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A riparian conservation network for ecological resilience

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ABSTRACT

A crucial gap exists between the static nature of the United States' existing protected areas and the dynamic impacts of 21st century stressors, such as habitat loss and fragmentation and climate change. Connectivity is a valuable element for bridging that gap and building the ecological resilience of existing protected areas. However, creating terrestrial connectivity by designing individual migration corridors across fragmented landscapes is arguably untenable at a national scale. We explore the potential for use of riverine corridors in a Riparian Connectivity Network (RCN) as a potential contributor to a more resilient network of protected areas. There is ample scientific support for the conservation value of riparian areas, including their habitat, their potential to connect environments, and their ecosystem services. Our spatial analysis suggests that they could connect protected areas and have a higher rate of conservation management than terrestrial lands. Our results illustrate that the spatial backbone for an RCN is already in place, and existing policies favor riparian area protection. Furthermore, existing legal and regulatory goals may be better served if governance requirements and incentives are aligned with conservation efforts focused on riparian connectivity, as part of a larger landscape connectivity strategy. While much research on the effectiveness of riparian corridors remains to be done, the RCN concept provides a way to improve connectivity among currently protected areas. With focused attention, increased institutional collaboration, and improved incentives, these pieces could coalesce into a network of areas for biological conservation.

1. Introduction

The key challenge for biodiversity conservation in the Anthropocene is counteracting the accelerating rate of species extinctions resulting from habitat loss and fragmentation, climate change, and invasive species (Baron et al., 2009; Griffith et al., 2009). In response to this challenge, reconstructing connectivity between protected areas is an important element of *conservation infrastructure*, defined as landscape attributes resulting from actions or policies designed to foster biological conservation, such as protected areas, conservation easements, and so forth (Hannah et al., 2002).

In the United States, national parks, wilderness areas, and wildlife refuges were set aside primarily to preserve scenic geological wonders, migratory birds, and game species, and now form the core of the de facto public land system. Conserving biodiversity was not the primary consideration in selection and siting of this system (Aycrigg et al., 2013). The administrative boundaries of these areas were often located to avoid existing development rather than for ecological reasons (e.g., Wilderness Act, 16 CUS. §§ 1131–1136). In addition, the majority of these areas were protected before ecological science recognized the importance of large-scale ecological processes, such as migrations, metapopulation dynamics, and gene flow (Mills, 2012; Minor and Lookingbill, 2010). It is only recently that attention has been focused on securing or restoring areas that provide structural and functional connectivity between protected lands.

Concepts of social–ecological resilience indicate that governance and conservation actions need to increase a system's ability to respond to natural and human-induced perturbations (sensu Biggs et al., 2012). One approach is to increase connectivity (Bengtsson et al., 2003; Elmqvist et al., 2003). Developing spatially networked connectivity between existing protected areas enables species to move more readily in response to changing environmental conditions (Johnston et al., 2013). This spatial aspect allows species and communities to survive

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perturbations by avoiding them or resisting them, and responding afterwards by recolonizing. The recolonized communities might be similar to pre-disturbance ones or entirely transformed (Bengtsson et al., 2003). For example, connectivity fosters resilience to directional climate change (press disturbance) by increasing the potential for species' redistribution into climatically suitable areas (Crimmins et al., 2011). Habitat connectivity can also contribute to escape from or recolonization of occupied areas following events such as wildfires or floods (pulse disturbance) (Elmqvist et al., 2003).

If the goal, therefore, is to increase resilience through connectivity, riparian networks should be an important component because they connect headwaters to lowlands in a structured, complex, and dendritic pattern (Beier, 2012). Connecting riparian networks could complement the existing protected landscape in which higher elevation areas are typically emphasized and lowlands under-represented (Noss et al., 1996). Although data on the degree to which riparian areas serve as corridors for species movement is limited, there is evidence that even an anthropogenically disturbed riparian corridor has the potential to replicate many of the functions of an undisturbed one (Hilty and Merenlender, 2004). For example, Hilty and Merenlender (2004) found that, although native mammalian predators (e.g., coyote, *Canis latrans*; raccoon, *Procyon lotor*) preferred wider riparian corridors, they nonetheless used narrower, human-disturbed corridors in agricultural landscapes. In addition, wildlife movement through road underpasses associated with rivers and streams is well documented (Clevenger and Waltho, 2000; Santos et al., 2011). Although disturbed riparian corridors are not the equivalent of undisturbed ones (Battin, 2004), this body of literature suggests that species will use disturbed riparian corridors when undisturbed ones do not exist.

Riparian areas can play an important role in providing habitat connectivity for many species in fragmented or heterogeneous landscapes (Hilty and Merenlender, 2004). These areas typically support assemblages of hydrophilic organisms and are characterized by the influence of periodic water inundation and the exchange of materials and energy with the surrounding ecosystems, namely the stream and upland areas (Naiman and Decamps, 1997). Although riparian areas typically are not large, they do offer extensive linear networks that allow many species to move through otherwise inhospitable areas (Rouquette et al., 2013; Tremblay and St. Clair, 2011). The role that riparian areas play as corridors between and among protected areas is poorly documented, particularly with respect to what characteristics promote connectivity for which species. The use of riparian areas for movement is species-specific (Gilbert-Norton et al., 2010; Lees and Peres, 2008). Nonetheless, multiple terrestrial species rely on riparian areas at some point in their life history (Naiman and Decamps, 1997), most commonly for migration through human-modified landscapes (Santos et al., 2011). Additionally, a variety of species use riparian corridors for access to water, escape from predators, cover, food, nesting habitat, and dispersal or movement between habitat patches (Brost and Beier, 2012).

