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PERSPECTIVE

A scale dynamics approach to integrate landscape conservation within and across jurisdictional boundaries

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Abstract
Context Public-private partnerships are needed to conserve landscapes, waterscapes, and seascapes. Landscape conservation design (LCD) translates shared objectives into spatial priorities to guide conservation efforts and foster collaboration among partners at the landscape level.
Objective We examined LCD projects in the eastern United States to identify implementation and coordination challenges and propose solutions that facilitate integration across projects in instances when coordination and continuity of conservation efforts is paramount.
Methods We apply a scale dynamics approach to LCD that identifies *what* conservation actions to take (goals scale), *how* to conduct those actions (implementation scale), and where to take those actions (spatial scale) to benefit species and ecosystems (ecological scale). Additional steps include identify *who* (jurisdiction scale) will take those actions and *when* (threats scale) those actions should be taken.
Results We found that although LCD projects span ecological, spatial, temporal, and jurisdictional scales, focusing only on spatial or ecological scales resulted in poor integration among adjacent projects when few species or ecosystems were the target of more than one LCD project.
Conclusions Variation in approach among LCD projects poses a challenge to project coordination and project integration with existing conservation planning efforts and products. This challenge exists within and across jurisdictional boundaries. The scale dynamics approach provides a trans-project basis for integration across multiple LCD projects.

Keywords Conservation planning · Landscape conservation · Landscape management · Protection · Restoration · Social-ecological system

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Introduction

As the challenges affecting conservation increase in complexity and magnitude, there is a greater premium placed on solutions that can accommodate and address these issues. While a range of guidance exists for developing new conservation plans, there is little guidance as to how to integrate existing conservation plans being pursued by public and private conservation partners. Nonetheless, the need to integrate existing projects regularly arises when coordination and continuity of conservation efforts is paramount. For example, conservation issues typically span jurisdictional boundaries such as states, or existing, jurisdiction-specific plans overlap such as state and town plans. The need also arises when different goals are integrated in the decision process or when multiple goals are expressed as a prioritized map intended to guide shared conservation action. Such guidance would facilitate identification of shared and unique goals, translate those goals into implementable actions, improve communication among multiple conservation partners, reveal efficiencies gained by cooperative action, and enable performance evaluation (Bixler et al. 2016; Liberati et al. 2016). Large landscape conservation is an emerging field that espouses a holistic view of conservation as an activity that reaches across large geographic areas and encompasses a diverse suite of stakeholders spanning multiple sectors (Network for Landscape Conservation 2018). Within this field, landscape conservation design (LCD) is emerging as the primary means of landscape conservation planning for the USFWS National Wildlife Refuge System (Strategic Growth Policy 602 FW 5) and elsewhere to support species-based population objectives and contribute to ecologically connected networks of public and private lands (Leonard et al. 2017; Comer et al. 2018; Evans et al. 2019; Loeb and D'Amato 2020).

LCD is a framework applied within the context of landscape conservation for achieving partners' missions, mandates, and goals while ensuring sustainability of ecosystem services for current and future generations (Landscape Conservation Cooperative Network 2014). The LCD framework consists of a process (to design) and a product (a design) that identify what actions to take, where to take them, and for what purpose. The LCD process includes: convening partners with responsibilities and authorities in the geographic area of interest, identifying a shared vision and conservation goals, articulating measurable objectives for conservation features of interest from species to ecosystem processes, assessing current and projected changes in landscape patterns and process, identifying desired future conditions, modeling scenarios and conservation tradeoffs, and implementing strategies (Landscape Conservation Cooperative Network 2014, 2016; Campellone et al. 2018). The LCD products consist of maps, models, and reports that document key stages and outputs of the LCD process. Inherent in the definition of LCD is that the product(s) when implemented maintain(s) current landscape pattern where ecosystems are intact and invokes intentional change(s) of landscape pattern to provide sustainable ecosystem services in a social-ecological system context (Nassauer and Opdam 2008). A multi-disciplinary, partnership-based approach that includes experts in natural, cultural, economic, and policy domains can facilitate the design of landscapes that sustain natural and cultural resources (Bartuszevige et al. 2016).

