Multiplying the impact of conservation funding using spatial exchange rates

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Given declines in biodiversity and ecosystem services, funding to support conservation must be invested effectively. However, funds for conservation often come with geographic restrictions on where they can be spent. We introduce a method to demonstrate to supporters of conservation how much more could be achieved if they were to allow greater flexibility over conservation funding. Specifically, we calculated conservation exchange rates that summarized gains in conservation outcomes available if funding originating in one location could be invested elsewhere. We illustrate our approach by considering nongovernmental organization funding and major federal programs within the US and a range of conservation objectives focused on biodiversity and ecosystem services. We show that large improvements in biodiversity and ecosystem service provision are available if geographic constraints on conservation funding were loosened. Finally, we demonstrate how conservation exchange rates can be used to spotlight promising opportunities for relaxing geographic funding restrictions.

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Expanding protected area networks provides a renewed focus for the international conservation community with the development of a post-2020 framework for protecting biodiversity and related initiatives led by national governments (CBD 2020; Haaland *et al*. 2021). To slow declines in biodiversity, governments, multilateral organizations, nongovernmental organizations (NGOs), businesses, and other groups already invest on the order of US$100 billion each year (OECD 2020; Seidl *et al*. 2020). The severity of ongoing losses of species and habitats (IPBES 2019) demands the effective use of available funding. Fortunately, there are still conservation bargains to be had. These are locations rich in biodiversity where protection can be achieved at relatively low cost and where ecosystems will be threatened if action is not taken, meaning that the value added by conservation efforts would be large (Conde *et al*. 2015). However, financial support for conservation often comes with geographic restrictions on where funds can be spent, which can result in the most promising opportunities to improve conditions for biodiversity missing out on funding (Waldron *et al*. 2013).

In a nutshell:

- Funding for biodiversity and ecosystem services would have greater impact if there were fewer geographic constraints on where conservation dollars can be spent
- If donors to a US nongovernmental organization require conservation funding to be spent in their home state, it costs 68% of the improvement in biodiversity that would have been possible absent such restrictions
- We introduce a new approach that demonstrates to what extent allowing a small amount of flexibility increases conservation impact
- We summarize this information in "conservation exchange rates", analogous to exchange rates between financial currencies
- Spatial exchange rates demonstrate that large gains in biodiversity are available from relaxing constraints on conservation funding

Geographic limitations on conservation funding are common. In private land conservation, large financial donations not associated with a particular project or initiative are unusual (Clark 2007), and downstream effects on the geographic availability of funds can shape spending on land protection over large spatial scales (Larson *et al*. 2016). Why people donate to charitable causes, including conservation, varies, but motivations can be purely altruistic or tied to benefits enjoyed by the individual (Bekkers and Wiepking 2011). Some motivations are less compatible with supporting distant projects, and willingness-to-pay studies show that the amount that people are prepared to give to support conservation activities declines with distance (Glenk *et al*. 2020; Yamaguchi and Shah 2020) and across geographic borders (Dallimer and Strange 2015; Haefele *et al*. 2019). Geographic restrictions on spending are also embedded in public funding programs. In the US, the federal government provides grants to states to support land

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conservation. Many of these federal programs follow prescribed funding formulas that may not align with where the greatest conservation opportunities are located (Southwick Associates 2013; CRS 2019).

Large conservation gains would be possible if funders could be persuaded to allow greater flexibility over where donations can be spent. But how can this be achieved? Public and private funders are unlikely to be moved simply by growing the chorus of appeals for more flexible conservation dollars (eg Kark *et al.* 2009; Jeanson *et al.* 2020). As a practical way forward, we provide a means to demonstrate – to organizations, programs, and individuals supporting conservation – the potential efficiency gains available were they to allow greater flexibility over funding. We express these as "conservation exchange rates", which show how much greater conservation gains could be if dollars to support conservation came with fewer geographic restrictions. We provide a means to tailor these exchange rates to particular funders by quantifying the rates for different combinations of funder and potential investment opportunities. This includes showing how much more could be done to advance biodiversity goals if funders in one location allowed their conservation dollars to be directed toward a particular joint initiative shared with a neighboring region, perhaps one affiliated with a transboundary ecosystem or a migratory species (Vogdrup-Schmidt *et al.* 2019b; Mason *et al.* 2020).