Rebuilding habitat connectivity with riparian networks is no panacea, particularly in fragmented and altered landscapes (Goetz et al., 2009). The condition of riparian areas is highly variable and many riparian areas will likely require restoration before they serve as functional corridors (Theobald et al., 2010). However, even small sections of degraded riparian areas can act as chokepoints by limiting larger-scale connectivity and some animals might not use intact riparian areas surrounded by human structures and activity. It is yet unclear what buffer width provides connectivity for the widest breadth of species. Conversely, increased connectivity can have negative ecological influences (Simberloff et al., 1992). Regardless, although connectivity might facilitate the spread of invasive species and disease or increased disturbance, improved habitat connectivity is a net positive conservation outcome (Hannah et al., 2002; Shafer, 2014). Moreover, Haddad et al. (2014) found no broad evidence to support the possible undesirable side-effects of increased habitat connectivity and further suggested that wider corridors and softer corridor edges could ameliorate potential negative impacts.

Restoration of river and riparian areas benefits not only species conservation, but also water quality and esthetics (Bernhardt et al., 2005). Restoration actions, including reactivating floodplains, build upon existing efforts that protect valuable ecosystem services, such as water filtration, recreation, and flood control (Brauman et al., 2007; Fremier et al., 2013). Although they are often degraded (Theobald et al., 2010), riparian forests account for much of the remnant forests on numerous landscapes (Lees and Peres, 2008). Increased conservation efforts in these areas may also increase the ability of species to move through intensively managed landscapes. Restoring and protecting riparian areas thus can serve human needs while also providing a connected riparian connectivity network.

Furthermore, a riparian connectivity network could take advantage of existing policy mechanisms. That is, a project to establish such a network could leverage an existing suite of administrative, state, and federal policies that already protect riparian areas and thereby avoid the political battles that would be involved in enacting new laws (Citron, 2010; Lacey, 1996; Thompson, 2004). A key challenge, therefore, will be to coordinate restoration actions, conservation easements, and other conservation-related actions associated with existing policies to foster large-scale habitat connectivity at a continental scale.

We analyzed the current pattern of the protected area system in relation to riparian management on public and private lands for the contiguous United States (lower 48 states) to examine the practical potential of implementing a national Riparian Connectivity Network (RCN) that could coordinate protection, restoration, and management of riparian areas to build habitat connectivity among existing protected areas. We applied a coarse-scale spatial analysis to quantify the potential riparian linkages between existing protected lands. Recognizing that even an ideal physical solution is promising only to the degree that it can be implemented, we developed the concept of an RCN by combining initial evidence for its geospatial and ecological feasibility with a conceptual analysis of its practical and legal potential for implementation.

2. Materials and methods

To assess the biophysical potential of an RCN, we quantified the type, amount, and location of stream/riparian protection for continental US outside of Alaska using available spatial data. We employed a geographic information system (GIS) to analyze spatial and jurisdictional patterns in riparian management (ArcGIS version 10, ESRI 2011). We addressed four questions regarding distribution, area, and context of existing protected areas and their relationship to river corridors: 1) How many of the existing protected areas are connected to one or more protected areas via a river corridor? 2) What percentage of riparian corridors is buffered by protected areas? 3) What is the spatial pattern of riparian area protection across the lower 48 states? Finally, 4) are conservation easements spatially associated with riparian areas?

2.1. Geospatial data

We analyzed three publicly available spatial databases: 1) Protected Areas Database of the US (PAD-US); 2) National Conservation Easement Database (NCED); and 3) National Hydrography Database (NHD*plus*). PAD-US represents public land ownership and conservation lands, including privately owned protected areas (PADUS version 1.2 USGS-GAP accessed 2011). The native resolution of PAD-US is variable because data are provided by multiple agencies with a defined standard of 1:100,000 spatial accuracy (USGS-GAP, 2013). Lands are assigned conservation status codes (i.e., GAP Status codes) that both denote the level of biodiversity preservation and indicate other natural, recreational, and cultural uses (See Table 1 for code descriptions).

Table 1
GAP status codes within PAD-US denote the intended level of biodiversity protection and indicate other natural, recreational, and cultural uses. These status codes emphasize the managing entity rather than the landowner because the focus is on long-term management intent. Therefore, an area gets a status code of permanently protected because that is the long-term management intent (Aycrigg et al., 2013). Note: the descriptions do not detail specific riparian area protection because protection depends upon the managing agency.

Status	Description
1	Areas having permanent protection from conversion of natural land cover and a mandated management plan in operation to maintain a natural state where disturbance events (of natural type, frequency, intensity, and legacy) are allowed to proceed without interference or are mimicked through management.
2	Areas having permanent protection from conversion of natural land cover and a mandated management plan in operation to maintain a primarily natural state, but which may receive uses or management practices that degrade the quality of existing natural communities, including suppression of natural disturbance.
3	Areas having permanent protection from conversion of natural land cover for the majority of the area, but subject to extractive uses of either a broad, low intensity type (e.g., logging) or localized intense type (e.g., mining). This status also confers protection to federally listed endangered and threatened species throughout the area may be conferred.
4	Areas with no known public or private institutional mandates or legally recognized easements or deed restrictions held by the managing entity to prevent conversion of natural habitats to anthropogenic habitat types. Conversion to unnatural land cover throughout is generally allowed and management intent is unknown.

