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Contributed Paper

Mapping legal authority for terrestrial conservation corridors along streams

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Abstract: Wildlife corridors aim to promote species' persistence by connecting habitat patches across fragmented landscapes. Their implementation is limited by patterns of land ownership and complicated by differences in the jurisdictional and regulatory authorities under which lands are managed. Terrestrial corridor conservation requires coordination across jurisdictions and sectors subject to site-specific overlapping sources of legal authority. Mapping spatial patterns of legal authority concurrent with habitat condition can illustrate opportunities to build or leverage capacity for connectivity conservation. Streamside areas provide pragmatic opportunities to leverage existing policy mechanisms for riverine and terrestrial habitat connectivity across boundaries. Conservation planners and practitioners can make use of these opportunities by harmonizing actions for multiple conservation outcomes. We formulated an integrative, data-driven method for mapping multiple sources of legal authority weighted by capacity for coordinating terrestrial habitat conservation along streams. We generated a map of capacity to coordinate streamside corridor protections across a wildlife habitat gap to demonstrate this approach. We combined values representing coordination capacity and naturalness to generate an integrated legal-ecological resistance map for connectivity modeling. We then computed least-cost corridors across the integrated map, masking the terrestrial landscape to focus on streamside areas. Streamside least-cost corridors in the integrated, local-scale model diverged (~25 km) from national-scale least-cost corridors based on naturalness. Spatial categories comparing legal- and naturalness-based resistance values by stream reach highlighted potential locations for building or leveraging existing capacity through spatial coordination of policy mechanisms or restoration actions. Agencies or nongovernmental organizations intending to restore or maintain habitat connectivity across fragmented landscapes can use this approach to inform spatial prioritization and build coordination capacity.

Keywords: connectivity, landscape fragmentation, land-use planning, law, private lands, protected areas, riparian habitat, wildlife corridors

Mapeo de la Autoridad Legal para los Corredores Terrestres de Conservación a lo Largo de Ríos Stahl et al.

Resumen: Los corredores de fauna buscan promover la persistencia de las especies al conectar los fragmentos de hábitat a lo largo de paisajes fragmentados. Su implementación está limitada por los patrones de propiedad de tierras y se complica con las diferencias entre las autoridades jurisdiccionales y regulatorias que las administran. La conservación por corredores terrestres requiere de coordinación entre las jurisdicciones y los sectores sujetos a fuentes de autoridad legal que se traslapan y que son específicas del sitio. El mapeo de los patrones espaciales de la autoridad legal simultánea a la condición del hábitat puede ilustrar oportunidades para construir o hacer uso de la capacidad para la conservación por conectividad. Las áreas adyacentes a los cauces fluviales proporcionan oportunidades prácticas para hacer uso de los mecanismos políticos existentes para la conectividad de hábitats ribereño y terrestre a través de las fronteras. Los planificadores y practicantes de la conservación pueden usar estas oportunidades al armonizar las acciones para múltiples resultados de conservación. Formulamos un método integrativo orientado por los datos para mapear las múltiples fuentes de autoridad legal ponderadas por la capacidad

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para coordinar la conservación de hábitats terrestres a lo largo de ríos. Generamos un mapa de la capacidad para coordinar los corredores de protección a lo largo de los vacíos en los hábitats de fauna para demostrar esta estrategia. Combinamos los valores por medio de la representación de la capacidad de coordinación y la naturalidad para generar un mapa de resistencia legal y ecológica para el modelado de la conectividad. Después, computamos los corredores de menor costo en todo el mapa integrado, enmascarando el paisaje terrestre para enfocarnos en las áreas adyacentes al cauce fluvial. Los corredores de menor costo adyacentes a los cauces dentro del modelo integrado de escala local difirieron (~25 km) de los corredores de menor costo basados en la naturalidad a escala nacional. Las categorías espaciales que compararon los valores de resistencia basada en la legalidad y en la naturalidad por alcance del río resaltaron las localidades potenciales para la construcción o el uso de la capacidad existente por medio de la coordinación espacial de los mecanismos de política o de las acciones de restauración. Las agencias y organizaciones no gubernamentales con la intención de restaurar o mantener la conectividad del hábitat en un paisaje fragmentado pueden utilizar esta estrategia para informar la priorización espacial y construir la capacidad de coordinación.

Palabras Clave: áreas protegidas, conectividad, corredores de fauna, fragmentación del paisaje, hábitat ribereño, ley, planeación del uso de suelo, tierras privadas

摘要: 野生动物廊道旨在通过连接破碎景观中的栖息地斑块来提高物种的续存, 但其建设受限于土地所有制模式, 还会因管理土地的管辖及监管机构不同而更加复杂。陆地廊道保护需要多个司法管辖区和各地受到多种法定权威管制的部门之间的协调。将法定权威的空间格局与栖息地条件的分布地图相叠加, 将有利于开展廊道连接度保护的能力建设及利用。河流沿岸地区为现有的跨境河流及陆地栖息地连接度的相关政策机制的应用提供了实践机会。保护规划者和实施者可以利用这些机会协调多方行动以取得各方面的保护成效。我们制定了一个综合的、基于数据驱动的方法, 可以将协调河流沿岸陆地栖息地保护的能力作为权重来绘制多个法定权威来源的地图。为了演示这个方法, 我们绘制了一张协调跨越野生动物栖息地空缺地带的河流沿岸廊道保护力地图。我们将代表协调能力和自然特性的数值相结合, 生成了一张用于连接度建模的法律-生态抵抗力综合地图。随后, 我们忽略陆地景观, 将重点放在河流沿岸地区, 计算了整个综合地图的最低成本廊道。结果显示, 由局部尺度的综合模型得到的河流沿岸最低成本廊道与基于自然特性的国家尺度最低成本廊道偏离约 25 公里。河流沿岸基于法律和自然特性抵抗力比较的空间分类进一步展示了可以通过政策机制或恢复行动的空间协调来建设和利用现有能力的潜在地点。计划恢复或维持破碎景观之间的栖息地连接度的机构或非政府组织可以应用这种方法确定优先保护的空间并建立协调力。**【翻译: 胡怡思; 审校: 聂永刚】**

关键词: 连接度, 景观破碎化, 土地利用规划, 法律, 私有土地, 保护地, 河岸生境, 野生动物廊道

Introduction

The lack of protected-area connectivity worldwide hinders efforts to mitigate declining biodiversity (Haddad et al. 2015; Saura et al. 2018). Functional connectivity requires coordinated actions at ecological scales, but governmental authority operates within more finely spaced jurisdictional (land use and regulatory authority) and sectoral boundaries. We view the contrasting extents of legal authorities and habitat connectivity as a spatial mismatch that limits biodiversity conservation (Cash et al. 2006; Crowder et al. 2006; Brondizio et al. 2009; Ekstrom & Young 2009). Spatial mismatches between governmental structures and ecosystems can be addressed by bridging or coordinating actions among organizations and institutions with varying targets, strategies, locations, and scales of interest (Armitage et al. 2007; Chester 2012; Moss 2012). Existing policy mechanisms that span a range of scales (from parcel to national levels) may have untapped capacity (Garmestani et al. 2019) to facilitate landscape connectivity through further spatial coordination (e.g., Ament et al. 2014).

