

RESEARCH ARTICLE



Conservation planning for people and nature in a Chilean biodiversity hotspot

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Abstract

1. The Mediterranean-type climate region of Chile is a globally unique biodiversity hotspot but its protected area system does not adequately represent the biological diversity, nor does it provide equitable access to people.
2. We explored options to expand the protected area system to cost-effectively improve the conservation of forest ecosystem types while simultaneously enhancing social accessibility to protected areas. Social accessibility is defined as the access of municipalities to cultural ecosystem services provided by protected areas which depends on distance to highly demanded protected areas and income of the municipalities.
3. Using systematic conservation planning methods, we identified priority areas for extending the existing protected area system that: (a) minimise land acquisition cost, (b) maximise social accessibility and (c) optimise for both cost and accessibility.
4. The results show that it is possible to improve social accessibility while simultaneously minimising land cost. Considering cost alone, the protected area system could be expanded to improve biodiversity conservation by 86% at the cost of \$47 million USD, which would also increase the accessibility of protected areas by 12%. Accessibility can be increased by a further 18% by jointly considering cost and accessibility without compromising the cost or biodiversity performance.
5. New private conservation policy developed in Chile could help offset the costs of conservation through novel public-private partnerships. Our results can provide

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specific guidance to policymakers to strategically identify new locations for protected areas which cost-effectively improve biodiversity conservation, while at the same time reducing inequality in social accessibility. The consideration of social access in reserve design could increase the success of protected areas as a conservation tool by bringing people closer to nature.

KEYWORDS

biodiversity, conservation planning, cost-effective, inequality, protected areas, scenarios, social accessibility

1 | INTRODUCTION

Protected areas are an essential management strategy for conserving biodiversity (Gray et al., 2016) and delivering multiple ecosystem services vital for human wellbeing (Naidoo et al., 2019; Oldekop et al., 2016; Pullin et al., 2013). To respond to environmental threats, such as habitat loss, climate change and land-use change, international conservation policy (CBD, 2010; IPBES, 2019; United Nations, 2015) has made important calls to expand protected area networks by establishing new reserves or enlarging existing ones to improve ecosystem representation, increase connectivity and expand the coverage of areas important for biodiversity and ecosystem services (Aycrigg et al., 2013; Rodrigues et al., 2004). The consideration of ecological and social objectives in conservation decision making can help increase the flow of benefits to people and thereby improve wellbeing (Iwamura et al., 2018; Lanzas et al., 2019). However, optimising the spatial configuration of the expansion of protected area networks for conserving biodiversity and ecosystem services is a challenge, given limited resources and information (Palomo et al., 2014), and compounded by increasing threats to biodiversity and conflicting societal and economic interests for land use (Remme & Schröter, 2016).

Systematic conservation planning offers a robust approach to assess policy options and respond to international conservation policy commitments such as protected area targets post 2020 (CBD, 2010, 2019) and the Sustainable Development Goals (United Nations, 2015), particularly Goal 10 'Reduced Inequalities' and Goal 15 'Life on Land'. This approach involves a transparent process of setting conservation goals and objectives and finding an optimal solution to reach these objectives (Pressey et al., 2007; Watson et al., 2011). In Systematic conservation planning objectives include the representation of biodiversity and ecosystem services while solutions involve the optimal selection of a network of areas that best meet the defined conservation goals, strategising when and how to add them to the network (Adams et al., 2016; Chan et al., 2006; Dinerstein et al., 2019; Margules & Pressey, 2000; Reyers et al., 2012). It also involves the identification of surrogates for conservation features, the setting of quantitative and operational targets, and the recognition of how these targets can be met by conservation areas at minimal cost using explicit, yet simple, heuristic methods to locate and design conservation areas (Ball et al., 2009; Possingham et al., 2000).

Accounting for costs, such as the cost of acquiring land, has the potential to improve the delivery and effectiveness of conservation planning outcomes (Carwardine et al., 2010; Evans et al., 2015; Naidoo & Ricketts, 2006; Remme & Schröter, 2016) and helps avoid expensive mistakes (Ban & Klein, 2009; Schöttker & Santos, 2019).