We use the term ‘protected’ throughout this paper in two different ways. First, in the data analysis, we define ‘protected’ as GAP Status 1 and 2 lands, plus GAP Status 3 lands but only for riparian areas. These lands have permanent protection from conversion of natural land cover (Table 1). We excluded GAP status 3 lands that are not riparian and GAP status 4 lands because either no formal protection exists or its status is unknown. We note that protection, be it formal or administrative, does not mean full protection in all cases, nor does it mean the lands are not already degraded. This usage implies protection but not necessarily functional habitat. Second, outside of the data analysis, and consistent with the vision presented in the article, we use the term ‘protected’ in a more general sense to imply land cover protection from non-conservation related activities.

Briefly, GAP Status 1 lands include wilderness areas with permanent habitat protection that allows natural disturbance events to occur. GAP Status 2 lands have permanent habitat protection, but may receive uses or management practices that degrade the quality of existing natural communities, including the suppression of natural disturbances. GAP Status 3 lands have permanent protection for federally listed endangered and threatened species, although extractive uses are permitted, on typically upland areas (e.g., logging, mining, and grazing). Many of these lands also have administrative policies to protect riparian lands; however, the strength and status of this protection is highly variable (NRC, 2002). GAP Status 3 lands represent a large portion of the publicly managed lands, which are predominately managed by the US Forest Service and US Bureau of Land Management (approximately 300 million ha) (Aycrigg et al., 2013). GAP Status 4 lands have no mandated conservation protection, although conservation practices might occur (e.g., Department of Defense, State Land Board, Bureau of Indian Affairs). For the purpose of this analysis, all lands with no assigned GAP Status code were designated GAP Status 4 lands. Conservation easements were also designated as Status 4 because they have an unknown conservation-management mandate.

The NCED database is a continuously updated spatial database of conservation easement lands in the US, compiled from land trust and public agency records (NCED accessed June 2012). NCED includes approximately 16.2 million ha of privately owned conservation easement lands. Prior to conducting our analysis, we eliminated duplicate data between NCED and PAD-US.

The NHD*plus* database includes streamlines for the US, digitized from aerial photos and USGS quadrangles at a scale of 1:100,000 (NHD*plus* version 2). For a national analysis, NHD*plus* provides the best data available for representing the US stream network, but it also includes large irrigation ditches and other human-made waterways. It is important to highlight that our unit of analysis is the streamline and not the riparian corridor. Currently, there is no national inventory of riparian areas. Additionally, we recognize that riparian areas within the US vary significantly in habitat quality. While finer-grained analysis might be possible, this level of detail is beyond the scope of our national scale analysis.

We summarized protection by Strahler Stream Order. Stream order is a measure of the stream size and is a hydrographic metric for indicating the position of a specific stream segment within a watershed. Strahler stream order defines the smallest tributaries as order 1 and increases as streams join to a value of 10 at the seaward ends of the largest rivers. As an example, the last segment of the Mississippi River is a 10th order stream. Headwater (mainly first and second order) streams comprise up to 80% of the stream network by linear measurement. In addition, NHD*plus* delineates watersheds of varying sizes from topographic data to define Hydrologic Unit Codes (HUCs). Regions (i.e., 8-digit HUCs) are the largest delineations and are defined topographically for the largest terminal watersheds. Small terminal watersheds (10- or 12-digit HUCs) are clustered within regions but by definition are not hydrologically connected.

2.2. Data analysis

2.2.1. Protected areas connected through a stream network

For our analysis, we defined protected areas, both state and federal, as those lands with a GAP Status of 1 and 2; additionally, we include GAP Status 3 riparian lands because riparian areas have administrative protection in most cases (Table 1). We calculated the number of protected areas connected to at least one other protected area via the stream network. We counted protected areas as connected when a mapped river intersected the boundary of the protected areas. We found that every protected area had at least one mapped river flowing through its bounding polygon, while most areas had multiple connections. Any contiguous protected polygons with shared protected status 1 and 2, or 3 were merged into a single unit; we performed this operation to better reflect how species would use an adjacent protected parcel as a continuous habitat. A protected area was considered ‘connected’ through the stream network if it was connected to at least one other protected area within an 8-digit HUC. Protected areas that are located in separate 8-digit HUCs (the largest watersheds) cannot be connected through a riparian corridor, as they exist in separate watersheds.

2.2.2. Percent protection of stream network by conservation status, stream order, and HUC

We define “percent protected” as the percentage of linear river miles lying within either a protected area or a working landscape with administrative riparian protection (e.g., GAP Status land 1–3). “Percent protected” is thus a proxy for the amount of an RCN that is already implemented. We calculated the percentage of the current mapped stream network by GAP Status Code 1, 2, or 3, by Strahler stream order, and by governing agency. It is important to note that our estimate of riparian protection is in linear units (stream length), not areal units, and that this will impact the estimate and any comparison with terrestrial measures of protection (Aycrigg et al., 2013). In addition, our decision to include GAP status 3 riparian lands as “protected” significantly affects the percent protected lands. In our analysis, non-riparian GAP status 3 lands are not protected.