Spatial models can inform the use of policy tools to coordinate cross-level environmental governance (Salamon 2002; Pahl-Wostl 2009; Fales et al. 2016). Researchers have identified spatial mismatches and bridging opportunities by mapping jurisdictions, policies, and programs to represent conservation targets or inform planning (e.g., Wardropper et al. 2015; Qiu et al. 2017; Boisjolie et al. 2019). Social aspects of connectivity conservation, for example, public conservation orientation (Lechner et al. 2015) or collaborations among organizations (Sayles & Baggio 2017), can be mapped and analyzed in place-based contexts. Conservation planners and practitioners routinely consult land-use and ownership maps (e.g., USGS 2016) to inform corridor implementation. Connectivity conservation projects engaging a variety of stakeholders across boundaries and scales are underway (e.g., Gray et al. 2018; Jennings et al. 2019). Although connectivity models incorporate human impacts and protected-area status (e.g., McRae et al. 2008; Belote et al. 2016), researchers do not routinely or explicitly incorporate the legal authority to act into the process of identifying potential corridor locations or restoration priorities. Viewing

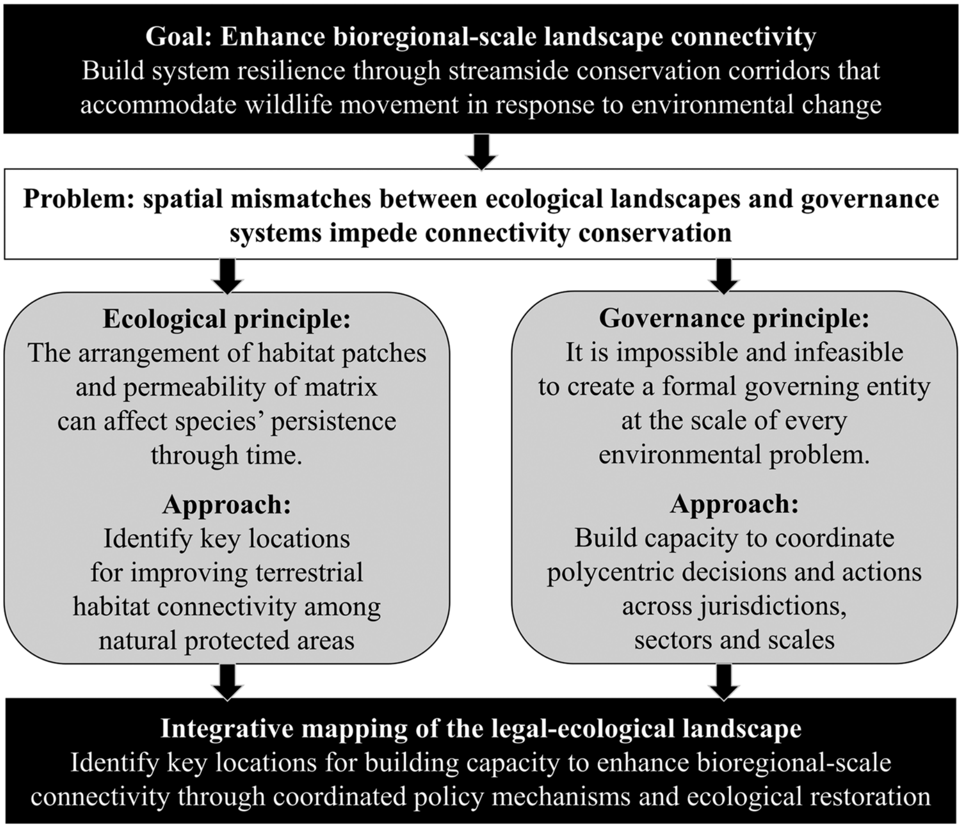

Figure 1. Concepts underpinning the derivation of integrated legal–ecological resistance maps for connectivity modeling.

the spatial mismatch in terrestrial connectivity conservation as a social–ecological problem (Ostrom 2009; Lubell et al. 2014), we conducted an integrative legal–ecological mapping approach to inform coordinated actions along corridors (Fig. 1).

Role of Governance in Conservation Corridors

Corridor conservation requires a governance system to coordinate protections across jurisdictions, sectors, and levels of actors (Lebel et al. 2006). Governance includes governmental or nongovernmental entities and formal (i.e., government) or informal institutions engaged in "organized efforts to manage the course of events in a social system" (Burris 2008). Conservation corridors spanning jurisdictional or sectoral boundaries created by formal governance must be feasible to implement and maintain under all applicable sources of legal authority (Brodie et al. 2016). We define *sources of legal authority* as formal governmental authority through constitutional, statutory, regulatory (including land-use planning and zoning), and management authority, as well as public or private ownership (Baldwin & DeMaynadier 2009; Boisjolie et al. 2019). Legal authority originates at the international, national, tribal, subnational, state or provincial, or local level of government. Each governing entity has a mission, structure, and mechanisms for implementation. These authorities vary in whether and the degree to which they protect habitat and have jurisdictional authority to extend protections beyond their ownership boundaries to achieve connectivity.

The areal extent and legal attributes of each authority can be mapped to a legal footprint on the landscape. The spatial arrangement of overlapping legal footprints can provide but also constrain the capacity to coordinate corridor planning, implementation, and maintenance across boundaries (e.g., Brondizio et al. 2009; Chester 2012; Brodie et al. 2016). For instance, practices to mitigate nonpoint source pollution for water quality may coincide with riparian habitat protections for aquatic species. Conservation measures under each of these authority sources may be either voluntary or mandatory and the nature or degree of enforcement varies from public to private lands or among landowners. The spatial overlap of the 2 authorities with potentially congruent goals represents capacity to coordinate actions; however, the realization of that capacity depends on site-specific factors (e.g., landowners' values or agencies' funding and personnel limitations).

