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A early successional forest management for biodiversity conservation on private lands as a coupled human and natural system

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Abstract
Facilitating voluntary conservation on private lands is a crucial element of policies that seek to mitigate forest habitat loss and fragmentation around the world. Previous research emphasizes the role of social factors (e.g., landowner characteristics, economics) in forest management, but environmental outcomes of past management can also affect landowner decisions. Our objective was to evaluate how positive outcomes for wildlife and habitat might reinforce or amplify landowner efforts to manage forest habitats. Conservation science addresses the complementary goals of preventing future biodiversity loss while sustaining critical human foundations. In this paper we use two case studies focused on land management to discuss how private lands conservation can be more effective by considering how planning and decision making reflects a coupled human and natural system (CHANS). The first case study focuses on conservation easements in the temperate forests of eastern United States; the second focuses on conservation opportunities in Midwestern agro ecosystems, in particular the value of agro forestry. For each case study we discuss the natural and human subsystems, how elements and interactions within and between subsystems (as organized by elements of CHANS) create challenges and opportunities for conservation, and the importance of considering relevant scales of subsystems. Review of these case studies demonstrates that additional insight gained by using a CHANS perspective, particularly given how the subsystems interact at different scales, improves identification of important points of social and ecological overlap, ultimately enhancing conservation research, planning, and practice. Our findings give insight into how private landowners respond to environmental effects of forest management. We conclude that positive environmental outcomes of these conservation programs are related to continued early successional forest conservation by private landowners.

Keywords: Habitat conservation, persistence, private landowners, wildlife, early successional forest agriculture, avian, Blue Ridge, conservation easements, Midwest, piedmont, scale

Introduction
Conservation biology is increasingly intersecting with sustainability science, where traditional nature conservation goals (Soulé 1985) are linked with priorities of food production (Quinn *et al*. 2014), poverty reduction (Brashares *et al*. 2014), and quality of life (Agarwala *et al*. 2014) [1]. Thus, conservation science researchers and practitioners are considering how conservation actions influence, and are influenced by, human systems (Kareiva and Marvier 2012) [13]. Understanding these connections is key to preventing future biodiversity loss while maintaining human social foundations (Raworth 2012). In this context, conserving biodiversity clearly becomes part of a coupled human and natural system (Liu *et al*. 2007). Given the benefits of systems thinking (Fiksel 2006) [8], conservation research, decision making, planning, and practice would benefit from formally incorporating elements of coupled human and natural systems (CHANS) including heterogeneity, feedbacks, time lags and legacy effects, nonlinear dynamics with thresholds, and surprises. Furthermore, mounting evidence of cross-scale feedbacks and drivers between systems requires that conservation not be focused just on a single scale or system but also interactions within and between them. Connections between human and natural systems are often implicitly discussed in regards to conceptualizations of conservation in human-modified ecosystems (reviewed in Martin *et al*. 2014). Explicit discussions of conservation biology as a CHANS are more limited. CHANS has been applied to evaluate how varied definitions of biodiversity affect practice and consideration of alternatives (Callicott *et al*. 2007),