For this analysis, streamlines with no stream order demarcation were not used in the analysis, as they typically include streamlines through lakes, reservoirs or irrigation canals. To calculate the percent protected, we assumed that if the stream centerline lies within a protected area, both sides of the stream's riparian areas are protected, except when the stream defines the border of the protected area. We processed a 30-meter buffer inside the perimeter of each protected area to limit this edge effect. We used these reduced polygons in our analysis to quantify the percentage of the total stream length protected. We believe our estimate is accurate in terms of administrative protection but also conservative in its extent. In addition, for publicly owned land we calculated the percentage of the stream network managed by each governmental agency.

2.2.3. Proximity of conservation easements to riparian areas

We hypothesized that conservation easements from NCED would be biased toward riparian areas. To estimate this bias, we used a distance-based analysis to capture those easements that might fall within a riparian area. Specifically, we calculated the Euclidean distance between each conservation easement edge and the closest stream centerline. We performed this analysis initially with the entire NHD*plus* dataset, then only for stream orders greater than 1 and again for stream orders greater than 2. Excluding the lowest order streams, which typically support little or no adjacent riparian habitat, should provide a more reasonable estimate of the association of easements with floodplain and riparian corridors.

3. Results

3.1. Protected areas are connected through a stream network

Ninety-five percent of all federally protected areas are connected by a stream network to at least one other protected area. In many regions, multiple connections exist between protected areas. The few protected areas without riparian connections are found in small basins directly draining to the ocean or basins with terminal drains into deserts (e.g., eastern Sierra Nevada rivers flowing into Nevada).

3.2. Stream network protection varies by conservation status, stream order, and HUC

The percentage of land along protected stream segments generally decreases as stream order increases (Fig. 1). The average protection of the stream network is 24.8%. Streams classified as orders 1–3 make up 80% of the overall network, in general. Although the general pattern of protection of streams decreases from smaller to larger streams (i.e., there is a bias in protection toward riparian areas in headwater streams, as expected), the percent of protection for riparian areas in large streams does not drop below 15%, with a range of 25.5–15.9% of lands with GAP Status codes 1–3. The average protection (24.8%) is closer to the highest protection (25.5%) because the stream network is composed of 80% headwater streams. As such, riparian areas around headwater streams generally have higher protection status than riparian areas associated with large rivers. The explanation for this higher protection is in part because of the amount of GAP Status 3 lands. We included these lands in the ‘protected’ category because they typically have administrative protection of riparian lands but not upland areas (Table 1); however, it is important to note that upland land use can impact riparian structure and function, and there is high variability in the strength of that protection and the ecological condition (NRC 2000). Stream orders 1–3 have the highest percent of stream length protected on GAP Status 3 lands, particularly in the western US (Fig. 2).

3.3. Conservation easements are often near to streams

Conservation on private lands through conservation easements may have a spatial bias toward riparian areas, most notably around larger rivers (Fig. 3). Of the 16.2 million ha of land in conservation easements, 57% are within 100 m of a stream channel and 93% are within 1 km of the stream centerline. The proportion decreases when first and second order streams are removed (19% and 68% respectively). For example, the pattern of easements and their distance to the Mississippi and Red Rivers in the southern portion of the US indicates numerous easements within the floodplain (Fig. 3). Conservation easements are clustered generally around main river corridors.

4. Discussion

Any conservation effort is only as good as its potential for implementation through action at relevant ecological scales, no matter how cleanly the proposed solution might map in networked space. We argue that: 1) current policies broadly reflect societal concern for the protection of riparian areas. Our analysis suggests that an RCN is an emerging property of the stream network, and therefore, a nascent backbone for the RCN may already exist; 2) scientific evidence supports the conservation value of an RCN to help mitigate the impacts of climate change and upland habitat fragmentation; and 3) although an RCN may be more easily

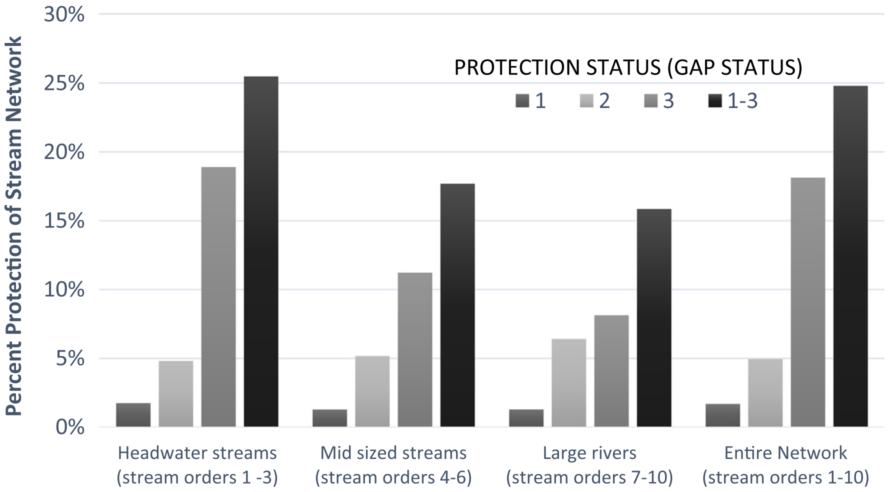

Fig. 1. Percent protection of stream network by groups of stream order. Based on PAD-US and NHD*plus* databases. See Table 1 for descriptions of GAP status codes. Over all stream orders the average protection is 24.8%. The average is highly skewed because headwater streams (stream orders 1–3) make up 80% of the total stream network by linear unit.