To evaluate legal capacity to coordinate conservation actions across boundaries, we referred to the literature on adaptive governance (Dietz et al. 2003; Folke et al. 2005), collaborative governance (Bodin 2017), and adaptive comanagement (Armitage et al. 2007; Olsson et al. 2007). These works discuss governance mechanisms under which nesting (overlapping authorities at multiple levels), social networks across jurisdictions and sectors and among public and private actors, and the existence of bridging organizations (e.g., conservation NGOs acting across boundaries) may legitimately function to improve the spatial fit between legal systems and ecosystems. Existing governance for landscape-scale problems is polycentric and multilayered (i.e., there are multiple centers of authority at various levels rather than a centralized, top-down system) for unrelated historical reasons. It would be inefficient and impossible to create a formal governing entity at the scale of every potential problem (Folke et al. 2007), yet polycentric governance provides an avenue to fit governance to problem scale through informal networks. Although there is little empirical evidence that polycentricity alone improves environmental management (Lebel et al. 2006; Huitema et al. 2009), polycentric governance systems provide the potential flexibility to manage cross-scale and cross-sector interactions, respond to problems at the most relevant scales, and provide an avenue for coordinated management across boundaries (Folke et al. 2005; Lockwood et al. 2010), once connected. Previous work has focused on nesting in a polycentric political system (Huitema et al. 2009) and the capacity to bridge across sectors and levels of government and society (e.g., Lebel et al. 2006; Lockwood et al. 2010; Bodin 2017). We focused on the capacity to bridge gaps in a polycentric system to connect governance at the landscape scale by identifying opportunities to enhance spatial coordination within existing governance systems.

Social–Ecological Basis for Focusing on Streamside Corridors

Habitat corridors are designed to facilitate movement, dispersal, or persistence at appropriate levels (individuals to populations) and scales (local to international) for target taxa; yet, it is impossible to anticipate the requirements of every taxon under varied stresses or disturbances (Hilty et al. 2006). Building social–ecological system resilience by enhancing habitat connectivity while aiming for other positive outcomes may increase the likelihood of success (Cimon-Morina et al. 2013). Streamside areas, a nexus of biodiversity and water-related ecosystem services (Brinson 2002), show promise for enhancing connectivity, where corridor building would otherwise be impractical, by leveraging actions over small areas for multiple outcomes (Hilty et al. 2006; Baldwin & DeMaynadier 2009). Systematic riparian and terrestrial habitat conservation along stream networks could link protected areas for wildlife (Fremier et al. 2015).

To illustrate challenges in corridor governance, we considered the large investments in piecemeal river restoration actions in the United States (Bernhardt et al. 2005) that fell short of securing longitudinal connectivity for the public good (e.g., clean water [Brinson 2002] or wildlife movement [Fremier et al. 2015]). Streamside areas receive greater protection than uplands, but lack integrated management across governing entities (i.e., across scales, jurisdictions [aquatic or terrestrial], and sectoral boundaries) (Brinson 2002). On private lands, the mechanism of protection and manner of compliance varies by parcel (Pannell 2008), influencing the distribution of high-quality habitat (Zimbres et al. 2018). For instance, timber harvest restrictions along headwater streams on public forested lands aimed at fish recovery are inadequate due to downstream conditions (mainly under private ownership) that limit survival and completion of the anadromous life cycle (Grantham et al. 2017; Reeves et al. 2018; Boisjolie et al. 2019). Each authority source applies to a fragment of the ecosystem; there is a spatial mismatch (Folke et al. 2007; Young et al. 2007) between riverine corridor ecology and governance. Achieving connectivity-dependent goals would require bioregional-scale coordination of actions across the spatial scales of dynamic riverine ecosystems (Crowder et al. 2006; Ekstrom & Young 2009). Although individual sources of streamside conservation authority may not match the scales of species' migration or dispersal, they span local to continental scales, suggesting that further coordination could build capacity to enhance ecological connectivity (Olsson et al. 2007; Brondizio et al. 2009; Fremier et al. 2015).

We devised a novel approach to mapping capacity to coordinate bioregional-scale corridor conservation by incorporating spatial patterns in legal authority into landscape connectivity modeling and spatial prioritization. We addressed the complexity of corridor governance by selecting a scale most parsimonious to the focal landscape. We used our approach to identify priority areas for restoration or capacity building (e.g., by bridging organizations or stronger links in institutional networks) for coordinated corridor conservation. We addressed the following questions: To what degree is the legal landscape fragmented with respect to actions needed to conserve ecological connectivity? How can we spatially represent legal authority to inform efforts to build bioregional-scale coordination capacity? How might the inclusion of legal authority in spatial ecological modeling inform the prioritization of conservation actions along potential corridors? We also considered future applications of legal–ecological mapping to inform capacity building for connectivity conservation.

Methods

Study Area

Okanogan County, northeastern Washington State (U.S.A.) spans a habitat gap between the Cascade Range and Rocky Mountains (Fig. 2). The study area (~14,000 km^2) included protected areas, public multiple-use lands, tribal lands, and privately owned agricultural lands (Fig. 2; USGS 2016). Protected high-quality habitat (e.g.,