While increasingly prominent, LCD it is not the only landscape-level planning approach, nor do LCD projects supplant previous efforts. Conservation scientists and practitioners have implemented systematic conservation planning to identify new areas that conserve biodiversity (Margules and Pressey 2000) and strategic conservation planning to develop and implement management strategies in conserved areas (Groves and Games 2016). Frameworks such as Conservation Action Planning (The Nature Conservancy 2007), Conservation by Design (The Nature Conservancy 2016), and the Open Standards for the Practice of Conservation (Conservation Measures Partnership 2013) provide guidance for conservation planning inclusive of systematic and strategic approaches. However, LCD are a primary planning instrument of several federal agencies.

Landscape Conservation Cooperatives, led and staffed by the US Fish and Wildlife Service, were the primary entity for coordinating and developing LCD projects at regional to national levels in North America. The Landscape Conservation Cooperative Network formed in 2010 as a coalition of 22 partnerships comprised of federal, state, and local governments, Tribes and First Nations, non-governmental organizations, universities, and interested public and private organizations who defined, designed, and delivered landscapes that could sustain natural and cultural resources at desired levels into the future. Although Landscape Conservation Cooperatives pursued individual LCD projects within their own boundaries, lack of funding coupled with the unique ecological, cultural, and sociopolitical setting of each partnership, and the variety of planning and design options, hampered efforts to assemble LCD projects at the Network level cohesively. Towards that effort, Landscape Conservation Cooperatives established several regional and national-level initiatives, including the Southeast Conservation Adaptation Strategy, Nature's Network, and the Midwest Landscape Initiative. Despite substantial progress and reviews documenting their successes in facilitating planning, development of new methodologies, and engagement and public outreach (National Academies of Sciences, Engineering, and Medicine 2016; Baldwin et al. 2018), Landscape Conservation Cooperatives were underfunded from the start and systematically underfunded or eliminated beginning in 2017 such that only six of the 22 cooperatives were extant by 2019. As a result, core challenges of consistency, applicability, and scalability of LCD at regional to national levels persist (Baldwin et al. 2018).

Our goal was to identify options for integrating existing LCD projects using case studies across Landscape Conservation Cooperatives. We examined existing LCD projects led by five Landscape Conservation Cooperatives of eastern North America. We used a scale dynamics framework (Cash et al. 2006) to classify and organize LCD project attributes based on common scales (e.g., spatial, temporal, and ecological) and identify additional scales relevant to LCD (e.g., goals, jurisdictional, and implementation) as a form of network governance (Scarlett and McKinney 2016), which enabled us to highlight challenges that emerge when working across multiple LCD projects whether within a particular jurisdiction or across them. In doing so, we illustrate how LCD projects can be re-framed from conservation defined by spatial and ecological scales to one defined by conservation goals and actions to protect, restore, and manage species and ecosystems. Although we use LCD projects as specific examples, the approach is applicable generally and provides a framework for including social scales in landscape conservation. We conclude with recommendations to planners, managers, and scientists for applying the scale dynamics approach to existing and future landscape conservation projects.

Case studies of landscape conservation design

Landscape Conservation Design projects are complex. A typical LCD project spans several states, multiple organizations and agencies, and addresses conservation needs of 10 to 100 s of species and habitats. We used a scale dynamics approach (Cash et al. 2006) to classify and organize LCD projects into scales and levels. In scale dynamics, scale refers to a domain (i.e., spatial, temporal) and level refers to a particular extent, duration, organization, or unit within each domain (Table 1; Gibson et al. 2000). For example, the spatial scale includes levels of patch, landscape, region, and continent. In this way, the scale and level terminology is more descriptive and less ambiguous than scale alone and enables application to additional scales relevant to human-environment interactions (e.g., Brown and Murtha 2019; Ogletree et al. 2019). Using this terminology allowed us to work with multiple scales simultaneously, facilitated comparisons for LCD projects operating at different levels, and enabled identification of scale challenges.

An LCD project defined by spatial scale only connects to projects that overlap in spatial extent or contain the same species or ecosystems. To overcome the spatial boundary, we conducted a simple key word analysis of goals or objectives statements of LCD projects to identify one or more trans-project scales for integration of LCD projects. The most common key word was conserve (6), followed by sustain (3), manage (2) and protect (1). Based on this simple key word analysis, we suggest conservation constitutes the highest level with conservation actions of protect, manage, and restore constituting lower levels (Fig. 1). In this way, protect, manage, and restore simultaneously constitute action-specific objectives that connect the goal scale to other scales. Action-specific objectives also may address ecosystem services (Albert et al. 2014), human livelihood and well-being (Chan et al. 2012), or landscape connectivity and partnership opportunities (Liberati et al. 2016).