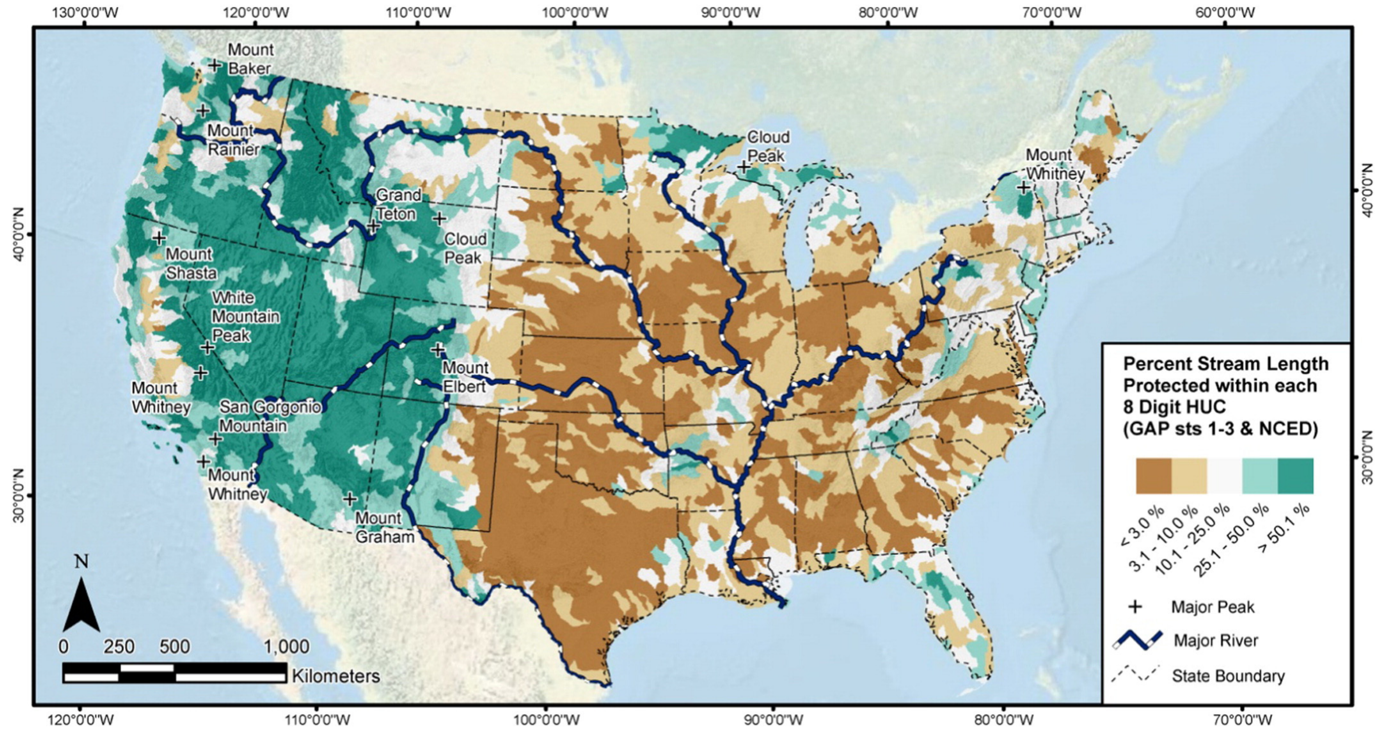

Fig. 2. Percent of stream length protected within NHD*plus* 8-digit HUC watersheds across the contiguous US. Protection of stream and riparian areas in the western US is far greater than in the Midwestern states and to a lesser degree the Eastern states. Protection is defined as lands with GAP status codes 1–2 and conservation easements.

implemented than other connectivity approaches from policy and management standpoints, conservation is better served if riparian connectivity is part of a larger landscape connectivity strategy. Our vision is that the RCN would coordinate protection, restoration, and management of riparian areas to build habitat connectivity among existing protected areas. The primary value of this research is its conceptual and integrative approach. Questions remain about the benefits, integrity and management activities in riparian areas. However, the RCN provides context for future research and management on these issues. A research program to flesh out the RCN concept would necessarily follow this conceptualization.

The spatial distribution of conservation easements is additional evidence of an emerging RCN. Our analysis indicates that conservation easements on private lands have a bias toward proximity to rivers (57% within 100 m and 93% within 1 km). Although the motivation for establishing conservation easements varies, the spatial pattern of easements suggests that protection of land close to rivers is important (Kline et al., 2000; Ryan et al., 2003). Although there are concerns that conservation easements do not fully protect lands from non-conservation-related activities (Rissman et al., 2007), conservation easements nevertheless provide a mechanism for protection of riparian corridors and could be tailored to meet that need. The increasing interest in conservation easements by private landowners suggests the motivation to protect riparian lands exists (Mann et al., 2013).

