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Making habitat connectivity a reality

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Abstract: *Although a plethora of habitat-connectivity plans exists, protecting and restoring connectivity through on-the-ground action has been slow. We identified challenges to and opportunities for connectivity conservation through a literature review of project implementation, a workshop with scientists and conservation practitioners, 3 case studies of connectivity projects, and interviews with conservation professionals. Connectivity challenges and solutions tended to be context specific, dependent on land-ownership patterns, socioeconomic factors, and the policy framework. Successful connectivity implementation tended to be associated with development and promotion of a common vision among diverse sets of stakeholders, including nontraditional conservation actors, such as water districts and recreation departments, and with communication with partners and the public. Other factors that lead to successful implementation included undertaking empirical studies to prioritize and validate corridors and the identification of related co-benefits of corridor projects. Engaging partners involved in land management and planning, such as nongovernmental conservation organizations, public agencies, and private landowners, is critical to effective strategy implementation. A clear regulatory framework, including unambiguous connectivity conservation mandates, would increase public resource allocation, and incentive programs are needed to promote private sector engagement. Connectivity conservation must move more rapidly from planning to implementation. We provide an evidence-based solution composed of key elements for successful on-the-ground connectivity implementation. We identified the social processes necessary to advance habitat connectivity for biodiversity conservation and resilient landscapes under climate change.*

Keywords: case studies, framework, lessons learned, planning-implementation gap, wildlife corridors

Vías para que la Conectividad de Hábitat sea una Realidad

Resumen: *Aunque existe una plétora de planes para la conectividad de hábitat, la protección y la restauración de la conectividad por medio de acciones en el lugar han sido lentas. Identificamos los retos y las oportunidades para la conservación por conectividad mediante una revisión de la literatura sobre la implementación de proyectos, un taller con científicos y practicantes de la conservación, tres estudios de caso sobre proyectos de conectividad, y entrevistas con profesionales de la conservación. Los retos y las soluciones para la conectividad tendieron a ser específicas del contexto, dependientes de los patrones de propiedad de tierras, factores socioeconómicos, y el marco de trabajo político. La implementación exitosa de la conectividad tendió a estar asociada con el desarrollo y la promoción de una visión común entre los diversos conjuntos de accionistas, incluyendo a actores no tradicionales de la conservación, como los distritos acuáticos y los departamentos de recreación, y con la comunicación con los socios y el público. Otros factores que derivan en la implementación exitosa incluyeron el comienzo de estudios empíricos para priorizar y validar corredores y la identificación de los co-beneficios relacionados de los proyectos de los corredores. El compromiso de los*

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socios involucrados en el manejo y la planeación de las tierras, como las organizaciones no gubernamentales, agencias públicas, y terratenientes privados, es de suma importancia para la implementación efectiva de las estrategias. Un marco de trabajo regulatorio evidente, incluyendo los mandatos inequívocos de la conservación por conectividad, incrementaría la asignación de recursos públicos, además de que los programas de incentivos son necesarios para promover el compromiso entre el sector privado. La conservación por conectividad debe avanzar más rápidamente de la planeación hacia la implementación y debe proporcionar una solución con base en evidencias compuesta por elementos clave para tener una implementación exitosa de la conectividad en el lugar. Identificamos los procesos sociales necesarios para avanzar la conectividad de hábitat para la conservación de la biodiversidad y los paisajes resistentes ante el cambio climático.

Palabras Clave: corredores de fauna, estudios de caso, lecciones aprendidas, marco de trabajo, vacío en la implementación de la planeación

摘要: *尽管存在着大量连接栖息地的计划, 保护和恢复栖息地连接度的实际行动却很少。通过对项目实施情况进行文献综述、组织科学家与保护实践者的研讨会、三个栖息地连接项目的案例分析, 以及与保护专家访谈, 我们确定了连接度保护面临的挑战和机遇。栖息地连接面临的挑战和解决方案往往是情境特定的, 取决于土地所有权类型、社会经济学因素和政策框架。而栖息地连接的成功实施则需要发展和促成多方利益相关者 (包括非传统的保护参与者, 如水源区和休闲场所) 之间的共同愿景, 并与合作者和公众进行沟通。保护成功实施的其它因素还包括进行实证研究来确定廊道建设的优先性和可行性, 以及廊道建设项目的相关效益。吸引非政府保护组织、公共机构和私人土地所有者等合作者参与到土地管理和规划中, 对于保护战略的有效实施也至关重要。一个清晰的监管框架 (包括明确的连接度保护规定) 能够提高公共资源配置效率, 另外还需要激励制度来推动私营部门的参与。连接性保护必须更快地从规划转向实施, 并提供基于经验的解决方案其中含有栖息地连接性保护的成功实施的关键要素。本研究确定了在气候变化背景下, 为生物多样性保护和景观恢复而提高栖息地连接性所必需的社会过程。* ***【翻译: 胡怡思; 审校: 聂永刚】***

关键词: 案例分析, 框架, 经验教训, 规划-实施的差距, 野生生物廊道

Introduction

For over four decades, wildlife corridors have been used to mitigate the impact of habitat fragmentation and to maintain landscape connectivity, resulting in a variety of corridors, linkages, and wildlife-friendly road crossings worldwide (Hilty et al. 2012). Ambitious efforts at the continental scale include the Yellowstone to Yukon Conservation Initiative in North America, the Gondwana Link in Australia, and the Mesoamerican Biological Corridor (Shadie & Moore 2008). However, with continuing habitat loss and fragmentation (Theobald et al. 2016) and climate change driving species range shifts (Hannah 2011), there is an urgent need to speed up implementation of habitat connectivity projects.