We illustrate our methods with an application to funding allocations among states in the conterminous US, where funding is to be used to establish new protected areas. We first describe exchange rates that result when prioritizing protected areas to support species conservation before broadening to include ecosystem services as well. Conservation studies applying spatial optimization to prioritize future areas for protection (Groves and Game 2016), including applications to the US (Withey *et al.* 2012; Kroetz *et al.* 2014), provide important antecedents for our analyses. However, these analyses typically assume that conservation resources can be re-allocated freely across space (with exceptions; Kark *et al.* 2009; Ando and Shah 2010; Pouzols *et al.* 2014). Beyond conservation, our approach builds on several published precedents, including efforts to enhance the impact of charitable giving (MacAskill 2015; Freeling and Connell 2020).

Conservation exchange rates and how to calculate them

We based our definition of exchange rates in conservation on the concept of financial exchange rates between currencies. Assuming no arbitrage, financial exchange rates reflect the ratio of prices for an identical basket of goods in two currencies. Because it seemed more relevant to conservation applications, we used the reciprocal measure (how much can conservation objectives be advanced for a given level of investment) to calculate conservation exchange rates. For instance, if considering conservation funding originating in New York being invested in Texas, the relevant exchange rate would be:

$$\frac{\textit{Conservation gain per dollar in Texas}}{\textit{Conservation gain per dollar in New York}} \quad \text{(Equation 1).}$$

Derivation of our conservation exchange rates requires a representation of the available funding landscape for conservation and how this compares to the landscape of conservation priorities. When seeking to represent the current funding landscape in the US, we first relied on data on philanthropic giving to a major conservation NGO: The Nature Conservancy (TNC) (Fishburn *et al.* 2013). We then considered funding programs for conservation run by the US federal government (Southwick Associates 2013; CRS 2019).

To represent the landscape of conservation priorities, we calculated the conservation gain per dollar offered by investing in different places. We based our exchange rate estimates on funding being allocated according to an optimization model. Specifically, we solved an optimization problem where the goal was to allocate available conservation funds to deliver a shared national conservation objective while subject to constraints on where funds could be spent. Initially, we assumed funds could be spent only in the state where they originated. While admittedly a stringent assumption, funding constraints of this type are commonly encountered in conservation (Pouzols *et al.* 2014). Examining optimal solutions to this spatially constrained problem allows calculation of the marginal gain in the national conservation objective available if a state's budget constraint were to be relaxed by a small amount. We represented exchange rates between pairs of states as ratios of these marginal gain statements. Most previous studies have emphasized potential gains if conservation funding was freely reallocated in space (eg Underwood *et al.* 2009a), which seems unlikely. In contrast, spatial exchange rates calculate potential conservation gains from allowing even a small degree of additional flexibility (eg a donor or funding program allowing a portion of a planned gift to be allocated to a conservation project in a neighboring region, where it could still benefit shared species or ecosystems).

We first derived exchange rates when focused on terrestrial vertebrate species currently assessed as being vulnerable to extinction or worse – including those listed as Vulnerable, Endangered, and Critically Endangered (hereafter collectively referred to as "vulnerable") – by the International Union for Conservation of Nature (IUCN). Our optimization framework involved allocating the budget to different counties where funds were used to acquire new protected areas. Although we recognize the value in applying our methods over different spatial extents and grains, our chosen illustration required patterns of relative variation in conservation return on investment between US states. For that purpose, working with county-grain variation sufficed.

For our optimizations, we adapted an existing framework that focused on prioritizing counties based on how investing in them will affect the number of species expected to persist in 2040 in light of projected land-cover change (WebPanel 1; Armsworth *et al.* 2020). This framework accounted for species persistence, ecological complementarity, and the ecological contribution of private land, as well as spatially heterogeneous conservation costs and conversion threats. We extended this existing framework by imposing state-level budget constraints, which enabled us to calculate conservation exchange rates between states. A full specification of the optimization problem is given in WebPanel 1, which also describes the behavior of the optimal solution and the numerical techniques we used to find it. The optimal solution shares characteristics with the efficient design of emissions trading systems when abatement costs and environmental damages are spatially heterogeneous (Muller and Mendelsohn 2009). In the optimal solution, available funding within each state is shared among counties offering the largest gains in the national conservation objective per dollar spent, in such a way as to equalize marginal gains across these counties within the state. State funding constraints prevent these marginal gains from also being equalized across states, as would be optimal if no state funding constraints applied.