Action-specific objectives specify what actions to conduct and for what purpose, but they do not say how to conduct those actions. For this, we identified an implementation scale, which consists of the policy and management options for conducting conservation (Fig. 1). Common policy options include acquiring lands or rights (e.g., fee simple or easement), offering financial incentives

Table 1 Scales and levels in landscape conservation design

Scale	Attributes	Organization	Levels
Goals	Purpose of LCD effort expressed as actions to conserve natural and cultural resources	Hierarchical, prioritization, or sequential	Protect Restore Manage
Implementation	Outputs of the LCD process expressed as plans, maps, and policy and management tools for implementing LCD	Unordered	Strategies Conservation opportunity areas Policy tools Management tools
Spatial	Geographic extent of project area. Resolution = minimum mapping unit	Hierarchical	Continent Region Landscape Patch
Ecological	Biological organization Resolution = list of species, vegetation types, or ecosystems	Hierarchical	Ecosystems Communities Species
Jurisdictional	Administrative organization consisting of political units within the project area	Hierarchical	National State Municipality
Threats	Actual (current) and anticipated (future) impacts to the conservation targets	Prioritization or sequential	Climate change Land-use and land cover change Sea level rise
Temporal	Time frame expressed as project horizon Resolution = time steps	Hierarchical	Century Decade Year
Model	Qualitative and quantitative methods of translating natural and cultural resource information into maps	Unordered	Landscape attributes Waterscape attributes Species attributes
Decision-making	Methodology for selecting a course of action among alternative possibilities	Hierarchical	Structured decision making (Spatial) optimization Prioritization Stacking

(e.g., cost-sharing, tax credits), providing technical assistance (e.g., workshops, demonstration areas), or regulating the amounts or types of activities that may occur (e.g., zoning, best management practices). Common management options include actions that alter landscape or waterscape conditions, such as revegetation (e.g., establishment of vegetation), habitat enhancement (e.g., forest management, stream bank stabilization), remediation (e.g., replacement of degraded or destroyed habitat, removal of culverts), and mitigation (legally mandated remediation).

The implementation scale leads to the spatial scale (project extent) and ecological scale (species, communities, and ecosystems of conservation interest). In the scale dynamics framework the spatial and ecological scales may be nested, but rather than nesting within project boundaries they nest by policy and management options within goals. In this way, multiple spatial-ecological scale combinations may be embedded within each broader goal that defines LCD projects individually and in aggregate.

The scale dynamics approach outlined here identifies what conservation actions to take (goals), how to conduct those actions (implementation), and where to take those actions (spatial) (Fig. 1). This approach is extensible and can incorporate additional scales that further connect the goals and implementation scales to the spatial scale (Table 1). For example, at times, it may be valuable to include a jurisdictional scale, which identifies administrative or political units within the project area and identifies who (i.e., conservation agencies, organizations, or partners) will take those actions. Similarly, a threats scale identifies