Many local, regional, and national connectivity studies and plans exist (e.g., Merenlender et al. 2010), but implementation has been slow (Tiemann & Siebert 2009). The failure to translate connectivity research and scientifically informed plans into conservation action is often referred to as the research-implementation gap or planning-implementation gap. This gap can be bridged by scientists engaging with conservation practitioners throughout an entire project, from the initial study questions through project implementation and monitoring (Knight et al. 2008). Because academic norms do not often promote such long-lasting engagement, applied conservation science should be conducted by scientists working within resource management agencies or environmental organizations or involve formal agreements between practitioners and academic scientists to ensure comprehensive collaboration (Cook et al. 2013). However, "conservation is a social process that engages science, not a scientific process that engages society" and there is a need to reconceptualize the planning-implementation gap as a space that needs to be filled by a diversity of social processes to achieve conservation implementation (Toomey et al. 2017).

We investigated the challenges and opportunities of moving from connectivity conservation planning to implementation by examining the available literature and the personal experiences of practitioners. We distilled components critical to successful implementation of connectivity projects, considered relationships among these components, and created a guiding framework. The components of the framework constitute the social processes necessary to enable successful implementation of scientifically informed connectivity planning. Although there is no single solution to successful implementation, our analysis of the challenges and successes may help future implementation efforts be successful.

Scholarship

Although corridor science is well studied, the literature on corridor implementation is limited. We define *corridor* as spatially constrained habitats that provide connectivity between larger habitat areas. We found 27 peer-reviewed papers, 13 reports, and 5 book chapters

that included information on implementation and corridors in Web of Science and the top 100 Google search results in May 2017 (Supporting Information).

To improve understanding of factors that may increase or jeopardize success of connectivity implementation projects, we conducted 30 interviews with practitioners in conservation organizations and public agencies. The interview protocol was approved by the Committee for Protection of Human Subjects of the University of California, Berkeley (permit 2016-09-9118). We also convened scientists and practitioners from resource agencies and organizations to brainstorm ways to best plan and implement connectivity in the face of continued human land use and climate change. The interviews and workshop were conducted with practitioners in California, where connectivity projects span a diversity of socioecological contexts and institutional participation. Interview questions were formulated to obtain information on the interviewee's role with respect to connectivity conservation, background on the project, type of information used for planning, and perceived challenges and opportunities encountered during implementation (Supporting Information).

Challenges and Opportunities

In the literature challenges and opportunities to corridor implementation varied, were context-specific, and depended on land-ownership patterns, the intensity of development and fragmentation, socioeconomic factors, institutional capacity, and regulatory framework (Worboys & Francis 2010; Worboys & Lockwood 2010; Fitzsimons et al. 2013; Brodie et al. 2016) (Supporting Information). A challenge in one context may be an opportunity in another. For example, political support, when present, is an opportunity, but when absent a challenge. Challenges can be based on customs, values, or the belief that projects will have negative impacts on the rights and economic opportunities of landowners (e.g., Naumann et al. 2011) (Supporting Information). They can stem from historical factors such as ingrained land-use patterns or a lack of alignment among project partners. Lack of funding and political will poses challenges as does lacking project or political leadership. Strategies for success fall into 6 broad categories that consolidate perspectives in the field.

Build Partnerships

Building partnerships is key for corridor implementation in regions with diverse landownership. Public–private partnerships can accomplish implementation because the 2 complement each other (Naumann et al. 2011; Gleason et al. 2013). Sometimes, private landowners refuse to deal with public agencies due to previous negative experiences, but the door may be open to nongovernmental organizations (NGOs). Private landowners and NGOs can often respond quickly to specific project needs. They can also attract and manage private charitable foundation funds, which are more flexible than agency funds (Gleason et al. 2013). Public agencies manage public lands and public funds, the transportation network, and natural resources and therefore are essential partners in connectivity conservation.

Involving agencies at appropriate levels and agency people in the right position can be challenging. For some high-profile agency-led projects, involvement of agency leaders is advantageous, whereas for many projects, such as road wildlife-mitigation projects, agency staff can address connectivity aspects in their routine work. For the latter to occur, agencies need to be required to address the issue of landscape fragmentation and have policies mainstreaming connectivity considerations in everyday decision making (Morrison & Boyce 2009).

Although many projects are started by one dynamic individual who inspires others to participate (Fitzsimons et al. 2013; Pulsford et al. 2015), a collaborative team is key to maintaining momentum and ensuring succession of leadership (e.g., Tiemann & Siebert 2009). Involving diverse stakeholders as equal partners from the beginning and maintaining regular communication is key to success. Early participation improves understanding of the need for and approach to connectivity conservation, increases buy-in, and encourages continued involvement (Rottle 2006; Jongman 2008). Ongoing dialogue and information exchange gives partners and communities a sense of ownership and responsibility (e.g., von Haaren & Reich 2006). An atmosphere of cooperation promotes productivity and success, but if relationships get complicated, professional moderators may be needed (Tiemann & Siebert 2009). Although more effective in the long-term, collaborative efforts with multiple partners take longer to develop. When there are many partners, organizing leadership into a core team may be necessary.

Diverse private landownership may complicate connectivity implementation (e.g., Naumann et al. 2011). Opportunities to assign private lands conservation status can advance implementation of corridors. Involving landowners as critical partners, who have defined rights and responsibilities in the connectivity project and, if necessary, entering into formal agreements to manage land across property boundaries can lead to success.

Develop a Common Vision

Establishing a common vision of a connected landscape that integrates social, ecological, and economic outcomes proposed by partners and stakeholders is essential and can generate energy and enthusiasm among stakeholders and create a momentum for project implementation.

Table 1. Three U.S. case studies illustrating a framework for implementation of habitat connectivity.