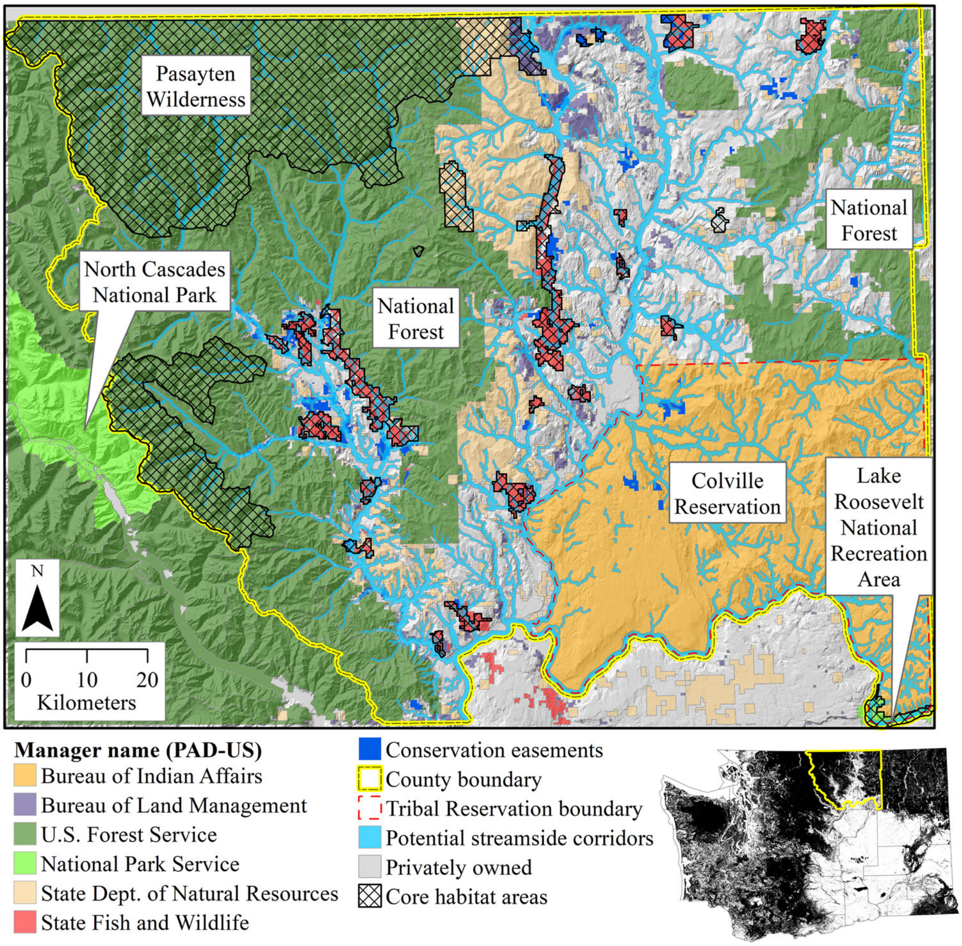

Figure 2. Location of Okanogan County within the state of Washington (northwestern United States) (black, areas of vegetative cover) and potential streamside corridor network that spans boundaries of land ownership and jurisdiction. Map sources: U.S. Geological Survey (2013, 2016), Washington Department of Fish and Wildlife (WDFW) (2015), U.S. Census Bureau (county outlines from the TIGER/Line Shapefile).

Wilderness areas, State Conservation Areas) was symbolized by 25 polygons (~19% of the study area). Restoring connectivity to accommodate potential movement patterns of montane species (e.g., American black bear [*Ursus americanus*] and Canada lynx [*Lynx canadensis*]) is a regional conservation goal (GNLCC 2016). The core areas and adjacent multiuse lands are administered by federal and state agencies. The remainder is divided into numerous parcels subject to local or tribal land-use regulations. Capturing variability in streamside corridor protections among these jurisdictions and parcels required a review of local- to national-level legal authority.

Mapping Legal Footprints

In a geographic information system (GIS), we represented the maximum potential extent of a streamside corridor network (potential network) by multiplying reach-scale Strahler stream order by 60 m (ESRI ArcMap Buffer tool) (USGS 2013) (Fig. 2). This delineated an area adjacent to stream centerlines that was roughly proportional to stream size. The selection of 60 m as a multiplier was a simple first-pass assumption to outline a reasonable area for streamside connectivity analysis that is consistent with the corridor literature (Hilty et al. 2006).

We reviewed the national, tribal, state, and local statutes, regulations, rules, and plans pertaining to conservation actions within the potential network under the federal Endangered Species Act (ESA) and Clean Water Act (CWA), state laws, tribal code, and local government zoning, distilling 17 sources of legal authority (Supporting Information). To symbolize the legal footprint of each source, we used publicly available GIS data or generated polygons consistent with reviewed documents and available data sets (e.g., USGS 2016). We then attributed each legal footprint (polygon or polygons) with the statutory or regulatory basis of authority and implementing organizations (Supporting Information). We symbolized critical habitat designations separately because each is contingent on its ESA listing status and has a unique legal footprint. We mapped CWA authority for both wetlands and watershed-level measures to mitigate nonpoint source pollution. We represented the Washington State Shoreline Management Act in 2 layers, state and local levels of enforcement (Supporting Information).

Quantifying Capacity to Coordinate Corridor Protection

We converted each layer of authority ($n = 17$) into a 30×30 m raster to spatially represent patterns in

Table 1. Rubric used to code each source of legal authority across a potential streamside corridor network and relative ranking scores for each source in 3 categories*.

	Category		
Relative ranking score applied to each category	degree of streamside area protection provided (P)	potential enforcement (E)	effect on continuity of streamside area protection across boundaries (C)
2 = strongest	protects riparian or streamside (not explicitly riparian) areas	mandatory	extends beyond jurisdictional boundaries of a governing body
1 = moderate	may provide streamside area protection	voluntary, subject to agency discretion, or dependent on local policy determinations	extends beyond parcel boundaries within jurisdiction of same governing body
0 = weak or absent	does not provide streamside area protection	none	ends at property or jurisdictional boundaries of adjacent uplands

**These scores are relative values specific to the context of this study and have no absolute meaning. This rubric should be contextualized before it is applied to inform planning or to any other study context. The sum of the 3 scores equals the conservation authority index (CAI) value (CAI = P + E + C) in each row of Table 2.*

legal authority without being unnecessarily computationally intensive. In each authority raster, we assigned a value of 1 to each cell of the potential network within the legal footprint and 0 to all other pixels. We used these authority rasters to compile 2 data sets. First, the sum of overlapping legal footprints (Supporting Information) provided a reconnaissance-level illustration of the patterns in legal authorities but did not account for the reality that authority sources vary in their capacity to provide coordinated streamside corridor protections. Thus the second data set incorporated differences in this capacity as reflected in the language, potential for enforcement, and conservation goals described in the legal documents reviewed. We developed a rubric (Table 1) to rate each source with a conservation authority index (CAI). The CAI value coarsely reflects comparative capacity to contribute to coordinated streamside corridor protection across jurisdictional and sectoral boundaries. Focusing on this capacity rather than the finer points of legal authority, we coded a relative ranking score (0, 1, or 2) based on a textual analysis of 3 parameters characterizing each authority source: degree of streamside protection (explicit riparian habitat protection or broader protections that apply to streamside areas), potential for enforcement, and extent of cross-boundary continuity (Tables 1 & 2). The CAI value for each source equaled the sum of these 3 scores. Higher CAI values suggest greater capacity (i.e., more direct language and potential enforcement for coordinated streamside corridor protection). For example, under the CWA, best management practices (BMPs) to address nonpoint source pollution may be similarly implemented across property boundaries, but BMPs are voluntary (coded 1), apply only within watershed (jurisdictional) boundaries (coded 0), and do not explicitly protect streamside areas (coded 0). This summed to a CAI of 1. The Washington State Shoreline Management Act received the highest CAI (coded 6) because it explicitly protects streamside areas (coded 2), enforcement is mandatory (coded 2), and it provides a framework for continuous protection along designated streams statewide, spanning local governments' jurisdictions (coded 2).