To parameterize our optimization model, we integrated data on ranges of terrestrial vertebrate species (birds, mammals, reptiles, and amphibians; IUCN 2016; BirdLife International 2016); on costs faced by TNC and public agencies in the US when protecting land (Le Bouille *et al.* 2023); and on the threat of future habitat conversion (Wear 2011). For the initial analysis, we included data on spatial variation in philanthropic giving to US conservation, using TNC as an example (Fovargue *et al.* 2019). Later we used data on state and federal funding for conservation (Southwick Associates 2013; CRS 2019).

We examined the sensitivity of the exchange rates to the choice of conservation objective by considering six additional conservation objectives. First, we used the same framework but considered all terrestrial vertebrate species (that is, not only those considered vulnerable). Next, we examined conservation objectives that equally weighted ecosystem services and biodiversity goals, using our focus on vulnerable vertebrate species to represent the latter. For ecosystem service benefits, we first included avoided losses of forest carbon due to land conversion for agriculture and development. Next, we considered a set of ecosystem service indicators that emphasized investing near people: improving recreational opportunities and open space amenities, maintaining natural land cover near withdrawal points for water for public supply or domestic use, and relying on an additional benefit function that valued both recreation and maintaining water quality in this way while emphasizing benefits to low-income households. For comparability with the biodiversity models, we focused on improving these outcomes in the year 2040, by drawing on land-cover, population, and income projections. Finally, to examine the degree to which our results were a consequence of relying on the same cost and conversion threat data across scenarios, we included an optimization focused on avoiding habitat conversion without considering the importance of remaining habitats for biodiversity or ecosystem services.

Conservation exchange rates reveal potential biodiversity gains

We illustrate our conservation exchange rate approach by first considering an application to philanthropic giving to TNC, a large nonprofit land trust, and to conserving vulnerable terrestrial vertebrate species through land protection. If donors require that conservation funding be spent in their home state (Figure 1a) instead of being directed toward top priorities for protection (Figure 1b), it would cost 68% of the potential improvement in conservation status of vulnerable vertebrates that could have been achieved had no such geographic restriction applied (Figure 2a). Focusing on state-level budget constraints makes sense for this application. TNC is structured into semi-autonomous state chapters that play key roles in soliciting gifts from donors and in protecting land (Fishburn *et al.* 2013). As one might therefore expect, the amount TNC spends on land protection in different states correlates strongly with philanthropic giving to the organization from within states (Spearman's $r_s = 0.54$, $P < 1 \times 10^{-4}$, $n = 48$).

Even if unwilling to provide gifts with no geographic restrictions, funders could still greatly increase the biodiversity impact of their giving by allowing financial support to be used for particular shared regional programs. Our exchange rates highlight obvious candidates, as shown by the arrows in Figure 1c for neighboring states. For example, a donor in Washington State, a state that gives at a relatively high rate, could be asked to support a conservation project in the Lower Snake River catchment, allowing funds to be invested in neighboring western Idaho. Donors in Washington State could multiply their biodiversity impact by a factor of 11.5 by supporting such a program, with potential gains from Oregon donors being larger still.

The more geographic flexibility donors allow, the greater the biodiversity impact that is possible. In Figure 3a, exchange rates are shown for all pairs of states, not just neighboring ones. To understand why some exchange rates are larger and others smaller, we need to examine spatial covariation between available funding and conservation priorities in more detail. For the TNC application, coastal states like California and New York are among the top givers (11.7% and 10.6% of overall donations, respectively), although large donations also come from the areas around Chicago, Minneapolis/St Paul, Jackson Hole, and other cities