	Huy 17, Santa Cruz County	*Sonoma Valley Wildlife Corridor*	*Desert Renewable Energy Conservation Plan*
Source	Nancy Siepel (California Department of Transportation) http://pathwaysforwildlife.com/hwy_17_wildlife_connectivity_improvement_project	Bob Neale, Tony Nelson (Sonoma Land Trust, California) https://sonomalandtrust.org/pdf/WildlifeCorridorOnline.pdf	Jim Weigand, Vicki Campbell (U.S. Bureau of Land Management) http://www.drecp.org/
Objective	Create a safe passageway across a busy, congested 4-lane highway that poses a barrier to wildlife movement.	Maintain and restore a regional wildlife corridor across Sonoma Valley, California, that encompasses approximately 4,000 ha and stretches from the top of Sonoma Mountain across Sonoma Creek and the valley floor to the Mayacamas Mountains to the east. The corridor is part of a much larger network of proposed linkages connecting habitats from the coast through the coastal mountains providing a vital connection for wildlife movement within the northern San Francisco Bay Area.	Prescribe land-use allocations on public land in the desert region of California, aiming to balance natural resource conservation, including landscape connectivity, with renewable energy development. For private lands, the plan provides a vision for biological conservation to inform conservation planning and investments
Partners	Land Trust of Santa Cruz County, Santa Cruz County Regional Transportation Commission, California Department of Transportation, California Department of Fish & Wildlife, University of California, Santa Cruz Puma Project	Sonoma Land Trust, other local conservation organizations, county and state parks, landowners, academia	main planning agencies: California Energy Commission, California Department of Fish and Wildlife, U.S. Bureau of Land Management, U.S. Fish and Wildlife Service, other state and federal agencies, tribal and local governments, NGOs, private entities
Intended conservation outcomes	Provide connectivity for multiple species to prevent genetic isolation and population fragmentation.	Facilitate wildlife movement and range shifts under climate change.	Establish landscape-scale system of connected conservation areas and ecologically functional natural communities and conservation of viable self-sustaining populations of focal species.
Planning: data and analysis	camera trap data mountain lion (*Puma concolor*) telemetry data road-kill data regional wildlife linkage models	wildlife camera grids and underpass monitoring and analysis of species detection rates parcel scale mapping landscape permeability analysis climate analysis comparing maximum summer and winter minimum temperatures between corridor termini	resource distribution in the planning area data on species occurrences, movement, dispersal, and population structure and trends species habitat models maps of natural communities expert knowledge of the resources climate modeling and climate change resiliency plans

(continued)

Table 1. ***(Continued)***.

	Hwy 17, Santa Cruz County	*Sonoma Valley Wildlife Corridor*	*Desert Renewable Energy Conservation Plan*
Opportunities	public-private partnership media campaign to generate public support land trust engaging lobbyists to generate agency support pilot agreement created advanced mitigation credits for wildlife connectivity sufficient biological data for project planning safety concern for humans (agency desire to decrease animal-car collisions)	interest by locals in wildlife long-standing positive relationship between partners large parcel of public hospital land closing and up for repurposing	politically motivated integration of sensitive biological resource conservation with renewable energy development high-level (U.S. secretary of interior, California governor) political support financial and staff support from federal and state agencies
Challenges	funding for construction of crossing structure lack of precedence for funding model	lack of funding for stewardship and cost sharing with landowners to improve habitat condition and corridor function private and public land in corridor threatened by intensive agricultural and residential development busy roadways and increasing recreation pressure lack of mechanisms and opportunities for organizations to work together initial lack of species presence and movement data, vegetation maps uncertainty of climate predictions (especially precipitation) and lack of climate predictions at preserve scale not clear how to measure success for the project given limited capacity and funding	high level of project complexity very large number of stakeholders integrating biological data collected at different scales ensuring that most of the sensitive species in the desert were considered staff inexperience with large project development
Implementation tools	crossing structures conservation easements	public engagement and development of a shared vision conservation easements in the corridor removal and mitigation of barriers to animal movement riparian area restoration land management for permeability sharing best management practices with landowners manage recreation to minimize impacts to wildlife	land-use allocation required management action (habitat restoration; land acquisition; mitigation, avoidance, and minimization action)
Monitoring and evaluation	plans to monitor underpass effectiveness with camera traps, telemetry studies, and roadkill surveys	wildlife monitoring	guidelines for monitoring and adaptive management

Table 2. Overarching recommendations and best practices for governments, public agencies, and conservation organizations relevant to most implementation contexts.

*Recommendation**	*Justification*
Create clear regulations and policies for public agencies.	This is important for spurring government agencies to address connectivity conservation.
Create voluntary incentive programs for private landowners.	Private landowners likely respond better to incentive programs than to regulations.
Offer incentives to diversify agricultural lands and cityscape.	This would increase general landscape permeability.
Use zoning with incentives to promote land conservation.	Especially in landscapes where development is sprawling, zoning can keep key areas open for wildlife, averting the need to purchase land for connectivity conservation in the future.
Create connectivity-specific funding sources.	This would enable connectivity projects that may otherwise fall through the cracks, e.g., because conservation legislation focuses on endangered species, which may not be present in all corridors. It would also mainstream connectivity conservation, which is necessary for rapid, landscape-wide implementation.
Use the level of threat of land-use conversion to development and intensive agriculture as a basis for identifying the most critical locations for corridors.	Focus connectivity conservation in high-risk areas.
Avoid planning at parcel scale in private lands without landowner engagement.	Landowners will often feel targeted by what are perceived as new regulations or restrictions on rights.
Land acquisition should be phased to complete a minimum viable linkage.	If linkage implementation involves multiple private properties this strategy ensures a continuous corridor that can be widened with time to allow for redundancy and possibly greater functionality into the future.
Set clearly-defined spatial priorities and implementation timelines where possible, and appropriate.	This ensures that connectivity goals are being met.
Run state/country-wide and regional public campaigns.	Public outreach galvanizes support and participation.
Wildlife agencies should coordinate and facilitate the collection of solid biological baseline data.	These data are vital for justifying corridor projects to stakeholders and the public, as well as for determining the best location for a corridor in priority connectivity areas.
Offer training for conservation practitioners on how to interpret and use connectivity data.	This ensures that science is used to maximum benefit.
Focus connectivity programs within regions with similar ecological and social attributes.	Implementing connectivity in ecologically and socially similar regions may be more successful than spanning diverse areas.