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vulnerability of geophysical conditions in urban landscapes (Fan *et al*. 2014), and, uniquely, conservation of language and biodiversity on islands (Tershy *et al*. 2015). More closely aligned with a discussion of private lands, Strohbach *et al*. (2014) present urban wildlife conservation as an example of CHANS. Likewise, in a recent special issue on CHANS in this journal, Carter *et al*. (2014) discuss a CHANS approach to wildlife conservation, highlighting its value for linking different disciplines and leading to identification of new relationships and feedbacks that may not have been identified in previous analyses. Additionally, they discuss the value of considering relationships between people and biodiversity (or wildlife) across scales. Applications of CHANS to biodiversity conservation, particularly the recent comparable case studies (e.g., Carter *et al*. 2014), focus largely on publicly protected land designated for conservation by government authorities, e.g., national parks or scientific reserves. Although a critical element of conservation efforts, these publicly protected lands are limited to 14.8% of global terrestrial area and 13.8% in the United States (World Bank 2015). Private lands, not managed by government authorities, cover 60% of the United States (USDA 2002). Given the extent of habitat loss and land use change and the lack of formal protection, private land represents an important conservation arena (Wallace *et al*. 2008) [23]. Private land conservation presents a different set of challenges to meeting conservation goals. Private lands are individually managed for multiple purposes including recreation, natural resource extraction, conservation, agriculture, aesthetics, and habitation. Decisions are often made on smaller units of land and reflect a different set or ordering of conservation priorities (Quinn *et al*. 2015, Dayer *et al*. 2016). That each parcel is embedded within different biome and anthrome types presents unique couplings within and between human and natural subsystems. To address this complexity, we illustrate the value of framing private land conservation as a coupling of human and natural systems across spatial and temporal scales, using case studies about local and landscape decisions from two crisis ecoregions (Hoekstra *et al*. 2005). These case studies highlight dynamics within natural and human systems and how associated subsystems interact. The first case study focuses on the systems, elements, and interactions associated with conservation easements and temperate forest biomes threatened by urbanization. In the second case study we address the conservation value of agro forestry systems as a tool to align biodiversity conservation with biomass production. For both, we demonstrate how concurrent analyses of multiple systems provide opportunities to improve on past conservation efforts and reduce suboptimal decision making associated with conservation on private lands.

Natural subsystems
We first review natural subsystems in conservation efforts for temperate forest and agricultural biomes and anthromes. The scale of each subsystem is presented to frame discussions about land management within the context of the case study. Though we focus initially on natural systems, it is clear that human systems shape the primary scale of interest (i.e., easements and farms), emphasizing the coupled nature of these systems. We frame our review with global trends and local habitat requirements of key species, choosing bird species as a lens with which to highlight

implemented management practices and conservation strategies. Consideration of global change and local habitat frames the natural subsystems involved and provides a useful context for discussing specific conservation practices under a CHANS framework.

Case study #1: Conservation easements in the western Carolinas
The first case study focuses on private land conservation in temperate forests, in particular forests threatened by rapid urbanization. Over 45% of global temperate forest cover has been lost (Hoekstra *et al*. 2005) while less than 10% of this biome is protected (Hoekstra *et al*. 2005). Historically dominated by mixed temperate hardwoods, the western halves of North and South Carolina have recently experienced a net loss of temperate forest cover, driven by socioeconomic shifts and population growth since the 1940s (Drummond and Loveland 2010) [5]. Much of the region's forests are fragmented, with isolated second and third successional growth forest patches scattered between developed urban and peri-urban areas. Consequently, the region might be better described as a populated or residential woodland anthrome (Ellis and Ramankutty 2008) [6]. Like patterns of protection in forest biomes, woodland anthromes comprise 11% of terrestrial surface but hold only 2% of protected lands (Martin *et al*. 2014). Regions represented by the two case studies (bold black boundaries) embedded in their natural biome type and current anthrome (Ellis *et al*. 2010). Forests in the western Carolinas fall within the Blue Ridge and Piedmont ecoregions. Blue Ridge forests range in area, provide habitat for a diversity of species, and are thought to be important hotspots for resiliency in the face of climate change (Anderson *et al*. 2014). Despite recent land use change, some large contiguous forest blocks and old-growth patches remain, in part because of steeper terrain and complex topography, which is less suitable for logging. Down slope, the forests in the Piedmont region largely comprise small isolated patches of deciduous, mixed, and pine forests. As in the Blue Ridge forests, species found in these forest patches are diverse (Hunter *et al*. 2002, Pimm *et al*. 2014). For simplicity in the case study, we focus on two birds; Golden-winged Warbler (Vermivora chrysoptera) and Brown-headed Nuthatch (Sitta pusilla), both species of conservation concern (Partners in Flight 2012). The Brown-headed Nuthatch has declined at a rate of 0.54% per year in the last half-century (Sauer *et al*. 2014). A pine specialist (Without and Smith 1998), the nuthatch was traditionally thought to prefer large mature stands of pine. Golden-winged Warblers have declined at a steeper rate of 2.6% per year (Sauer *et al*. 2014). A neotropical migrant, the southernmost extent of their breeding range reaches western North Carolina and they primarily favor scrubby, early successional habitat at elevations above 600 m (2000 ft.) for breeding (Confer 1992). For both species, fragmentation of remaining habitat patches creates significant complications because sustained abundance is spatially determined by factors like movement, dispersal, and resource availability (Driscoll *et al*. 2013). Successful conservation of these species is clearly dependent on outcomes of private land management decisions in Blue Ridge and Piedmont forests.