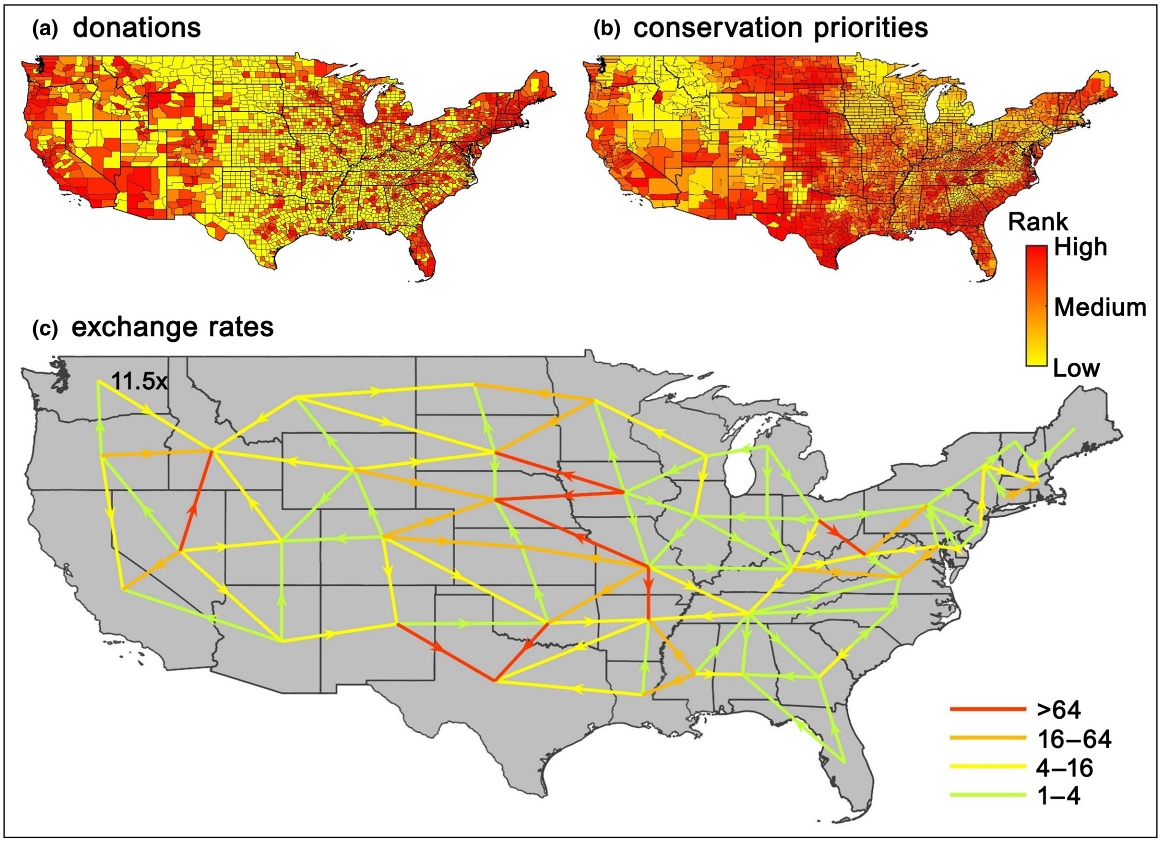

Figure 1. In the conterminous US, counties ranked by (a) donation levels to a major nongovernmental organization and (b) conservation return on investment when seeking to protect vulnerable, terrestrial vertebrate species. Redder counties receive more donations in (a) and are a higher priority for investment in (b). (c) Conservation exchange rates between neighboring states (arrows), assuming states allocate funds to priority counties within their borders. Arrow direction indicates that the movement of funds improves conservation outcomes and arrow color shows the size of exchange rate. For example, the impact of donors in Washington State would be multiplied by a factor of 11.5 if their financial support were allowed to support a watershed-scale program in the Lower Snake River, which spans areas within both Washington State and the neighboring state of Idaho.

(Figure 1a). These are not places that offer the highest return on conservation investment, when focused on vulnerable vertebrate species. Instead, the greatest conservation impact would be made if these funds were invested in parts of the southern US, particularly in Texas and coastal Louisiana (Figure 1b), where vulnerable endemic species overlap areas where land can be protected relatively inexpensively. These differences manifest as striping patterns in Figure 3a. Horizontal striping indicates states that emerge as consistently higher (red) or lower (blue) priorities for investment. Vertical striping indicates consistent improvements (red) if funding originating in some states could be directed toward places that represent higher conservation priorities.

Having used this first example to illustrate the idea of conservation exchange rates, we explored the generality of our approach and of the particular exchange rates obtained through two sets of sensitivity tests (WebPanel 2). First, we recalculated conservation exchange rates when assuming six alternative objectives that conservation organizations and their funders might pursue. Exchange rates for these alternative objectives were highly correlated to those for vulnerable species protection (Figure 2c). Moreover, the direction of exchange favored between pairs of states remained unchanged in 72–81% of cases (Figure 2d). Some consistency in exchange rates should be expected because of correlations built into the assumed benefit functions themselves and because of the role of the shared covariates of cost and threat (black bar in Figure 2, c and d). The results indicated that certain states (eg Texas) were consistently high priorities for funding for the different conservation objectives (Figure 3). At the same time, exchange rates were more variable in magnitude when pursuing some conservation objectives than others, reflecting differences in patterns of spatial variability in underlying conservation benefit measures (Figure 2b). Constraining funding to be spent in states where it was given again imposes a large efficiency cost as compared to having full flexibility over where funds can be allocated. These efficiency costs ranged from 77% to 86% for the additional objectives we considered and were somewhat larger than those when focused only on vulnerable vertebrate species (Figure 2a).