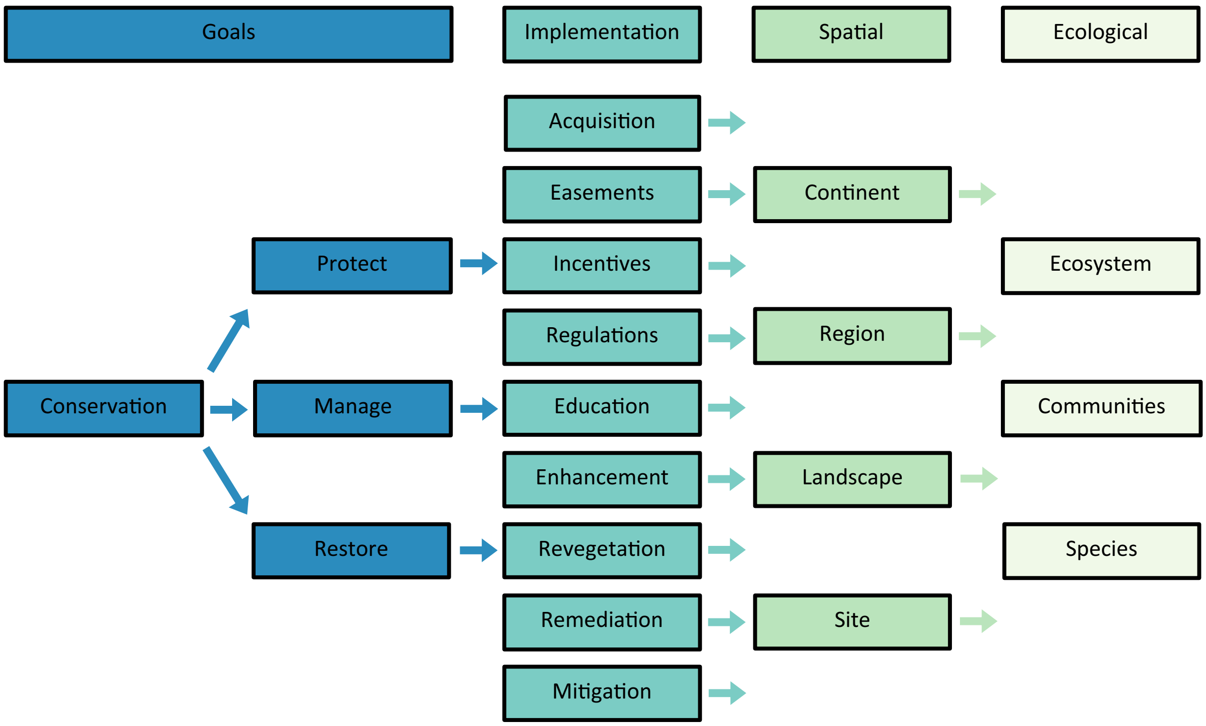

Fig. 1 Scale dynamics approach to landscape conservation design. Each goal defines pathways that describe what to do (goals scale), how to do it (implementation scale), where to do it (spatial scale), and for what benefits (ecological scale). Multiple maps, each corresponding to a project goal, communicate the landscape conservation design to partners, stakeholders, and the public

when it may be appropriate to take conservation actions.

We applied the scale dynamics approach to five LCD projects led by Landscape Conservation Cooperatives in the eastern United States. We selected projects that were completed or close to completion, meaning that final products and maps of the LCD were available to us. Some LCD projects were revised or updated during our study, in which case we used the most recent information available. We reviewed LCD reports, presentations, databases, and map resources provided online or by LCD project team members, and qualitatively coded and organized words and text passages by scales and levels.

Connect the Connecticut

The North Atlantic Landscape Conservation Cooperative's Connect the Connecticut (http://connecttheconnecticut.org; hereafter, Connect the Connecticut) project was a collaborative effort to identify and map lands and waters within the Connecticut River watershed that simultaneously support the needs of human and wildlife communities (Supplementary Fig. 1). Connect the Connecticut was considered a pilot approach for a LCD design that could be used in other large watersheds or at the regional level. The project horizon was 2080, with circa 2015 and 2080 as time steps (Supplementary Table 1). The core team that guided this effort comprised more than 30 conservation partners representing private organizations, state agencies, and federal programs within the watershed. The core team identified two shared goals:

1. Sustain a diverse suite of intact, connected, and resilient ecosystems that provide important ecological functions and services that benefit society, such as clean water, flood protection, and lands for farming, forestry, and recreation.

2. Sustain healthy and diverse populations of fish, wildlife, and plant species for the continuing benefit and enjoyment of the public.

Conservation blueprint

The South Atlantic Landscape Conservation Cooperative's Conservation Blueprint (version 2.0; hereafter, Conservation Blueprint) was a living, spatial plan to conserve natural and cultural resources for future generations (Supplementary Fig. 2). The Conservation Blueprint identified opportunities for shared conservation action in the face of future threats of climate change, urban growth, and increasing human demands on resources that are reshaping the lands and waters of the South Atlantic (http://www.southatlanticlcc.org/blueprint/, https://www.southatlanticlcc.org/indicators/). The Conservation Blueprint time horizon was 2050, with circa 2015 and 2050 as time steps (Supplementary Table 1). More than 400 people from 100 organizations participated in workshops, recommended conservation actions, and developed priority watersheds in which to work. The stated goals of the Conservation Blueprint were to:

1. Protect lands and waters.
2. Manage lands and waters.
3. Address livelihood and economic incentives.
4. Manage species.
5. Inform through education and awareness.
6. Inform laws and policies.