Case study #2: Agro ecosystems in the Midwest and Great Plains
The second natural system we consider is agricultural land, in particular row crop agriculture that has replaced temperate grasslands and scrublands of the Midwestern

U.S.. Like temperate forests, grasslands, savannas, and shrublands have declined in area by 45% with only 4.6% protected (Hoekstra *et al.* 2005). As an anthrome, croplands are 15% of ice-free surface but only 7% of protected areas (Martin *et al.* 2014). Both the loss of natural habitat and the intensification of existing agricultural systems are resulting in declining biodiversity across farming types and regions (Krebs *et al.* 1999, Johnson *et al.* 2011) [14]. The predominance of agriculture as a land use and the need to sustain food for human populations necessitate conservation solutions for habitats embedded in productive farm systems. The clear evidence of agriculture's negative effects on biodiversity and perceived homogeneity of agroecosystems might suggest a relative clarity for conservation, a perception perhaps best exemplified by the argument for land sparing (Green *et al.* 2005) [9], where ecosystems are subdivided into native lands (or natural systems) and farmland (or the human system), with little interaction between systems (Fischer *et al.* 2008). Despite the evidence presented for land sparing, conservation in agricultural ecosystems requires a careful examination of the interactions between human and natural subsystems across scales (Balmford *et al.* 2012, Fischer *et al.* 2014). Framing conservation on agricultural lands as a CHANS better aligns with land sharing (Fischer *et al.* 2008), which acknowledges and capitalizes on the linkages between farming and nature. One well-developed practice reflecting the principles of land sharing is agro forestry, or working trees embedded in different agricultural landscapes. Hedgerows, windbreaks, fence lines and field edges, silvopasture, and other woody vegetation are examples of agro forestry found in agro ecosystems. These examples of planned diversity (Matson *et al.* 1997) [16] provide environmental benefits including mitigation of climate change (Schoeneberger 2009) [20], regulation of nonpoint source pollution (Udawatta *et al.* 2011) [22], and provisioning of habitat for native pollinator and wildlife species (Mize *et al.* 2008, Batáry *et al.* 2011, Quinn *et al.* 2014). This case study draws upon wildlife conservation efforts in the eastern half of Nebraska via woody cover in the extensive and intensive agricultural systems emblematic of the Midwestern United States. Although grassland birds are traditionally the focus of the region, recent work has focused on the conservation value of woody cover for resident and migratory birds (e.g., Puckett *et al.* 2009, Quinn *et al.* 2014). One species of particular interest is the Bell's Vireo (Vireo bellii), a Tier One species of conservation concern under the Nebraska Legacy Project. The Bell's Vireo is a shrub-nesting species whose populations have declined 0.98% annually in the central U.S. since 1966 (Sauer *et al.* 2014). Unlike many grassland species, this vireo represents a scalable conservation opportunity on farmland with a low opportunity cost to farmers (Gunton *et al.* 2016) [10].

Human subsystems
The above discussion of natural subsystems reflects the traditional focus of wildlife management and biodiversity conservation. The breadth of research focused on natural systems would suggest that conservation biology is able to recognize and suggest solutions to practitioners. However, translation of conservation research to practice involves understanding motivations, attitudes, and external controls of human systems (e.g., Quinn and Burbach 2008) [18]. Thus, the subsequent step in CHANS-thinking is adding the