We reclassified each authority raster so that each cell of the potential network within its legal footprint contained the corresponding CAI value. We then spatially summed the CAI-value rasters to represent the number of overlapping authority sources weighted by corridor coordination capacity. The summed CAI value ($_{\Sigma}$CAI) map (Fig. 3a) illustrated the spatial arrangement of this capacity across the potential network under existing legal authority. The $_{\Sigma}$CAI represented spatial patterns in the capacity to coordinate. It was not assumed that overlaps in authority are conducive to coordinating corridor protections. Normalizing by the number of overlapping authorities would not be appropriate because our focus was the cumulative capacity to coordinate corridor protections based on the arrangement of legal footprints. In any given location, one source of authority could be an obstacle to corridor building; such information would be lost if we normalized or averaged values. We regard the $_{\Sigma}$CAI as one possible metric of corridor coordination capacity. In any setting, the pertinent characteristics of each authority source and use of a CAI must be contextualized.

Next we reclassified the $_{\Sigma}$CAI values for combined legal-ecological landscape analysis. In resistance surfaces for habitat connectivity modeling, each pixel is assigned a relative frictional cost value that represents the relative difficulty of movement (resistance) across it for focal taxa (McRae et al. 2008). This resistance value is indirectly tied to a biological (e.g., energetic) cost through habitat characteristics hypothesized to influence the ability of taxa to move across that pixel. The resistance raster is input into GIS tools that compute the least-cost corridor—the corridor of lowest accumulative cost among all possible corridors connecting habitat patches. To symbolize the legal aspect of coordination capacity in equivalent terms of resistance, we reclassified the $_{\Sigma}$CAI values by

Table 2. Conservation authority index (CAI)[a] values assigned to the sources of legal authority for streamside corridor conservation actions in Okanogan County, Washington (WA), in the northwestern United States.

Source of authority for conservation actions	*Organizations overseeing conservation actions*	*Degree of streamside area protection provided (P)*	*Potential enforcement (E)*	*Effect on continuity of streamside area protection across boundaries (C)*	*CAI value*
Best management practices to address nonpoint source pollution (U.S. Clean Water Act)	WA Ecology[b], U.S. Environmental Protection Agency	0	1	0	1
Conservation easements that protect streamside areas by parcel	various governmental and nongovernmental organizations	1	0	1	2
Critical habitat designation for bull trout (*Salvelinus confluentus*) (U.S. Endangered Species Act [ESA])	U.S. Fish and Wildlife Service	0	2	0	2
Critical habitat designation for spring-run Chinook salmon (*Oncorhynchus tshawytscha*) (ESA)	National Marine Fisheries Service	0	2	0	2
Critical habitat designation for steelhead and rainbow trout (*Oncorhynchus mykiss*) (ESA)	National Marine Fisheries Service	0	2	1	3
Wetlands protection through reporting and permitting requirements (U.S. Clean Water Act)	U.S. Environmental Protection Agency, U.S. Army Corps of Engineers, WA Ecology	1	2	0	3
Forest Practices' Riparian Management Rules to protect water quality and fish habitat	WA Department of Natural Resources	2	1	0	3
Critical habitat designation for Canada lynx (*Lynx canadensis*) (ESA)	U.S. Fish and Wildlife Service	2	2	0	4
Critical habitat designation for Northern Spotted Owl *(Strix occidentalis caurina*) (ESA)	U.S. Fish and Wildlife Service	2	2	0	4
Tribal zoning authority may require setbacks on private areas within outer reservation boundaries	CCT[c] Comprehensive Planning Department (tribal government)	1	1	2	4
Local government (county) zoning authority may require set-backs on private areas	local (county) government	1	1	2	4
WA Growth Management Act requires local governments to protect ecosystem functions and values of fish and wildlife habitat conservation areas through Critical Areas Ordinances or the Voluntary Stewardship Program	WA Department of Fish and Wildlife	2 (riparian habitat) or 1 (other Priority Habitats and Species)	1	2	5 (riparian habitat)or 4 (other Priority Habitats and Species)
Government-owned protected areas and multiple-use areas (public lands) managed by governmental agencies under applicable mandates	U.S. Forest Service, National Park Service, WA Department of Fish and Wildlife, WA Department of Natural Resources	2	2	1	5

Continued

Table 2. Continued.

Source of authority for conservation actions	*Organizations overseeing conservation actions*	*Degree of streamside area protection provided (P)*	*Potential enforcement (E)*	*Effect on continuity of streamside area protection across boundaries (C)*	*CAI value*
Local government shoreline master programs restrict privately owned shoreline development and use	local (county) government	2	2	1	5
WA Shoreline Management Act requires restrictions on shoreline development and land use for designated streams	Ecology	2	2	2	6
CCT Shoreline Code restricts shoreline development and use within outer Reservation boundaries	CCT Comprehensive Planning Department	2	2	2	6
Government-owned aquatic parcels are managed by governmental agencies under applicable mandates	WA Department of Natural Resources	2	2	2	6

[a] *Quantifies the comparative capacity each source of legal authority may contribute to coordinated streamside corridor protection across boundaries of land ownership and jurisdiction. Each source of legal authority is coded with a score (0–2) in each column based on the degree of streamside protection, potential enforcement, and effect on continuity of streamside protection across boundaries it provides. In this study, 2 is the highest possible rating, 1 indicates a moderate rating, and 0 indicates no contribution to the CAI value. The sum of the 3 values in each row equals the CAI value (CAI = P + E + C). See Table 1 and Supporting Information for additional details on CAI value assignments.*

[b] *Department of Ecology*

[c] *Colville Confederated Tribes*

natural breaks into deciles, such that 1 represented greatest capacity (highest $_{\Sigma}$CAI values, 37–48) and thus the lowest legal resistance in the study context. A value of 10 represented lowest capacity (lowest $_{\Sigma}$CAI values, 1–6) and thus greatest legal resistance (Fig. 3a). We added 1000 to all upland cells to make them relatively impermeable and focused subsequent analyses on the relative resistance among possible streamside corridors. Rescaling $_{\Sigma}$CAI values with ($_{\Sigma}$CAI/48∗1000)+1 did not produce substantially different results than the decile classification (Supporting Information). We present the most parsimonious model inputs and outputs.