Conservation scenarios

The Peninsular Florida Landscape Conservation Cooperative's Statewide Conservation Scenarios Project (hereafter, Conservation Scenarios) provided visualizations of land cover conditions under three alternative futures for the state of Florida in 2020, 2040 and 2060 (Vargas et al. 2014; Supplementary Table 1). The Conservation Scenarios illustrated interactions among climate change, human population change, available conservation funding, and conservation strategies. Particular attention was paid to the potential role of large increases in voluntary private conservation, such as conservation easements. The goals of Conservation Scenarios were to:

1. Develop and integrate core science and harmonize datasets, geographic extents, and categorical classifications that will support the development of a comprehensive set of scenarios.
2. Develop a set of alternative futures to identify a series of climate-aware conservation scenarios that incorporate a variety of conditions generated by projected population growth, climate change, financial resources, and land and water policies.
3. Evaluate potential impacts of the various scenarios based on a selected set of conservation strategies and mechanisms.
4. Plan for future land uses and conditions based on adaptation strategies and modeling outcomes.

Ozark highlands conservation strategy

The Gulf Coastal Plains and Ozarks Landscape Conservation Cooperative, in collaboration with the states of Missouri, Oklahoma, and Arkansas, developed the Ozark Highlands Conservation Strategy (hereafter, Conservation Strategy), which also fulfilled the desire to include Conservation Opportunity Areas in their State Wildlife Action Plans (Supplementary Fig. 3). The Conservation Strategy was a collaborative effort to unify the vision for conservation across the Ozark Highlands in those three states (https://lccnetwork.org/resource/ozark-highlands-comprehensive-conservation-strategy, Bonnot et al. 2019). The project team included six organizations spanning state and federal agencies, non-governmental organizations, and academia (Supplementary Table 1). The goals of the Conservation Strategy were to:

1. Take an ecoregional approach to designing landscapes capable of sustaining healthy plant and animal communities in the Ozark Highlands.
2. Develop a preliminary network design to serve as a basis for engaging the broader community in the conservation of the Ozark Highlands.

Mississippi river Basin-Gulf hypoxia initiative

The Mississippi River Basin-Gulf Hypoxia Initiative (hereafter, MRB-GHI) project created an integrated framework to support planning, design, and delivery of wildlife-friendly conservation practices that address nutrient retention within the Mississippi River watershed. The project was a collaborative effort spanning 7 Mississippi Basin Landscape Conservation Cooperatives and included 53 state and federal agencies, organizations, and universities (Supplementary Table 1).

The ultimate goal of the MRB-GHI was to prioritize agricultural conservation areas by mapping the most cost-effective and receptive places for implementing practices with multiple benefits. The MRB-GHI focused on the intersection of watersheds where each of the following factors was high: nutrient export to the Gulf of Mexico; fish and wildlife habitat value, social capacity to network and offer extension and outreach, as well as visibility of projects to encourage appropriate adoption and economic drivers for conservation practices. The intent was to optimally site conservation practices using stakeholder input on desirable water quality, economic, and ecological impacts (personal communication: G. White, Coordinator of the Eastern Tallgrass Prairie and Big Rivers Landscape Conservation Cooperative).

Challenges of landscape conservation projects

There are three common challenges recognized in scale dynamics: omission, mismatch, and plurality (Cash et al. 2006). Omission (or ignorance *sensu* Cash et al. 2006) occurs when important scales and levels, or their interactions, are not included in the LCD process. We identified two new scales highly relevant to LCD, a goals scale and an implementation scale. The goals scale orients the planning teams, stakeholders, and end-users of LCD around action-specific objectives. The implementation scale consists of the policy and management options for conducting conservation.