**Detailed recommendations necessarily need to be project specific because the socioecological context affects the whole process of connectivity implementation.*

The process of developing a shared vision during multipartner regional planning processes allows people with different interests and priorities to express their concerns and aspirations for the project that can be addressed or acknowledged so that, for example, if land needs to be removed from production this will not come as a surprise to the community and compensation can be discussed (Beunen & Hagens 2009; Goldman 2009; Wyborn 2015). Once a shared vision is established, priority areas for restoration or conservation can be determined by the stakeholders (Beunen & Hagens 2009). The resulting increased public engagement for a local project can also encourage government to adopt regulations focused on advancing connectivity conservation.

In Australia, the conservation community recognized that it could slow species loss and effects of climate change by facilitating species movements if landscapes were connected. Their work led to the drafting of a National Wildlife Corridors Plan and connectivity initiatives in every state of Australia (Wyborn 2015).

In several European countries, despite a strong vision for a connected landscape resulting in planning efforts at multiple scales and policies at the continental and national levels, little progress beyond planning has been made (Beunen & Hagens 2009), indicating that a vision alone may not be sufficient for successful implementation. Lack of public engagement, no deadline for network completion, deficiencies in legal definitions, and a history of conflict between resource agencies and landowners may explain implementation failures (Tiemann & Siebert 2009).

Communicate with Partners, Stakeholders, and the Public

Regular meetings of project partners, conferences, and webinars facilitate coordination and maintain interest (Rottle 2006; Tiemann & Siebert 2009). This is vital when unconventional partners with different interests are involved, such as counties, business communities, and developers. To retain stakeholder interest and promote a feeling of progress, defining a set of measurable criteria for success, developing a transparent strategy for monitoring progress, and agreeing on a regular review process for approved projects can help (Dettman 2006; Tiemann & Siebert 2009). Clearly communicating the goals and objectives of a connectivity project, openly discussing a project's implications for the landowners, and acknowledging and addressing the financial realities of conservation on private land are important aspects of building trust. For larger, complex projects, early success can lead to greater acceptance in the community. Thus, starting out with easy steps, such as small visible stewardship projects, is recommended (e.g., Rottle 2006). Specifying realistic timelines for completing phases of a connectivity project avoids delays and potential failure (Tiemann & Siebert 2009).

Outreach campaigns are an important strategy for building public support, which can be critical for success (Dettman 2006; Naumann et al. 2011). Depending on the goal, the audience is the public, specific communities, private landowners in priority areas, or for the longest time horizon, children. The objectives can be short term (sharing information about a specific project) or long term (educating the public about the effects of habitat fragmentation and the need for connectivity). Outreach campaigns broaden the base of support for implementation among private landowners and enhance trust among NGOs, agencies, and local communities. Charismatic species are useful in communicating the concept and need for connectivity conservation among local communities (Tiemann & Siebert 2009). Wildlife studies engage the public because resulting photos, videos, and movement paths of charismatic animals inspire people. For high-profile projects, a formal public-outreach strategy with in-depth and widespread media coverage on progress can further successful implementation (Schlotterbeck 2012).

Forms of communication include websites and social media, newspaper columns, newsletters, public presentations, workshops, school visits, field trips, volunteer days, and one-on-one communications with landowners (Fitzsimons et al. 2013). When communicating with the public, the use of stories and nontechnical, evocative language are most effective.

Base Implementation on Sound Science

All projects rely on a combination of empirical data, such as animal movement (e.g., from telemetry studies, camera traps, roadkill surveys, or genetic studies), connectivity and prioritization models, and expert input, which inform planning, prioritizing, and validating connectivity zones and corridors. Coarse-scale analyses inspire and guide connectivity action, but individual projects need to be informed by detailed, fine-scale plans (Beier et al. 2011). Having animal movement data for a specific linkage can help convince stakeholders of the need for implementation (White & Penrod 2012) and garner political support and funding (Naumann et al. 2011). Although scientists should design field research and conduct analyses, involving partners in the discussion about study objectives, input parameters, and focal species makes the process transparent and inclusive and allows consideration of partners' perspectives and local knowledge (Beier et al. 2008). A high level of stakeholder participation from the project's inception increases the likelihood stakeholders will follow through with the final research-driven recommendations. The level of project-staff expertise can limit their ability to implement and manage for habitat connectivity. Staff training on landscape fragmentation effects, interpretation, and use of connectivity data, and guidance on how to work with modeled outcomes is useful.

Seek to Create Multiple Benefits

Multiple benefits can emerge from land protection and restoration, including increased potential for species to adapt to climate change, carbon sequestration, improved water quality, recreation, and preservation of open space and working lands. Promoting these benefits in addition to protecting wildlife and biodiversity can increase support for connectivity projects in areas with diverse landownership (e.g., Jongman 2008; Beunen & Hagens 2009). Coalition building by involving multiple partners whose objectives align with these co-benefits, including nontraditional conservation actors such as water districts, planning agencies, and recreation departments, increases advocacy, taps a greater variety of funding sources, and improves the odds of overcoming implementation barriers.

