and new conservation efforts.

In 2006, the Northern Appalachian/Acadian ecoregional assessment was released as part of a broader report that aimed to measure and summarize the status of nature conservation in the Northern Appalachian/Acadian ecoregion. Using sophisticated quantitative and spatial analysis tech-

niques, the report summarized three decades of ecological inventory data, geological, hydrological, and land cover mapping, advanced predictive modeling techniques, and expert knowledge from the abundant store of academic, state, provincial, and independent conservation scientists in the region.

Additionally, the report used The Nature Conservancy’s recently compiled Secured and Protected Lands database representing over 150,000 tracts of land in the eastern United States and Maritime Canada that have conservation value. The report aims to answer the question, “Where and how protected are the places that sustain the biodiversity of the region?” Some places harbor unique features or rare populations, others have the best examples of common or representative ecosystem types, and still others have large and influential remnants of once contiguous forest. All of these places are important in maintaining biodiversity and natural processes across the entire region.

To assess conservation status, The Nature Conservancy and its partners examined the condition and spatial configuration of three factors: ecological features, existing threats to and constraints on conservation, and land management status.

The intersection of the first two factors produced what The Nature Conservancy refers to as the portfolio of critical occurrences. The portfolio is an estimate of the most important places to protect to conserve biodiversity. Adding the third factor—land management status—allowed determination of the protection status of the lands on which the critical features occur, and is thus a gauge as to where we stand with respect to the conservation of nature.

The conservation portfolio was developed to identify those places that are the most critical to conserve. It reflected the understanding that some places play a more important role than others in maintaining biodiversity across the landscape. Examples of critical occurrences include source habitats for interior forest species, complete and functional examples of common ecosystems, viable populations and breeding sites of rare species, and flowing stream systems connected from headwater to mouth.

These critical occurrences were evaluated based on their size, condition, and landscape context, and had their importance confirmed by over 18,000 ground inventory points provided by U.S. State Natural Heritage Programs and Canadian Conservation Data Centers. Additionally they reflected the knowledge and best judgment of over 40 ecologists, biologists, forest managers, and wildlife specialists from academic, state, provincial, and federal institutions across the region.

The portfolio of critical occurrences (Figure 3.1) took nearly four years of collaborative effort to develop, and is revised and maintained annually based on new information and conservation progress. There are five major types of critical occurrences:

- 1) **Terrestrial Intact Forest Blocks** (Matrix Forest Blocks): Large (4,000–40,000 ha [10,000–100,000 acres]) areas of contiguous forests with few roads and mostly intact interior forest ecosystem features;
- 2) **Terrestrial Non-forest Ecosystems** (including specialized patch-forming forest types): Alpine ecosystems; Summits and ridges; Cliffs, steep

slopes, bowls & ravines; Barrens and flats; and Coastal dunes and beaches;

- 3) **Wetland Ecosystems**: Forested swamps; Bogs and fens; Freshwater marshes; Tidal salt and brackish marshes; Seeps and swales; Floodplains; and Shoreline meadows;
- 4) **Aquatic Stream Networks**: Large rivers; Medium-sized streams; and Small headwater, feeder and coastal streams; and
- 5) **Species**: Rare mammals, birds, reptiles, amphibians, fish, invertebrates, plants, and global endemics; Wide-ranging vertebrates; and Breeding, wintering, and stopover concentrations of migratory waterfowl and other birds.

Forests are the dominant ecosystem of eastern North America, which is the center of distribution for many trees such as red spruce and striped maple as well as thousands of shrubs, ferns, herbs and forest-dwelling species. To identify representative examples of the “matrix forests” that make up so much of the Northern Appalachian/Acadian ecoregion, TNC/NCC and their partners developed a multi-step

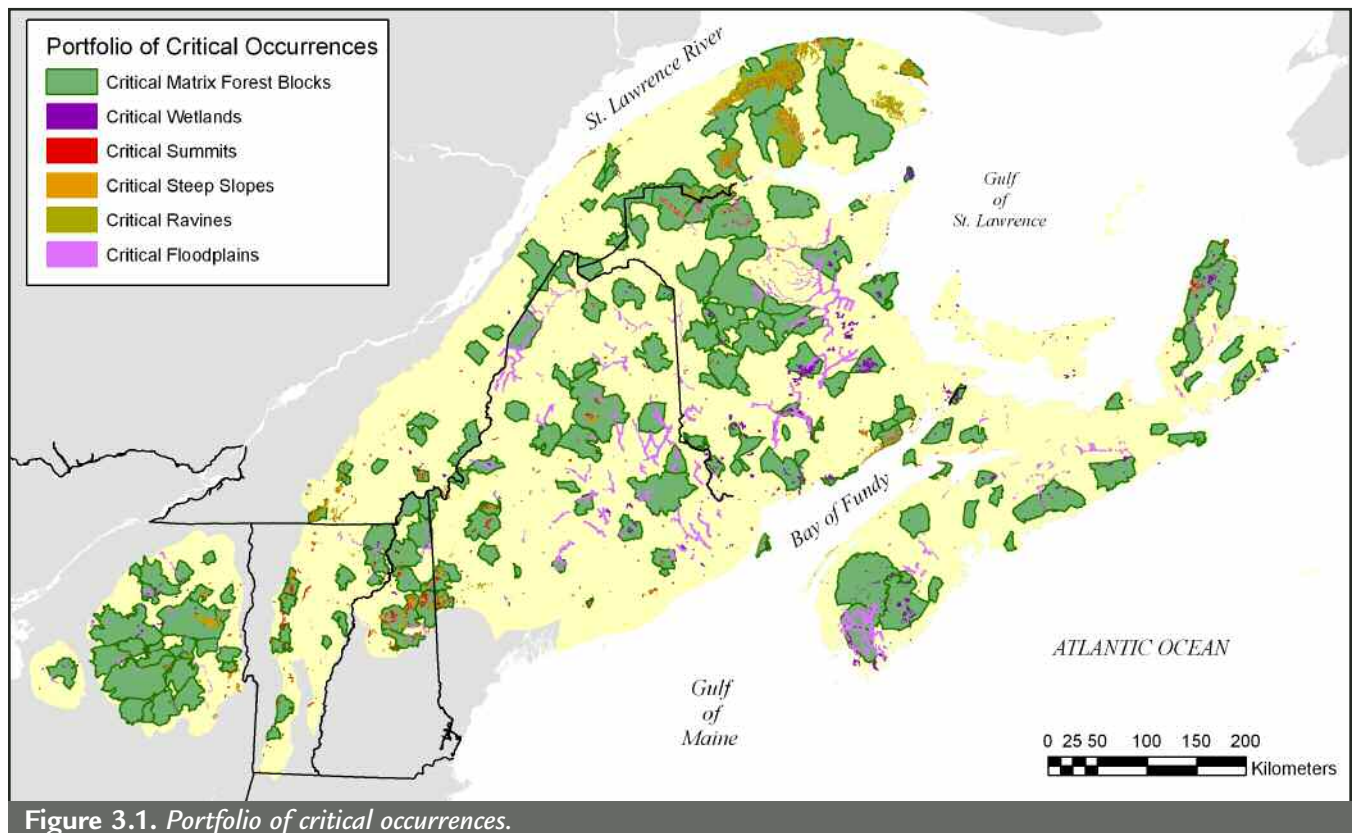


Figure 3.1. Portfolio of critical occurrences.

strategy to assess the matrix forest system:

- ~ Subdivide the entire forest into smaller semi-discrete “forest blocks” using roads and other fragmenting features;
- ~ Classify all forest blocks into representative forest landscapes;
- ~ Screen each forest block, using size, condition, and land cover in the surrounding landscape as indicators of biodiversity value and resilience; and
- ~ Identify for conservation action a network of functional forest blocks representative of the diversity of forest types and landscape elements of the ecoregion.

Once forest blocks were identified and their forest-landscape types characterized, they were screened using size, condition, and landscape context criteria. Blocks had to be a minimum of 10,000 hectares (25,000 acres), have little internal fragmentation, contain some elements of old-growth or mature forest, have outstanding features like high-quality headwaters or examples of smaller-scale

ecosystems and species, and be substantially surrounded by natural or semi-natural land cover.

The planning team then stratified forest-block selections across all forest-landscape types in the ecoregion to maximize the inclusion of different communities and species within the blocks. Ecological lands units (ELU’s) based on elevation, topography, and bedrock were used to identify 72 distinct strata or ELU types. ELU’s are important to the distribution and abundance of ecological communities in the ecoregion, and analyses by TNC/NCC and their partners indicate that the locations of smaller-scale ecosystems, communities, and species are highly correlated with the types and diversity of ELU’s. One or more blocks were then selected within each group based on biodiversity values, forest condition, feasibility of protection, landscape context, and complementarities to the other blocks. A total of 174 “Tier 1” matrix forest blocks were identified (Figure 3.2).

Tier 2 blocks were also identified. These met the criteria detailed above, but because of current condition, feasibility, or other factors, Tier 2 blocks were deemed lower priority or alternate candidates.

From this analysis, several key findings emerged:

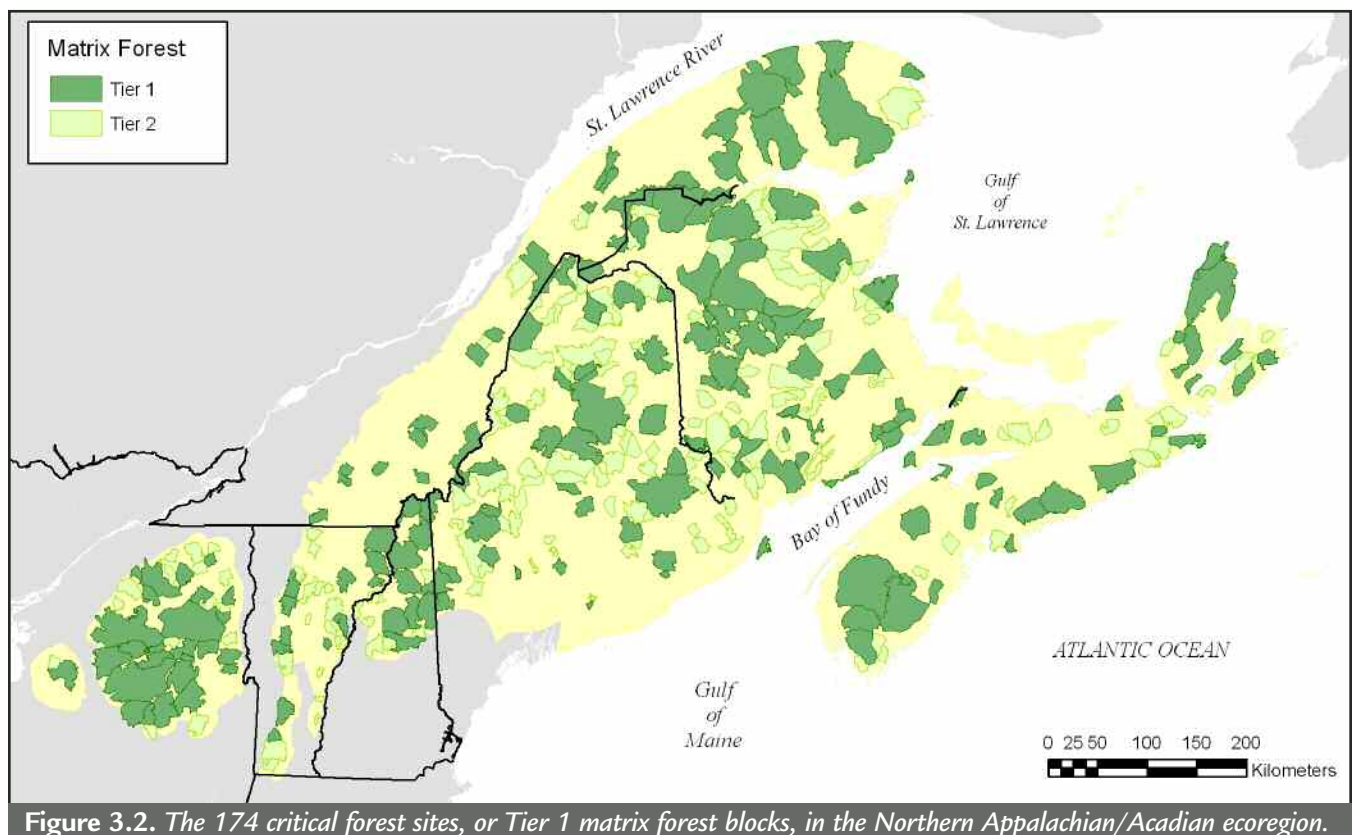


Figure 3.2. The 174 critical forest sites, or Tier 1 matrix forest blocks, in the Northern Appalachian/Acadian ecoregion.

- ~ As of 2006, 7% of the region is exclusively devoted to biodiversity protection. Another 28% is secured from conversion to development (e.g., Crown or public land, privately-owned conservation areas, or nature reserves). Most secured lands are in mountainous areas. Coastal regions and lowland valleys are the least protected (Figure 3.3).
- ~ The proportion of land secured from conversion to development is three times greater than that of land converted to agriculture or development. This is the only ecoregion in the eastern U.S. where land secured from conversion is proportionally higher than converted lands. This is most likely due to the historical prominence of a regional forest-products economy, which has maintained forest cover across the region and slowed conversion to agriculture.
- ~ Large carnivores such as the wolf and mountain lion have been extirpated from the region.

Another 148 endemic species (plants, vertebrates, and invertebrates) are identified as specific conservation priorities because their populations are too small or few, or are declining too fast, to rely on broad-scale ecosystem protection alone as a conservation strategy. Of these, 62% have fewer than ten protected populations.

- ~ Contiguous and ecologically complete forest ecosystems that once dominated the region are now largely young, simplified, and increasingly fragmented by roads and development. Some 174 priority areas were identified that still maintain relatively intact interior forest systems greater than 25,000 acres in size. However, only 28% of these have core protected areas that are large enough to maintain these ecosystems over time.
- ~ The extent of forest cover has increased since the extensive deforestation of the 19th century. As a result, excluding developed land, agricul-

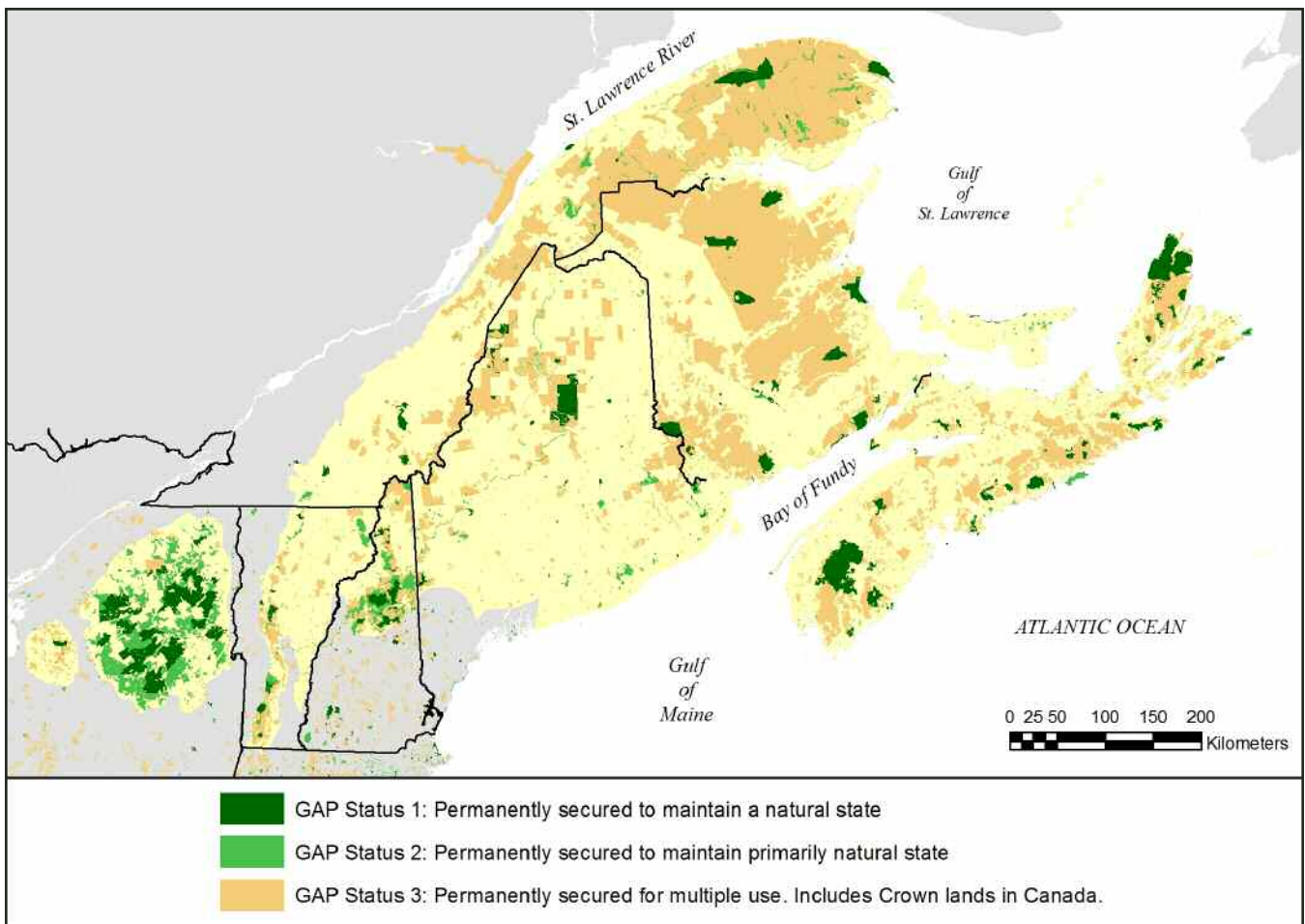


Figure 3.3. Lands permanently secured from conversion to development.

tural land, and roads, the remaining areas with over 80% natural cover amount to more than 50% percent of the region. With respect to land cover, the Northern Appalachian/Acadian ecoregion is the most intact ecoregion in the eastern U.S. and contains the broadest extent of nearly contiguous natural forest.

- ~ Non-forested upland ecosystems harbor extensive biodiversity. Over 400 sites containing more than 6000 examples of beaches, barrens, alpine balds, grassy openings, stunted woodlands, and stands of distinct forest types have been targeted for conservation. Of these, only very high elevation areas and serpentine bedrock features are more than 50% protected for biodiversity. Protection of key places for coastal dunes and shores, acidic and calcareous barrens, and clay-plain forests is less than 30%.
- ~ Critical wetland ecosystems have considerably less secure protection than their upland counterparts, averaging 13%. Acidic wetlands, such as peatlands, enjoy the highest level of protection with about 37% protected for biodiversity. Floodplain and riverside systems as well as coastal and tidal wetlands all have less than 20% of their best examples on protected lands.
- ~ Conservation in this ecoregion is a collective effort. The protection of large contiguous areas of forest from conversion to non-forest conditions occurs mostly on state and provincial lands. Conservation of rare species and ecosystems is the result of actions by dozens of different public agencies and private organizations. Private ownerships account for 4% of the land protected for biodiversity in the ecoregion. Three-quarters of that is held by The Nature Conservancy and Nature Conservancy of Canada.
- ~ Threats to conservation in this region are on the rise. While in general the ecoregion is currently less threatened by housing development than other regions in the east, coastal and floodplain ecosystems are vulnerable to intense pressure in the future. Further, there are emerging threats that cannot be prevented by land protection alone, such as impacts from atmospheric deposition, climate change, and invasive species,

especially forest tree pathogens. Addressing these threats will require new conservation strategies that involve cooperation even beyond the boundaries of the ecoregion.

THE WILDLANDS PROJECT ANALYSIS³

In 2003, the Wildlands Project initiated an analysis for a wildlands network design for the Greater Northern Appalachians. This project focused on designing a connected network of areas of high conservation priority within the Northern Appalachian/Acadian and St. Lawrence/Champlain Valley ecoregions of the northeastern United States and southeastern Canada (hereafter referred to as the Greater Northern Appalachians). The Wildlands Project chose this expanded study area because important wildlife linkages that connect portions of the Northern Appalachians/Acadian ecoregion likely fall outside of that ecoregion. The conservation planning methodology that the Wildlands Project applied in the Greater Northern Appalachians region focused on three “tracks” of ecological data: environmental variation, special elements, and focal species. The first two tracks were derived directly from the TNC/NCC analysis (described above).