human systems to conservation planning and practice. Case study #1: Conservation easements in the western Carolinas Conservation easements are a management tool, most often employed by private entities, to preserve land for natural value or historical, personal, or economic reasons (Wallace *et al.* 2008, Rissman 2013) [23]. Human systems associated with easements include landowners, land trusts, regional and national institutions and actors, and the legal terms of the easement itself. Though conservation easements are a local system and reflect individual-level decisions, they are embedded within larger human subsystems. Land use change in the western Carolinas is driven by a growing population and urban development (Terando *et al.* 2014) and a demand for woody biofuels (Johansson and Azar 2007). In the Blue Ridge ecoregion, high-elevation development is responsible for loss of habitat, particularly because good habitat is also desirable for homes with a view. Likewise, suburban development in the Piedmont ecoregion of South Carolina is driving forest loss and land use change. This latter ecoregion falls within the center of the rapidly developing Southern Megalopolis (Terando *et al.* 2014) where population is expected to increase by over 100% by 2050, resulting in greater urban development and continued stress on existing forest patches. Because of these increasing pressures on the land, and limited resources of county, state, and federal landholders, tools are needed for planning beyond the actions of government and particularly ones that involve private landowners. Conservation easements are legally binding agreements that outline prohibited activities, i.e., "negative language covenants," and reserved rights of the grantors, but do not transfer away ownership of the land. Importantly, easements do not exist to mandate affirmative actions for the landowner, but rather outline which future development or management rights have been given up by the landowner (Rissman 2013) [23]. The easement holder (a land trust or sometimes a government agency) works with the landowner to ensure compliance with these covenants and thus protect local ecosystems and their associated benefits for current and future users. Land trusts, organizations tasked with easement oversight and stewardship across a large spatial scale, preserve the land indefinitely. In total, U.S. land trusts conserve over 19 million hectares (47 million acres, Land Trust Alliance 2010). Over 37,600 and 19,800 hectares (93,000 and 49,000 acres) are held in the Blue Ridge and Piedmont, respectively (NCED 2015). Both individual landowners and land trusts affect conservation on private land. Decisions about future use and development of land, in the context of drafting easements, are complicated and influenced by economic and personal factors. It is important, though challenging, to recognize human motivations in such processes. Indeed, Monticino *et al.* (2007) speak to the difficulty of quantifying and predicting factors like "tradition value" to property owners. Likewise, the process of negotiating a conservation easement is arduous and sometimes contentious, requiring an investment of time, financial capital, legal background work, documentation of the property, and negotiations among parties about reserved rights. Accounting for human/social variables (motivations, attitudes, external controls) is highly important for successful land conservation transactions. Land trusts, too, can directly influence decision making on a particular conservation easement property, though the amount to which they pursue specific conservation

objectives varies (Dayer *et al*. 2016). Some land trusts interact more deliberately with landowners, presenting management practices that benefit a species of conservation concern, which may or may not be facilitated by the landowner. However, the conservation goals of land trusts may not be as specific or intentional and thus not as useful as they have the capacity to be if systems, objectives, and goals were better aligned (Dayer *et al*. 2016). Land trusts frequently make decisions at a landscape or regional scale, beyond the individual parcel subject to an easement. Because of limited funds and stewardship capacity, land trusts have to make strategic decisions about which properties to protect within a given landscape, creating heterogeneity in the spatial arrangement of easements and conservation success on the ground. Understanding natural systems aids land protection prioritization, but the human factor is critical in decision making and its outcomes. For example, the appeal of a particular region may drive a land trust's efforts more than species conservation if its resources are limited and public appeal translates into more funding. Other human subsystems directly and indirectly affect conservation via easements at regional and national scales, including governmental, nonprofit, and other private institutions. For example, organizing bodies exist to make land trusts more effective across a larger scale. In the United States, the Land Trust Alliance is a national organization that approves accreditation of individual trusts, assuring prospective partners that these land trusts abide by defined standards and policies. Government representatives may step in to uphold ordinances and regulations at the local, state, or federal level. State funds are often drawn upon to help promote land conservation projects in both states (e.g., South Carolina Conservation Bank, North Carolina Clean Water Management Trust Fund). Federal programs and grants provide essential funding for some land transactions (e.g., United States Department of Agriculture, Land and Water Conservation Fund) and stewardship objectives (e.g., United States Fish and Wildlife Service).