Our second set of sensitivity tests examined how considering different sources of conservation funding would change our exchange rate estimates. We calculated exchange rates when considering one particular federal conservation program (the Land and Water Conservation Fund or LWCF; CRS 2019) as well as for federal conservation funding in aggregate (Southwick Associates 2013). Our exchange rate estimates proved very insensitive to the source of funding data we used. This lack of sensitivity in exchange rates applied even though the overall conservation budgets involved were large enough to result in diminishing returns in conservation benefits on offer in some states (WebPanel 2).

Putting conservation exchange rates into practice

Exchange rates can help inform: individual donors seeking to enhance the impact of their giving to conservation, NGOs planning future philanthropy and conservation campaigns, policy debates over public funding programs, and prioritization of possible transboundary initiatives. Taking first the example of philanthropy, NGOs tailor messaging to potential donors to align with individuals' motivations for giving (Bekkers and Wiepking 2011). Some donors are motivated by benefits realized within their local communities, whereas others are motivated more by how effectively their gifts are being used to achieve an organization's mission (Kolhede and Gomez-Arias 2022). Messaging using conservation exchange rates is well suited for donors in this second category. An example is provided in Figure 4, which presents an infographic illustrating trade-offs involved in requiring that donations be used in-state versus allowing them to be used for conservation projects in adjoining states. The infographic is tailored for potential donors in Colorado who are interested in conserving vulnerable species and providing ecosystem services to low-income communities. When soliciting a gift, philanthropy staff typically present potential donors with alternative projects needing funding. Communication products like the one shown in Figure 4 provide a justification for including projects in neighboring regions within the menu of opportunities presented to donors who are motivated by evidence of the efficacy of potential gifts.

Geographical constraints on where conservation funding can be spent have other implications. For example, these constraints impose a degree of dispersion on allowed funding patterns, such that locations that might not otherwise have been priorities receive at least some support. As well as broadening the set of species, ecosystems, and human communities that benefit from conservation (Kareiva and Marvier 2003), more dispersed funding strategies may also stimulate a larger pool of donors to give. The history and structure of large conservation organizations both responds to and reinforces these dynamics. For instance, TNC's state chapter structure positions the organization to reach potential donors across the breadth of its geographic footprint. Conservation NGOs must balance expanding projects to encourage more people to give against more narrowly targeting available funds toward locations where they will have the greatest impact (Ando and Shah 2010). Spatial exchange rates can help when balancing such trade-offs. Developing additional ways to connect data on conservation needs and effectiveness with information on the different ways that people are motivated to give will enable more effective conservation philanthropy strategies.