The third track, focal species, was unique to the Wildlands Project’s analysis and was included as an additional source of data for 2C1Forest’s irreplaceability analysis. Focal species warrant special attention in conservation planning because they are not adequately captured by other considerations, such as coarse-scale representation of environmental variation or fine-scale special element occurrences (e.g., hotspots of diversity or rarity). A variety of characteristics can result in a species being considered a useful focal species for conservation planning, including that they are: (1) functionally important to an extent out of proportion to their numerical abundance (keystone species); (2) wide ranging, thus potentially acting as surrogates for other species that have similar habitat requirements (umbrella species); (3) sensitive to habitat quality (indicator species); and (4) charismatic (flagship species), thus encouraging public support for conservation initiatives.⁴ If sufficient habitat is maintained to support viable populations of a carefully-selected suite of focal species over time, many other species may also be conserved.⁵

The Wildlands Project conducted focal-species analyses⁶ that identified areas of high-quality (source) habitat for three species of carnivores: Canada lynx (*Lynx canadensis*), American marten (*Martes americana*), and eastern gray wolf (*Canis lupus*, or *Canis lycaon*). These three mammalian carnivores are native to the study area but are considered threatened or extirpated in some or all of the ecoregion. These species differ in their basic habitat requirements and the factors responsible for their decline. Such carnivores play important top-down regulatory roles in the ecosystem; however, because they have large area requirements, sufficient habitat to maintain their populations is not generally captured within isolated conservation areas. Carnivores are used as focal species because they are vulnerable or sensitive to human activities and human-induced landscape change.⁷ Lynx and marten are especially important in the Greater Northern Appalachians (including the Northern Appalachian/Acadian ecoregion) because their populations represent peninsular extensions of broader boreal ranges⁸. As such they may be particularly sensitive to climate change, such as changes in snowfall, and represent unique ecotypes of these species at the southern limit of their ranges.

High-quality source habitat was identified by conducting a regional-scale analysis of habitat and population viability for these species. Population viability analyses help predict the ability of a population to remain viable given demographic, genetic, environmental, and other variables (e.g., survival, fecundity, mortality risk, and habitat productivity) over specified periods of time and under various scenarios (e.g., changes in land cover, trapping pressures, and climate). Through such analyses, potential source (where births exceed deaths) and sink (where deaths exceed births) habitats can be predicted. These predictions can then help inform questions relevant to conservation planning such as: where are the high value habitats, how much area is needed to support viable populations, and where are wildlife movement linkages needed?

The analyses were conducted in two steps. First, the Wildlands Project developed static regional-scale models that relate GIS-based habitat data to relative survival and fecundity rates in differing habitats for focal species, which produced landscape maps that described the locations of suitable and unsuitable

habitat patches. Then, they incorporated these static habitat models into a dynamic spatially-explicit population model, PATCH, including habitat-specific demography and detailed dispersal behavior to predict potential source and sink habitats.

While several source and threatened source habitats were identified under various current and future scenarios for each of the three focal species, three in particular were selected for use in 2C1Forest's irreplaceability analysis (Figure 3.4):

- ~ Wolf source habitat under current landscape conditions;
- ~ Lynx source habitat under the scenario of no population cycling; and
- ~ Marten source habitat under the scenario of continued trapping.

These results demonstrate that there is broad habitat potential for these species in the Northern Appalachian/Acadian ecoregion. For historical reasons, as well as current management practices, only portions of the predicted source habitats are currently occupied by lynx and marten, and the wolf continues to be absent from the landscape entirely. Despite the absence of these species from some or all of their ranges, their demands for large amounts of relatively secure habitat (low road and human population density) provide a critical perspective on the placement and size of conservation lands. For example, sufficient conservation lands to allow for their recovery would require large, connected areas of habitat. At the same time, these large, contiguous areas would encompass many other species that share the same habitat. Thus, identifying the habitat needs of these focal species would not only contribute to their long-term recovery and viability but would aid numerous other species as well.

Moreover, the broad potential distribution of these species across the ecoregion highlights the desirability of conservation planning at an ecoregional scale, as described in Section 1. For example, there are substantial differences in management regimes for these species across the ecoregion. These local differences may have far-reaching effects, as noted in the marten and lynx analysis. Lynx are relatively abundant and commercially trapped in the Gaspé region of Québec, but threat-

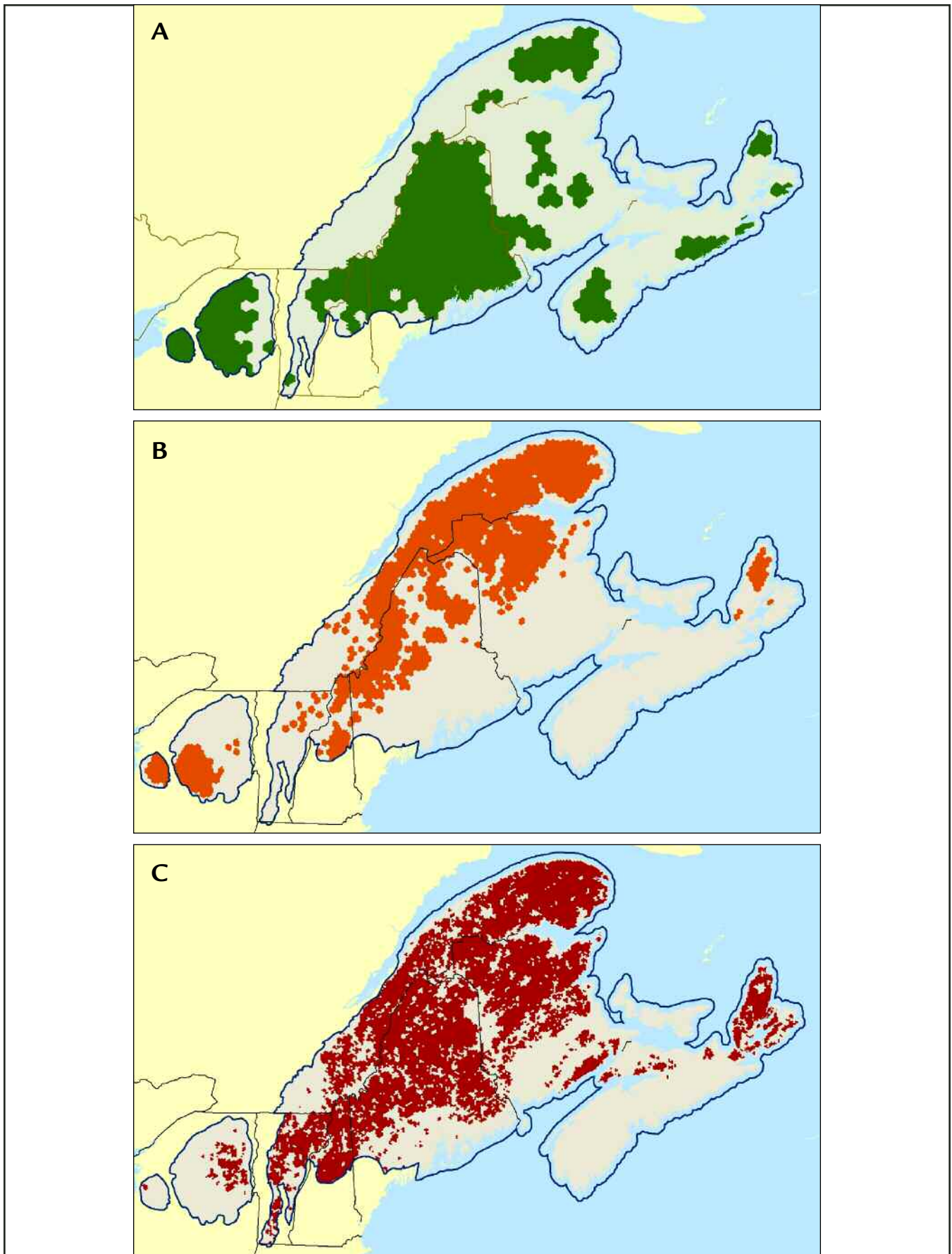


Figure 3.4.a. Predicted source and threatened source habitats for wolf (A), lynx (B), and marten (C).

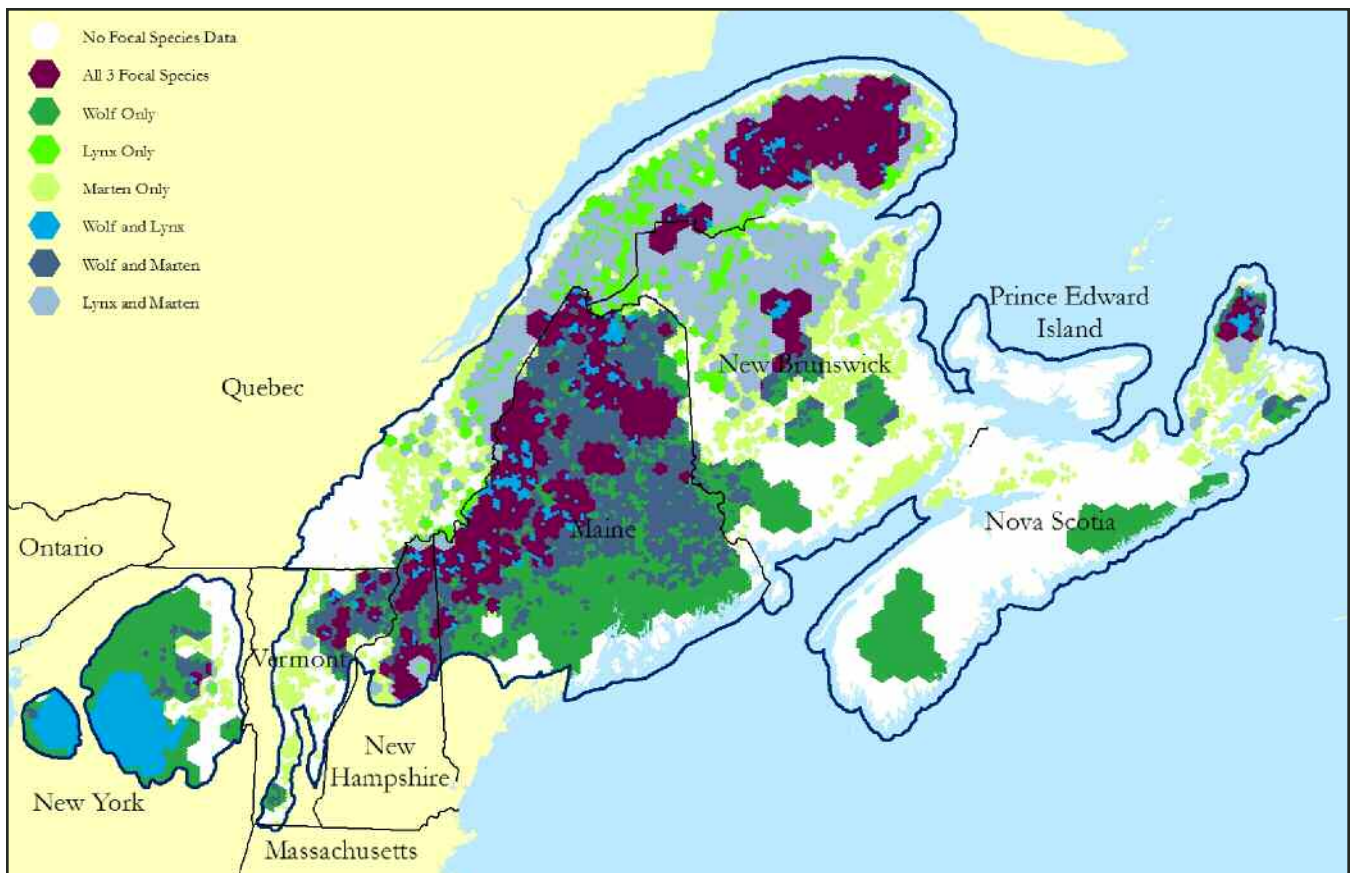


Figure 3.4.b. When source habitat for all three species is overlain, the spatial extent covers a large portion of the ecoregion, and significant area of overlap is evident.

ened or extirpated elsewhere in the region. Ecoregional analyses such as these that encompass all components of the regional metapopulation, although necessarily less detailed than state/province-level efforts, are required to understand the underlying drivers of species' vulnerability that can make conservation policy more effective.⁹

These analyses also provide insight into complex population dynamics across the ecoregion in the face of climate change. The analysis of lynx and marten is one of the first comprehensive assessments of how climate change will interact with other threats, such as trapping and habitat conversion, to affect carnivore population viability. Indeed,

the results suggest that climate change will interact with other threats to form an “extinction vortex” in this ecoregion that may substantially affect population viability of lynx and marten. As the lynx and marten analysis notes, such a possibility highlights the need to move to a “more precautionary and regionally-coordinated management of these species ... or they may suffer range contraction in areas that are now considered the core of their regional range (Gaspé for the lynx and northern Maine for the marten).”¹⁰ This conclusion is reinforced by new findings that there may be a latent extinction risk for mammals throughout the Eastern Canadian Forests.¹¹

4. Threats on the Landscape

Most of the Northern Appalachian/Acadian ecoregion has been used by humans for a very long time. Immediately after the last glaciation (10,000–12,000 years ago), people were living in the river valleys and along the coastlines. Land uses included small-scale agriculture, fisheries, and harvesting of wildlife. The impacts of these First Peoples on the land—although real and measurable—were dispersed and would be barely noticeable to the casual observer. The 1600’s saw an intensification of settlement and land use along coasts, floodplains, and otherwise arable lands. As a result of European colonization, the landscape transitioned from being heavily forested to open over vast areas, particularly near coasts and large rivers. Agricultural use peaked over much of the region in the mid-1800’s, followed by abandonment of marginal land and a prolonged period of extensive reforestation.¹²

Today, the Northern Appalachian/Acadian ecoregion is still largely rural, characterized by a patchwork of forests, farms, and scattered urban areas. Increasingly, low-density residential development has invaded the rural areas adjacent to cities. Industrial forests and mills—once the lifeblood of communities—have declined in economic importance, leaving large areas traditionally used for resource harvesting vulnerable to conversion for “amenity” development, such as resort and cottage community developments around lakeshores. Furthermore, if these lessons teach us anything, it is that the dynamic history of land use change here is not finished.

A central aspect of our research has been to characterize and map the threats to biodiversity on the landscape as they are today and as they may change in the future. This section describes broadly the threats posed to the Northern Appalachian/Acadian ecoregion, the land use/land cover threats we chose to model and map, how we produced these maps, and our results and conclusions with particular relevance for conservation planning.

OVERVIEW OF THREATS TO THE NORTHERN APPALACHIAN/ACADIAN ECOREGION

Threats to biodiversity in the Northern Appalachian/Acadian ecoregion from human activity are so pervasive as to affect almost every aquatic, terrestrial, and marine ecosystem. Airborne pollutants from the Midwest of both the U.S. and Canada fall out over this ecoregion contaminating rivers, lakes, ponds, and marine ecosystems as well as changing the biogeochemistry of surrounding forests. Acid rain, mercury and other heavy metals, particulates, and ground level ozone (from more local sources) penetrate even the most pristine areas and affect functioning of ecosystems.¹³ Meanwhile, industrial effluent enters food webs and bioaccumulates in marine and terrestrial predators, affecting both reproduction and survival.

The very conditions for life are also changing, as human-induced climate change threatens to affect the ranges of plants and animals in this region where many exist at the southern or northern limits of their physiological capacities.¹⁴ Only a connected system of lands that are protected from conversion from their natural condition and which capture representative ecosystems and habitats along altitude and latitude gradients will provide adequate protection for such range shifts.

While these threats are pervasive, there is no single factor affecting biodiversity more than physical habitat destruction.¹⁵ Although many species were able to recover from overexploitation in the late 1800’s and early 1900’s after regulation of hunting and trapping, intensive land use often results in permanent changes to their populations. When we need land for our uses (e.g., agriculture, livestock grazing, mining, timber harvesting, housing, and transportation), we transform natural landscapes to human dominated ones. Often this process of habitat conversion introduces additional threats such as pollution and invasive species, and natural processes such as fire and water flow are altered. While not all human activities are detrimental to biodiversity, the cumula-

tive effect of human activities on the land surface is the dominant force shaping ecosystems today.¹⁶

The global map of the Human Footprint¹⁷ (see below) estimates that 83% of the earth's land surface is measurably impacted by human activities, while other authors estimate that between one-third and one-half of the land surface has been transformed from natural land cover to habitat severely modified for human use. Land surface transformation contributes to detrimental changes in the global carbon and nutrient cycles, increases in soil erosion, degradation of freshwater ecosystems, and changes in climate, and is the single most important cause of biodiversity loss. For example, in North America more than one-third of carnivore and ungulate species have experienced a range contraction of at least 20% due to human settlement patterns.¹⁸ We also know that geographic isolation of national parks (due to intensification of land use beyond park boundaries) has resulted in loss of mammal species from those parks.¹⁹ In the Northern Appalachian/Acadian ecoregion, land

transformation has been going on for thousands of years due to natural and anthropogenic causes, but in recent centuries, anthropogenic changes in land cover have predominated and underlie pronounced changes in both ecosystem structure and function. Changes on the landscape include measurable shifts in plant and aquatic community structure and composition (caused largely by disturbance) and viability of economically and ecologically significant populations of fish and wildlife.²⁰

2C1FOREST APPROACH TO MODELING THREATS

Because of the ecological significance of human transformation of the land's surface, 2C1Forest has focused on quantifying the "Human Footprint" (relative human influence on the land's surface) as a basis for conservation planning. The Northern Appalachian/Acadian ecoregion is heterogeneous with regard to land use, land ownership, habitats, and degrees of transformation, so we needed to

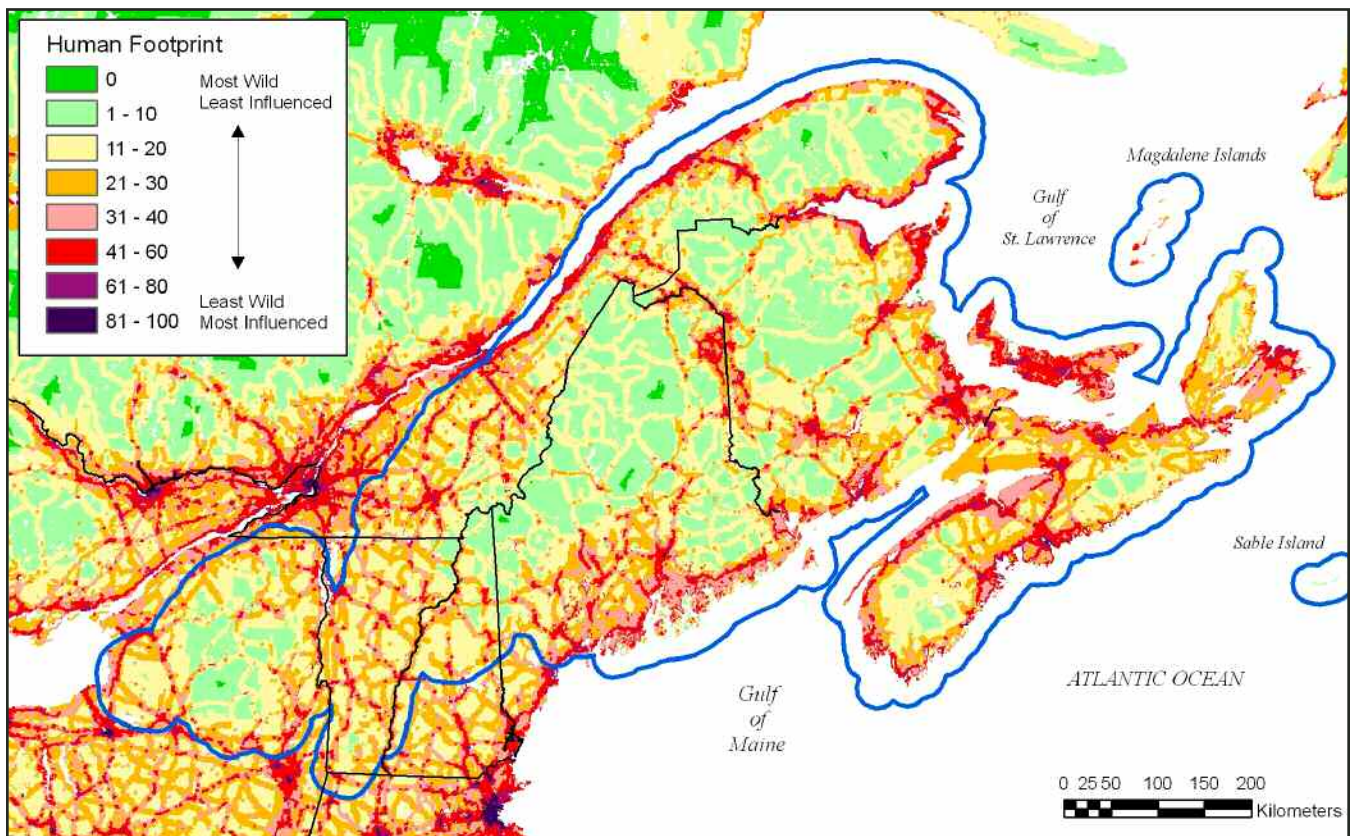


Figure 4.1. *The Human Footprint of the Northern Appalachian/Acadian ecoregion as mapped by the Global Human Footprint Project.²² The green areas are those that are least impacted by human activity and can be considered the most wild, while those areas in red and purple are areas of increased human impact and conversion to a developed condition.*

employ a methodology sensitive to this complexity. We applied established methods to map human impacts with the greatest accuracy possible, and then developed simple, repeatable models to project selected, salient aspects of those threats into the future. By so doing, our goal was to provide a time-sensitive picture of how threats are distributed on the landscape now, and then how they may be distributed in the future (circa 2040).