We acknowledge the potential limitations of re-building habitat, particularly in the face of complex topography, rapid change in elevation, or micro-climatic variation along the length of a corridor, not to mention current condition of most riparian areas. Many riparian areas will require restoration before they serve as functional corridors (Theobald et al., 2010) and the buffer width to facilitate connectivity remains unclear, particularly through human dominated areas. Additionally, concerns about the potential undesirable side effects of increased connectivity exist (Simberloff et al., 1992), but the existing nascent RCN could also serve as a research focus for assessing the validity of these concerns.

4.1. A riparian conservation network is emerging

The geospatial patterns suggest that the backbone for an RCN is emerging through a combination of existing policy on public lands and incentives for conservation easements on private lands (Figs. 1–3). Although riparian lands are not managed as a formal system, streams already have greater protection than upland areas. Riparian areas are managed through various mechanisms, including protected lands management (e.g., wilderness, parks, and forests), measures taken in response to the requirements of regulatory programs (e.g., the Clean Water Act (CWA), the Endangered Species Act (ESA), and the state-level implementation programs), and through incentive-based programs, such as the USDA's Conservation Reserve Program (CRP) (NRC, 2002).

We interpret this legal and administrative protection as strong evidence of the perceived importance of riparian area management. Moreover, this level of protection (24.8%) is more than double the level of protection of terrestrial areas (10%; Aycrigg et al., 2013), mainly because riparian areas have protection on public lands. This elevated protection stems from the ecosystem services provided by riparian areas. For example, placement of lands in GAP Status 3 (national forest and BLM public lands) provides protection of riparian areas that may assist in meeting water quality requirements (e.g., temperature, pollutants). Administrative protection, of course, does not always mean functional protection, and a great need remains for restoration of degraded riparian areas, including in some areas a widening of protected riparian buffers (Kondolf et al., 1996). Nonetheless, it is a beginning. Furthermore, active tracking of the actual protection of riparian areas may assist land managers in meeting area goals, but certainly more research is necessary to understand if administrative protection of riparian areas leads to functional connectivity. Our classification of GAP Status 3 lands as functional habitat denotes formal protection but is probably optimistic given degraded land and proximity to human activities.

A viable RCN could build on the existing governance that supports societal interests in clean water and naturally functioning rivers,