We used a continental map of human modification (Theobald 2013) as a proxy for ecological resistance (Supporting Information). We reclassified the human modification index (with values from 0 to 1) by natural breaks into deciles, such that 1 represented the least human modification (i.e., highest naturalness) and thus the lowest ecological resistance. A value of 10 represented highest degree of human modification and thus greatest ecological resistance. To generate a combined legal-ecological resistance raster for connectivity analysis, we spatially summed the legal and ecological resistance rasters (Fig. 3a & Supporting Information). We generated 4 alternative resistance surfaces with different scaling methods to coarsely assess sensitivity (Supporting Information).

Computing Least-Cost Corridors

We computed least-cost corridors with the ArcMap Corridor tool, which sums the accumulative costs of 2 input cost-distance rasters. We divided core areas into 2 groups: first, North Cascades National Park, Pasayten Wilderness, and smaller protected areas in the vicinity; and second, Lake Roosevelt National Recreation Area, which extends eastward beyond the county boundary. We then paired each core area input with the legal-ecological resistance raster (Supporting Information) to generate 2 cost-distance rasters and compute the least-cost corridor (alternative corridor outputs in Supporting Information).

Comparing Legal and Ecological Components of Connectivity

To visualize differences in the legal and ecological components of connectivity by location, we devised a spatial social–ecological categorization scheme similar to a decision-support matrix (e.g., Sayles & Baggio 2017). We distinguished 4 context-specific categories based on capacity (high or low) to coordinate protections ($_{\Sigma}$CAI) and naturalness (high or low) (human modification index [Theobald 2013]) (Fig. 4a). We summarized reach-scale values for capacity (Fig. 3a) and naturalness (Supporting Information) by calculating zonal statistics

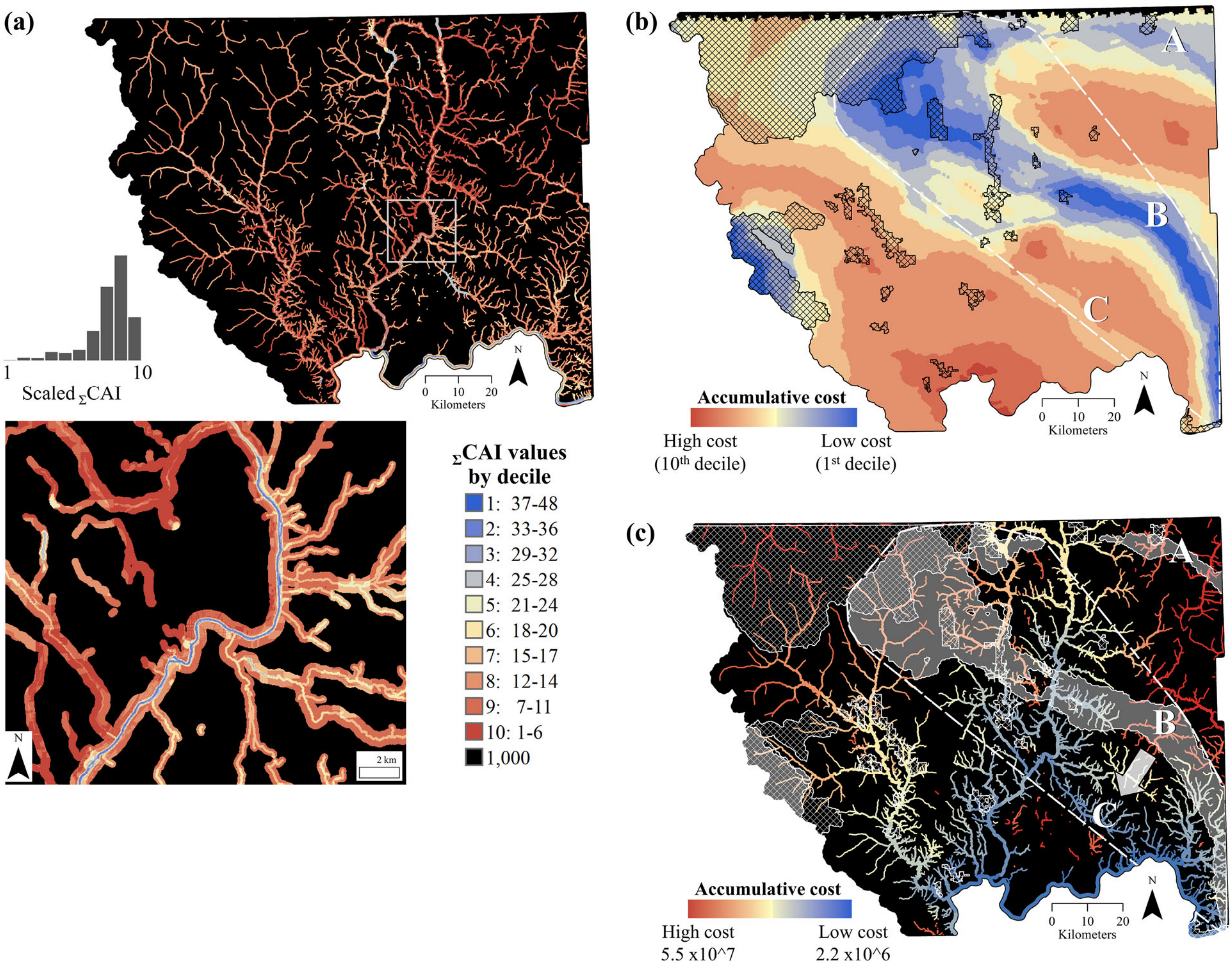

Figure 3. (a) Classification of summed conservation authority index ($_{\Sigma}$CAI) values (1–48) into deciles to represent legal resistance to building terrestrial habitat connectivity across the study area (values of 37–48, decile 1 represent the least legal resistance); values in streamside areas; and least-cost corridor models (hatched areas, core habitat) for (b) composite corridor value model (Belote et al. 2016) clipped to the study area, resampled, and classified (quantile) into deciles for visual comparison and (c) the integrated legal-ecological corridor model (Supporting Information) (black, uplands masked to highlight relative costs among possible streamside corridors; white overlay, superimposed least-cost corridors from [b] onto [c]); dashed white line, minimum bounding polygon; example, A and B are unsuitable for streamside corridors, but C could enhance regional connectivity).