We modified the Human Footprint methodology developed by the Wildlife Conservation Society (WCS) at the global scale (1 km resolution)²¹ to a regional planning scale (90 m resolution), providing a powerful tool for mapping and measuring threat. The Human Footprint is a multi-variable, ecologically weighted map that integrates sources of human influence in four categories: human settlement, human access, human land use, and electrical power infrastructure. Each human influence source is coded on a scale from 0 to 10 as to degree of human transformation and ecological impact (0 being no or minimal impact, 10 being maximum impact reflecting complete and permanent conversion to development). The scores are then combined to produce a single index that is then normalized within ecological subregions to produce a map of ecologically relative human influence—or impact—on a scale from 0–100, which is the map of the Human Footprint. Figure 4.1 shows the global Human Footprint map for this ecoregion.

The Future Human Footprint, developed by 2C1Forest, attempts to project the dynamic, ecologically salient features of the regional footprint into the near future. Of course, whenever a researcher wishes to project the behavior of natural systems over time, problems of uncertainty arise. Thus, projections must be based on fairly simple parameters and cover a range of scenarios so that decision-makers can choose from among several plausible “futures.”²³ Still, recent trends may not continue and new events may occur that are unanticipated. So the purpose of the Future Human Footprint is not so much to say “this is how the future will be” but “this is how the future *might* be.”

CURRENT HUMAN FOOTPRINT

To map the Current Human Footprint in the Northern Appalachian/Acadian ecoregion, we com-

pared spatial data layers comparable to those used to map the global Human Footprint,²⁴ and followed its general methodology by (a) selecting a spatial resolution of analysis based on the scale of the best available data, (b) selecting data sets representing the different sources of landscape transformation and then assigning aggregate Human Influence (HI) scores, (c) combining HI scores across data sets to quantify direct human influence, which results in a map of the Human Influence Index (HII), and (d) normalizing the HII scores across ecological subregions to calculate relative human influence within each subregion, resulting in an ecoregional map of the Human Footprint.

To fully capture the human influences on the periphery of the ecoregion boundary, we buffered our analytical boundary to 40 km and mapped the Human Footprint to a 20 km buffer around the ecoregion. We assessed human influence on terrestrial ecosystems only, and did not attempt to assess human influences on freshwater or coastal systems.

For this ecoregion, we used ten data sets to represent the four categories of human influence used in the global Human Footprint:

- ~ Human settlement: population density, dwelling density, and urban areas;
- ~ Human access: roads and rail lines;
- ~ Human land use: land use/land cover, large dams, watersheds, and mines; and
- ~ Energy infrastructure: utility corridors.

We chose data layers to capture those human activities and trends relevant to human influence in this ecoregion in the present time. For example, we included dwelling density to capture the influence of second homes related to amenity developments and decreasing household size, but we did not use navigable rivers as a source of human access because they do not presently serve as significant transportation corridors in the ecoregion separate from the existing. We assigned Human Influence (HI) scores to each data layer to reflect relative contribution to human influence on the land on a scale from 0 (low) to 10 (high). Scores were assigned based on published studies relevant to this ecoregion and on expert opinion.

To understand the results of the Current

Human Footprint (Figure 4.2) it is important first to simply examine the map and see where similar human influence scores are accumulated and land transformation to human uses is most intense. Three main patterns jump out.

First, there are still large areas with low Human Footprint scores—and only a portion of these (62%) are found on lands that are permanently secured against conversion to development. Second, separating these areas are areas with high levels of human activity. These appear to fragment the region into large blocks of less-transformed land—the Adirondacks, Northern New England, Gaspé Peninsula, New Brunswick, and parts of Nova Scotia. Third, even within these large blocks with low Human Footprint scores, human impacts are still present, suggesting that human land use is widespread even outside of the heavily settled valleys and coastlines.

On average the region is still only moderately transformed by human impacts relative to the maximum amount present anywhere in the ecoregion. The distribution of HF scores peaks in the HF 11–20 range and declines steadily with greater HF scores (Figure 4.3). Greater than 90% of the ecoregion has

an $HF \leq 50$. However, the vast majority of the area experiences some human influence; only 0.2% of the ecoregion has a score of $HF = 0$ (indicating no human transformation of the landscape given the measures we incorporated in our analysis).

Although 53,790 km² (16%) in the ecoregion have an HF score ≤ 10 , they are distributed in 17,813 blocks ranging in size from < 1 km² to 1,930 km². Most of these blocks are small; 14,368 (80.7%) are ≤ 1 km² in size, and only 79 (0.004%) are $> 1,000$ km². Thus, despite the appearance of large areas of land with low HF scores, most such areas in the ecoregion are quite small and fragmented.

FUTURE HUMAN FOOTPRINT

To map the Future Human Footprint (FHF), we chose salient features of the Current Human Footprint (CHF) known to have ecological impacts and to be sensitive to change, and we adapted existing models to project them into the future. After projecting these features, they were combined with the features of the CHF that were not modeled, so as to provide a comparable surface to the CHF. The salient features chosen for modeling were:

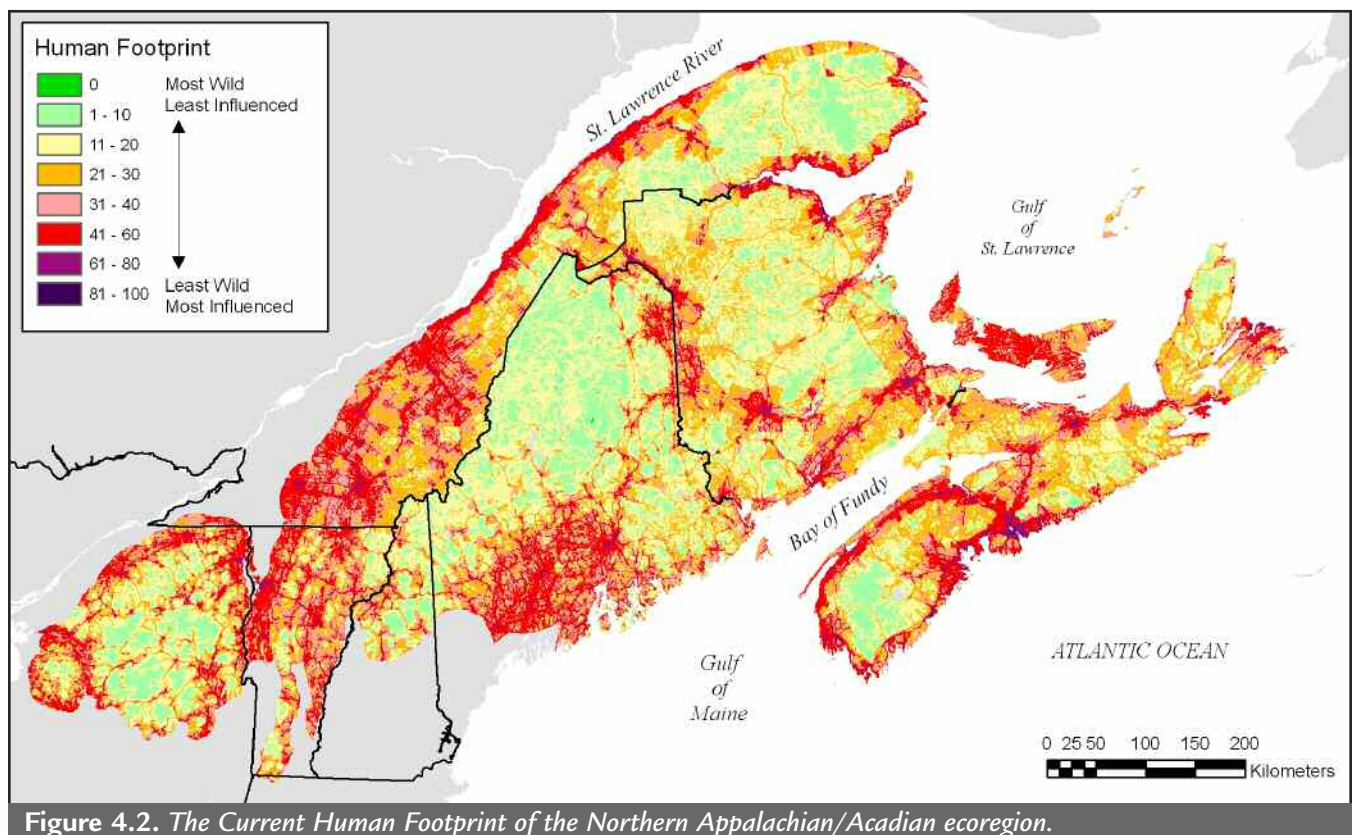


Figure 4.2. The Current Human Footprint of the Northern Appalachian/Acadian ecoregion.

- ~ human settlement (the maximum of projected population density or current housing density);
- ~ residential, public roads; and
- ~ amenity environments outside of settled areas.

As when we chose spatial resolution and data layers for the CHF, we applied the concept of parsimony. We chose to model the future based on best available data and simplest available models, and over time scales for which we felt confident, knowing that the further one projects into the future, the greater the uncertainty encountered.²⁵ Human settlement was projected forward by taking the county-level 1990's growth rate from the U.S. and Canadian census, and multiplying it by the year 2000 (U.S.) or 2001 (Canadian) census block (U.S.) or dissemination area (Canada) densities, compounded by decade, over four decades. This approach conforms to the “neighborhood” philosophy of modeling change, in which the conditions of a geographical neighborhood (being the county growth in our case) affects the smaller scale densities within it.²⁶

Residential public roads are salient ecological features because roads have far reaching ecological effects.²⁷ We chose to model their probability of

occurrence in the future because this class of roads is highly dynamic in our ecoregion, and their expansion is directly related to human settlement—particularly the phenomenon of residential expansion commonly called sprawl.²⁸ Because this analysis (a logistic regression analysis using geographical proxies) is based on 17 years of historical data²², we feel confident that this projection points to areas of higher and lower risk for receiving new residential, public roads somewhere within a 10–25 year horizon.

Finally, we chose to model risk to undeveloped, unprotected lakeshores as an estimate of amenity development. Amenity development is also called beta development and represents new growth nodes disjunct from typically expanding urban areas (alpha development).²⁹ These new growth nodes in lightly settled forestlands typically occur around ski areas, undeveloped shorelines, and coastlines. In our region there are many lakes potentially vulnerable to development due to lack of protected status, and embedded within lands owned by companies with a published predisposition to sell for real estate, and within a day's drive of the region's 16 major urban centers. Thus, we used these factors to select land in lightly settled landscapes likely to experience conversion to development in the near future. Specifically,

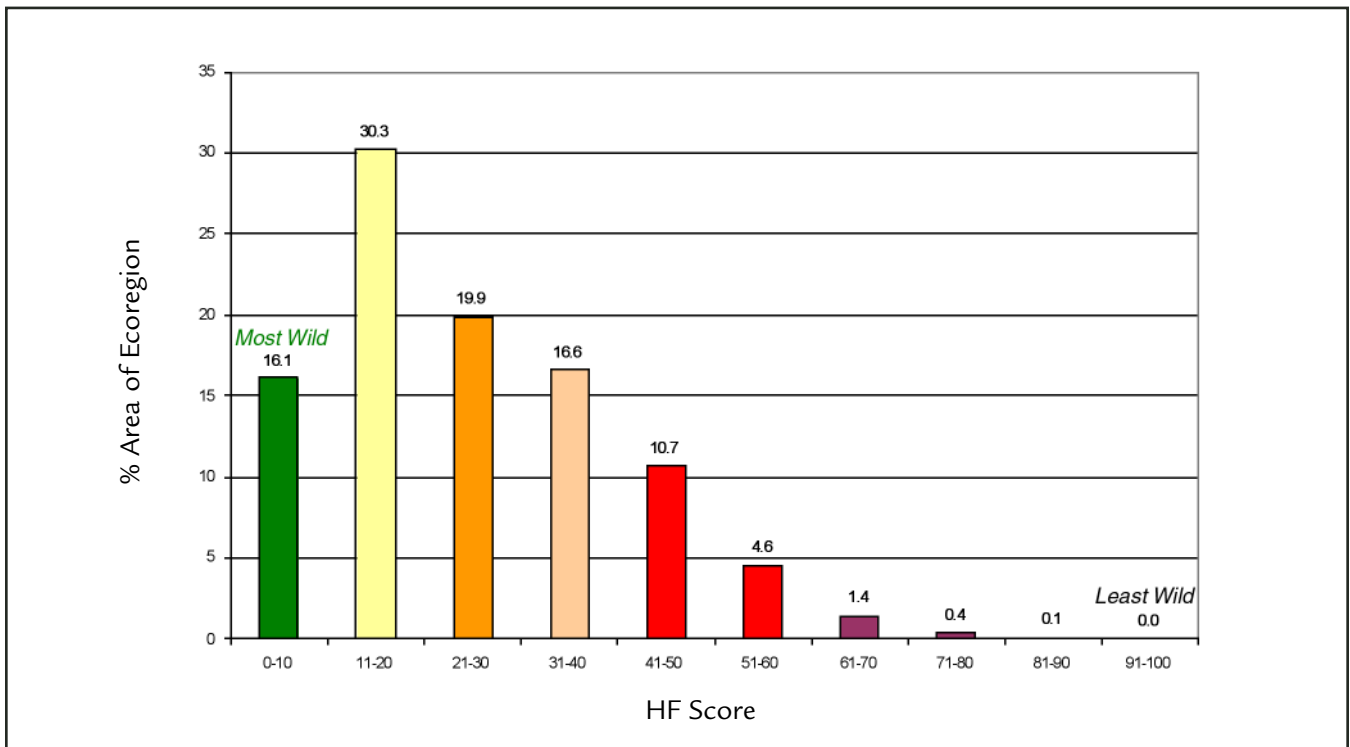


Figure 4.3. Histogram of Current Human Footprint scores of the Northern Appalachian/Acadian ecoregion.

we modeled risk to those lands around lakes (500 m “developable zones”) most likely to transition from primarily forest, to representing amenity development, over approximately a decade.

Together, these projections represent two distinct processes of development recognizable to most living in the Northern Appalachian/Acadian ecoregion. First, there is the process of incremental expansion in existing settled landscapes represented by population expansion and residential road expansion models. Second, there is the process of “leapfrogging,” or the establishment of new nodes of development, often in areas associated with recreational amenities—a process represented in the FHF by the lakeshore risk model.

The outputs of the projections were assigned impact (HI) scores, combined with the existing CHF layers that were not deemed salient, and normalized in the same way as the CHF to produce a FHF for three future change scenarios. These scenarios were developed based on two assumptions: (1) that the region will continue to grow and change as it has in the recent past, and (2) that the region will grow and change in a manner analogous to similar regions of North America (the Pacific Northwest and the Upper Midwest of the United States). Each scenario incorporates the two processes (incremental: process 1; instantaneous or amenity: process 2).

Specifically, the FHF scenarios are as follows:

~ **Current Trends:** Under the Current Trends scenario, the rates of change in human settlement experienced during the 1990’s continue to drive new settlement patterns into the future (Process 1). Coupled with this is a modest rise in wilderness development around heretofore undeveloped lakeshores—“instantaneous transition” of forested landscapes to developed ones (Process 2).

Process 1: (a) current trends of population growth projected 40 years; (b) projected 80% probability surface for regular, public roads.

Process 2: Ownership-weighted risk to wilderness lakeshores, within 100 km from major urban areas.

The second and third scenarios illustrate what might happen in our region if the rates of change are greatly accelerated due to changing conditions outside of the region leading to increased immigra-

tion (Process 1). Coupled with this is a heavy rise in wilderness development reflecting greater pressure from urban areas (Process 2).

An example of changing conditions leading to increased immigration would be new industries that have regional economic effects (e.g., the “Microsoft phenomenon” of the Pacific Northwest). Another is the possibility that until now, the Northeast has lagged behind the Upper Midwest in growth due to demographic and economic factors, and if those change we may experience rapid exurban growth and accompanying development of rural “amenity” landscapes.

~ **Rapid Influx A: Pacific Northwest Model** (high urban growth and low amenity development).

Process 1: 1990’s population growth from Pacific Northwest counties, weighted as urban or non-urban, projected 40 years.

Process 2: Risk to wilderness lakeshores, 100 km zone from major urban areas.

~ **Rapid Influx B: North Central Lakes Model** (high urban growth and high amenity development).

Process 1: 1990’s population growth from North Central Lakes region counties, projected 40 years.

Process 2: Risk to wilderness lakeshores, 200 km zone from major urban areas.

It is useful to examine what the FHF does not model and why. The FHF does not model changes in forest cover and composition. After much consideration, we decided that such projections—while possible on a limited sample of landowners or management districts—are at the regional scale dependent on too many landowners with differing harvest plans to credibly capture these vegetation changes. Likewise, the FHF does not model changes in spatial distribution of logging roads. Ecological impacts of logging roads are significant, as these roads provide access to remote areas, but—especially on private lands—those that are the most dynamic also tend to be the most ephemeral. For example, the smallest are used for access to a tract of land, and then left to partially regenerate back to forest. Thus, we

decided that this process was too dynamic to model accurately at the ecoregion scale using currently available data and methods.

As an example of how one scenario forecasts the FHF, Figure 4.4 shows the FHF based on growth patterns in the North Central Lakes region (Rapid Influx B scenario).

With the FHF produced by a particular scenario, we can examine a “difference map,” showing the degree of difference, negative or positive, with the CHF. Difference maps are one reason to use a scalable index such as the Human Influence Index. Figure 4.5 shows such a difference map, illustrating where—compared to the present—impacts may accumulate (pink and red) and where they may abate (blue).

The FHF analysis shows two trends regardless of scenario: 1) intensification and spreading outwards of human impact around settled areas, and 2) spreading of human impact throughout areas with low Human Footprint scores under the CHF. Both of these trends pose significant risks to biodiversity. Intensifying settlement (e.g., in the greater Montreal metropolitan area, or along the Green Mountains) threatens wildlife that depend on local-scale habitat. For example, conditions for pool-breeding amphibians will worsen.³⁰ Likewise, intensification of settlement will cause greater landscape fragmentation at the ecoregion scale, threatening wildlife dependent on connectivity among and within large forest blocks. Many carnivore species are negatively impacted by roads and have inherent conflicts with human settlement.³¹

At the same time, spreading human impact through lightly settled areas introduces two new significant threats. First, it introduces and “hardens” human infrastructure including housing development, resorts, and paved roads in areas previously dominated by timber harvesting. Second, isolated resort developments can become new development nodes, leading to future incremental growth typical of settled landscapes.

It is helpful to understand some of the underlying components of the FHF and how they affect the overall outcome. Remember that the FHF incorporates two distinct land use change processes—one that is incremental expansion of settled areas, and one that represents the risk posed when undeveloped lands, far from towns and cities, instantly

transition from existing, natural resource use to amenity development. As an indication of the power of incremental expansion to transform the landscape at the ecoregion scale, the accumulation of new, residential roads over a 20-year horizon will likely double the area susceptible to those roads, adding another 500,000 km to the existing network.

Likewise, instantaneous transition of currently little transformed areas poses a significant risk to landscape connectivity in the future. Lakeshores vulnerable to development within 200 km of major urban centers represent only 1,118 km² (0.3% of the ecoregion); less within 100 km: 625 km² (0.2% of ecoregion). At the same time, these areas are scattered throughout the most wild and remote portions of the ecoregion and all occur on private lands (i.e., can be developed if permits are received). Essentially, these kinds of changes may transform what is now forest (albeit managed and often measurably transformed) to a landscape that has a new kind of human infrastructure: vacation homes, resorts, and roads to service them, further spreading the human footprint outside of settled areas shown in the CHF.

Human impacts in the Northern Appalachian/Acadian ecoregion today reflect the historical pattern of settlement. The Current Human Footprint map reveals that settlement is still concentrated around valleys, coastlines, and other low lying areas. Our region is still so rural that its settlement pattern reflects what ecologists consider the “primary productivity” and “industrial” phases of settlement, where human impacts first accumulate³². Today, much of the ecoregion is on the verge of the third and final phase of human settlement, the “information/communication” phase where people can settle and work from virtually anywhere. Areas at risk during this phase typically have high aesthetic values and reasonable access to urban areas and other service centers.³³ In fact, there is already significant evidence of this wherever one looks: the foothills of the Green Mountains, the coast and lakes of central of Maine, the Sutton Mountains of Québec, and the areas outlying Halifax in Nova Scotia, for example. These and many other areas already show the pattern of the future: parcelization of large farms and woodlots, development of shorelines and ridgetops, increasing road infrastructure, and in most cases habitat degradation.