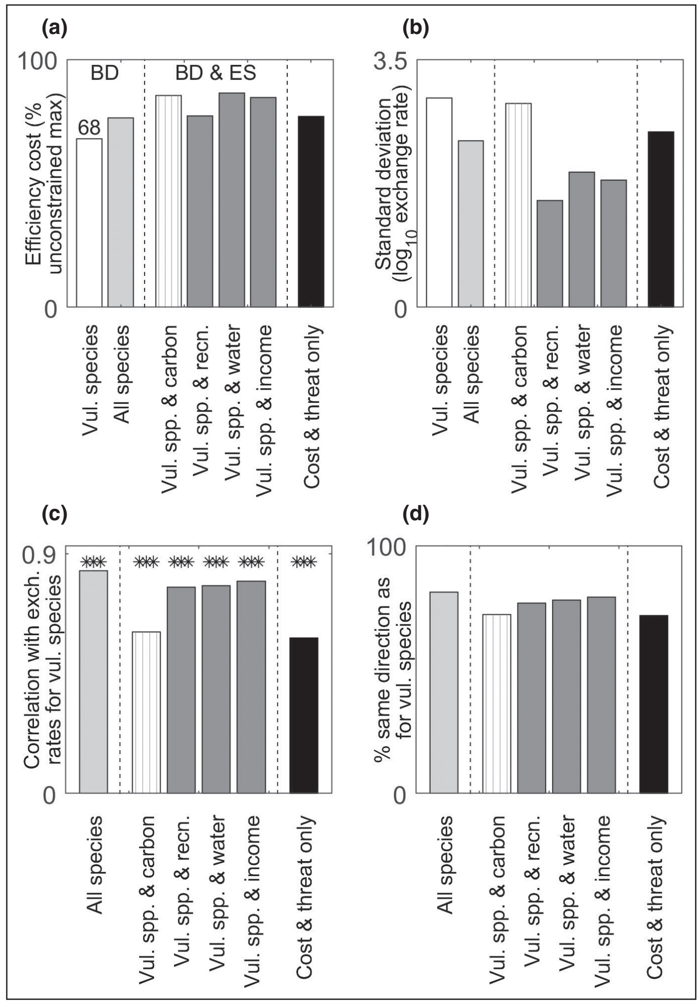

Figure 2. (a) Efficiency cost when funds are spent in donor state, as a percentage of gain possible without this constraint. Conservation objectives: biodiversity only (vulnerable species – white; all species – light gray); biodiversity and avoiding losses of forest carbon (striped) or ecosystem services that depend on proximity to people (recreation, water quality, and benefits to low-income communities – dark gray); averted habitat loss considering only cost and threat (black). (b) Variation in relevant exchange rates. (c) Correlation of log exchange rates and (d) direction agreement when protecting vulnerable species (white bars in panels [a] and [b]) versus remaining objectives. Significance in (c): $P << 0.001$ (***). BD = biodiversity; ES = ecosystem services; vul = vulnerable; recn = recreation; exch = exchange.

Conservation exchange rates are also relevant to how public funding for conservation is allocated, with intergovernmental grants an obvious example. State governments in the US receive funding to support conservation projects from the federal government through State and Tribal Wildlife Grants (USFWS 2020) and the LWCF (CRS 2019),