Sometimes, finding means of integrating conservation and economic development (e.g., by developing sustainable forestry or farming practices in corridors) improves the probability of success (Bennett 2004). In some cases, combining corridor implementation with advancement of local economic development detracted from the original purpose of biodiversity conservation. Because information about biodiversity conservation was lacking at the local level, economic development originally tied to implementing the biological corridor became the main focus and the corridor concept was reinterpreted in an economic sense, now referring to, for example, ecotourism corridors (Dettman 2006). Hence, associating a corridor project with multiple benefits can be a double-edged sword when it comes to operationalization (Naumann et al. 2011). Effective communication of the primary ecological objectives and creation of baseline ecological data and a monitoring program ensure project goals are met. Specifying how other benefits are synergistic with primary objectives and providing guidelines on how to manage or restore land in corridors will help reconcile conflicting objectives as more stakeholders and goals are bundled into single projects (Dettman 2006).

Adopt Regulations, Incentives, and Funding Mechanisms

Resource agencies interested in advancing habitat connectivity argued for binding regulations rather than guiding regulations even though in some countries regulations have become so complex that potential players avoid becoming involved (Beunen & Hagens 2009). A legal framework requiring government agencies to include connectivity conservation in project planning can ensure early internal and external coordination of connectivity projects between agencies with different mandates (Shadie & Moore 2008). Without such a framework, action is left to motivated employees who act without the support of the agency's bureaucracy, resulting in piecemeal connectivity implementation.

Promoting connectivity through laws that regulate private landowners may be perceived as over-regulation and can result in a decreased willingness to participate in conservation projects. Instead, successful projects are led by private conservation organizations and implemented independent of regulations, contain voluntary incentive programs with cost-sharing for compatible land uses, and apply consensus-based approaches (e.g., Rottle 2006; Morrison & Boyce 2009).

Although regulations can instigate conservation action and justify the need for connectivity implementation to the public, without funding it can be difficult to comply with regulations. Funding for on-the-ground efforts is a prerequisite for successful implementation. Incentive programs can be coupled to regulations at the national, state, or local level or be site specific and can be run by governmental agencies, private organizations, or public–private partnerships. Alternative funding strategies include fundraising from individuals, applying for public funds, creating public–private partnerships, planning multi-benefit projects, linking to climate-adaptation funding, using seed money to start projects, developing partnerships with businesses, and working with volunteers (Bennett 2004).

A specific challenge arises when a pinch-point corridor needs to be protected if key lands are relatively small but very expensive and slated for city development. Although environmental regulations can advance corridor implementation, often, these small parcels do not harbor listed species, rare environments, or other conservation priorities. In this case, it can be harder to fund the project with sources that focus on threatened and endangered species. Even with local land-use and state regulations that pay homage to the benefits of habitat connectivity, real regulatory requirements and funding mechanisms are often absent, making it difficult to retroactively incorporate connectivity measures into, for example, existing highways. A funding source specifically for habitat connectivity projects makes project implementation in this and many other instances more feasible. Funding is increasingly available through climate-change adaptation programs and can be used to strengthen climate-wise connectivity conservation. Even with funding, regulations provide important motivation and justification for resource agencies to engage in habitat connectivity efforts.

Evidence-Based Framework and Case Studies

We propose a framework to guide implementation of connectivity projects (Fig. 1). This framework shows how the evidence-based elements we synthesized from interviews and the literature are critical to the implementation process. Our framework builds on existing frameworks to guide conservation action, focuses on connectivity conservation, and emphasizes the role opportunities and challenges play in establishing corridors and other solutions (e.g., Margules & Pressey 2000; Salafsky et al. 2001; Conservation Measures Partnership 2013; Bunnefeld et al. 2017). We used 3 case studies to illustrate the components in the framework and to demonstrate that it can be applied to multiple contexts (Fig. 2 & Table 1). The projects range from local to landscape scales and differ in their ecological objectives (Fig. 1a): reducing wildlife roadkill and facilitating animal movement, connecting large landscape blocks and facilitating range shifts, and endangered species recovery and ecosystem resilience. The projects rely on different data sources (Fig. 1b). The first project used primarily wildlife presence and movement data, the latter 2 projects integrated a broad array of land-cover and land-use change information and climate information. Partners varied from