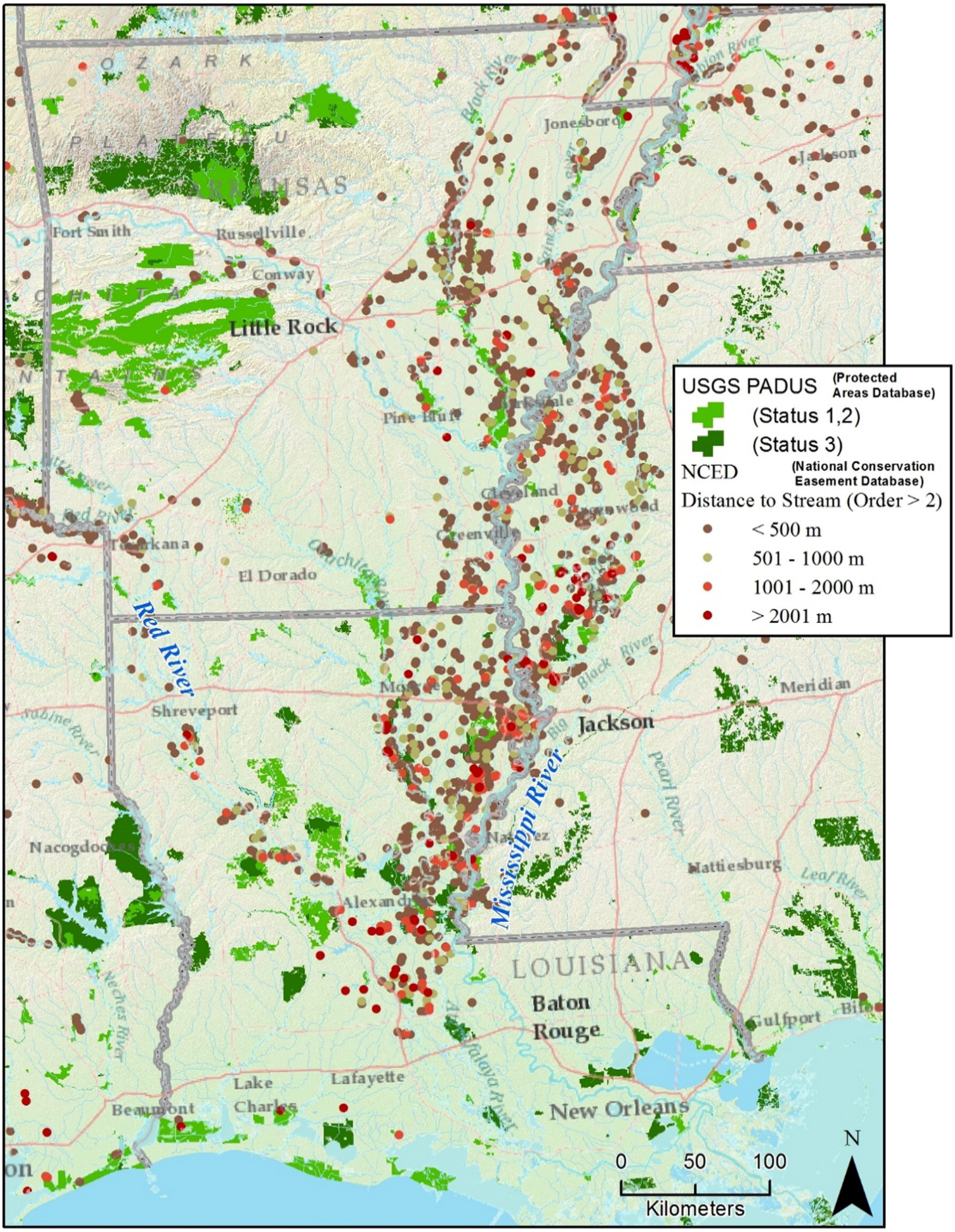

Fig. 3. Riparian connectivity emerging from current policy. The map shows the concentration of easements near or within the floodplain along the Mississippi and Red Rivers, which collectively start to form a de facto corridor.

governance that is nevertheless not currently coordinated for purposes of connectivity (Arthington et al., 2010). Such mechanisms have been put in place for a variety of services, including water quality (CWA), single species protection (ESA), or soil conservation (CRP). The CWA has already helped to restore and prevent degradation of many riparian areas to improve water quality through its direct controls on polluters and restrictions on aquatic habitat destruction (Adler et al., 2013). Nevertheless, many waters across the United States remain impaired, in part because of failure to integrate land use regulation with implementation of federal laws such as the CWA and ESA (Cosens and Stow, 2014). Mechanisms already have emerged to address the failure of regulatory programs like the CWA and ESA, such as incentive based programs like the USDA-CRP (NRC, 2002).

The value of riparian protection for achieving habitat connectivity and the need to meet water quality standards may increase incentives for riparian protection from land conversion with minimal change in existing law. The CWA provides some incentives to develop an RCN, as shown by the role it plays in driving riparian corridor protection (e.g., the US EPA's promotion of watershed-scale management and other state level efforts; Section 404's restrictions on destruction and adverse modification of wetlands and other aquatic areas). For example, to achieve temperature requirements of discharge permits under the CWA, entities governing watersheds, such as the Willamette River and the Virginia regions of the Chesapeake Bay watershed have set up trading programs in which a municipality pays for restoration of shade in upstream riparian areas, rather than the expensive alternative of mechanical cooling.

Implementation of the ESA has also encouraged riparian area protection. A high percentage of species listed for protection under the ESA are aquatic (Craig, 2014). Compliance with both the CWA and ESA are factors in developing habitat conservation plans (Native Fish Habitat Conservation Plan). Similarly, forestry programs at federal (Northwest Forest Plan) and state (Idaho Forestry Program, Nez Perce Term Sheet, Nez Perce–Idaho Water Rights Settlement) levels require buffer zones along riparian corridors in timber harvest areas. The implementation of the ESA in the Pacific Northwest has placed the Federal Emergency Management Agency under pressure to change the National Flood Insurance Program (NFIP) by removing incentives to separate rivers from their floodplains to allow insured development in the former flood zone (see National Wildlife Federation v. Federal Emergency Management Agency, No. C11–2044–RSM, 2014 WL 5449859, W.D. Wash. Oct. 24, 2014).

In short, CWA water quality standards, ESA habitat requirements, and flood risk management goals may all be advanced by protecting small amounts of land in riparian corridors. In addition to these regulatory incentives, planning approaches—including ESA Section 7 jeopardy assessments and the National Environmental Policy Act (NEPA), and its state counterparts the California Environmental Quality Act (CEQA)—can allow for or even mandate coordination of riparian corridor protection. Other extant legal and policy protections include financial incentives to protect riparian lands, such as incentive programs for agriculture in the US Farm Bill (although these incentives were reduced in 2014). Another alternative is the purchase of private riparian lands by public entities or non-governmental organizations, such as The Nature Conservancy's water programs (Greenway program, conservation easements, and other water programs Rollins Palmer, 2008).

Other legal mechanisms associated with land management are already playing a role in the emergence of riparian conservation, particularly across the federal public lands. Notably, 78% of public lands are managed by four agencies––USDA Forest Service, US Bureau of Land Management, US National Park Service and US Fish and Wildlife Service—increasing the potential for inter-agency coordination (Aycrigg et al., 2013). Additionally, an RCN could enable a scalable policy, with nested efforts to integrate currently independent and loosely coordinated federal, state, tribal, local, and private actions.

In addition, riparian areas are pre-defined by the stream network, which simplifies the process of selecting corridor routes compared to species-specific terrestrial corridors (Hilty et al., 2006). By simplifying the corridor selection procedure, the RCN thus offers a simpler implementation strategy. Nonetheless, although this simplicity is attractive at conceptual and policy levels, the effectiveness in improving connectivity and species survival through an RCN must be evaluated at the field level. For example, the RCN cannot serve as a replacement corridor selection procedure in situations where species will not use riparian areas or the areas might not have suitable riparian corridors. In addition, more detailed, local-scale analysis is needed to determine how and where local riparian corridors should be concentrated. RCN research along these lines could dovetail with research already being completed, such as the Riparian Climate-Corridors, which incorporates mapped riparian areas and climate projections (Beier, 2012; Krosby et al., 2014).