with Reach Code (USGS 2013) with a minimum operator (because the fine details were lost with a median operator). We divided the naturalness and capacity values into 2 classes, respectively: higher naturalness and capacity (1–5) and lower naturalness and capacity (6–10). We used conditional statements to place each reach into one of 4 categories (Fig. 4b): low naturalness, low capacity (barriers); high naturalness, high capacity (bridges); high naturalness, low capacity (opportunities to build capacity); and low naturalness, high capacity (opportunities to leverage capacity by restoring ecological condition). All processes were completed in ESRI ArcMap 10.

Results

Legal Resistance and Least-Cost Streamside Corridors

The number of legal footprints (Supporting Information) and $_{\Sigma}$CAI values (coordination capacity) (Fig. 3a) were heterogeneously distributed across the potential network, illustrating legal landscape fragmentation within the habitat gap. The highest capacity ($_{\Sigma}$CAI) values were adjacent to stream reaches, where multiple critical habitat designations coincided with water-related protections. The lowest capacity ($_{\Sigma}$CAI) values and the most finely spaced contrasts were among parcels under varying private or tribal ownership. Comparing the

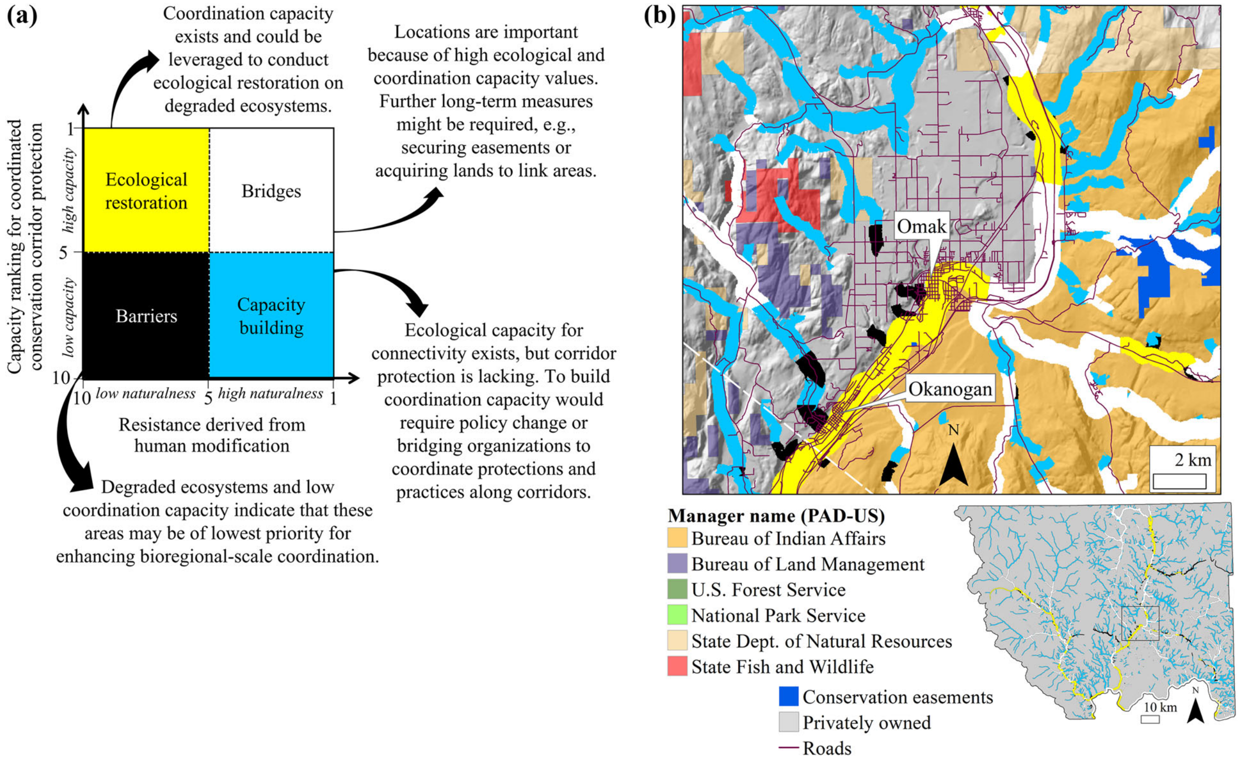

Figure 4. (a) Example categorization scheme based on pairing resistance values derived from human modification and legal authority (capacity) into 4 groups that determine opportunities to inform local prioritization within the broader context of achieving habitat connectivity and riverine ecosystem conservation goals. (b) Scheme applied to an example location to illustrate spatial patterns in the opportunities for further conservation actions.

legal–ecological least-cost corridor model for the study area to the composite corridor value model of the United States (Fig. 3) illustrated the effects of masking connectivity analysis to streamside areas and incorporating legal resistance. For instance, locations A and B were within least-cost corridors based on naturalness at the national-scale (Fig. 3b), but in the streamside corridor model (Fig. 3c) these areas had high accumulative costs relative to other streamside areas in the county. The different accumulative cost patterns at A and B were consistent with the low densities of streams in those areas. In contrast, location C marked a least-cost corridor in the streamside model, but in the naturalness-based model the same area showed moderately high accumulative costs. Incorporating legal authority in the least-cost computation captured the high density of sectoral boundaries, lack of designated critical habitat, and discontinuous shoreline jurisdiction at location B. The integrated model identified a potential alternate route for building habitat connectivity along streams (through location C, ~25 km southwest of B) that may be more feasible to implement than a corridor based primarily on naturalness. The corridor output illustrates areas where a streamside approach to building connectivity may direct conservation efforts differently than an approach based primarily on naturalness.