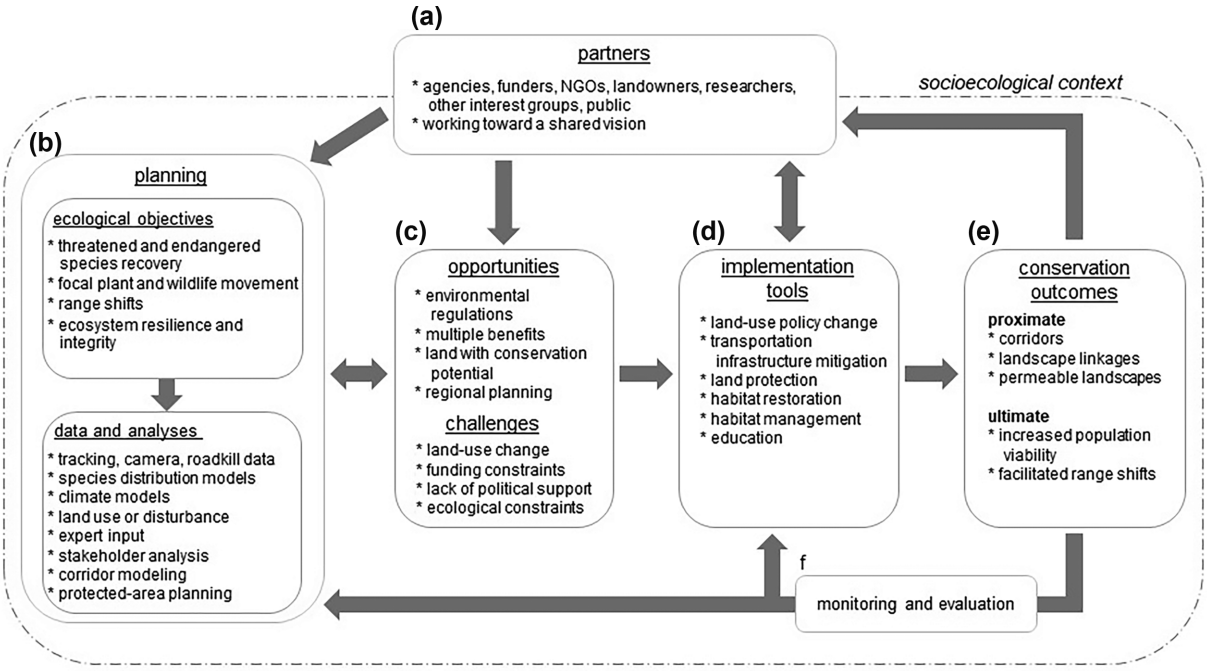

Figure 1. A framework for connectivity implementation: (a) early partner engagement; (b) clear ecological objectives that drive data type and analysis; (c) opportunities and challenges that may advance or hinder implementation and should be addressed in the planning phase; (d) strategies to overcome challenges and ensure success; (e) resulting outcomes that increase connectivity and foster continued conservation by the partners; and (f) monitoring and project evaluation for adaptive management.

federal land management and state agencies to private land trusts. The final conservation outcomes (Fig. 1e) were a corridor, a landscape linkage, and conservation of a permeable landscape, respectively.

Highway 17 Crossing

This highway project was triggered by frequent vehicle–wildlife collisions on a busy highway. Although California's regulatory context encourages agencies to consider wildlife connectivity in new project designs (CA-AB498), retrofitting existing highways was not part of standard procedures and lacked funding. Concern for human safety presented an opportunity (Fig. 1c) for the Department of Transportation to engage with conservation organizations concerned about the barrier effect of the highway and work on a wildlife-crossing project. The local land trust raised funds to protect land on either side of the proposed crossing. University researchers collected extensive biological data and modeled regional wildlife connectivity to determine the best location (Fig. 1b) and inform a media campaign to generate public and agency support (Fig. 1c). The main challenge that remained after garnering public and agency support, deciding on the best site and design for a wildlife tunnel, and securing the surrounding properties was funding for the structure itself. Realizing the need for mitigation was not limited to this location, the partners developed a pilot agreement to use advanced mitigation credits to fund connectivity projects that, if successful, could be applied throughout California. Strategies that made this project successful were the collection of extensive biological data, a media campaign, partners that secured land, and development of a creative strategy to fund the crossing structure. Implementation of the crossing structure (Fig. 1d) is slated for completion in 2020.

Sonoma Valley Wildlife Corridor

The Sonoma Valley Wildlife Corridor contains open land in an otherwise highly used valley between two mountain chains, making it a critical location for wildlife movement. Because it was identified as an important state and regional linkage (Spencer et al. 2010; Bay Area Open Space Council 2011) (Fig. 1b), the Sonoma Land Trust took the lead to permanently preserve it. They partnered with scientists to document the corridor's significance for daily wildlife movement and climate resilience. The trust took advantage of three opportunities to develop a comprehensive implementation strategy: interest by the local community in wildlife, positive relationship between landowners and the trust, and the upcoming repurposing of a large publicly owned land parcel (Fig. 1c). Continued monitoring by the trust and their