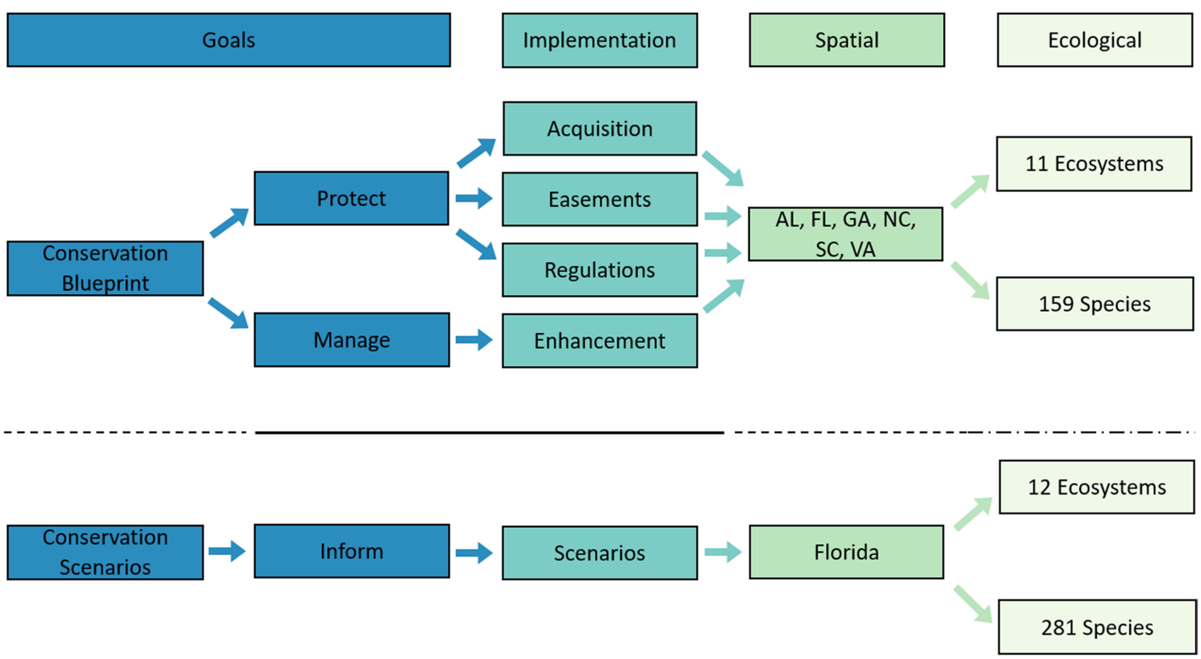

Fig. 2 Application of the scale dynamics approach to two landscape conservation design projects that overlap in space and jurisdiction, the Conservation Blueprint of the South Atlantic Landscape Conservation Cooperate and the Statewide Conservation Scenarios Project of the Peninsular Florida Landscape Conservation Cooperative. Mismatches, indicated by the solid black line, arose from differences in goals and implementation, and largely non-overlapping list of species and ecosystems. AL = Alabama, FL = Florida, GA = Georgia, NC = North Carolina, SC = South Carolina, and VA = Virginia, U.S.A

Mismatches occur when two or more LCD projects share a common scale but operate at different levels within it. For example, only the Conservation Blueprint and Conservation Scenarios projects overlapped in spatial extent, and only in northern Florida (Fig. 2). Additionally, no LCD projects had the same project horizons or time steps (Supplementary Table 1). Mismatch among and within spatial and temporal scales may be addressed through resampling or interpolating information produced at one level to another (higher or lower) level. For example, the Conservation Strategy was mapped and summarized at the catchment level (Supplementary Table 1). Catchments are a subset of HUC 12 watersheds (a more common unit for prioritization among the LCD projects we examined; Supplementary Table 1), and thus catchments may be aggregated to the HUC 12 level to provide a common spatial level (i.e., resolution) across LCD projects.

Mismatch among ecological, model, and goal scales is more complex and less easily addressed through resampling or interpolating information. For example, the ecological scale included 58 ecosystems (or habitat types) across the 5 projects of which many were represented in multiple LCD projects, yet only a few land uses (e.g., agriculture) and water features (e.g., lakes and ponds, beaches and sand, rivers and streams) were similarly defined in two or more LCD projects (Supplementary Table 1). The majority of ecosystems were uniquely defined within each LCD project and with few exceptions did not follow a national, hierarchical vegetation classification scheme. Ecological mismatch also occurred at the species level when the same species occurred in two or more LCD project areas but were not represented in all LCD. For example, > 200 species or species groups were present in the Conservation Blueprint and Conservation Scenarios projects, but relatively few species were included in both projects due to differences in LCD-specific inclusion criteria, conservation priority, or species ranges (Fig. 2). The Connect the Connecticut (16 species) and the Conservation Strategy (8 species) projects had only Prairie Warbler and Wood Thrush in common. In some cases, a species was used as an indicator of multiple species with similar habitat requirements, which may reduce ecological mismatch. Model mismatch paralleled ecological mismatch, as many of the landscape attributes, waterscape attributes, and species attributes were associated with species and ecological systems unique to each LCD project.