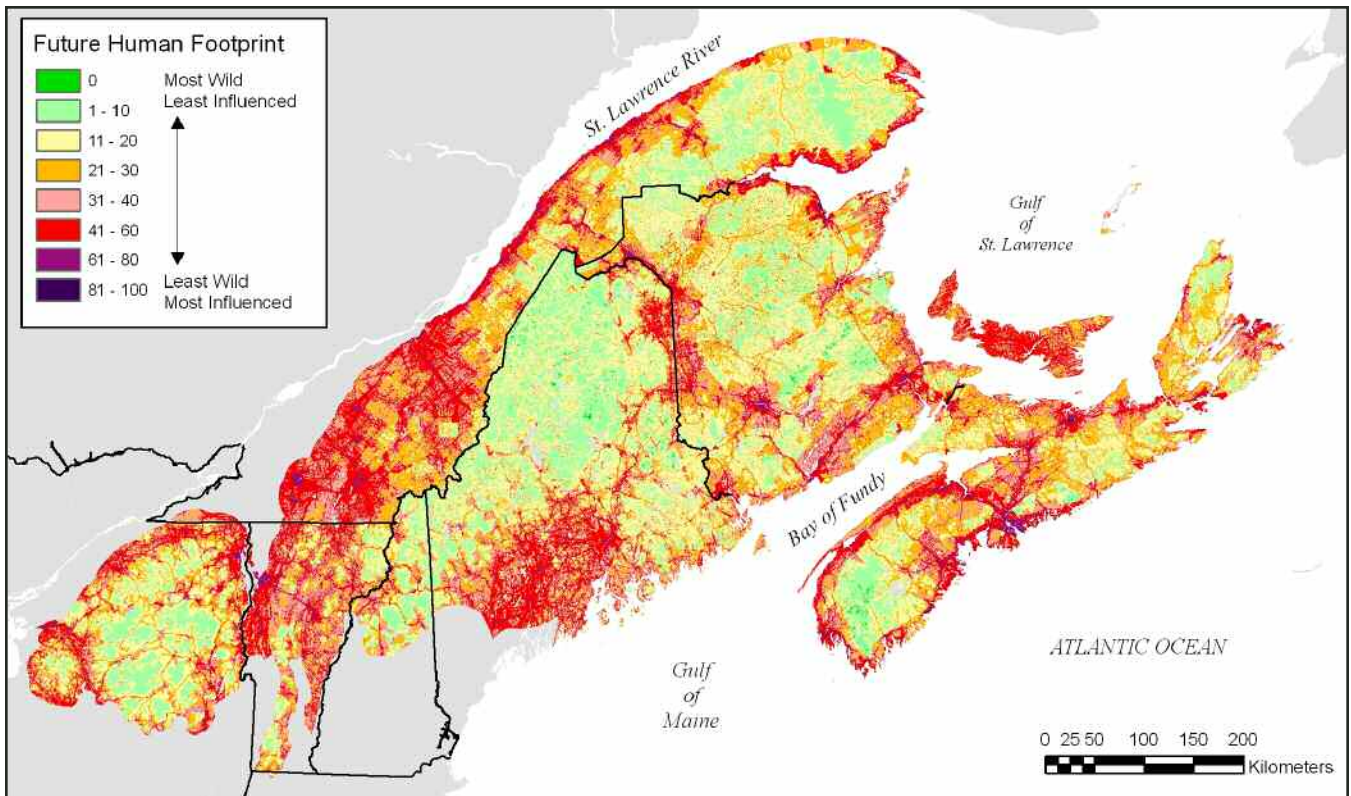


Figure 4.4. The Future Human Footprint in the Northern Appalachian/Acadian ecoregion in the Rapid Influx B (North Central Lakes region) scenario.

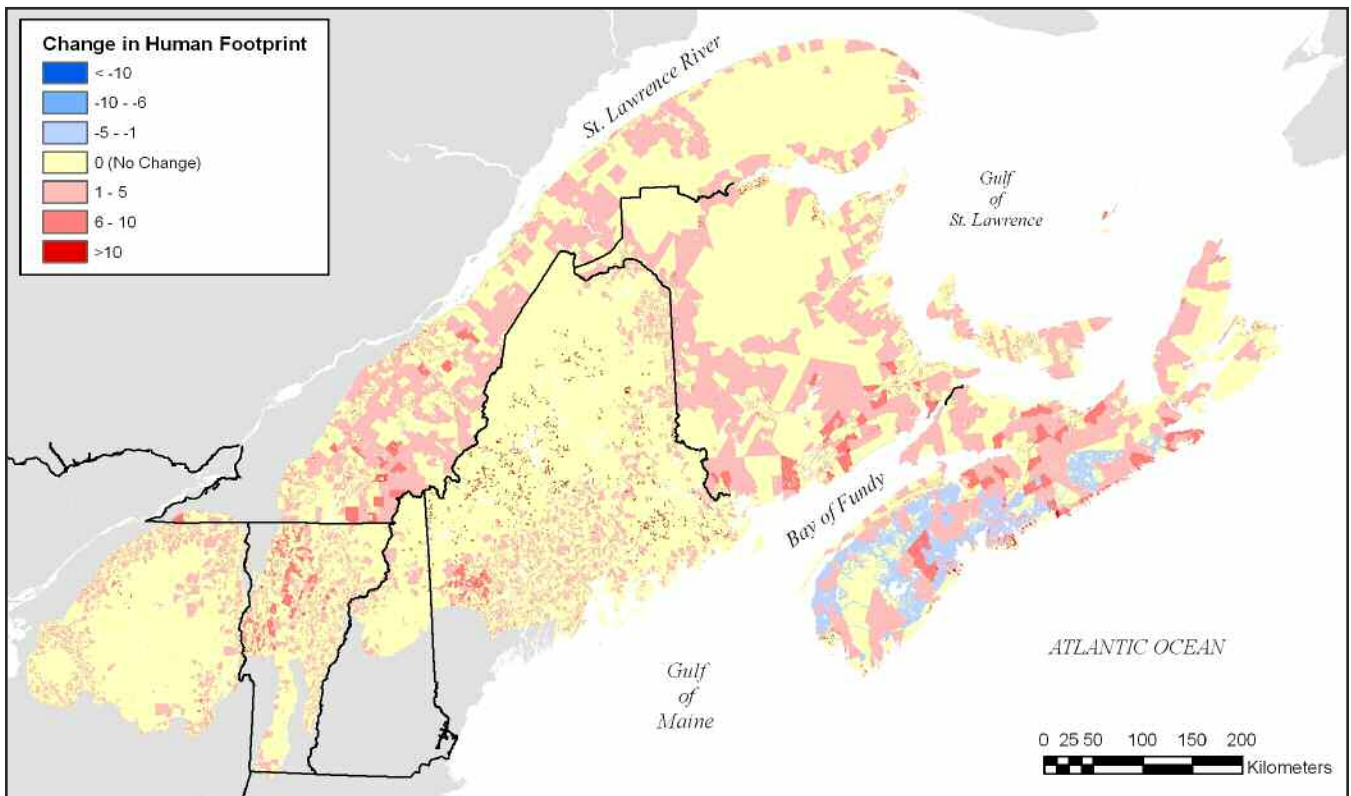


Figure 4.5. The difference between the Current Human Footprint and the Future Human Footprint (Rapid Influx B scenario) for the Northern Appalachian/Acadian ecoregion. Areas colored pink and red are projected to experience increased transformation—or threat—in future years. Areas in blue are projected to experience reduced threat.

The Future Human Footprint scenarios are based on the assumption that the region will experience similar kinds of growth to similar regions and that the incremental, relatively low level of growth experienced in the recent past throughout most of our region will inevitably change. The basis for this change is that human impacts are measurably distributed through almost the entire ecoregion. Even the majority of wildest areas score above 0 and the road network, in particular, reaches every corner. Resource harvesting industries and recreation have driven exploitation of even the most remote landscapes, and these impacts could well expand and intensify in the future.

A lack of protected areas can further hinder our ability to combat permanent land conversion. In the Northern Appalachian/Acadian ecoregion, slightly more than a third (35%) of the land area is under some form of protection (Figure 3.3), which means that 65% is currently not secured from conversion to development. Protection in this case is broadly taken to mean “secured from conversion to development” because nearly all of it allows resource harvesting or extraction. Only 7% of the landscape is designated as highly protected land (GAP status 1), indicating that 93% is not managed specifically to protect ecosystems, ecosystem processes, populations of individual wildlife species, and other components of the catch all term “biodiversity.”

Likewise, sweeping social and economic changes that have occurred in other regions like the Upper Midwestern United States may lead to unprecedented rates of development along lakeshores, coastlines, ridgetops, and other such attractive areas, while at the same time accelerating expansion of existing urban areas. Alternatively, such changes may not occur, and we may see growth as we have seen in recent decades—rapid in some areas, and slow in others. Because land use is closely tied to climate change through the carbon cycle and other ecological processes (e.g., nutrient cycles, hydrology, invasion by non-native species), if the kind of land use changes anticipated by the FHF come to pass, there will be numerous interacting ecological effects, and biodiversity conservation could be dra-

matically affected.

Finally, we can conclude that this ecoregion is threatened by a great deal of uncertainty: what private landowners and public lands managers will choose to do with their lands in the coming decades will dictate the future for plants and animals. Likewise we cannot be certain how changing climatic conditions will interact with changes in land use. The only way to respond to uncertainty (nothing in nature is the same now as it was at any historical point in time) is to continually observe, document, monitor, and anticipate new changes.

CONCLUSIONS

While the Northern Appalachian/Acadian ecoregion is still one of the most forested and “wild” ecoregions in eastern North America, it may be one of the most vulnerable simply because so much undeveloped land is unprotected and within reach of densely populated areas. Threats to the Northern Appalachian/Acadian ecoregion’s land area are currently concentrated in settled landscapes but may rapidly expand outwards given changes in social or ecological conditions that would encourage migration (e.g., climate, location of large industries, and availability of land with high amenity value). Conservation planning in this ecoregion should recognize the potential for the human geography to rapidly change. In particular, ecological reserve systems should not rely on the matrix forest being maintained primarily as managed forest; large tracts could and currently are being transformed to multiple uses including large scale development for recreational housing and services. Conservation planners should seek partnerships with private landowners and government agencies to insure that (a) large-scale fragmentation of existing forest blocks does not occur, and (b) new nodes of development inside large forest blocks are clustered and kept to a minimum, and that infrastructure to service them (roads, in particular) is built and maintained to minimize fragmentation and other adverse impacts (e.g., salt spray, collisions with wildlife, alterations in hydrology of wetlands and other water bodies).

5. Irreplaceability for Conservation

Another approach to identifying priorities for conservation action is to identify locations that are highly important for achieving conservation goals. The entire landscape can be assessed with respect to all ecological features that are deemed to be important in order to identify the suite of locations that are necessary for achieving all of the specified conservation goals. A set of locations that achieves all the conservation goals while simultaneously achieving some other set of constraints, such as minimizing the amount or cost of the land needed, is considered to be a conservation “solution”: one solution represents one set of locations that, taken together, achieves all specified conservation goals.

However, it is highly likely that there is more than one possible solution that will achieve all of the goals. In other words, the contribution that some locations make to achieving the goals can often be made by other locations as well. On the other hand, some locations are consistently included in all solutions, perhaps because they contain rare species or high-quality examples of ecosystems that are found in few other locations, or they contain a high diversity of ecological features so that it is always efficient to include them in a solution. These locations are then considered to be “highly irreplaceable”: highly irreplaceable locations are priority locations because they are necessary for achieving conservation goals under a large number of different solutions.

Based on the importance to conservation planning of being able to identify areas that are important for achieving broad conservation goals, another aspect of our research has been to assess the levels of irreplaceability for specific locations across the ecoregion. This section describes both the methods we used to conduct this assessment, as well as our results and conclusions with relevance for conservation planning.

OVERVIEW OF METHODS FOR ASSESSING IRREPLACEABILITY

Identifying highly irreplaceable locations is simply a matter of comparing a range of possible solutions and identifying those areas that are in a large pro-

portion of them. Once the number of locations and ecological features that need to be considered grows large, however, it becomes nearly impossible to identify correctly the optimal set of irreplaceable areas without the help of a computer to analyze the data efficiently.³⁴ Fortunately, recent advances in the field of conservation reserve design have provided the computational tools necessary to evaluate alternative scenarios.³⁵ Numerous computer programs exist, including MARXAN,³⁶ which gives the user a large amount of control over identifying the important ecological features, the conservation goals for each feature, and the computational algorithm used to search for solutions. Consequently, 2C1Forest used MARXAN to carry out its analysis of irreplaceability.

Several decisions must be made in order to generate landscape solutions and measure irreplaceability. The first decision is which computational algorithm will be used to search for solutions. Numerous algorithms have been proposed over the years by conservation planners. However, the one that permits identification of numerous possible solutions for landscapes involving very large numbers of locations and ecological features is called “simulated annealing.”³⁷ This algorithm is highly flexible and fast in searching through a large number of different combinations of locations and identifying a solution that effectively achieves the conservation goals while fitting all of the constraints (such as the amount of area or cost). One MARXAN run, called a simulation, can compare a vast number of different combinations of locations to identify an effective solution. Numerous simulations can then be run to compare solutions. For our analyses, each simulation compared 1 million separate combinations of locations to identify an effective solution, and for each set of constraints (described below) we ran 100 separate simulations to create 100 separate solutions.

Each location can then be assessed for what percentage of the simulations it is included in a solution. A planning unit’s irreplaceability is thus a score between 100 (always present in a solution and therefore required to achieve the specified conservation

goals) and 0 (never present in a solution and therefore never required to achieve the specified conservation goals). The higher a location's score, the more important it is for conservation in this ecoregion.

The other important input decisions that must be made involve (a) the locations, (b) the ecological features, (c) the conservation goals, and (d) the constraints on the solutions.

MARXAN refers to locations as "planning units," discrete spatial areas into which the study area is divided for the purposes of analyses and with which the data are associated, typically as hexagonal or square grid cells of a consistent size. For our analysis, we subdivided the ecoregion into 65,378 hexagons, each 10 km² in size. Thus, the entire ecoregion is included in the analysis. MARXAN, however, gives the user the ability to control whether any particular planning unit must be entered into or excluded from a solution. We took advantage of this ability in two ways. First, we specified that the Tier 1 matrix blocks and existing protected areas (GAP 1 and GAP 2), as identified by TNC/NCC (see Section 3), should be included in the solutions; planning units that mostly overlapped with Tier 1 matrix blocks or existing GAP 1 and GAP 2 protected areas were locked in to the MARXAN solutions. Second, we excluded existing urban areas from being included in any solution. Planning units that mostly overlapped with existing urban areas, identified from the most recent census data, were locked out of the MARXAN solutions.

We focused on 178 ecological features divided into four categories, each derived from The Nature Conservancy/Nature Conservancy of Canada or the Wildlands Project analyses described in Section 3:

- ~ **Portfolio (i.e., "special") ecosystems** (TNC/NCC): wetland basins, mountain summits, steep slopes, ravines, floodplains, coastal wetlands, and Tier 1 streams (7 features);
- ~ **Focal carnivores** (WP): wolf source habitat under current landscape conditions, marten source habitat with continued trapping, and lynx source habitat without population cycling (3 features);
- ~ **Portfolio species** (TNC/NCC): those in the region that are categorized as rare, threatened, or endangered at some level (G1, G2, G3, and G4-G?) (4 features); and

~ **Ecological land units** (TNC/NCC): Discrete combinations of elevation, bedrock, and topography (164 features).

Each planning unit was assessed in terms of the presence/absence of each feature.

Conservation goals are specified in MARXAN as "targets" that need to be achieved for a solution to be considered successful. Targets can be defined individually for each feature, and are expressed as a percent of all planning units where the ecological feature is present. For example, if a target for a feature is set to be 30% and the feature is present in 100 planning units, then a solution must include at least 30 planning units where the feature is present. It can include more than 30 planning units with that feature, but it cannot include fewer. In practical terms, the target levels influence the number of planning units included in solutions and the level of ecological redundancy obtained; the higher the target levels, the greater the redundancy and the greater the number of planning units included in a solution.

Following the approach taken by the Wildlands Project,³⁸ we developed a series of three target scenarios—low, medium, and high—which are defined as a low, medium, and high percentages of the occurrences of these features that must be included for a solution to be considered successful (Table 5.1). For portfolio ecosystems, focal carnivores, and portfolio species, target levels were the same for all features within a feature type.

For ecological land units (ELU's), the exact target percentage varied according to how common an ELU is in the ecoregion, with greater percentages required for rare ELU's than for common ones (Table 5.2).

For example, under the low target scenario, a solution is only successful if it includes 50% of the occurrences of each portfolio ecosystem, 30% of the critical habitat for each of the focal carnivores, 50% of the occurrences of each of the portfolio species, and 5-20% of the occurrences of each of the ELU's (5% of common ELU's, 20% of rare ELU's, and 10-15% of ELU's in between).

We imposed a number of different constraints on solutions. The first of these constraints was a penalty or cost imposed on a combination of planning units that failed to meet targets for the ecolog-

ical features (Table 5.1). This biased solutions towards achieving targets even if they required more area to do so. Penalties were assessed in relative terms; for example, the penalty for failing to meet the target for a portfolio ecosystem was four times greater than failing to meet the target for a portfolio species.

A second constraint was a cost for including planning units in a solution as a function of both their protection status and the condition of their land cover (Table 5.3). As the level of security against conversion to development and the quality of the land cover declines, the greater the cost imposed for including a planning unit into a solution.

A third constraint influenced the degree of spatial cohesiveness for the planning units in the best solutions. One measure of cohesiveness (and its inverse, fragmentation) is the length of the boundary of a group of planning units relative to the area of those units. For a given total area of a set of units, a longer total boundary length would be characteristic of low cohesion, while a shorter length would characterize high cohesion. In MARXAN, cohesion is controlled by a “boundary length modifier” (BLM). The greater this value, the greater the cost imposed on a planning unit that is not adjacent to another planning unit already in a solution.

We selected a single boundary length modifier (BLM = 0.00035) to influence the degree of cohesion among the planning units (Figure 5.1). This value represented an optimal trade-off in the Northern Appalachian/Acadian ecoregion between the total amount of land that would be required to meet the conservation goals and the amount of cohesion shown by the solution. BLM’s less than 0.00035 dramatically increased fragmentation with no decrease in the total area required to meet conservation goals; BLM’s greater than 0.00035 dramatically increased the area required with little decrease in fragmentation.

We emphasize that we are not using these measures of irreplaceability as a surrogate for a reserve network design. While such measures can play a role in designing reserve networks, our intention here is to evaluate the extent to which locations on the landscape are replaceable with respect to achieving the conservation goals we have specified. Ultimately, the design of a reserve network would require coupling this kind of analysis with dynamic

models that assess the ability of individuals of focal species to move across the landscape (thus achieving landscape-scale connectivity) and that assess projected changes in the landscape over longer time scales (thus accounting for climate change and changes to the built environment).

Feature Type	Target Scenario			Penalty
	Low	Medium	High	
Portfolio ecosystems	50	65	80	4
Focal carnivores	30	45	60	1
Portfolio species	50	65	80	1
ELU’s	5–20	25–40	45–60	2

Table 5.1. The percentage targets and costs for each of the four ecological feature types under the three target scenarios.

Proportional Representation	Target Scenario		
	Low	Medium	High
> 1%	5	25	45
0.1–1%	10	30	50
0.01–0.1%	15	35	55
< 0.01%	20	40	60

Table 5.2. The percentage targets for ELU’s as a function of target scenario and commonality in the ecoregion.

Protection Status	Land cover			
	Tier 1	Tier 2	Not Tier 1–2/ Natural	Not Tier 1–2/ Unnatural
GAP 1–2	1	1	1	1
GAP 3	1	2	3	5
Not GAP 1–3	1	3	4	6

Table 5.3. Cost incurred for planning units based on their status as areas secured against conversion to development and land cover. Protection status and land cover data were all derived from the TNC/NCC analysis. All GAP 1–2 and Tier 1 planning units are already locked into the solutions.

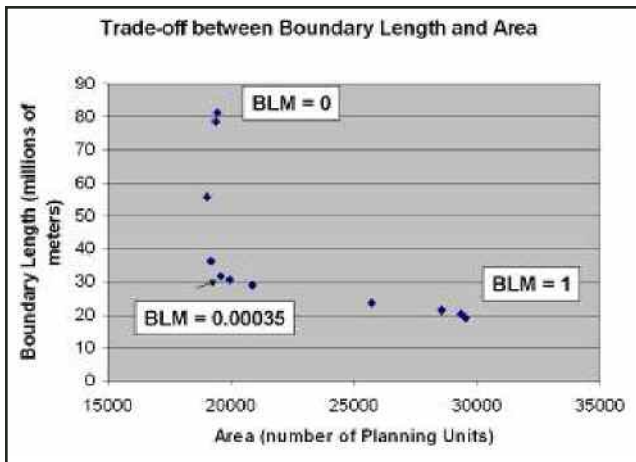


Figure 5.1. Relationship between fragmentation (as measured by total boundary length) and the amount of land in an optimal solution as a function of the boundary length modifier.

RESULTS: IRREPLACEABILITY WITH LOW, MEDIUM, AND HIGH TARGETS

Under the low target scenario, measures of irreplaceability are strongly influenced by the planning units that are locked into (Tier 1 matrix blocks and existing GAP 1 and 2 protected areas) and out of (urban areas) solutions (Figure 5.2, Table 5.4). 141, 250 km² have an irreplaceability score of 100 (planning units are always included in the best solutions), representing 27.6% of the ecoregion. Conversely, 260,770 km² are unimportant or unavailable for achieving conservation goals (irreplaceability scores of 0), representing 51.0% of the ecoregion.

The remaining 109,370 km² (21.4%) are neither locked into nor out of solutions, yet have intermediate irreplaceability scores ranging between 1 and 99. Intermediate scores are strongly skewed toward low values (1-20, Table 5.4), indicating that most of the locations in the ecoregion that are not highly irreplaceable (100) or unimportant (0) are highly replaceable, being included in at most 20% of the best solutions.