Case study #2: **Agro ecosystems in the Midwest and Great Plains**
Like conservation easements, conservation in agro ecosystems reflects multiple scales of human subsystems. Though the case study focuses on the primary scale of decision making, i.e., the farm, decisions reflect regional and global drivers and interacting institutions and actors. Farmers manage almost 40% of terrestrial ice-free surface, but their decisions are influenced by individual consumer food choices through local, national, and international food policy. A growing world population, a demand for biofuels, and changing diets are increasing pressure on existing agricultural land and the humans who manage these systems. Given the extent and competing demands for farmland, understanding the linked human systems is essential to optimize trade-offs. At a local scale, farmers are the primary decision makers of land they own and rent. Their first priority is biomass or food production (Balmford *et al*. 2012). Conservation goals are thus a secondary priority (unlike easements discussed in the case study above) and most conservation decisions consider opportunity costs. Furthermore, a farmer's attitude toward conservation and subsequent likelihood of adopting proenvironmental practices is influenced by multiple social factors and external controls, e.g., family history, policy,

land ownership, farm location (Quinn and Burbach 2008) [18]. For example, ownership patterns can influence implementation of conservation practices when motivations and incentives for conservation differ for renters or absentee landowners as compared to individuals owning and living on the land (Soule *et al*. 2000) [21]. Beyond the farm, choices emerge from a network of systems that have varied perceptions, perspectives, and motivations regarding conservation. These include state and federal agencies, a diversity of farming nongovernmental organizations (NGOs) with varied perspectives, and conservation groups that may have competing goals. Farm policy is one important external control, setting funding priorities at local and national levels and articulating best management practices. In the United States the Farm Bill, like the European Union Common Agricultural Policy, sets national conservation priorities for farmland and distributes funds to farmers. In the U.S., state and university outreach (e.g., Brandle and Finch 1991) and the federal Natural Resource Conservation Service (NRCS) provide advice and the latter provides funding for the adoption of conservation practices like windbreaks on individual farms. Consumers are an additional important but indirect component of these subsystems. Consumer preferences create demand for specific products and for particular production methods, like organic farming. Lastly, as Wendell Berry notes (Inhofe and Baumgartner 2006:5), "Why should conservationists have a positive interest in, for example, farming? There are lots of reasons, but the plainest is: Conservationists eat." This case study builds on collaborative work between farmers, researchers, and conservationists. Researchers from the University of Nebraska Lincoln partnered with the Nebraska Sustainable Agriculture Society (NSAS) and Nebraska Forest Service to obtain funding, via a capacity building grant, to improve success and adoption of conservation practices associated with agro forestry systems in eastern Nebraska. Funding for this grant from the Nebraska Bird Conservation Partnership allowed for an exchange of information between systems, including private, state, and federal farming conservation organizations, increasing awareness of the importance of conservation on private farmland. This cross-institution and cross-discipline collaboration was beneficial in that it forced each group, or subsystem, to articulate its needs and find common ground with the other groups. In this relationship, farmers, via NSAS, shared with researchers what conservation questions they most wanted answered. Likewise, university researchers were able to better frame their research questions to reflect conservation practices that farmers would be more likely to adopt.

Chans elements and interactions
Identification of relevant subsystems helps understand institutions and actors that play a role in biodiversity conservation on private lands (e.g., Turner *et al*. 2003, Carter *et al*. 2014). However, as shown above, subsystems do not work in isolation and just describing systems is insufficient to understand conservation opportunities and costs. The CHANS framework provides a model to understand the interactions between human and natural systems, environmental and social concerns, disciplines, and scales of action. Recognizing and understanding these elements and interactions is essential to successful and sustainable conservation. Below we discuss specific

CHANS elements and interactions individually, as they relate to our case studies, to better illustrate how they function within the contexts of the systems discussed above. Through this process, it becomes clear that framing a perceived isolated element in the CHANS framework often reveals an unidentified interaction with another element. Furthermore, an awareness of connections between elements and interactions allows researchers, practitioners, and stakeholders to better evaluate trade-offs and compromises when making decisions on private lands. We start with the idea of scale, building on different scales of the human and natural subsystems across elements and interactions. Next we discuss how heterogeneity, feedbacks, time lags and legacy effects, nonlinear dynamics with thresholds, and surprises function in our example regions to affect research, planning, and practice on private lands.