Mismatch at the goal scale largely stemmed from various definitions of landscape conservation. In the Connect the Connecticut and the Conservation Strategy projects, landscape conservation sustains fish, wildlife and plant species or communities. In the Conservation Scenarios project, landscape conservation identifies potential impacts from conservation actions or lack thereof. In the MRB-GHI, landscape conservation prioritizes places that offer multiple benefits. The Conservation Blueprint provides the most comprehensive and explicit definition of landscape conservation, which protects lands, waters and species; manages lands, waters, and species; provides livelihood and economic incentives, and informs people, laws, and policies on conservation. Although these differences in goals appeared minor, they affected how models were constructed. The net effect was prioritized layers that looked relatively similar (Supplementary Figs. 1, 2, 3) but reflected different conservation priorities and decisions.

Scale challenges also include plurality—a challenge that occurs when different people, groups, and institutions perceive and value scales and levels differently. With plurality, heterogeneity in perspectives, values, and approaches resulted in different emphases on LCD goals and outputs. Yet, a common output of LCD was a prioritized map with data layers that simultaneously met multiple goals and interests (Supplementary Figs. 1, 2, 3). For example, the objectives of the Conservation Blueprint included cultural resources, biological diversity, and ecological integrity, and the output—the conservation blueprint—was a prioritized map that integrated those factors. This “many to one” philosophy of integrating goals, species, and ecosystems in models and decision-making reduced the number of map products but did not simplify the map. In fact, there is growing concern that the underlying complexity of map products may actually decrease uptake by conservation partners (Theobald et al. 2000; Azzerad and Nilon 2006; Stein 2007).

The challenges of mismatch and plurality stem from a common paradox of conservation planning and design: we want to focus our efforts, but everything is unique and important. In the broadest context, conservation focuses on species and ecosystems with the explicit intent of conserving biodiversity and maintaining viable populations and sustainable ecosystems. Certainly, each species and ecosystem is worthy of conservation. Landscape Conservation Design did and should continue to focus on species and ecosystems. However, species- and ecosystem-centric LCD limits cross-boundary transfer and integration within and across landscape conservation efforts when few of the species and ecosystems of conservation interest are present above the regional level of the spatial scale.

Discussion

We illustrated the challenges of omission, mismatch, and plurality that arise when using a spatial approach to integrate LCD projects where the focus was primarily on species and ecosystems. Comparison of five LCD projects conducted by Landscape Conservation Cooperatives in the eastern United States demonstrated these challenges in practice. We presented the scale dynamics approach as an alternative that focuses on conservation goals and actions so that LCD products may effectively integrate within and across Landscape Conservation Cooperatives regardless of species or ecosystems. The scale dynamics approach identified conservation goals of protection, restoration, and management in landscape conservation, and used an implementation scale to connect those goals to spatial and ecological scales (Fig. 1).

The scale dynamics approach provides several benefits to landscape conservation efforts, particularly those centered on network governance (Scarlett and McKinney 2016) and using existing conservation standards (Conservation Measures Partnership 2013). First, it articulates some of the essential components of LCD, namely goals and implementation scales and the pathways to the ecological scale. Adoption of standards relative to these components provides a common language for LCD specifically and large landscape conservation generally that would increase uptake by and transferability across organizations, institutions and agencies that participate in landscape conservation planning.

Second, the scale dynamics approach distinguishes what is and is not a LCD by distinguishing decision support from conservation action. Conservation planning in general and LCD in particular are iterative processes: plan, implement, evaluate, and adjust the plan or implementation accordingly. There are many incremental steps and versions in the LCD processes. One important step is the development of decision support tools, such as maps of habitats, species, or other resources, as well as analytical models that help clarify relationships within and among habitats, species, and other factors of interest (Campellone et al. 2018; Hanks et al. 2019). In the Conservation Scenarios project, the outputs were spatial data layers that displayed likely future conditions for the scenarios under consideration. Yet, the Conservation Scenarios project lacked an explicit statement of action-specific objectives: what conservation actions to implement, where, and for what purpose; and thus informed decision processes, but did not constitute LCD.

Another benefit of the scale dynamics framework is the ability to identify and make clear linkages between objectives and conservation actions both within and across LCD projects, which then lay a foundation for consideration of LCD within a general outputs-outcomes-impacts framework (Mascia et al. 2014). Under this broader framework, outputs of LCD are the spatial data layers and supporting information that portray where implementation of conservation actions best meets LCD objectives. Outcomes of LCD are the means and methods by which conservation and management actions are implemented. The inclusion of an implementation scale in the scale dynamics approach makes the link between outputs of LCD (spatial data layers) and outcomes (conservation and management actions) explicit.