This pattern suggests that under the low target scenario, (a) a subset (27.6%) of the ecoregion is highly irreplaceable for achieving the conservation goals under the constraints we set, and (b) the conservation goals that cannot be met on the highly irreplaceable lands can be met by a wide variety of other locations. Furthermore, large portions (51.0%) of the ecoregion are never included in a solution,

indicating that, given the availability of other locations for achieving the specified conservation goals, they are never needed under the low target scenario.

Almost two-thirds (92,960 km²) of the area that scores as highly irreplaceable does so because it is locked in to solutions by virtue of being Tier 1 matrix blocks or existing GAP 1 and 2 protected areas. However, that leaves another one-third (48,920 km²) that is highly irreplaceable even though it is not locked into a solution (Table 5.4). These lands tend to be adjacent to lands that are locked into solutions (Figure 5.3), indicating the tendency for solutions to prioritize locations that will maximize cohesion (and thus minimize fragmentation) of priority lands throughout the ecoregion. Conversely, only about 4% of the unimportant lands are deemed so because they have been locked out of the solutions (9,530 km²).

Very similar patterns are seen under the medium targets scenario (Figure 5.4, Table 5.4). The primary changes observed are (a) a decrease in the amount of land that is never required to achieve conservation goals (from 51.0% to 36.0%), (b) a negligible increase in the amount of highly irreplaceable land (27.6% to 27.8%), and (c) a slight shift among intermediate irreplaceability lands to be included in more solutions. In short, the highly irreplaceable lands largely remain the same, less land never contributes to achieving conservation solutions, and the increased target levels require a larger range of the lands that remain.

The same patterns are again largely true under the high targets scenario (Figure 5.5, Table 5.4). Generally, the same lands are highly irreplaceable (28.3%) as under both low and medium target levels. However, only 25.0% of the land is deemed unimportant (compared to 51.0% and 36.0% under the low and medium target levels, respectively). Intermediate irreplaceability lands are again skewed towards higher values, indicating that under high target levels, specific locations are becoming more irreplaceable for achieving conservation goals.

CONCLUSIONS

From these analyses, several key messages emerge:

- ~ A large fraction of the specified conservation goals, even under high target levels, can be achieved by the Tier 1 matrix blocks and the

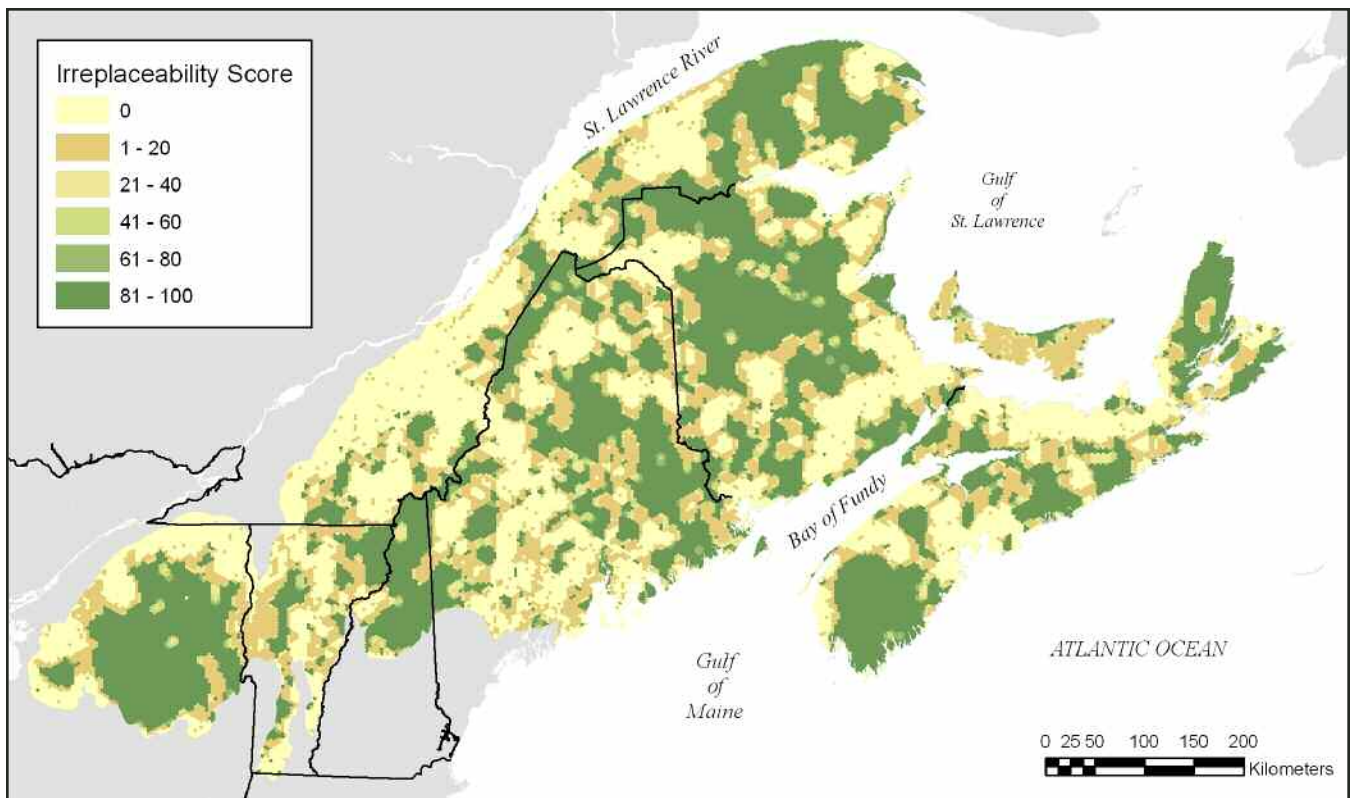


Figure 5.2. Irreplaceability of planning units under the low target scenario.

Target Scenario	Locked out 0	Neither locked in nor locked out							Locked in 100	Total
		0	1-20	21-40	41-60	61-80	81-99	100		
Low	9,530 (1.9)	251,240 (49.1)	81,390 (15.9)	10,620 (2.1)	7160 (1.4)	4860 (1.0)	5340 (1.0)	48,290 (9.4)	92,960 (18.2)	511,390
Medium	9,530 (1.9)	174,670 (34.1)	130,020 (25.4)	28,410 (5.6)	12,800 (2.5)	7450 (1.5)	6390 (1.2)	49,160 (9.6)	92,960 (18.2)	511,390
High	9,530 (1.9)	118,310 (23.1)	106,520 (20.8)	54,940 (10.7)	34,300 (6.7)	25,900 (5.1)	17,470 (3.4)	51,460 (10.1)	92,960 (18.2)	511,390

Table 5.4. The amount of land in square kilometers (with percentage of total area in parentheses) in different categories of irreplaceability under different target level scenarios. Irreplaceability scores are shown in the second line in italics. Unimportant lands (Irreplaceability score = 0) are subdivided into lands that are categorized as such because they have been locked out of all solutions because they represent existing urban areas (column 2), and lands that were not locked out but never appeared in any solution (column 3). Highly irreplaceable lands (Irreplaceability score = 100) are subdivided into lands that are categorized as such because they have been locked into solutions because they are existing GAP 1-2 lands or have been identified as Tier 1 matrix blocks (column 10), and lands that were not locked in but appear in all solutions anyway (column 9).

existing public lands managed primarily for ecological values (GAP 1-2). Including these lands as required parts of conservation solutions results in a relatively small amount of additional lands to capture all highly irreplaceable areas (Table 5.4), and these lands are largely located adjacent to or as connectors between Tier 1 matrix blocks and GAP 1-2 lands (Figures 5.3).

~ As target levels increase, the amount of land needed to meet overall conservation goals necessarily increases. However, there is a great deal of replaceability for those additional lands. Thus, achieving higher target levels requires greater replication of protected lands for ecological features, which can be achieved with many different configurations of lands apart

from the limited amount of land identified as completely irreplaceable.

~ When target levels are low, broad areas of the ecoregion never contribute to achieving the specified conservation goals. However, as targets increase, the potential contribution of much of these areas also increases, indicating that virtually all areas in the ecoregion have the capacity to contribute to achieving conservation goals if the desired level of ecological replication is high enough.

~ With all three target scenarios, there are areas of highly irreplaceable lands throughout the ecoregion that are not included within existing Tier 1 and GAP 1-2 lands and thus represent important additional areas for conservation.

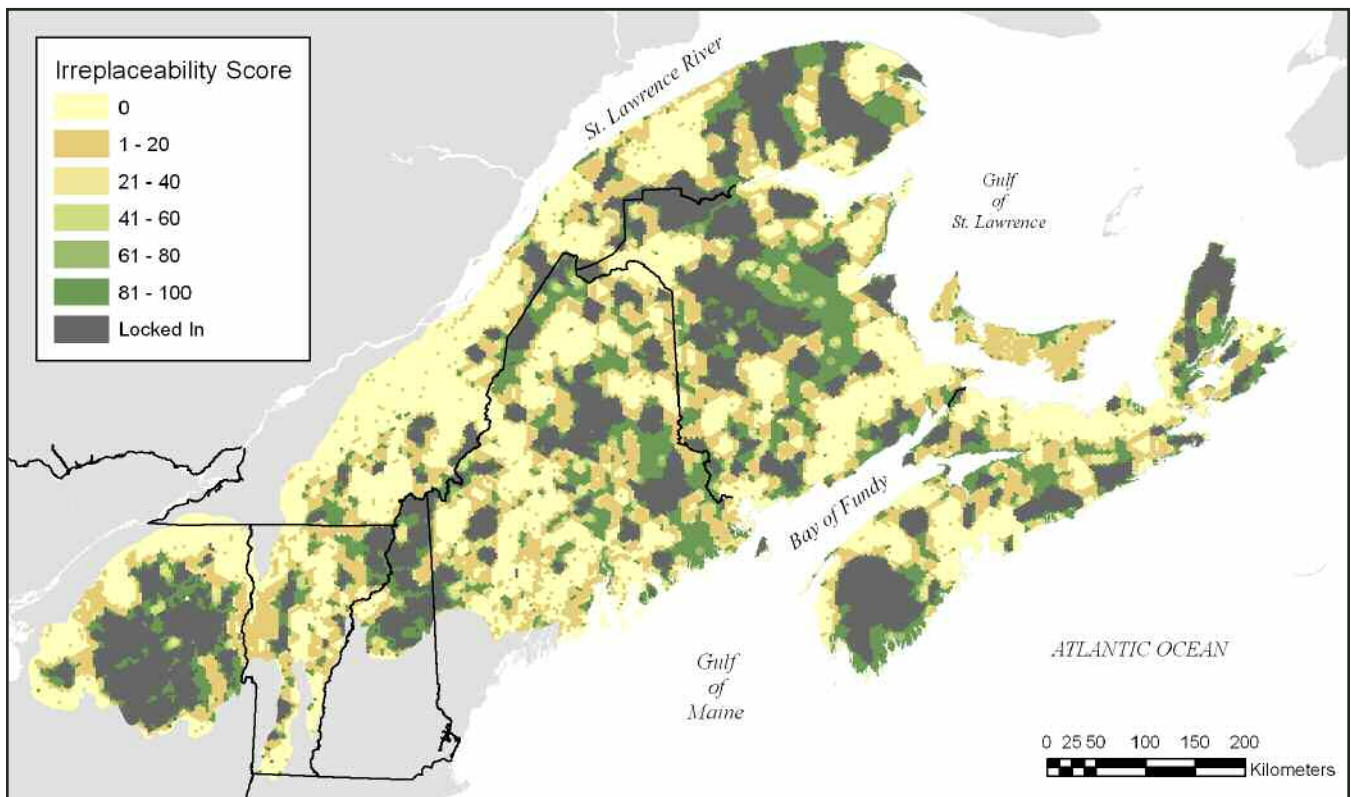


Figure 5.3. Irreplaceability of planning units under the low target scenario with scores shown only for planning units that have not been locked in to solutions (Tier 1 matrix blocks and GAP 1-2 protected areas).

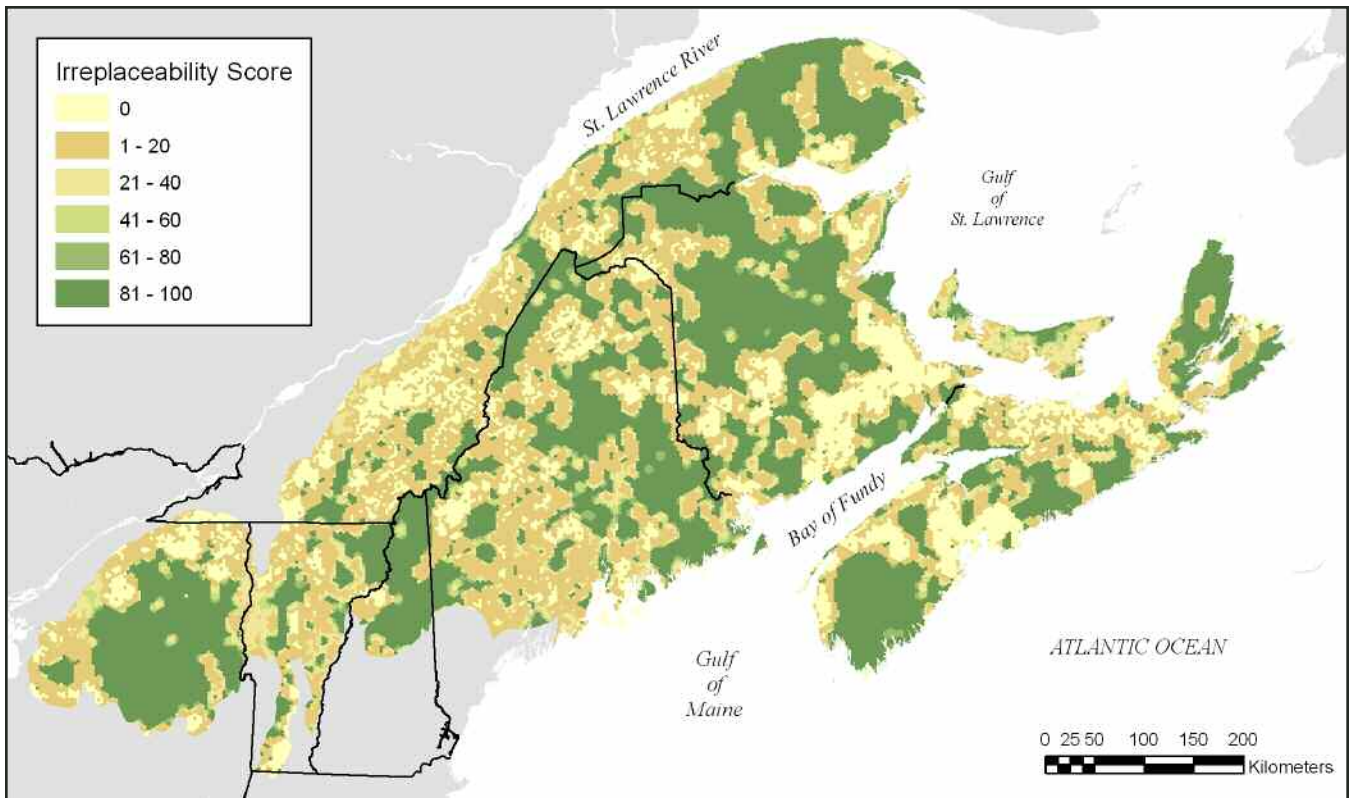


Figure 5.4. Irreplaceability of planning units under the medium target scenario.

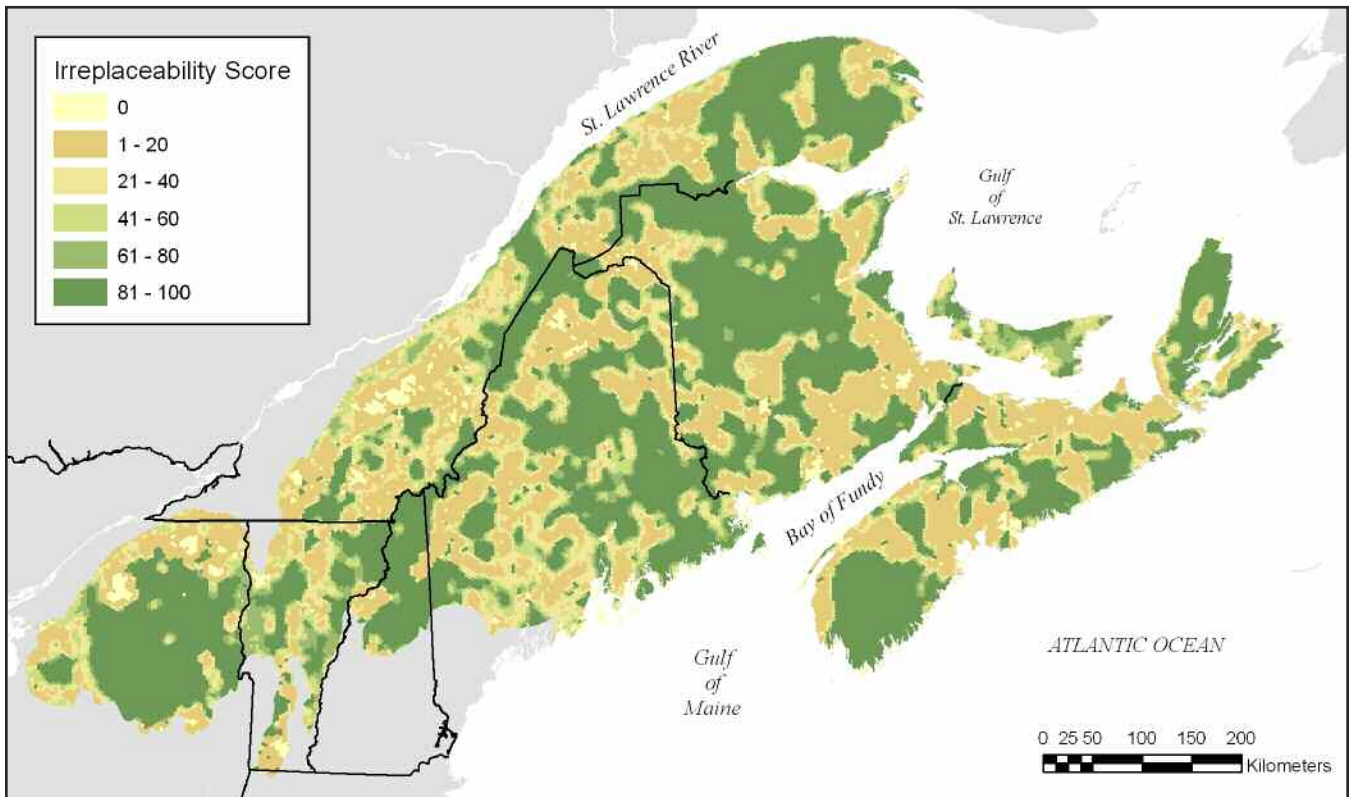


Figure 5.5. Irreplaceability of planning units under the high target scenario.

6. Priority Conservation Areas: The Intersection of Irreplaceability and Vulnerability

In the previous sections of this report we describe four initiatives that provide a picture of the ecological status and trends of the Northern Appalachian/Acadian ecoregion, framed in terms of the distribution of conservation values (Sections 3 and 5) and the threats to those values (Section 4). These studies demonstrate the geographic gradient of irreplaceability and vulnerability facing the landscape in the present as well as in the context of possible future scenarios. They also provide multiple alternatives for prioritizing conservation action. For example, a conservation planner might want to target his/her efforts towards safeguarding those places in the region where rare biological communities continue to persist, or alternatively where the most space-demanding species in the region have the best chance of maintaining viable populations. Other options include targeting areas that have the highest opportunity for protection by virtue of an as-yet low Human Footprint, or where the greatest chances of permanent land conversion loom in the future. Each view of the world, therefore, is unique.

Systematic conservation planning ideally takes all such elements into account in formulating an overarching plan based on the key concepts of irreplaceability and vulnerability under an analysis framework that can combine the many different ways to view the landscape. Irreplaceability refers to the relative ecological importance of a given area in the context of the region at large, a measure of its contribution to the realization of the stated conservation goals. Our approach for evaluating ecological importance incorporated a three-track strategy with focus on ecological representation, focal species habitat, and rare species, using the results generated from the work presented in Section 5. Vulnerability, on the other hand, is assigned on the basis of the extent to which it has been subjected to land conversion and the prospects thereof under various future scenarios. For this we used quantitative forecasts of threats from human activity from the Current and Future Human Footprint analyses presented in Section 4 to objectively assess current and future threats to the region.

In an analysis modeled after work in the Greater Yellowstone Ecosystem by Noss et al.,³⁹ we divided the ecoregion into planning units which we simultaneously assessed for levels of irreplaceability (ecological importance) and vulnerability (threat) and plotted on an x-y axis. The position of each planning unit within the resulting graph (e.g., high vulnerability/low importance; low vulnerability/high importance) provides a framework within which to evaluate relative urgency or opportunity when ordering conservation priorities (Figure 6.1). By employing a systematic, data-driven, and spatially and temporally sensitive planning approach, we have sought to inform and support decision making at multiple scales within and across the eight states and provinces that make up the Northern Appalachian/Acadian ecoregion.