Comparison of Legal and Ecological Components of Connectivity

The classified map of coordination capacity and naturalness in the study context (Fig. 4) showed spatially heterogeneous opportunities for future conservation actions. Reaches with low naturalness coincided with cities, highways, privately owned agricultural lands or semi-arid areas (Fig. 2). Barrier reaches were mainly along smaller streams spanning finely spaced private or tribal parcels, where habitat was highly fragmented and streamside protections are fewer, less explicit, or determined by parcel. Ecological restoration reaches were mainly adjacent to major rivers in developed areas or working lands, where aquatic-riparian habitat protections provided capacity that could be leveraged for streamside restoration. Bridge reaches and capacity-building reaches were located on federal, tribal, state, and private lands, mainly outside of urban centers. Capacity-building reaches were associated with fewer, less explicit, or discontinuous protections across boundaries. Building capacity for bioregional-scale coordination across these areas would require policy incentives or bridging organizations to link corridor protections and practices across jurisdictions, sectors, and scales (Fig. 1).

Discussion

Our mapping approach integrated governance concepts with ecological landscape analysis, identifying opportunities to address a spatial mismatch through bridging actions within existing governance systems. The results demonstrated that spatially explicit legal authority can be analyzed with ecological data sets to evaluate capacity for connectivity conservation. Including local-scale legal footprints and applying a streamside mask yielded different accumulative cost patterns than a national-scale model based primarily on naturalness (Fig. 3). Reach-scale comparisons between coordination capacity and naturalness values indicated variable potential streamside actions (Fig. 4), yielding a local-scale prioritization scheme that incorporated congruent landscape-scale conservation goals (Redford et al. 2003; Chester 2012). This approach can reveal opportunities to enhance connectivity by transparently illustrating local conservation actions (e.g., riparian restoration projects) within a broader context. Fish, wildlife, or resource management agencies or NGOs could combine this with existing tools to identify priorities while coordinating decisions and actions across jurisdictions, sectors, and scales (Ament et al. 2014; Sayles & Baggio 2017).

We interpreted overlapping legal footprints as capacity to coordinate protections for connectivity, relying on environmental governance theory and empirical studies (Fig. 1). Mapping alone cannot determine whether this capacity will be used to enhance spatial fit or it will be overcome by the inefficiency of polycentric, multilayered governance systems (Huitema et al. 2009). Rather, it is one potential indicator of the social–ecological landscape to be considered in systematic conservation planning. Application of a CAI-based method produces a series of context-specific map layers with attributed legal footprints. Pertinent attributes include source GIS data sets, references to documents, and entities involved in policy, planning, or implementation. It is essential to engage stakeholder groups and consult maps at the parcel level of detail before proceeding with planning. Participatory mapping can help engage stakeholder groups (Wong et al. 2015).

The capacity to coordinate local actions for connectivity and system resilience is influenced by spatial patterns in ecological condition and legal authority (Fremier et al. 2015; Cosens et al. 2017) as well as social relationships (Sayles & Baggio 2017) and institutional networks (Folke et al. 2007; Lubell et al. 2014) (e.g., the success of conservation plan implementation may be spatially related to existing policy and past conservation actions [Carter et al. 2015]). Areas of success (bridges) can be stepping stones for building connectivity. Clearly displaying cross-scale spatial relationships between legal authority and ecosystems may help foster new collaborations or prioritize local actions (Redford et al. 2003; Wong et al. 2015). Including connectivity-dependent outcomes and cobenefits (Supporting Information) in spatial models may incentivize coordination among entities with congruent goals, offering opportunities to leverage existing policy and funding (Fremier et al. 2015; Boisjolie et al. 2019). For instance, agencies or NGOs might incentivize conservation easements along corridors (e.g., location C [Fig. 3c]), where policy and funding for anadromous fish recovery could be leveraged to restore riverine ecosystem connectivity, improve water quality, and enhance terrestrial habitat connectivity.

Maps comparing legal authority with habitat characteristics can inform local-scale decision making by land managers, local governments, or NGOs by providing a basis for social–ecological evaluation and prioritization (Hobbs & Kristjanson 2003; Sayles & Baggio 2017). In our example categorization scheme, bridge reaches could be preserved as elements of an emerging conservation network (e.g., bridging NGOs could coordinate conservation easements to link these areas [Brondizio et al. 2009; Graves et al. 2019]); barrier reaches could be dismissed as areas of lowest priority. The remaining reaches could be prioritized either to leverage existing capacity for restoration actions or build capacity to link areas in good condition.

Our method is subject to the assumptions and limitations of resistance-based connectivity modeling (McRae et al. 2008; Zeller et al. 2017). Although our ordinal ranking system is an oversimplification and the numerical values have no absolute meaning, it provides a repeatable process for contextualizing and symbolizing a spatially explicit legal landscape. We presumed that uplands would have fewer protections and lower coordination capacity than streamside areas, biasing least-cost pathways toward dense stream networks (Fig. 3). Where streamside areas are not positioned to span a habitat gap or are unsuitable for target taxa, alternate corridor locations should be considered (Hilty et al. 2006).

Future work should consider local to international conservation settings, contextualize CAI rubrics and resistance surfaces, and evaluate the sensitivity of analytical-area selection and landscape definition. Conservation planners' and practitioners' knowledge (e.g., stakeholders' perspectives, taxon-specific information, bridging organizations) can inform the generation of resistance surfaces capturing relevant details of the social-ecological landscape. Where overlapping sources of authority inhibit coordination, CAI rubrics and resistance surfaces can reflect lower capacity for building connectivity. Future development of this modeling approach could incorporate such nuances with other integrative social–ecological toolsets, (e.g., social–ecological network analysis [Sayles & Baggio 2017] or participatory GIS programs [Wong et al. 2015]).

Systematically codifying existing knowledge of the legal–ecological landscape increases transparency and may facilitate communication among stakeholders with different interests and knowledge bases. Both products and process of this approach can provide a platform for collaboration and capacity building by effectively communicating place-based, social–ecological dimensions of connectivity conservation across scales. This type of communication is essential to a multistate, multiscale, social–ecological approach to conservation planning for connectivity (Brondizio et al. 2009). This approach is transferable to other cases where a spatial mismatch between governance and ecosystems limits connectivity conservation.

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Supporting Information

A summary of legal authority data (Appendix S1) and additional maps (Appendices S2–S5) are available online. The authors are solely responsible for the content and functionality of these materials. Queries (other than absence of the material) should be directed to the corresponding author. Raster data sets are available from https://doi.org/10.5063/F1BR8QHK.

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