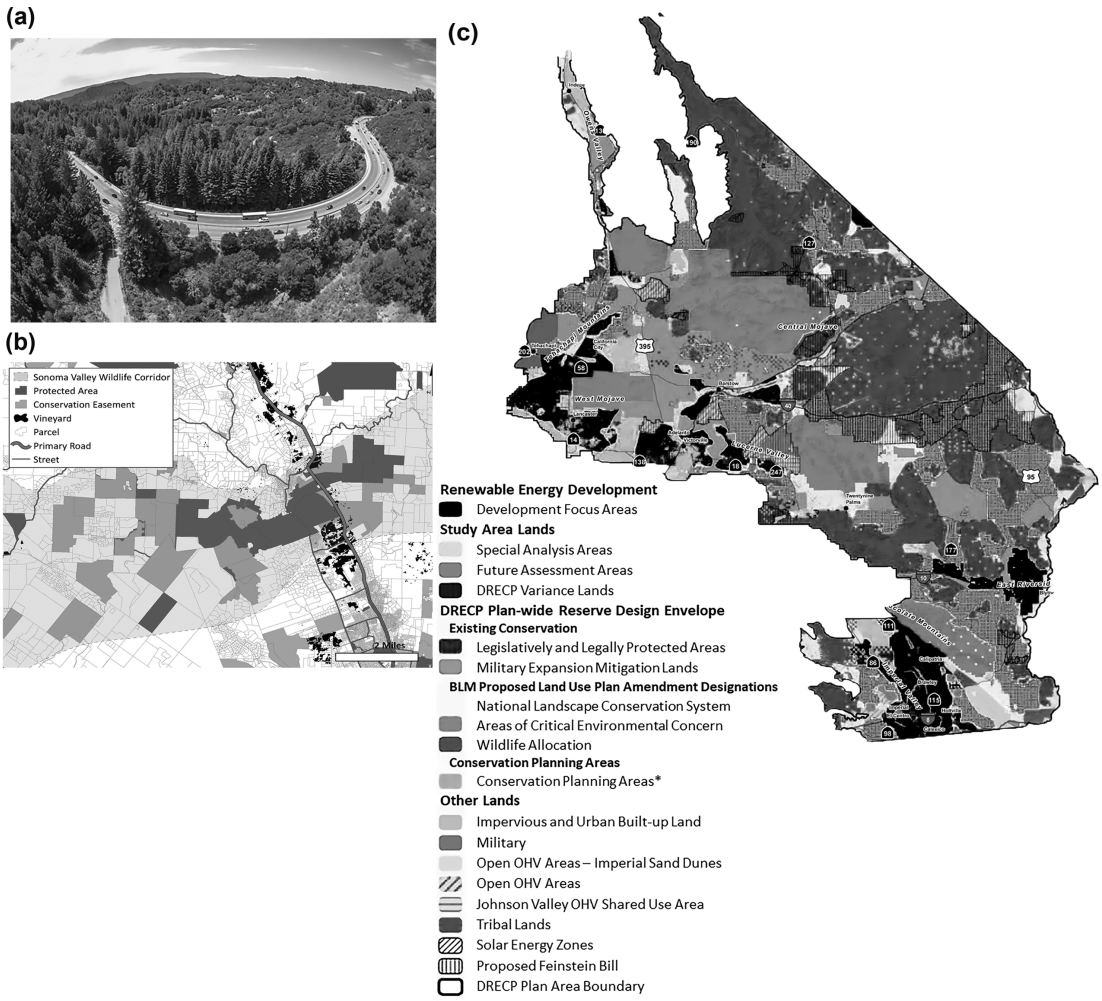

Figure 2. Location for the planned wildlife crossing structure under Highway 17 in Santa Cruz County, California (photo used with permission from Land Trust of Santa Cruz County); map of Sonoma Valley wildlife landscape linkage in Sonoma County, California (used with permission from Morgan Gray); and zoning map of the Desert Renewable Energy Conservation Plan in southeastern California (source: U.S. Bureau of Land Management 2016. Record of Decision. BLM/CA/PL-2016/03+1793+8321).

volunteers (Fig. 1f) is valuable not just for adaptive planning and management but also to maintain interest from the public. Communication with the public and key participating landowners resulted in a shared vision, which is preserving the corridor through land protection and management.

Desert Renewable Energy Conservation Plan

The Desert Renewable Energy Conservation Plan (DRECP) was created to balance development of renewable energy projects on public lands with natural resource conservation. Partners from state and federal agencies, industry, and conservation organizations (Fig. 1a) developed a vision of a permeable landscape accommodating new renewable energy projects. Because renewable energy development has been a political and economic priority in California, the plan received extensive political and financial support. Due to ambitious ecological objectives, including the recovery of the endangered desert tortoise (*Gopherus agassizii*) and increased ecosystem resilience, considerable data acquisition, mapping, and species and climate modeling (Fig. 1b) was conducted; however, integrating biological data collected at different scales was challenging (Fig. 1c). The high-level political support presented an opportunity to develop land-use allocation prescriptions to maintain a connected landscape. Primary challenges were balancing energy development and conservation needs, the large extent of the project area, and complexity of aligning stakeholder objectives. The large landscape of the DRECP required a different strategy from those of the other examples (Fig. 1d). The project resulted in land-use allocations that promote either natural resource conservation

or energy development. Ongoing development of management guidelines, habitat restoration, and private-land planning are not yet complete. The strategy to achieve a permeable landscape acceptable to the large number of stakeholders with widely varying perspectives was to base the effort on compliance with state and federal conservation regulations and employ extensive field and spatial data.

Conclusion

Although the process of connectivity implementation from planning to monitoring in our framework appears linear, activities often overlap in time, there are feedback loops between major actions, and adjustments are needed to accommodate opportunities or challenges that arise. The different categories of opportunities (community visioning, communication, partnerships, and laws and regulations) are needed to fill the planning-implementation space. Although natural science is necessary for effective corridor planning, these social processes may be as important for project success, and we argue for increased input from social scientists to inform conservation planning and implementation. By outlining the components important for implementation and pointing out their relationships, the framework effectively fills the planning-implementation space. When operating in this space, flexibility, creativity, transparency, and persistence are necessary for success in accomplishing connectivity conservation.

Our research revealed overarching recommendations that are relevant in most contexts (Table 2). We hope these and other suggestions discussed here will ensure a large number of existing planning efforts can be translated into habitat connectivity conservation and restoration.

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Supporting Information

Literature search strategy and results (Appendix S1), interview questions (Appendix S2), interview quotes (Appendix S3), sources of opportunities and challenges to connectivity implementation (Appendix S4), and a synopsis of connectivity-related legislation in California (Appendix 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.

Literature Cited

Bay Area Open Space Council. 2011. The Conservation Lands Network: San Francisco Bay area upland habitat goals Project Report. Bay Area Open Space Council, Berkeley, California.

Beier P, Majka DR, Spencer WD. 2008. Forks in the road: choices in procedures for designing wildland linkages. Conservation Biology **22:**836-851.

Beier P, Spencer W, Baldwin RF, McRae BH. 2011. Toward best practices for developing regional connectivity maps. Conservation Biology **25:**879–892.

Bennett G. 2004. Integrating biodiversity conservation and sustainable use: lessons learned from ecological networks. International Union for Conservation of Nature, Gland, Switzerland.