There are three elements of this analysis that extend the methodology developed by Noss et al., and demonstrate several advances in this approach for conservation planning:

- 1) All data incorporated into this conservation planning framework were quantitative in nature. When it comes to assessing the relative threat

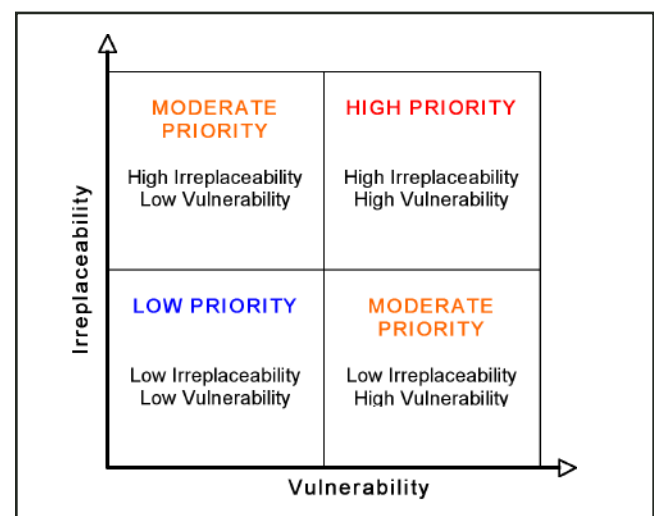


Figure 6.1. A conservation planning framework for assessing the conservation priority of sites within an irreplaceability (importance) and vulnerability (threat) matrix.

faced by a conservation area, practitioners are often restricted to qualitative information or expert opinion, in contrast to calculations of irreplaceability.⁴⁰ The assessments of threats to the planning units in this exercise were derived from high-resolution analyses of regionally-available spatial data that collectively represented human impact. Expressing degree of threat to a planning unit as its position along a continuum maximized the objectivity of data used for the analysis;

- 2) The relative vulnerability of a planning unit was based not only on the degree of human land transformation that each has already undergone—the Current Human Footprint—but was also based on the relative risk of undergoing conversion in the future under multiple scenarios—the Future Human Footprints. This added to our ability to assess urgency of conservation action, by drawing attention to how likely a given planning unit would shift from relatively untransformed to a state of increased conversion within the next 40 years; and
- 3) Results are offered for three different types of planning units. As such, these results are portrayed with the acknowledgement that conservation practitioners in this region operate from various vantage points that differ in scale or perspective, each perceiving different boundaries surrounding their position in the landscape. Some may be operating from within a municipality and are chiefly concerned with decisions facing individual land parcels, while others are more interested in biologically meaningful boundaries, such as watershed, and others operate at a necessarily broader scale. This approach offers an excellent opportunity to evaluate the extent to which a given area will stand out or fade in priority depending on the size and nature of the planning unit in question.

ASSIGNING IRREPLACEABILITY AND VULNERABILITY SCORES TO PLANNING UNITS

We calculated Irreplaceability and Vulnerability scores for each planning unit. This exercise determined the relative position of a given planning unit

on the continuum of priority action for the Northern Appalachian/Acadian landscape.

The Irreplaceability score for each planning unit was derived from the results of the MARXAN site selection analysis using the High target levels, described in Section 5. This analysis selects hexagon units—or sites—that achieve a conservation solution that satisfies a set of user defined conservation goals. The analysis is run 100 times and the more times a given unit is selected as being part of a solution and thus shown to be more important for conservation in the ecoregion, the higher the unit’s score. Irreplaceability is therefore a relative score between 100 (always selected in the solution to achieve the stated conservation goals) and 0 (never selected).

For planning units that straddled hexagon unit boundaries, we calculated the Irreplaceability score of each planning unit using an area-weighted calculation of the amount of a hexagon in a unit:

$$I_{\text{unit}} = \frac{\sum (\text{Irreplaceability} * \text{Area}_{\text{Hexagon}})}{\sum \text{Area}_{\text{planning unit}}}$$

We quantified vulnerability (threat) separately for each planning unit as the mean scores of the Current Human Footprint and three Future Human Footprint scenarios, resulting in four Vulnerability scores per planning unit.

We plotted each planning unit on a graph representing Irreplaceability (using the High target levels) on the y-axis and Vulnerability on the x-axis, repeating this exercise separately for each of the three planning unit types and for each of the four Vulnerability scores. We then assigned each individual unit a level of conservation priority depending on its position in one of four quadrants (Figure 6.1). Those units with a relatively high score in both irreplaceability and vulnerability were designated the highest priority. These were followed by those of moderate priority either because they were relatively replaceable but under threat, or highly irreplaceable but less vulnerable. In this latter case, the reduced priority is a function of the lesser urgency to for its conservation, even though it remains of high important or irreplaceable. Finally, those planning units that were relatively replaceable and facing less

severe threats were considered the lowest priority in this ecoregion. We assigned the cutoff between High irreplaceability and Low irreplaceability as the median (61) of the Irreplaceability scores (High target levels) from the MARXAN analysis (Section 5), while the cutoff between High and Low vulnerability was assigned as the median of the Current Human Footprint values (21). For each planning unit type, we compared scatterplots and the position of individual planning units between the four scenarios representing current and future threats (see Figure 6.2 for one example).

PLANNING UNITS

The sites that are compared against one another performed a key role in this analysis. We conducted the same analysis on three different types of planning units (Figure 6.3):

1) **10-km² hexagon planning units** (n = 36,684) that were the basis of the MARXAN analyses from

which Irreplaceability scores (see Section 5) were derived. This scale of planning remains one that is most convenient for spatial analysis and also enables a fine-scale view of the results given the number of planning units that receive scores across the region. While hexagons may have little meaning as planning units based on either management constraints or biological realities, they provide a view useful to conservation planners who work over small spatial extents or who might otherwise be interested in fine-scale variability over broader regions. They also provide the added benefit of being of equal size, thus enabling more relevant comparison of values across planning units.

2) **Hydrologic units** (n = 147) bound the land drained by a river and its tributaries with boundaries based on the hydrologic cycle. Rather than jurisdictional boundaries drawn by humans, hydrologic units (nearly but not precisely equivalent to watersheds⁴¹) represent one

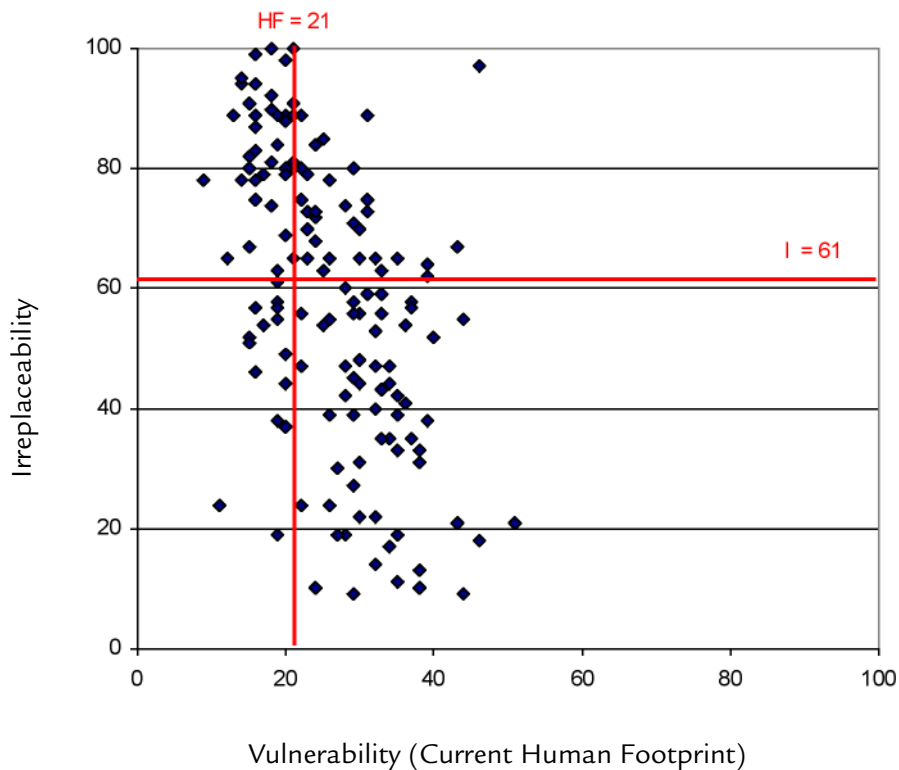


Figure 6.2. An evaluation of hydrologic units as planning units using the Irreplaceability (High targets) against Vulnerability (Current Human Footprint) framework.

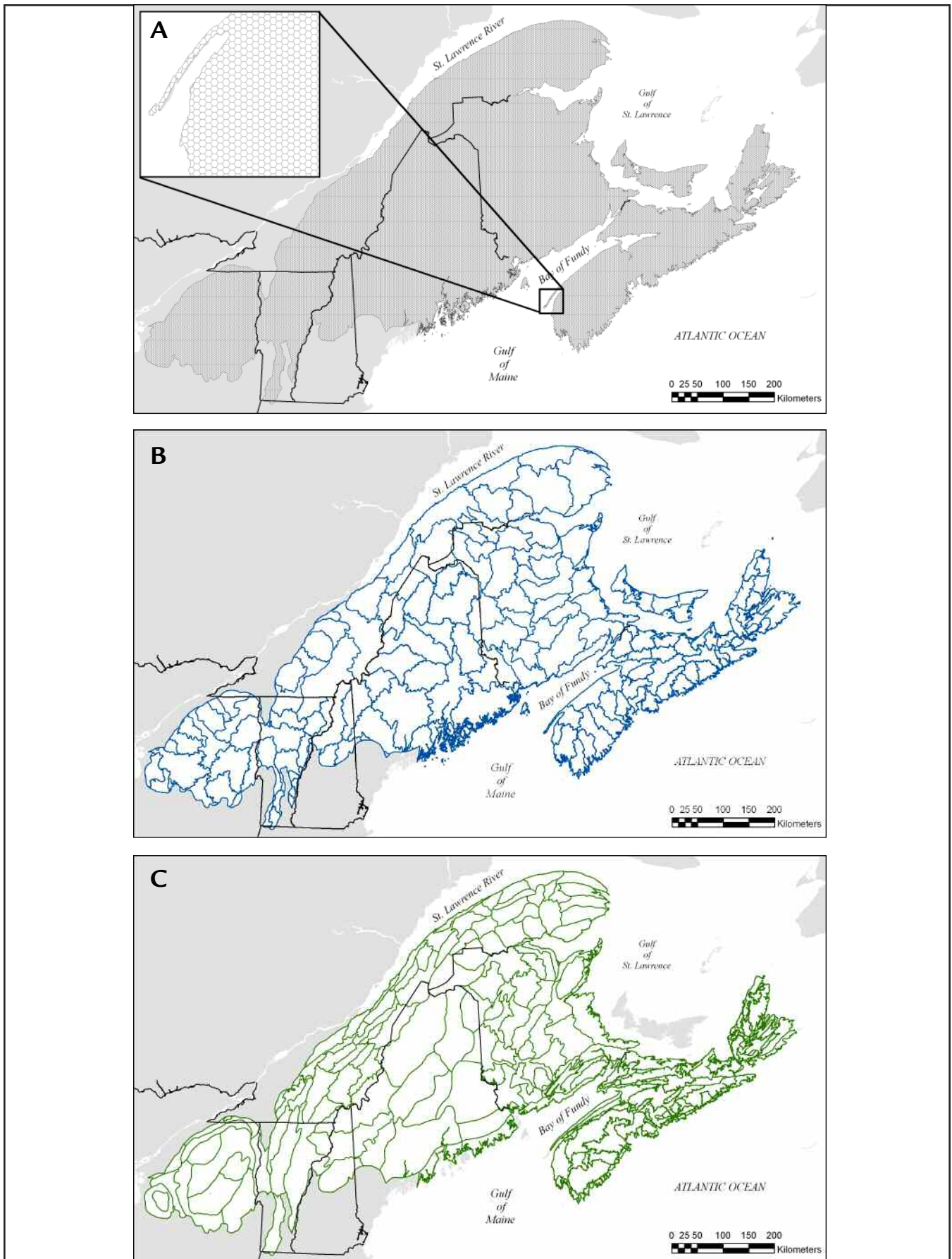


Figure 6.3. Three planning units employed in the analysis: A) hexagons, B) hydrologic units, and C) biophysical units.

example of natural geographical limits for managing the interaction between human activities and the natural environment. Hydrologic units in the Northern Appalachian/Acadian ecoregion were compiled from US HUC 8 drainage units⁴² and Canadian sub-sub-drainage areas.⁴³ This ecoregion contains 147 hydrologic units, ranging in size from 1.5 km² to 8,988 km (mean area of 2,355 km²).

3) Biophysical units (n = 242), which are based on a combination of U.S. Forest Service subsections and Canadian ecodistricts, comprise a third category of planning unit. These biophysical units, although primarily terrestrial in nature, are derived from both ecological and geological features on the landscape. The ecoregion has been divided into 242 land units (not including Prince Edward Island), with a mean area of 1,390 km² and ranging in size from 2.5 km² to 16,647 km².

We emphasize that there are many additional types of planning units that could serve as the basis of an exercise of this nature. These range from those that correspond with other biophysical parameters (ecoregion, other order watersheds, elevation, etc.) to management boundaries (municipalities, counties, states, provinces, school districts, or electoral districts) to ones that are customized, taking into account local or cultural resonance for residents and conservation practitioners alike. Rather than settling on one planning unit to assess overall importance and vulnerability of this landscape, however, we have chosen to compare planning units that exhibit differences from one another in size and boundary locations, for the purpose of exploring the extent to which results vary as a function of the chosen unit of planning. This approach can also highlight places that withstand multiple boundary shifts yet still emerge as those with the highest combined vulnerability and importance, or alternatively, that remain low-scoring regardless of the chosen scale or vantage point of planning.

RELATIVE CONSERVATION PRIORITIES

The mean Irreplaceability and Vulnerability scores were similar across all types of planning units (Table

6.1), and there were also broad patterns of agreement with respect to relative priorities across the three different types of planning units. Several regions—including the heart of the Adirondack Mountains, northern New Brunswick, the Gaspé Peninsula, western Nova Scotia, and Cape Breton Island—showed up as regions of high irreplaceability but on the lower end of the continuum of vulnerability (labeled in Figure 6.1 as “moderate priority”), comprising about 30% of the total ecoregion (mean = 102,945 km² for the three types of planning units; Figures 6.4–6.6). While these areas are highly important or irreplaceable, the lower vulnerability values reduce the urgency of their conservation.

General areas that scored highest in both irreplaceability and vulnerability (“high priority” in Figure 6.1) were more scattered in nature, took up less area (18%, mean = 64,092 km²), and exhibited more variability depending on the type of planning unit used for the analysis. In general, however, these tended to concentrate in Vermont/New Hampshire, southern Maine, and Prince Edward Island.

Those areas with high vulnerability and low irreplaceability (“moderate priority”) covered about 37% of the ecoregion (mean = 127,797 km²) and were located in the Bas-St. Lawrence region of Québec, the outskirts of the Adirondack Mountains, south-western Maine, southern New Brunswick, and central Nova Scotia.

Finally, the places that scored lowest on both the irreplaceability and vulnerability continuum (“low priority”) lay predominantly in northern Maine and parts of Nova Scotia, although they were scattered throughout the ecoregion across 13% of the area (mean = 48,016 km²).

COMPARISON BETWEEN TYPES OF PLANNING UNITS—CURRENT HUMAN FOOTPRINT

Although all three analyses generated a similar picture of the contrast in irreplaceability and vulnerability across the Northern Appalachian/Acadian ecoregion, we found that the results of these analyses demonstrated some important differences with respect to geographic priorities due both to variability in scale and positioning of the planning units (Table 6.1). In general, the amount of area assigned to a quadrant on the Irreplaceability/Vulnerability

	n	Irreplaceability			Vulnerability			High Irreplaceability-Low Vulnerability		Low Irreplaceability-High Vulnerability		High Irreplaceability-Low Vulnerability		Low Irreplaceability-High Vulnerability	
		Min	Max	Mean	Min	Max	Mean	n	Area km ²	n	Area km ²	n	Area km ²	n	Area km ²
Hexagons	36,684	0	100	58.5	0	81	25.7	11,074	108,864	7,387	68,174	5,925	56,038	12,298	113,062
CHF															
FHF—Current Trends					0	81	25.7	11,133	109,443	7,328	67,595	6,104	57,810	12,119	111,289
FHF—North Central Lakes					0	80	26.9	10,513	103,449	7,948	73,589	5,384	50,765	12,839	118,334
FHF—Pacific Northwest					0	80	27.9	9,906	97,642	8,555	79,396	4,970	46,720	13,253	122,380
Hydrologic Units	147	9	100	57.5	9	51	26.4	39	99,488	30	66,096	14	37,467	64	143,082
CHF					9	52	26.4	39	97,827	30	67,757	13	35,900	65	144,650
FHF—Current Trends					10	51	27.7	37	95,666	32	69,918	11	34,857	67	145,692
FHF—North Central Lakes					9	51	28.7	28	70,925	41	94,660	8	27,897	70	152,652
FHF—Pacific Northwest															
Biophysical Units	242	2	100	61.7	7	66	29.7	50	100,483	73	58,005	16	50,542	103	127,247
CHF					7	68	29.7	54	105,721	69	52,767	21	57,566	98	120,223
FHF—Current Trends					8	69	31.3	46	98,246	77	60,242	14	48,260	105	129,529
FHF—North Central Lakes					8	69	32.6	39	90,427	84	68,061	12	41,654	107	136,135
FHF—Pacific Northwest															

Table 6.1. A comparison of Irreplaceability (High targets) and Vulnerability scores for the three spatial units of analysis; hexagons, hydrologic units, and biophysical units. Included is a breakdown of the number of units (n) and the area they represent that fall into each quadrant of the prioritization framework (Figure 6.1) under the Current Human Footprint (CHF), the Future Human Footprint (FHF) Current Trends Scenario, the FHF Rapid Growth North Central Lakes Scenario, and the FHF Rapid Growth Pacific Northwest Scenario.

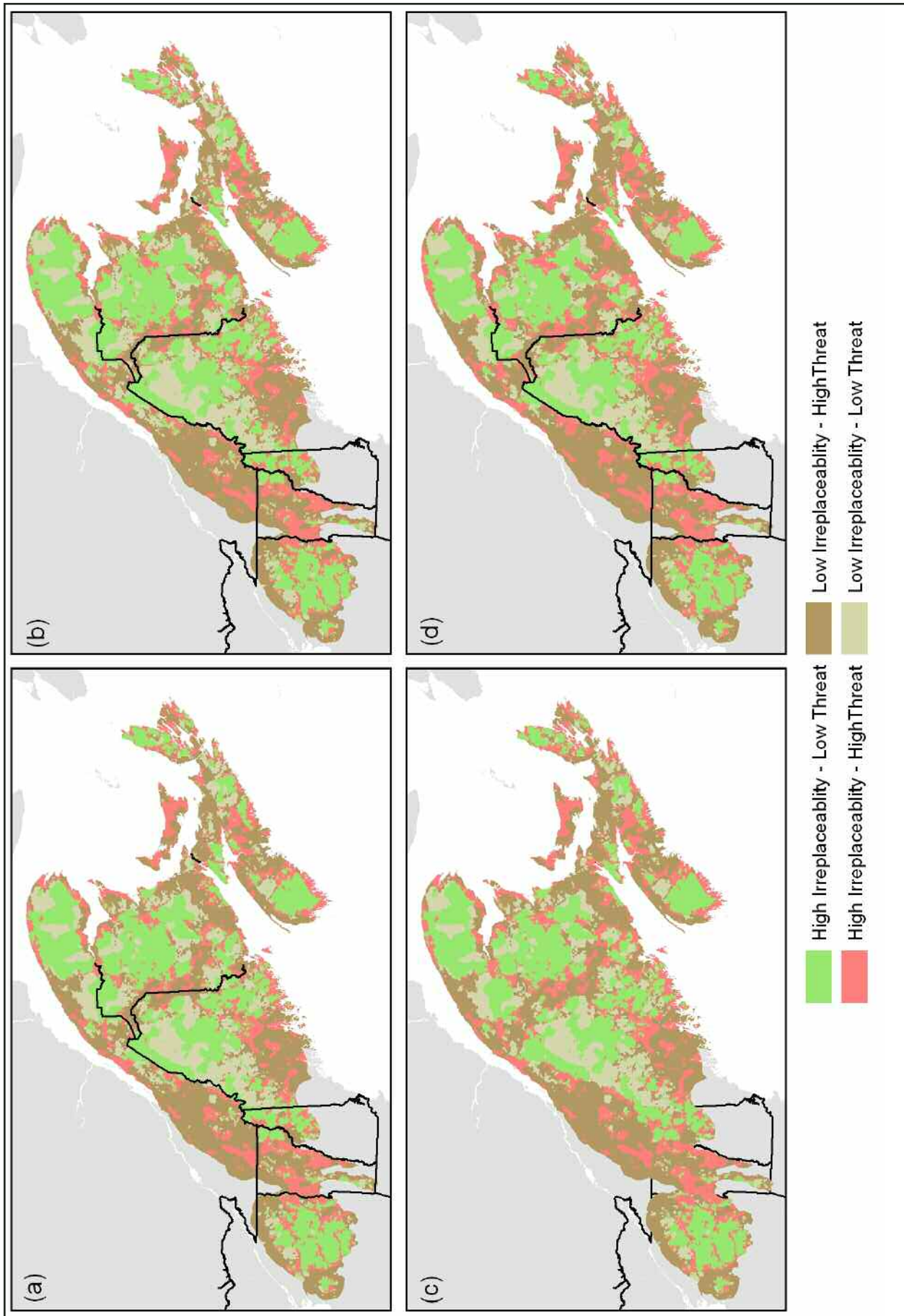


Figure 6.4. Hexagons as planning units: (a) Current Human Footprint, (b) FHF Current Trends Scenario, (c) FHF Rapid Growth Northwest Scenario, and (d) FHF Rapid Growth North Central Lakes Scenario.