Scale
Although it is widely agreed that there is no correct scale at which to work (Levin 1992) [15], there is agreement that consideration of larger scales is necessary for successful conservation (Fahrig 2001) [7]. However, on private lands, a disconnect between scales of the human system (land ownership) and the natural system (species habitat requirements) can create challenges to conservation on private land. Though there are cases, e.g., western U.S., Patagonia, where one individual owns extensive lands, the spatial extent of management of any one private landowner is most often limited. Conservation objectives should therefore align with available resources. Given the complexity at the interface of human and natural systems, the question of how to expand the scale of conservation application, e.g., more easements, proximity to protected lands, or increased matrix quality, remains uncertain. Species conservation on private lands thus first requires identification of suitable practices that can be adopted by individual landowners. Then, beyond-the-parcel efforts should consider coordination between landowners to protect suitably large tracts of land (Powell 2012, McKenzie et al. 2013) and consider how the matrix type around a unit of land is managed because it has become clear that the larger matrix surrounding a patch is a significant modifier of local conservation success (Fahrig 2001) [7]. Two of the species highlighted in the case studies represent conservation opportunities that can be captured at smaller scales: the scale of a single habitat patch. Greater patch size, but not greater cumulative pine habitat on the landscape, is an important driver of Brown-headed Nuthatch abundance patch (Wood and Quinn 2016) [24]. Thus, interested private landowners can maintain and re-establish pine stands on their property regardless of their location on the urban-rural gradient or proximity to other forest patches. Likewise, Bell's Vireo abundance and daily nest survival are influenced by both crop and noncrop land use patterns within and immediately adjacent to a farm (Quinn et al. 2014; Quinn, unpublished data), including woody vegetation adjacent to crop fields. When conservation is not possible at local scales (a single easement or farm), planning and strategic partnerships between agencies and organizations can help create an opportunity for success. In the Highlands of Roan, whose grassy balds are well suited to Golden-winged Warbler habitat restoration, land trusts and conservation groups, e.g., Southern Appalachian Highlands Conservancy and Appalachian Trail Conservancy

protect and manage many contiguous tracts of land. In this way, private institutions help provide connectivity between available breeding habitat by complementing the U.S. Forest Service's limited land ownership. These efforts require that multiple stakeholders across human systems be engaged in the creation and execution of conservation plans. Planning at a regional or even county level helps to align the scales of human and natural systems and find strategic solutions that benefit both.

Social-ecological heterogeneity
Heterogeneity across natural systems reflects natural land cover change, disturbance, and anthropogenic land use change. Likewise, in human subsystems, heterogeneity exists as a function of variation in individuals, policy, political and social philosophy, socioeconomic incentives, institution legacies, and population demographics and growth rates. Individual and regional preferences for habitat types create different and shifting management goals, just as landscape heterogeneity reflects current and historical land use. The value of landscape heterogeneity at local and landscape scales as a conservation target in agro ecosystems has been demonstrated in multiple contexts (Farhig et al. 2011, Pickett and Siriwardena 2011, Quinn et al. 2014) [17]. Indeed, habitat heterogeneity is a key element of land sharing (Fisher et al. 2008). Agro forestry practices, including windbreak systems, hedgerows, field buffers, and fruit trees create heterogeneity while providing environmental and economic value to the farm. In eastern Nebraska, agro forestry creates habitat for the Bell's Vireo and other shrubland birds (Quinn et al. 2014). The same practices may, however, come at a cost as other species of equal conservation priority require a large area without trees and do not benefit from habitat heterogeneity (Quinn et al. 2012). The specific terms of an easement, land use and landowner history, and natural and socioeconomic conditions create heterogeneity in the regional distribution (Baldwin and Leonard 2015) [3] and in a land trust's portfolio of easements. Managing across this social and natural heterogeneity is challenging. Options negotiated in specific easements vary dramatically based on the conservation priorities at the time and place when the easement was negotiated and the priorities of the landowner (Wallace et al. 2008, Rissman 2013) [23]. Some easements include the right to harvest timber or clear specified habitat while others prohibit any such activities to maximize conservation objectives. Choices made over time on the land create heterogeneity as well as time lags and legacy effects. Heterogeneity in different economic and ecological values challenges a land trust that must manage for multiple conservation objectives across landowners and landscapes. For example, in the western Carolinas there are over 390 reported easements protecting over 44,515 hectares (110,000 acres) that vary in landscape resilience, connectivity, and diversity. Easements in flagship ecosystems with high ecological value, such as the Blue.