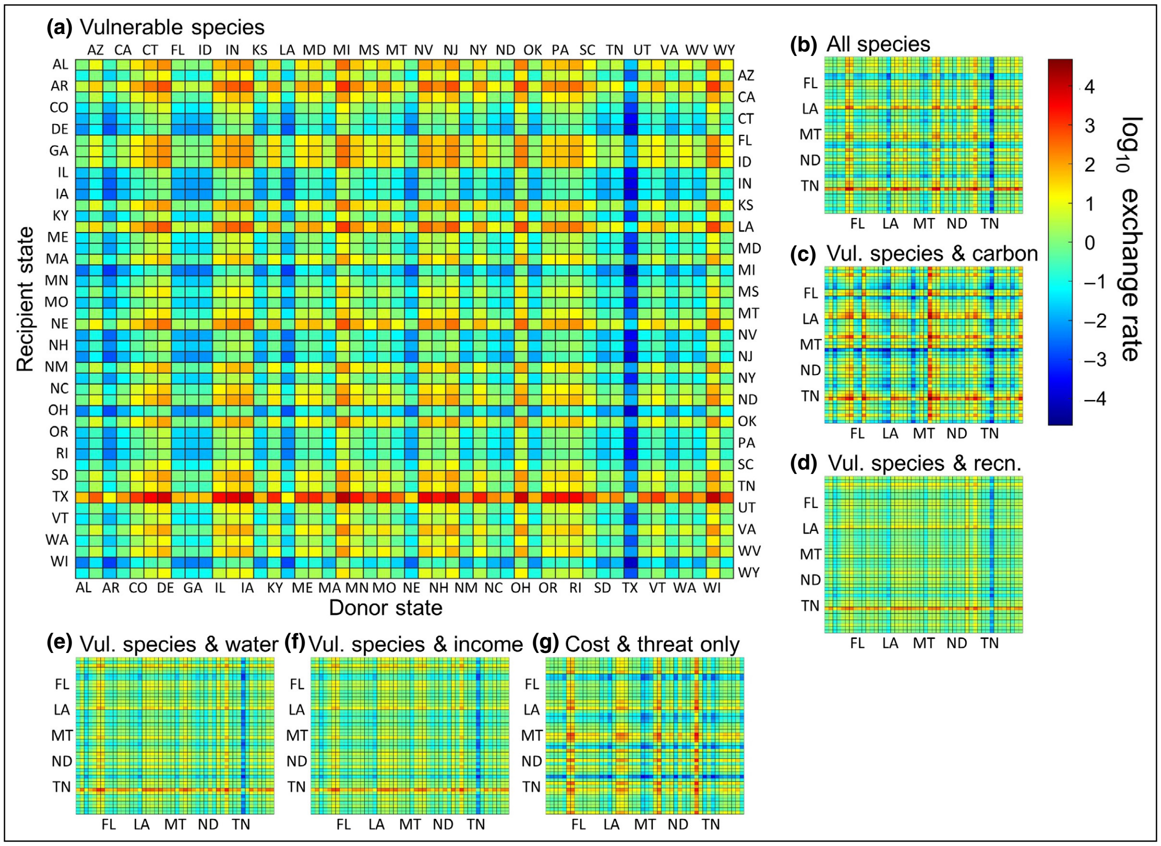

Figure 3. Log of conservation exchange rates for all pairs of states. Conservation objectives: biodiversity only for (a) vulnerable species or (b) all species; biodiversity and (c) avoiding losses of forest carbon or ecosystem services that depend on proximity to people (specifically: [d] recreation, [e] water quality, and [f] benefits to low-income communities); (g) averted habitat loss considering only cost and threat. Exchange rates show how much larger or smaller the conservation gain per dollar would be if funds generated in one state (horizontal axis) were spent in another (vertical axis).

among other programs. Intergovernmental grant programs like these often follow fixed funding formulas. The LWCF, for example, allocates some funding on an equal basis across states and other funding based on a state's population relative to the US population, with the restriction that no more than 10% of total funding can go to a single state (CRS 2019). Spatial exchange rates can inform policy debates about adjusting these funding formulas or how best to complement them with any additional funding that can be allocated more flexibly.

Another potential application of our conservation exchange rates is to inform the design of boundary-spanning initiatives. Because ecological systems can stretch across administrative boundaries, governments and NGOs establish transboundary initiatives to encourage cooperation in delivering conservation priorities (Mason *et al.* 2020). These initiatives also enable some sharing of resources. Exchange rates provide a means of assessing where, geographically, the ecological gains available from establishing a boundary-spanning initiative would be greatest. For our application, the Pacific Northwest's Lower Snake River watershed mentioned above is one potential candidate (Figure 1c). The exchange rates indicated the central Appalachians as another potential candidate (Figure 1c). Again, Appalachia is a region where the greatest conservation priorities (endemic species in Virginia and West Virginia) do not align with the greatest funding base. Indeed, the central Appalachians have provided a focus for recent transboundary initiatives in the public and NGO sectors (eg TNC Central Appalachians Whole System, Appalachian Landscape Conservation Cooperative).

Conclusions and next steps

Conservation efforts are underfunded relative to the scale of losses of biodiversity and ecosystem services, a problem exacerbated by the fact that conservation organizations are often unable to deploy available funding where it will have the greatest impact. We provide a method – conservation exchange rates – that could be used to demonstrate to interested funders how much greater their impact will be if they were to allow more flexibility in where funds can be invested. While many funding programs and private donors will be unmoved by generic appeals for greater flexibility, some may find more compelling data that showed they could have three times the impact with their conservation support if they allowed funds to be targeted toward shared regional priorities. Our method identifies numerous