The impacts of LCD are changes in or maintenance of landscape and waterscape attributes, condition, structure, or function, which result from implementation of conservation and management actions. Evaluation and monitoring constitute an important extension of LCD as they are the primary means of identifying whether or not LCD objectives are being met with the conservation actions implemented (Bixler et al. 2016). Several factors warrant consideration when assessing impacts of LCD. First, many ecological systems are subject to legacy effects of past land use that may contribute to different responses to conservation actions than expected (Reece et al. 2018). Second, ecological systems can exhibit time lags that delay or mask impacts (Ahlering et al. 2020; Moore et al. 2020). Third, ecological systems have many and sometimes confounding factors that contribute to the current conditions, such as drought. Fourth, landscapes with high percentage of private land ownership present information and access issues (Loeb and D'Amato 2020). Finally, measuring LCD impacts may be challenging because landscape attributes of species diversity, redundancy, ecological integrity, habitat capability, connectivity, and distribution require monitoring to quantify changes and few funding sources support long-term monitoring at regional- to continental-levels (Mansourian and Vallauri 2014).

Application of scale dynamics to landscape conservation projects

For existing LCD projects, the primary challenge to integration with other LCD projects is likely to be plurality: many objectives and few or one output in the form of a prioritized map to guide shared action. A prioritized map becomes a barrier to integration with other projects when different goals are integrated in the decision process or when multiple goals are expressed as a prioritized map. In this situation, we recommend looking to the penultimate components of the final outputs as well as supporting information to see if there is better alignment of individual objectives (goals) and outputs (maps) within each LCD project. Then, seek common objectives and outputs across LCD projects. For example, the Conservation Blueprint and Conservation Scenarios projects overlapped in north Florida. Initial outputs from the two projects exhibited moderate agreement, but differences existed in prioritization approaches. The Conservation Blueprint prioritized the top 10, 30, and 50% of the landscape. The highest two priority classes in the Conservation Scenarios covered 43% and 16%, respectively. With those differences elucidated, it became much easier to identify options for integrating these efforts. Simply converting the Conservation Blueprint's Highest and High priority classes to cover the same percentage of the landscape as in Conservation Scenarios created a smoother transition across the two projects.

Comparing the Conservation Blueprint and Conservation Scenarios projects emphasizes three important considerations for integration between or among existing LCD efforts. First, the intent is not solely to have a smooth map—rather it is to ensure coordination of effort along boundaries where continuity is paramount. Compromise solutions that alter prioritization schemes may be well-received in this situation. Second, ensure the process produces a continuous layer of priority instead of categories of priority (e.g., low, medium, high). A continuous layer allows for maximum flexibility in integrating with other LCDs, and may be converted to categories later. Third, commit to an iterative approach to prioritization for LCD projects. New information will arise and the ability to incorporate it in the prioritization process facilitates greater integration over time, particularly when the source of information is neighboring LCD efforts. Interestingly, the issue of spatial resolution (i.e., cell size) that was initially the focus of integration efforts was ultimately the least important barrier to integration.

We suggest the following steps to improve integration with existing or future LCD projects. First, identify scales and levels of the LCD, and potential scale challenges, and address them a priori. Start by identifying what conservation actions to take (goals), how to conduct those actions (implementation), and where to take those actions (spatial) to benefit species and ecosystems (ecological). Then, identify who (jurisdiction) will take those actions and when (threats) those actions should be taken. Answering these questions necessitates inclusion of all scales essential to LCD and thereby helps address the challenge of omission. Second, define separate and non-overlapping objectives. Each objective should be complete, concise, sensitive to the conservation actions under consideration, and independent of other objectives (Gregory et al. 2012). The language of action-specific objectives increases the specificity by which conservation may be achieved. Third, strive for a one-to-one correspondence of action-specific objectives and map outputs. This means that every objective to protect, manage, or restore has an objective-specific map and thereby helps address the challenge of mismatch. Projects that have multiple goals should have multiple map products. Landscape conservation design projects have many partners and stakeholders, each with different objectives, interests, and means of implementing landscape conservation design. Maps of action-specific objectives will illustrate and communicate to partners and stakeholders how their actions can contribute to a shared approach to landscape conservation.

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Data availability All data generated or analyzed during this study are included in this published article and its supplementary information file.

Declarations

Conflict of interest The authors have no conflict of interest to declare that are relevant to the content of this article.

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