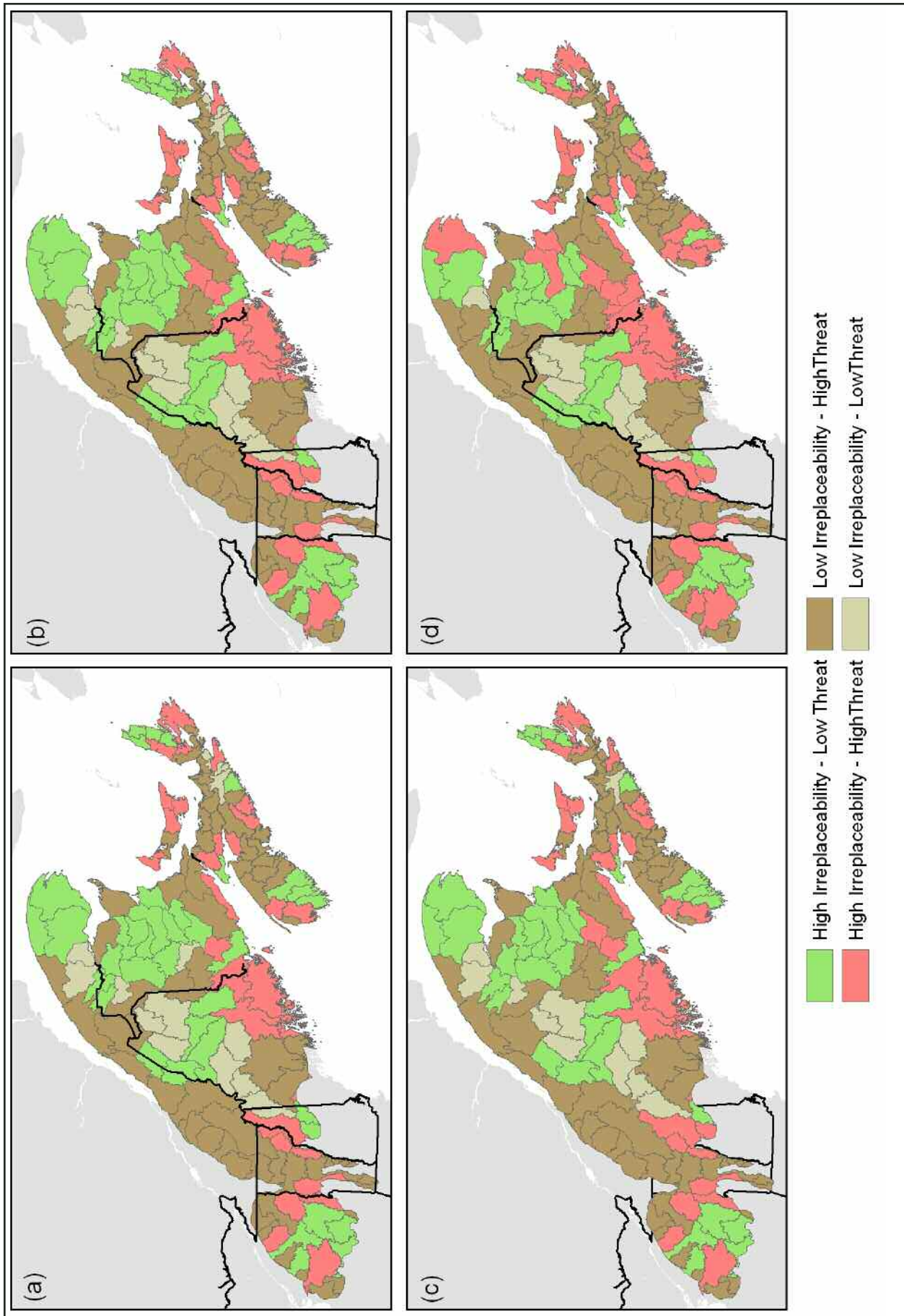


Figure 6.5. Hydrologic units as planning units: (a) Current Human Footprint, (b) FHF Current Trends Scenario, (c) FHF Rapid Growth North Central Lakes Scenario, and (d) FHF Rapid Growth Pacific Northwest Scenario.

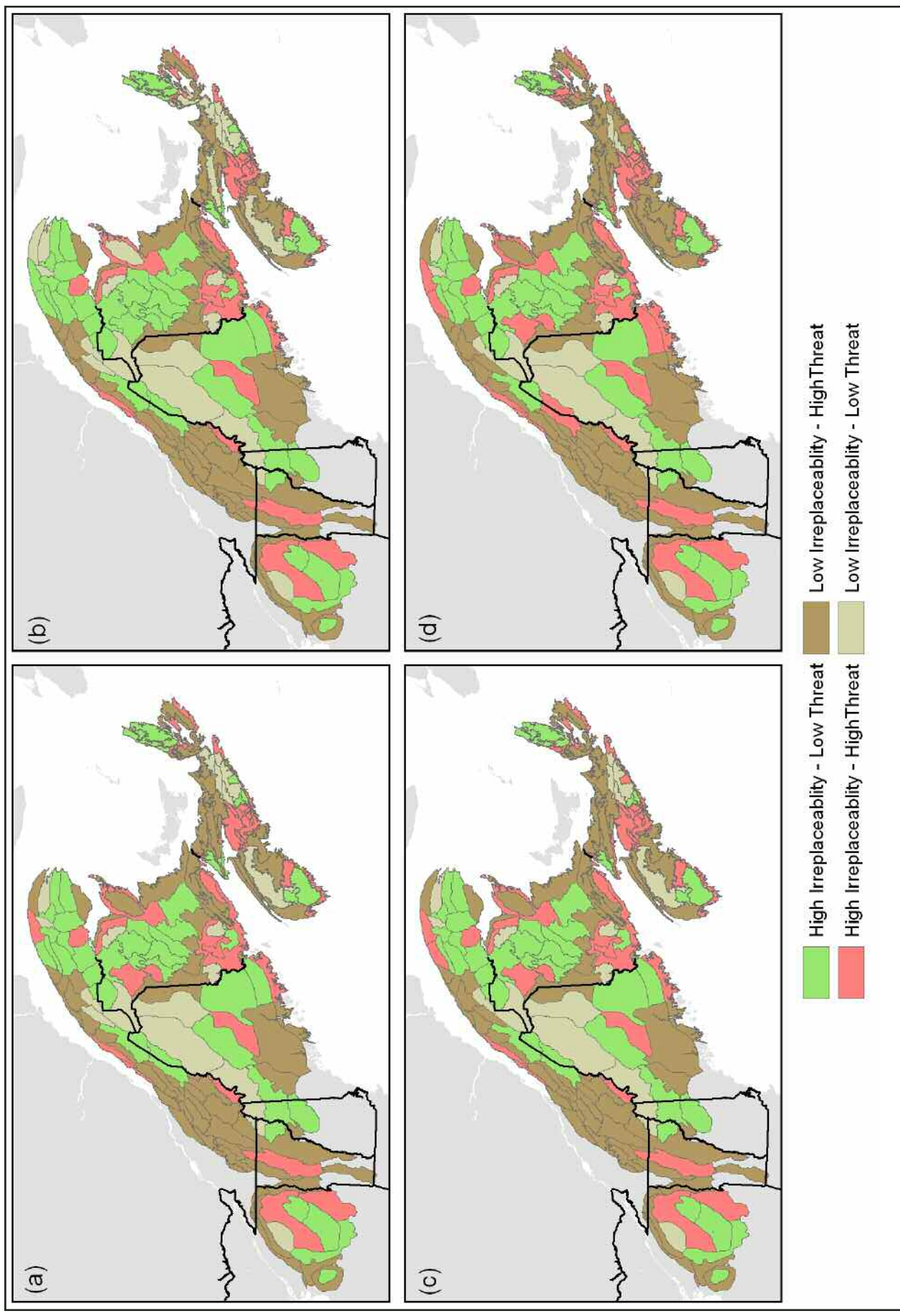


Figure 6.6. Biophysical units as planning units: (a) Current Human Footprint, (b) FHF Current Trends Scenario, (c) FHF Rapid Growth Pacific Northwest Scenario, and (d) FHF Rapid Growth North Central Lakes Scenario.

axes (Figure 6.1) varied among the three types of planning units deployed: the 10-km² hexagons in general placed more area in both the “high priority” and “low priority” quadrants than did either of the other two types of planning units that deployed fewer units across the ecoregion.

Retaining the 10-km² hexagons that were used as the original basis of analysis allowed for finer-scale interpretation of the results than hydrologic or biophysical units. When scrutinizing relative large areas, at the scale of the Adirondack Mountains or the Gaspé Peninsula, for example, the hexagon scale provided more detail. In both of these regions, areas that were identified as highly irreplaceable but largely unthreatened on the scale of both hydrologic and biophysical units were revealed by finer-scale analysis to contain patches that are under high threat, particularly around the outside edges. Similarly, hydrologic or biophysical unit boundaries at the front lines of human development but that contain features that are not particularly irreplaceable were shown in the 10-km² scale of analysis to include pockets of high-priority habitats where conservation action might best focus (Bas-St. Lawrence and south-central Maine).

There were some noteworthy differences in results between the biophysical unit and hydrologic unit analyses that were indicative of the respective position of planning unit boundaries. For example, in southeastern Maine the results for hydrologic units scored high in irreplaceability and vulnerability while, with the exception of the biophysical unit along the coast, the score remained high with respect to irreplaceability but not vulnerability for the other two planning unit types. The western tip of Nova Scotia emerged as high irreplaceability-low vulnerability for the southern section of the area with all planning unit analyses, while northward where threats are known to be more pronounced, all three units generated slightly different results.

To look more closely at the concordance among the types of planning units in terms of how where ranked the priorities for specific locations, we generated a set of 971 random points across the ecoregion, each separated by at least 5 km. In general, any two types of planning units only placed locations in

the same priority quadrant about 50% of the time:

- ~ Hexagons and hydrologic units: 496 of 971 locations (51.0%) in the same quadrant;
- ~ Hexagons and biophysical units: 528 of 971 (54.4%) in the same quadrant;
- ~ Hydrologic units and biophysical units: 515 of 971 (53.0%) in the same quadrant.

When all three types of planning units are compared at the same time, only 342 of 971 locations (35.2%) are placed in the same priority quadrant.

The amount of concordance varies dramatically among quadrants, however. For example, the average percentage of locations ranked with High irreplaceability/High vulnerability (“High priority”) under two types of planning units was low (hexagon and hydrologic unit = 28.3%; hexagon and biophysical unit = 35.1%; hydrologic unit and biophysical unit = 29.5%). Conversely, the average percentage of locations ranked with Low irreplaceability/High vulnerability (“Moderate priority”) under two types of planning units was high (hexagon and hydrologic unit = 64.5%; hexagon and biophysical unit = 65.4%; hydrologic unit and biophysical unit = 65.9%).

These analyses, while on first glance potentially confusing, yield a number of important messages with respect to conservation planning. Some locations are assigned consistent priority ranks regardless of the type of planning unit used for the analysis. Therefore, conclusions about these locations are robust and are little affected by the methods used to subdivide the landscape. Despite the robustness of the prioritization for some places, however, consideration must be given to the scale at which the results of the prioritization analysis will be used. The priorities for some locations vary dramatically depending upon the scale at which the measures of irreplaceability and vulnerability are aggregated. A location that has a high priority for conservation when it is considered only in the context of the surrounding 10 km² might actually score with a low priority when it is considered in the context of its associated watershed.

COMPARISONS BETWEEN CURRENT AND FUTURE THREATS

Priority scoring of planning units across the Current and Future Human Footprint scenarios remained relatively similar with respect to total area assigned to each quadrant (Table 6.1). One exception to this was the FHF Fast Growth Pacific Northwest Scenario, which had less area assigned to the High irreplaceability/Low vulnerability quadrant and a corresponding increase in High irreplaceability/High vulnerability for all three types of planning units. This is explained by the higher degree of threat produced by this scenario (see Section 5). Under the PNW scenario, the high county-level growth rates produced greater threats, especially where those threats coincided with higher scores for irreplaceability.

Of additional interest are the comparisons of priorities between Human Footprint scenarios as a means of assessing urgency of action (Figures 6.7–6.9). Again, retaining the 10-km² hexagon as a planning unit enabled more detail in assessing those areas scattered throughout the landscape that were most in danger of transitioning from low to high threat in the next 40 years regardless of the scenario. Many of these either surrounded or appeared in connectivity zones between blocks of relatively undeveloped land. Wholesale conversion from low to high vulnerability at the scale of a hydrologic unit or biophysical unit was much rarer in nature, with fewer than 5 in any given scenario undergoing this transition—most often under the FHF Fast Growth Pacific Northwest Scenario. These were markedly different depending on the type of planning unit used. For hydrologic units, those most likely to become converted were in southern Maine, Nova Scotia, and Québec. Several biophysical units most likely to shift from low to high vulnerability were concentrated in New Brunswick and western Nova Scotia, with others on the northern tip of Cape Breton and the Gaspé Peninsula.

IMPLICATIONS FOR CONSERVATION PLANNING

At a broad scale, particular places in the Northern Appalachian/Acadian ecoregion consistently stood out with regard to their position on the Irreplaceability/Vulnerability axes. In agreement with Noss et al.,⁴⁴ we consider those areas that are not under immediate threat but are nonetheless ecologically important to share priority status with those irreplaceable planning units that are currently under siege. Proactive protection of such sites that are relatively intact is merited, given some of the trends of intensifying human activity projected for other parts of the region. Regarding specific points on the landscape, however, this analysis has shown that there is only a moderate likelihood that they will be consistently assigned to the same quadrant on the Irreplaceability/Vulnerability axis depending on the type of planning unit being deployed.

For those seeking detailed information, assigning priority rankings to the smallest planning unit may appear preferable because the hexagon scale provides the best window into the variability inherent in the landscape. Indeed, Noss et al. remarked on the fact that scaling planning units up “hides information.” This was particularly the case for pinpointing sites that are most likely to increase in vulnerability status, many of which lie within zones of connectivity between important relatively intact areas. On the other hand, the ecological or management relevance governing the choice of planning unit cannot be underestimated. For example, hydrological processes merit focus at watershed scales and wide-ranging species warrant attention at larger scales. While the 10-km² planning units provide one useful scale for analyses, biologically meaningful units should be the targets of conservation action. This analysis, however, should if nothing else demonstrate that the selection of the planning unit has great bearing on the ultimate results in priority ranking, and must therefore be chosen carefully. Furthermore, individual layers that collectively contribute to assessments of irreplaceability and vulnerability should not disappear from view, and will be equally valuable to planners characterizing the landscape in question.

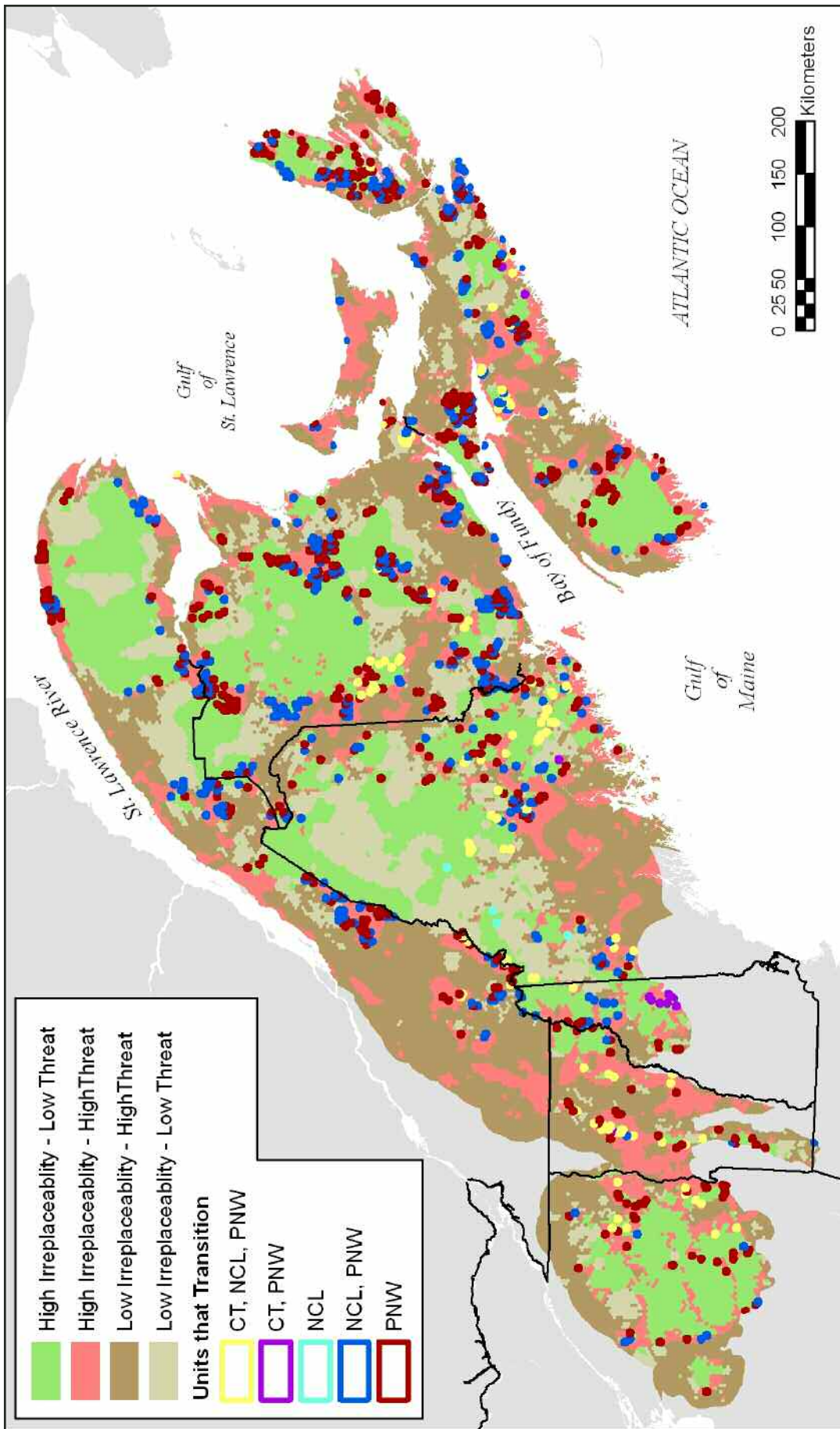


Figure 6.7. Hexagons that transition from a current state of High irreplaceability/Low vulnerability to a state of High irreplaceability/High vulnerability are highlighted in varying colors reflecting the future scenario under which the level of threat transitions from low to high. CT = FHF Current Trends Scenario, NCL = FHF Rapid Growth—North Central Lakes Scenario, PNW = FHF Rapid Growth—Pacific Northwest Scenario.