Beunen R, Hagens JE. 2009. The use of the concept of ecological networks in nature conservation policies and planning practices. Landscape Research **34:**563–580.

Brodie JF, Paxton M, Nagulendran K, Balamurugan G, Clements GR, Reynolds G, Jain A, Hon J. 2016. Connecting science, policy, and implementation for landscape-scale habitat connectivity. Conservation Biology **30:**950–961.

Bunnefeld N, Nicholson E, Milner-Gulland EJ. 2017. Introduction. Pages 1–16 in Bunnefeld N, Milner-Gulland EJ, editors. Decision-making in conservation and natural resource management: models for interdisciplinary approaches. Cambridge University Press, Cambridge, United Kingdom.

Conservation Measures Partnership. 2013. Open standards for the practice of conservation. Available from http://cmp-openstandards.org/ (accessed July 2018).

Cook CN, Mascia MB, Schwartz MW, Possingham HP, Fuller RA. 2013. Achieving conservation science that bridges the knowledge–action boundary. Conservation Biology **27:**669–678.

Dettman S. 2006. The Mesoamerican Biological Corridor in Panama and Costa Rica: integrating bioregional planning and local initiatives. Journal of Sustainable Forestry **22:**15–34.

Fitzsimons J, Pulsford I, Wescott G. 2013. Lessons from large-scale conservation networks in Australia. Parks **19:**115–125.

Gleason M, et al. 2013. Designing a network of marine protected areas in California: achievements, costs, lessons learned, and challenges ahead. Ocean & Coastal Management **74:**90–101.

Goldman M. 2009. Constructing connectivity: Conservation corridors and conservation politics in East African rangelands. Annals of the Association of American Geographers **99:**335–359.

Hannah L. 2011. Climate change, connectivity, and conservation success. Conservation Biology **25:**1139–1142.

Hilty JA, Chester CC, Cross MS, editors. 2012. Climate and conservation: landscape and seascape science, planning, and action. Island Press, Washington, D.C.

Jongman R. 2008. Ecological networks are an issue for all of us. Journal of Landscape Ecology **1:**7–13.

Knight AT, Cowling RM, Rouget M, Balmford A, Lombard AT, Campbell BM. 2008. Knowing but not doing: selecting priority conservation areas and the research–implementation gap. Conservation Biology **22:**610–617.

Margules CR, Pressey RL. 2000. Systematic conservation planning. Nature **405:**243–253.

Merenlender AM, Reed S, Kitzes J, Feirer S. 2010. Mayacamas connectivity report. Report. Sonoma County Agricultural Preservation and Open Space District, Sonoma County, California.

Morrison SA, Boyce WM. 2009. Conserving connectivity: Some lessons from mountain lions in southern California. Conservation Biology **23:**275–285.

Naumann S, Davis M, Kaphengst T, Pieterse M, Rayment M. 2011. Design, implementation and cost elements of Green Infrastructure projects. Final report to the European Commission, DG Environment. Ecologic Institute and GHK Consulting.

Pulsford I, Lindenmayer D, Wyborn C, Lausche B, Worboys GL, Vasilijević M, Lefroy T. 2015. Connectivity conservation management. Pages 851–888 in Worboys GL, Lockwood M, Kothari A, Feary S, Pulsford I, editors. Protected area governance and management. ANU Press, Canberra.

Rottle ND. 2006. Factors in the landscape-based greenway: a mountains to sound case study. Landscape and Urban Planning **76:**134–171.

Salafsky N, Margoluis R, Redford K. 2001. Adaptive management: a tool for conservation practitioners. Biodiversity Support Program, Washington, D.C.

Schlotterbeck C. 2012. The Coal Canyon story. Ecological Restoration **30:**290–293.

Shadie P, Moore P. 2008. Connectivity conservation: international experience in planning, establishment and management of biodiversity corridors. Report International Union for Conservation of Nature, Gland, Switzerland.

Spencer WD, Beier P, Penrod K, Winters K, Paulman C, Rustigian-Romsos H, Strittholt J, Parisi M, Pettler A. 2010. California Essential Habitat Connectivity Project: a strategy for conserving a connected California. California Department of Transportation, California Department of Fish and Game, and Federal Highways Administration.

Theobald DM, Zachmann LJ, Dickson BG, Gray ME, Albano CM, Landau V, Harrison-Atlas D. 2016. Description of the approach, data, and analytical methods used to estimate natural land loss in the western U.S. Conservation Science Partners. Available from https://disappearingwest.org/ (accessed September 2017).

Tiemann S, Siebert R. 2009. Ecological networks implemented by participatory approaches as a response to landscape fragmentation: a review of German literature. Outlook on Agriculture **38:**205–212.

Toomey AH, Knight AT, Barlow J. 2017. Navigating the space between research and implementation in conservation. Conservation Letters **10:**619–625.

von Haaren C, Reich M. 2006. The German way to greenways and habitat networks. Landscape and Urban Planning **76:**7–22.

White MD, Penrod K. 2012. The Tehachapi connection: a case study of linkage design, conservation, and restoration. Ecological Restoration **30:**279–282.

Worboys GL, Francis WL. 2010. Themes and lessons from global experience in connectivity conservation. Pages 283–298 in Worboys GL, Francis WL, Lockwood M, editors. Connectivity conservation management, a global guide. Earthscan, Washington, D.C.

Worboys GL, Lockwood M. 2010. Connectivity conservation management framework and key tasks. Pages 301–341 in Worboys GL, Francis WL, Lockwood M, editors. Connectivity conservation management, a global guide. Earthscan, Washington, D.C.

Wyborn C. 2015. Connectivity conservation: Boundary objects, science narratives and the co-production of science and practice. Environmental Science & Policy **51:**292–303.