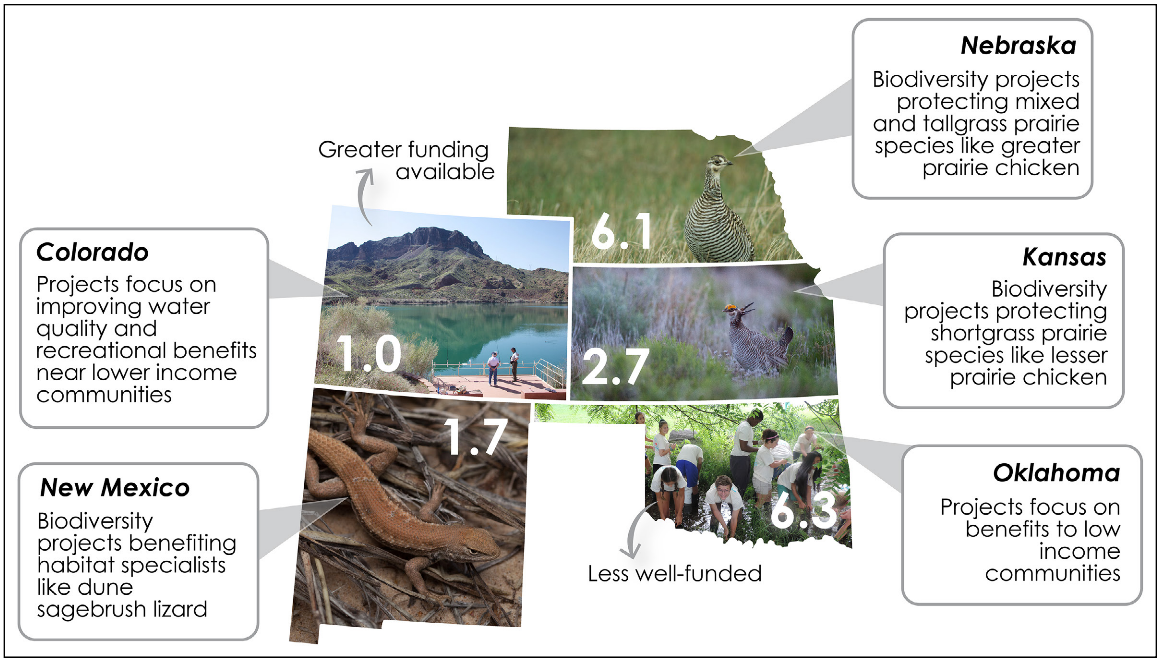

Figure 4. Infographic illustrating how exchange rates can be used by donors and by philanthropy staff at a conservation NGO. Example formatted for donors in eastern Colorado interested in improving conservation of vulnerable species and providing ecosystem service benefits to low-income households and who would consider investing in conservation opportunities in adjoining states. Numerical values are exchange rates when transferring funds from Colorado: for instance, if Colorado donors allowed gifts to be used in Nebraska instead of Colorado, each dollar could have 6.1 times greater conservation impact. Text descriptions based on the relevant state-constrained optimization. Images from the USFWS National Digital Library, with the following credits: Nebraska (D Menke), Oklahoma (E Hornbaker), Colorado (R Hagerty), Kansas (R Hagerty), and New Mexico (R Hagerty).

opportunities for regional conservation programs that would meet this standard.

Various extensions of our work would be worthwhile. We based our calculation of exchange rates on buying unconverted land to establish protected areas. It would be interesting to consider other conservation approaches, including habitat restoration, that are characterized by distinct spatial patterns of benefits and costs (Bodin *et al*. 2022). Moreover, although we focused here on conservation funding, there are other ways that people support conservation, such as through donating easements (Baldwin and Leonard 2015) or by volunteering (Armsworth *et al*. 2013), which are more spatially constrained than are financial donations. Another interesting extension therefore would be to explore how exchange rates could inform strategies for blending different types of support in conservation projects. We also focused our discussion on larger conservation organizations, whose work spans administrative boundaries. But conservation success is also critically dependent on the contributions of local communities and smaller organizations (Kothari 2006; LTA 2020). For these groups, exchange rates could suggest priorities for forming partnerships to bridge gaps between where support for conservation is most available and where conservation projects are most needed.

A particularly important next step would be to generalize our methods beyond the US so they can inform global conservation funding discussions. Countries with the most financial resources to support conservation are not those where the combination of biodiversity needs, conservation costs, threats, and institutional capacities promises the greatest conservation return on investment (Waldron *et al*. 2013; Butchart *et al*. 2015). Yet institutional constraints often require that resources for supporting biodiversity conservation be used within the borders of the country in which they originate (Pouzols *et al*. 2014). Extending our approach to derive global conservation exchange rates will therefore be important. As noted previously, the most immediate opportunities to relax constraints on funding may well come from promoting shared regional or thematic programs (Dallimer and Strange 2015; Vogdrup-Schmidt *et al*. 2019a). For example, biodiversity gains supported by US funding sources would be even greater than those we found if they were to encompass thematic connections, such as: California donors being asked to support a program focused on Mediterranean-type ecosystems (Underwood *et al*. 2009b), southern Florida donors being asked to support a wider Caribbean program (Maunder *et al*. 2008), or East Coast donors being asked to support an Atlantic Americas Flyway program (Kirby *et al*. 2008).

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Data Availability Statement

Data and code are available at https://doi.org/10.5061/dryad.zkh1893dj.

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