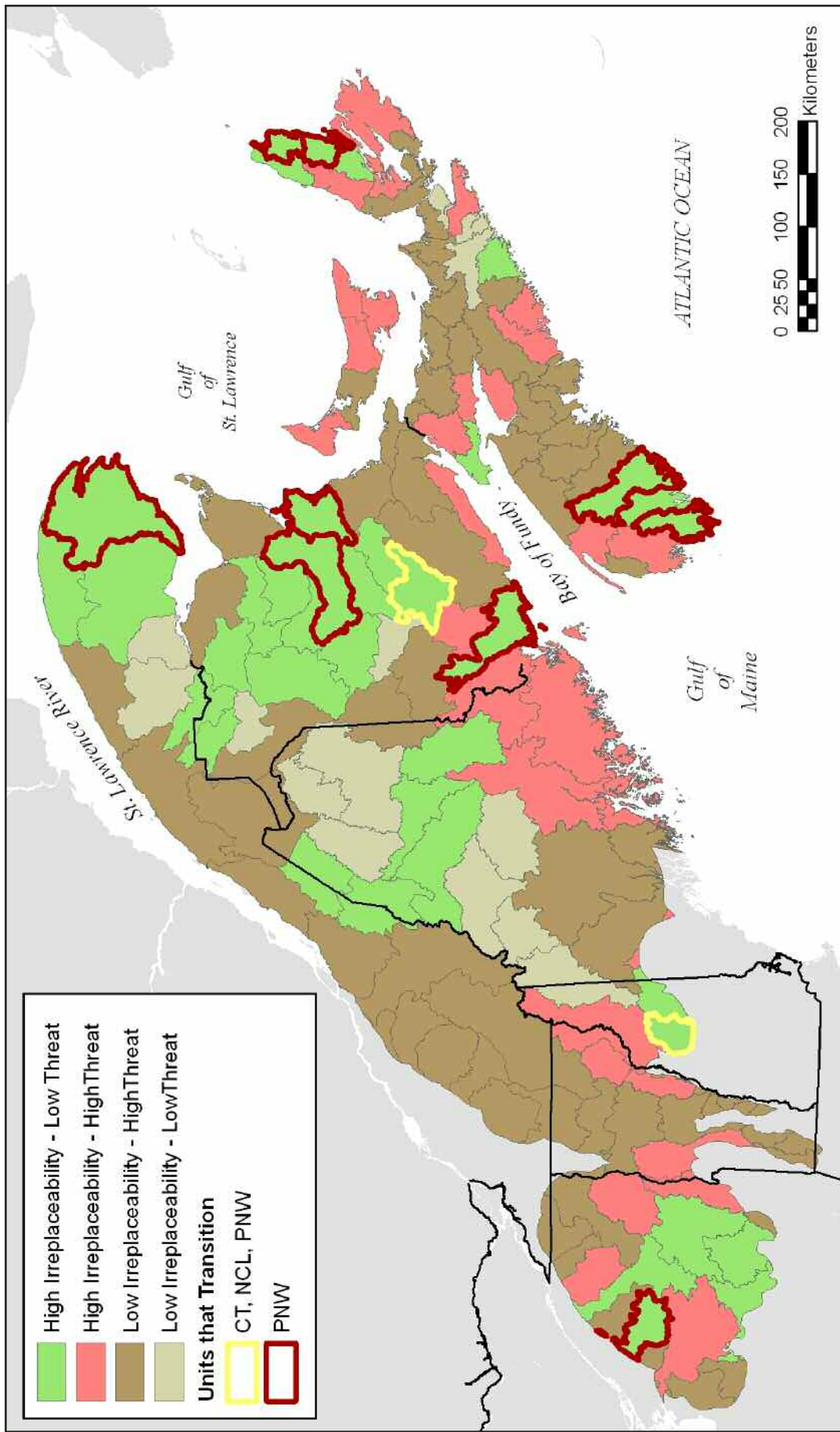


Figure 6.8. Hydrologic units that transition from a current state of High irreplaceability/Low vulnerability to a state of High irreplaceability/High vulnerability are highlighted in varying colors reflecting the future scenario under which the level of threat transitions from low to high. CT = FHF Current Trends Scenario, NCL = FHF Rapid Growth—North Central Lakes Scenario, PNW = FHF Rapid Growth—Pacific Northwest Scenario.

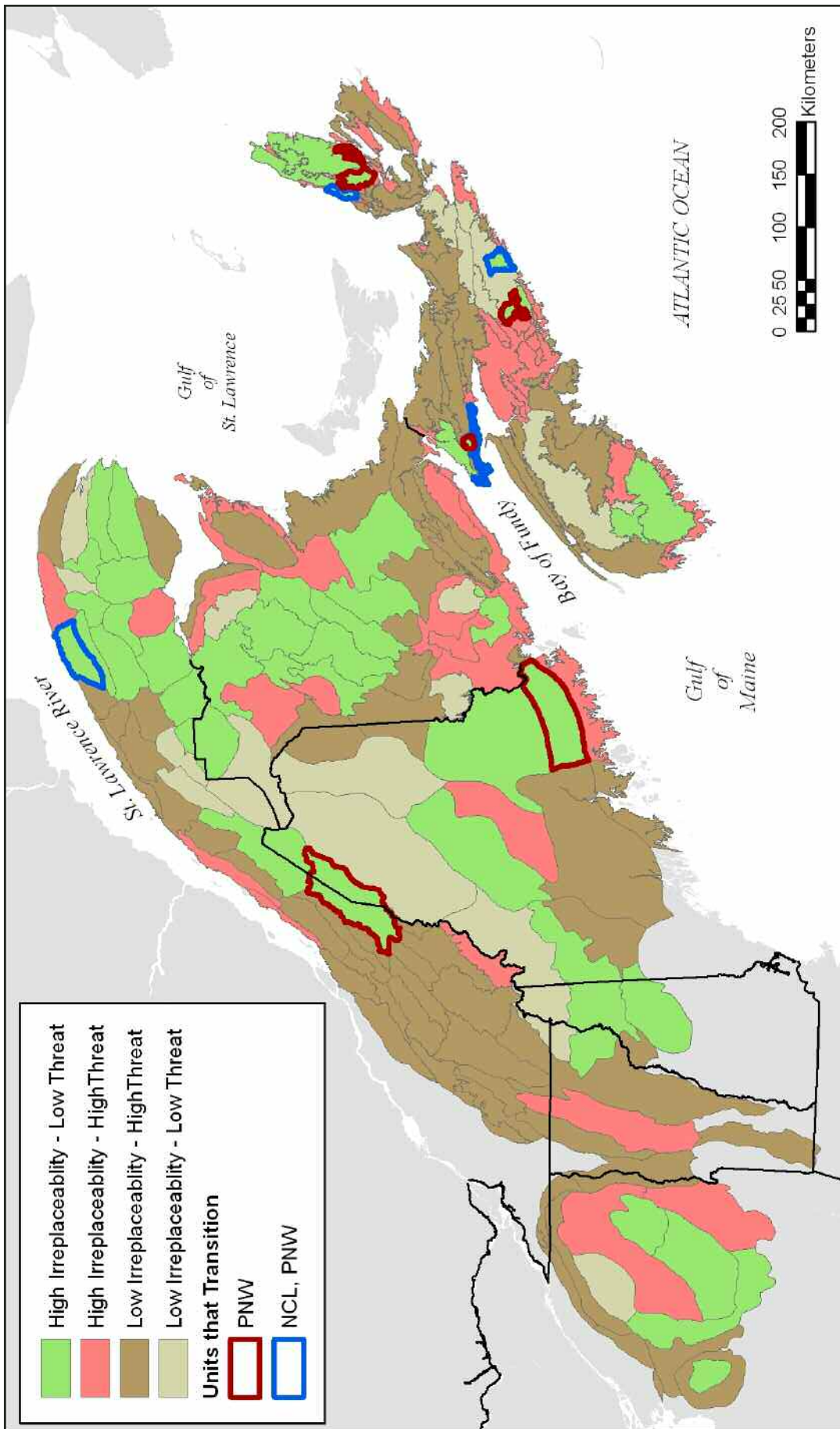


Figure 6.9. Biophysical units that transition from a current state of High irreplaceability/Low vulnerability to a state of High irreplaceability/High vulnerability are highlighted in varying colors reflecting the future scenario under which the level of threat transitions from low to high. CT = FHF Current Trends Scenario, NCL = FHF Rapid Growth—North Central Lakes Scenario, PNW = FHF Rapid Growth—Pacific Northwest Scenario.

7. Conclusions

KEY FINDINGS

This report provides a rich assortment of perspectives and conclusions that can help inform practitioners about how to assess priorities for conservation action in the Northern Appalachian/Acadian ecoregion. This conservation assessment was made possible through an enormous investment of time and resources over several years by numerous organizations and individuals to produce the component studies necessary for this planning process and to synthesize these into a comprehensive assessment. As such, this report represents a robust example of collaboration across a culturally and politically complex North American ecoregion. We hope that people working at smaller scales across the region as well as those working in other ecoregions will learn from, apply, and build upon our work.

The spatially explicit, high-resolution maps of the Northern Appalachians ecoregion that result from the work described in this report allow for the comparison of conservation irreplaceability and threats faced by locations throughout the region. Because of myriad local problems that may be addressed using these maps, the patterns and lessons that emerge from them are too numerous to list. Yet, the high resolution at which the mapping has been conducted allows meaningful patterns to be seen even by conservation practitioners working exclusively at the local level. However, our report does describe and evaluate broad patterns in this ecoregion, including (a) large areas that still retain characteristics of “wild” landscapes and that have not yet experienced permanent transformation to settlement, (b) large areas of permanent transformation that threaten and increasingly fragment the “wild” landscapes, (c) an increase in transformation in most locations under most future scenarios, and (d) areas of high irreplaceability and vulnerability across the region that are not currently protected or targeted for protection.

This analysis has taken some important steps forward from past landscape-scale planning exercises. By applying conservation planning science, we

have maximized the quantitative nature of the prioritization process. Further, we have evaluated how priorities differ when different divisions of the landscape are used as planning units (biophysical regions, hydrological units and 10,000 ha planning units) and have developed a new methodology for assessing the Future Human Footprint.

For conservation practitioners the key points that can be taken home from this report are the following:

- ~ The information can be used in two ways. First, it can be used to identify and address the most urgent priorities in the form of conservation triage. Thus, locations that are both highly threatened and highly irreplaceable could receive immediate attention. These locations will likely also be the most expensive to achieve conservation results. Second, it can be used to identify and secure those highly irreplaceable sites that are less threatened; this is a longer-term strategy and also in most cases less expensive. Individual circumstances will dictate the trade-off between these, with human and financial resources determining the extent to which a proactive approach can afford to be adopted. History and experience have made it clear that both are necessary elements for conservation action.
- ~ There are multiple systematic means of prioritizing areas for conservation action, many of which can be derived from data-driven processes. Priority locations for conservation can be identified based on the ecological features found in those locations or on the threat those locations are under, or a combination of the two.
- ~ Even in systematic approaches, the relative contribution of a location to the conservation of ecological features is based on value judgments, such as what ecological features are important, how much redundancy is desirable across the landscape, and how important it is to avoid fragmentation. However, if these judgments are

quantified and made transparent, comparisons of the ecological importance of different locations can be objectively made and subsequently adjusted as more information becomes available and values change.

- ~ Ranking locations within a landscape based on the relative degree to which they are threatened and irreplaceable for conservation within the landscape provides important information about priorities for conservation action. However, rankings can be highly sensitive as to how and at what scale locations in the landscape are grouped together into planning units. For example, a hydrologic unit that scores as being both highly irreplaceable and highly threatened may overlap with two or more biophysical units, none of which rank highly in either category. Thus, interpretation of the rankings presented in this report (Section 6) requires both careful consideration of the best way to group locations for a particular conservation goal (e.g., hydrologic units may be most relevant for addressing the conservation needs of aquatic features or preserving water quality) and a comparison of multiple ways to assess the robustness of the conclusions.
- ~ Some locations will consistently emerge with the same priority ranking for conservation action regardless of the assessment method used or how locations are grouped together to form planning units. In contrast, the priority ranking for other locations will vary and be highly sensitive to both the assessment method used and how locations are grouped. The fact that there is not one unique objective measurement of priority for all locations does not undercut this approach to assessing priority locations for conservation action. Rather, it highlights the importance of assessing the robustness of all spatially explicit conservation initiatives, as we have demonstrated.
- ~ When the priority ranking of a location remains constant regardless of assessment method or planning unit used the priority ranking of that location should be considered robust and with a high degree of certainty. However, when the

priority ranking of a location is sensitive to the assessment method or planning unit used the results can be considered less robust and should be subjected to a greater degree of evaluation to ensure that the scenarios, assumptions, and philosophies of the assessment methodology and the grouping of locations into planning units best matches the needs and expectations of the decision-making community.

- ~ For the Northern Appalachian/Acadian Ecoregion we have found that the choice of planning units (hydrological units, biophysical regions, or 1,000 ha hexagons) plays a significant role in the resulting priority ranking for many locations (Section 6). We recognize that many planners and practitioners will be politically or technologically constrained in their choice of planning units and, in some instances, their planning areas may have no particular ecological relevance (e.g., municipalities, states). In such cases, it is important to understand the constraints that the pre-defined planning area and planning units have on the results on the evaluation of conservation priorities. While overcoming such constraints may not be an option, understanding the elements driving the underlying patterns of priorities that emerge will result in better interpretations of the results and better planning decisions.
- ~ It is important to remember that we live in a dynamic landscape—both ecologically and in terms of human activity (of course, both are linked). The priorities set in exercises with the assumptions of today, will indeed shift as changes accrue in our region—changes not anticipated by our scenarios. Thus, we view our work as a first step in a continually updated, iterative process.

We believe that the strength of this prioritization assessment lies in the fact that we considered a diversity of ecological features, we incorporated both ecological importance and threat, both at present and in the future under plausible scenarios of human development, and applied the prioritization framework to multiple scales of planning units. However, when applying the results of this assess-

ment it is important that practitioners clearly understand that the resultant priority rankings are relative to all other locations across the entire Northern Appalachian/Acadian Ecoregion. For example, a location in Nova Scotia identified as having a low level of irreplaceability is ranked as such in comparison to all other locations in the ecoregion. However, within the bounds of Nova Scotia alone, this same location might be considered highly irreplaceable.

This stems from the fact that our work has been focused on identifying *ecoregional* priorities, and local priorities viewed only within the context of local conditions will be more properly set by more locally focused research. Furthermore, as we hope that we have convincingly argued in this report, an *ecoregional perspective* is important even while engaging in local or sub-regional planning and practice.

Although we did not perform an analysis of functional connectivity as part of this assessment we can make certain inferences regarding the value of areas within the ecoregion for structural connectivity. Indeed, our work clearly highlights areas where

the current and projected future Human Footprint is small and, therefore, are expected to allow movement of organisms over both short (e.g., via individual migration and dispersal) and long (e.g., in response to climate change) time frames. These broad areas notably include the Adirondack Mountains, northern New Hampshire and Maine, the Gaspé Peninsula, central New Brunswick, and southern Nova Scotia. Even without knowing the specific ecological requirements for all species in this ecoregion, the inverse of this map—focusing on where the Human Footprint is large—highlights areas where connectivity is highly likely to be compromised (Figure 7.1): between the Tug Hill Plateau and the Adirondack Mountains and from there eastward to the rest of the ecoregion; from the Green Mountains in Vermont northward through southern Québec and from there northeastward; between northern Maine and New Brunswick through the St. John River Valley; and between New Brunswick and Nova Scotia across the Chignecto Isthmus. These are locations whose current and



Figure 7.1. Areas identified as important for ecoregional connectivity.

projected future degrees of transformation suggest that ecological connectivity in general should become a priority for conservation action. The data sets developed in the analyses have the combination of ecological breadth and fine-scale resolution, both critical to future efforts to model connectivity design and multi-species linkages responsive to climate change in ways that will allow these problems to be addressed on the ground.

The connectivity potential for any given area will be responsive to intra- and interspecific variation in the migration and dispersal behavior of wildlife as well as changing ecological conditions, including land use and climate change, atmospheric deposition, and other threats. Landscape connectivity theory, climate change and atmospheric deposition models, and field studies of focal species will need to be employed to derive models of functional connectivity throughout the ecoregion. At the simplest level, corridors or linkages might be identified purely on the basis of the Human Footprint. However, it is much more likely that answering the connectivity riddle will entail a new set of analyses based on many of the input parameters described in this report.

By a similar token, while this analysis adopts a future perspective with respect to the degree of land transformation that can be projected, it has not incorporated any consideration of how future changes to climate might affect such patterns, or how priorities might shift as a result. These considerations, while important for all future landscape-scale conservation initiatives (especially in light of climate change), are dependent on further theoretical and analytical developments in the field of conservation biology, developments in which we are currently engaged.

NEXT STEPS

This report has been primarily created for practitioners as a guideline for decision making. Much of the data presented in this report are available online at the Northern Appalachian/Acadian Ecoregion Conservation Planning Atlas (<http://www.2c1forest.org/atlas>). This on-line resource is provided by Two Countries, One Forest/Deux Pays, Une Forêt as a service in order to promote the dissemination and enhance the utility of these results. It is our intention that this work be

viewed within an adaptive management framework. In fact, the ultimate success of the efforts represented by the analyses in this report cannot be measured until the applicability of the results has been tested on the ground, and the feedback loops made complete. 2C1Forest, and all of us who participated in this project, are continually engaged in the region and able to adjust the methodology and results as more and/or better information becomes available.

The next step is for conservation practitioners to apply these results at the various scales at which they work. We have provided a means to incorporate ecoregional priority into the local planning processes for conservation initiatives. The choices of whether to include these assessments and at what point in the planning process are, of course, up to the practitioner to make. However, our experiences over the last several years with presenting portions of these results to conservation practitioners throughout the region suggest that these results are remarkably effective at stimulating dialog among participants in the planning process. We are especially convinced that they help people understand the importance of scale, by realizing that planning efforts in one location are embedded in the realities of conservation planning in other locations. Introducing these data early in the planning process allows the practitioner the opportunity to incorporate these perspectives into their planning processes, increase the scope of issues addressed in these processes, expand the time frame over which conservation goals are set, increase an appreciation for how the potential for future trends can influence current decisions, and widen the circle of people included in the conversation. Time and again, conservation practitioners have seen that all of these characteristics improve the quality—and ultimately the success—of conservation planning.

Additional analyses that build upon those presented in this report are, of course, also necessary and relevant. These include, but may not be limited to, analyses of functional connectivity, future scenarios of transformation based on ecological and social responses to climate change, species-specific conservation strategies developed on an ecoregional scale, and evaluations of size needs of core areas and thresholds of landscapes transformation for the most vulnerable species.

We see this synthesis as a first step toward con-

conservation planning in the Northern Appalachian/Acadian ecoregion in this new century. We began this report by highlighting the significant advances in conservation planning in the 20th century, while noting the limitations in successful implementation on the ground, as evidenced by the continuing and accelerating losses of and threats to biodiversity. Transition to a new era of conservation entails attention to three main themes: consideration of the landscape context in which site-based conservation takes place; appreciation for how conditions relevant to conservation might change in the future; and a perspective that recognizes that conservation is made easier by attention to priorities in advance of crises.

In closing, we view this report as a reinvention of conservation for the Northern

Appalachian/Acadian ecoregion and, by example, for ecoregions everywhere. Other steps must follow, such as improving our approaches to conservation planning in the face of climate change and employing connectivity research, but these can now build upon the foundation we have laid.

Finally, we invite our colleagues throughout the region—from academia, NGO's, private industry, and government—to read, comment, and improve upon our study. We have laid open our methods, made our data available, and are open to meaningful collaboration to further this work. To conserve this dynamic ecoregion and others—the species, ecosystems and human communities that it contains—requires renewed vision, passion, inspiration, and thoughtful dedication in both science and practice. Together we can lead the way.

8. Resources for Practitioners

On one level, conservation planning is an intuitively obvious activity. The basic tenets of conservation are relatively easy to understand and apply. Most people understand the concepts of core areas and connectivity. However, in practice the science of conservation planning is far more complex. This is because nature does not conform to easy formulations. Dispersing animals, for instance, do not always follow the “corridors” that seem obvious to us when looking at air photos. As a result, the science of conservation planning has become a complex, quantitative endeavor beyond the time and resources of many practitioners to fully comprehend. Similarly, there is a rich history of ecological research in the region, and reading those foundational papers and books is a prerequisite for understanding science-based conservation initiatives currently taking place. Many readers will already be familiar with these resources and most are cited throughout this report. We have selected representative resources to highlight below, fully recognizing that a complete treatment would require writing a book on the topic.

SELECTED PEER-REVIEWED LITERATURE ON CONSERVATION PLANNING

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Scott, J. M., F. Davis, F. Csuti, R. Noss, B. Butterfield, C. Groves, H. Anderson, S. Caicco, F. D’Erchia, T. C. J. Edwards, J. Ulliman, and R. G. Wright. 1993. Gap analysis: a geographic approach to protection of biological diversity. *Wildlife Monographs* 57:5-41.

WEBSITES WITH INFORMATION OR TOOLS FOR CONSERVATION PLANNING

Two Countries, One Forest/Deux Pays, Une Forêt
<http://www.2c1forest.org>

Northern Appalachian/Acadian Ecoregion
Conservation Planning Atlas
<http://www.2c1forest.org/atlas>

MARXAN
<http://www.uq.edu.au/marxan/>

The Nature Conservancy: Northern Appalachian
Ecoregional Plan
<http://conserveonline.org/workspaces/ecs/napaj/nap>

Corridor Design
<http://www.corridordesign.org/>

CRITICAL READING FOR THE NORTHERN APPALACHIAN/ACADIAN ECOREGION

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Baldwin, R. F., S. C. Trombulak, M. G. Anderson, and G. Woolmer. 2007. Projecting transition probabilities for regular public roads at the ecoregion scale: a Northern Appalachian/Acadian case study. *Landscape and Urban Planning* 80:404-411.

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HUBBARD BROOK RESEARCH FOUNDATION SCIENCE LINKS: LINKING SCIENCE AND PUBLIC POLICY

http://www.hubbardbrookfoundation.org/science_links_public_policy/

INFORMATION ABOUT CLIMATE CHANGE IN THE NORTHERN APPALACHIAN/ACADIAN ECOREGION

Northeast Climate Impacts Assessment (U.S.)
<http://www.northeastclimateimpacts.org/>

Environment Canada
<http://www.ec.gc.ca/climate/home-e.html>

WHITE PAPERS THAT ADDRESS THE NORTHERN APPALACHIAN/ACADIAN ECOREGION

Anderson, M. G., A. Olivero, C. Feree, D. Morse, and S. Khanna. 2006. Conservation status of the Northeastern U.S. and Maritime Canada. The Nature Conservancy Eastern Resource Office, Boston, MA.

Carroll, C. 2005. Carnivore restoration in the Northeastern U.S. and Southeastern Canada: a region-scale analysis of habitat and population viability for Wolf, Lynx, and Marten. Special Paper No. 6, Wildlands Project.

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Endnotes

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