Time lags/legacy effects of past couplings on future possibilities
Recognition of temporal variation is key in research, planning, and practice (Ramalho and Hobbs 2012). Lag times between human-natural system interactions and their socioeconomic or ecological consequences introduce complexity to landscape conservation planning (Liu et al.

2007) and can make it more difficult to predict future change based on past trends alone. The natural systems of our case studies have shifted rapidly, but conservation priorities, actions, or perceptions may reflect legacy rather than reality. For instance, although temperate forests of the southeast United States were replaced by agriculture during the 20th century, today forested landscapes are being lost to rapid urbanization, a more recent threat (Terando *et al*. 2014). Likewise, decisions made during the late 1800s to convert native prairie to cropland across the Midwest, shifting it from a grassland biome or wild anthrome with low levels of human populations and land cover change to a cropland anthrome with little native habitat (Ellis *et al*. 2010), dictate the scope of current conservation options on private land in the Midwest (Quinn *et al*. 2014). At a local scale, management options are controlled by past landowner decisions and influenced by tradition (Monticino *et al*. 2007). Family tradition or historical success of an economically centered land use (agriculture, surface mining, logging) may discourage proenvironmental behaviors, e.g., windbreaks and conservation easements limiting impactful land uses, but past and present landowners also experience unequal payoffs for a property's ecosystem services. For instance, it can take decades for timber stands to be ready for reharvesting and the full benefits to the farmer and wildlife of a windbreak can take one generation to emerge. Current landowners may be influenced negatively by previous managers' or landowners' decisions because they deal in the present with negative lag effects such as erosion from poorly executed timber extractions or poor soil management, e.g., removal of terraces. The permanence of easements adds an interesting element of future time lags. Individual easement terms, based on the original landowners' objectives, will determine if variation occurs on particular properties over time, dictating the extent of future land use scenarios. Although the permanent temporal scale of a conservation easement may be appealing, the same permanence may limit future value because fixed boundaries limit the ability of an individual easement to adapt to or provide benefits under future climate change (Rissman *et al*. 2015). These examples of temporal effects creating challenges and opportunities for conservation efforts further illustrate how interconnected elements of CHANS are, as they also relate to feedbacks, nonlinear dynamics, and scale within and between the human and natural subsystems.

Nonlinear dynamics with thresholds
Identification of nonlinear responses in natural systems to loss or restoration may be some of the most critical pieces of information communicated between human systems. Identifying important ecosystem and habitat features, and their effects on biodiversity conservation, are key to developing models that can help leverage funds strategically. When resources or economic conditions limit options, in particular the spatial extent of contiguous land for conservation, identification of minimum thresholds can prevent investment in conservation at too small a scale to be effective. Private landowners interested in contributing to species conservation efforts would benefit from using data on minimum patch area (e.g., Bayard and Elphick 2010) [4] to determine if conservation is warranted. Our data on Bell's Vireo suggest that embedding small patches of Rough-leaf Dogwood (Cornus drummondii) in heterogeneous farm

systems can have an outsized benefit to conservation of the species with very little, if any, opportunity costs to the farmer. However, conservation of grassland species in this same region requires larger areas with minimum patches of 25–100 hectares depending on the species (Helzer and Jelinski 1999). Likewise, in the southeast U.S., interested landowners who are unsure if they have suitable habitat for Golden-winged Warblers can utilize thresholds based on the configuration of their management sites; a minimum size of 2 hectares (5 acres) of habitat can be created if the patch is within 300 meters (~1000 feet) of existing breeding habitat, while those over that distance should aim to create approximately 10 hectares (25 acres) of habitat (Golden-winged Warbler Working Group 2013). Given that an easement cannot be placed on every parcel and farmers cannot set aside all their land for species conservation, knowing thresholds of success can prevent a feedback where negative outcomes of ineffective efforts sours future conservation efforts.