4.2. A policy path to a riparian connectivity network

Although conceptually simple, building connected corridors requires coordination among governance agencies and private landowners. There currently is no federal policy mechanism for connecting landscapes at any scale. Although planning is underway for large-scale corridors (ecoregions, biomes), efforts lack sufficient generality for national-scale application (Hilty et al., 2006). Nevertheless, there are multiple examples of regional-scale cooperative restoration efforts that may offer governance models for building connectivity. The Chesapeake Bay region in Maryland and Virginia, the Florida Everglades, and the Greater Yellowstone Ecosystem in Wyoming, Montana, and Idaho are regional examples of multiagency collaborative management to maintain conservation integrity (Noss et al., 2002), as are the Western Governors' Association's discussions of a migratory corridor or Washington State's climate-change-related efforts to address connectivity. In addition, the Partners in Flight Migratory Bird Conservation program specifically targets migratory species and has had conservation-related successes throughout North America working at larger scales (Carter et al., 2000). This program functions at the regional scale, but is planned and coordinated through ‘joint venture’ partnerships and management at international scale.

Coordination at coarser scales can lead to protection at finer scales. For example, wetland and riparian areas play a key role in building connectivity for migrating waterfowl in the North American Waterfowl Management Plan (Williams et al., 1999). Many of these efforts to improve habitat connectivity attempt to optimize the construction of habitat corridors between individual preserves, focusing on specific species or small assemblages of species within the constraints of local geographies, and prioritizing riparian lands for restoration with their spatial configuration in mind (Theobald et al., 2012). However, a challenge for implementing an RCN, particularly in western states is the complicated planning and implementation of the allocation of water through private water rights (Adler et al., 2013).

Federal resource agencies have a checkered history of working together toward a common purpose, in part because each is governed by different legal requirements. Yet the Landscape Conservation Cooperatives (LCCs) in the US that began as the result of a Secretarial Order from the Department of the Interior in 2009 (Order No. 3289, Sept. 14, 2009), exemplify emergent coordination to solve issues that persist at larger scales (Millard et al., 2012). LCCs aim to provide scientific expertise and coordination among public and private institutions at a landscape scale. In addition, implementation of the ESA has led to coordination across multiple agencies in examples such as the Northwest Forest Plan. A more proactive, coordinated approach to building landscape habitat connectivity could be incorporated into the missions of relevant agencies (e.g., National Park Service, US Fish and Wildlife Service, Bureau of Land Management, USDA Forest Service). Presidential guidance through an Executive Order could be used to advance the development of a more comprehensive RCN. In addition, at least some states seem to be willing to pursue similar efforts for state public lands (Citron, 2010). Conversations on such ‘top-down’ options are already underway in national policy circles (USFWS, 2013). In addition, factors other than species conservation are already driving riparian protection, such as ecosystem services. One clear example of agency coordination to manage riparian areas for multiple benefits is the Yolo Basin near Sacramento, California (Opperman et al., 2009); other such solution have been recently proposed (Greco and Larsen 2014). This area supports multiple, typically competing interests by managing rice farming and wildlife conservation, while allowing flood water storage during critical times with the added benefit of migratory bird habitat. The multiple benefits of riparian protection illustrated in the Yolo Basin example can broaden actual and potential sources of support for an RCN, including efforts to improve aquatic ecosystem services, such as filtration, riparian vegetation and floodplain connectivity that improve water quality, bank stabilization and flood control as well as esthetics (Bernhardt et al., 2005; Fremier et al., 2013). Explicitly incorporating ecosystem services into conservation corridor protection mechanisms would open riparian protection efforts to a broader array of institutions and funding sources, including agencies charged with protecting water quality and reducing flood risks and private interest groups seeking improvements in hunting and fishing opportunities (Goldman and Tallis, 2009). Moreover, riparian landowners tend to become invested in the health of waters bordering their properties (Elmore and Beschta, 1987).

The basis for operationalizing an RCN lies in a coordinated policy that could be realized through the integration of independent and loosely coordinated federal, state, tribal, local, and private actions into a coherent larger set of outcomes. Because 78% of all public lands are managed by only four federal agencies, promoting collaboration between these agencies provides a conceptual pathway toward integration for larger conservation resiliency. Further, coordinating with existing private conservation easements that already are spatially biased toward riparian areas could amplify progress toward a coherent conservation network. Finally, governing entities supporting the further development of an RCN could reach beyond biological conservation to support conservation goals to leverage other existing mechanisms for protection, such as flood management policies, water quality requirements, and recreation policies. We have argued that the seeds for an RCN are already in place geospatially as well as institutionally. Mobilizing public, private, and multiparty efforts at local, regional, and national scales (Ostrom et al., 1999) will be necessary to achieve a fully-connected RCN. With the right motivation and action, including, but the already emerging RCN clearly could continue to grow in ways that increasingly promote socio-ecological resilience through collaboration among multiple levels of governance using existing legal, policy, and social mechanisms, the nascent RCN could grow and promote socio-ecological resilience.

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