Surprises
Examination of coupled human and natural systems reveals unexpected or unaccounted for conservation opportunities and challenges. Rare species discovered through annual monitoring or biological inventories on small patches of private lands can challenge conservation norms that prioritize large-scale protection. Indeed, the growing literature on conservation successes in human systems is full of surprises (Martin *et al*. 2014) where traditional conservation practice has focused on the pristine and untouched rather than on conservation opportunities within human-shaped ecosystems. For example, it was unexpected that the threatened Brown-headed Nuthatch was more abundant in pine patches embedded within residential developed land in the Piedmont than in patches embedded within rural or forested land use types (Wood and Quinn 2016) [24]. This surprise should be seen as a conservation opportunity given that suitable habitat is not always indicated by an undisturbed, large contiguous tract of pristine or native habitat disconnected from human systems. A conservative approach to easements may result in land trusts that only accept conservation easements in intact natural ecosystems, which might exclude suitable habitat for threatened species within suburban or agricultural landscapes. Likewise, conservation groups working in cropland anthromes would be remiss to not reach out to farmers to identify conservation opportunities in cropland anthromes, particularly given the bundled ecosystem service benefits of agro forestry. The intricacy of human systems can also cause surprise. Exactly who decides to participate in land acquisition for conservation, and why, is complex. It is within the power of a single private actor or stakeholder to make surprising strategic decisions in rapidly developing regions. For example, highly motivated individuals with financial capital can make a large difference, as evidenced by philanthropists and "conservation realtors" in North Carolina who make land purchases with no intention of development when land trusts cannot afford to do so. Conservation groups may not be able to identify these individuals beforehand, but the impact of those individuals should be celebrated and shared so that others may be motivated to take similar actions. Lastly, surprises are not always positive. It may surprise a landowner to learn that a land trust is not interested in his or her land because of its

limited ecological value, or to realize that unanticipated changes in market values of crops may create unexpected changes in the extent and effect of successful conservation programs. The latter point is perhaps best observed in the decline in Conservation Reserve Program lands following the rise in crop prices in the late 2000s.

Conclusion

Analyses of biodiversity conservation efforts on private lands benefit from consideration as a coupled human and natural system. Our formal synthesis of recent conservation actions under the CHANS framework illustrates new relationships and interactions that may not have been identified in previous analyses. Here the intersection of conservation research and practice, i.e., what lands are protected, how they are protected, why they are protected, clearly demonstrates coupling between systems. The application of CHANS thinking to our case studies suggests how multiple institutions will frame conservation priorities and how the interactions between institutions and priorities will create challenges and opportunities reflecting past, current, and future controls. In the eastern U.S., we see how coordination between private landowners and nonprofit conservation organizations can leverage resources for land protection and management. In the Midwest, we see that desire for conservation solutions at local scales can unite individuals and agencies to find common ground via agro forestry. Formalizing the process organizes the subsystems and their interactions in a way that allows for better and more thorough research, planning, and practice going forward. As traditional conservation goals align with priorities of human systems (public health, urban planning, and agriculture), providing a framework for individuals working on private land to work within will make it easier for conservation biology, as a field, to align with complementary goals of sustainability science. To move forward in creating a sustainable planet, we must remain under critical environmental thresholds while simultaneously addressing social foundations for all people (Raworth 2012). On private lands, engaging institutions and actors of human subsystems in a conservation outcome will help ensure multiple strategies for conservation success. New economic drivers, population change, and land management legacies will continue to affect the reality of conservation. The immense difficulty of this task requires communication between disciplines and among varied institutions and actors, especially those managing private lands. The CHANS framework provides a model for research and dialogue that bridges environmental and social concerns, disciplines, and scales of action.

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