The expanded use of spatial planning tools to simultaneously consider the conservation of both biodiversity and ecosystem services has gained attention in the last decade (Chan et al., 2006; Di Minin et al., 2017; Schröter et al., 2014; Snäll et al., 2016; Verhagen et al., 2017). In conservation planning, ecosystem services have been incorporated as benefits (e.g. regulating and cultural services) or, in the case of extractive provisioning services, as an opportunity cost of conservation since their use can be restricted (Chan et al., 2011). However, accounting for access to cultural ecosystem services has rarely been addressed when prioritising the expansion of reserve networks (Cimon-Morin et al., 2014; Verhagen et al., 2017; Watson et al., 2019). Cultural ecosystem services are the contributions that ecosystems make to human well-being arising from cultural practices and interactions that occur between people and a variety of environmental spaces such as the landscapes comprised by protected areas (Chan et al., 2012; Fish et al., 2016). These services encompass a diversity of benefits like nature recreation, scenic beauty, sense of place, local heritage, knowledge and educational value and social relationships among others (Chan et al., 2012; Hernández-Morcillo et al., 2013; Milcu et al., 2013). Improving access to cultural ecosystem services from protected areas could help create a broader set of cultural values about ecosystems that can influence how ecosystems acquire meaning and importance to people (Fish et al., 2016).

Expanding conservation networks by targeting just the biophysical supply side of ecosystem services can result in failure to position natural reserves where ecosystem services are likely to be most beneficial to people (Watson et al., 2019). Recent studies have shown that conservation targets for protected areas are met more often when conservation planning involves local communities, improves cultural benefits and decreases social costs (Naidoo et al., 2019; Oldekop et al., 2016). Using an approach focused on the location of beneficiaries to prioritise the expansion of the reserve network can ensure that sites selected for biodiversity conservation are more accessible, thereby increasing the flow of nature's contributions to people and enhancing wellbeing.

In this study, social accessibility is defined as the access of municipalities to cultural ecosystem services provided by protected areas

which depends on distance travelled through the road network to high demanded protected areas and average income of the municipalities (Martinez-Harms et al., 2018). Higher values of social accessibility indicate higher access to cultural services in existing protected areas. For example, if a municipality is located closer to protected areas which provide greater cultural ecosystem services benefits then the accessibility index is higher, particularly if the income of the municipality is also high. Conversely, those municipalities that are located further from the higher cultural service-producing protected areas have lower social accessibility to the cultural services provided by protected areas, particularly if they have lower incomes.

The positive effects of higher social accessibility to protected areas include improving the potential to motivate and sustain public support for pro-environmental attitudes and nature conservation, improving access to natural ecosystems and experiences, fostering an intuitive appreciation of nature and an improvement in the economic and socio-cultural level of the local livelihoods surrounding protected areas (Belsoy et al., 2012). However, higher social accessibility could lead to adverse effects and pressures on the environment and some forms of biodiversity. The main impacts from increasing accessibility to protected areas include the rise of resources consumption such as water and energy, the increase production of waste, altering natural ecosystems by the construction of new touristic infrastructures, the introduction of exotic species and can cause higher probability of forest fires among other pressures (Belsoy et al., 2012). Because of all the negative impacts that can be caused by an increase in access to protected areas it is very important to plan it in line with the management plan of the protected areas that regulate and restrict access to sensitive ecosystems within the protected areas.

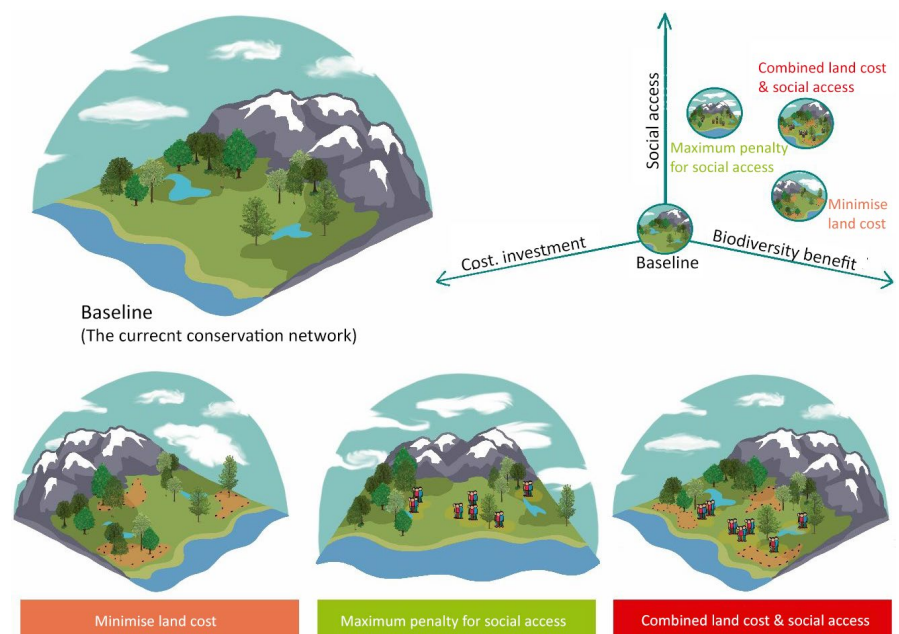
Conservation planning for both people and nature involves designing the expansion of protected areas to not only conserve biodiversity and enhance the supply of cultural ecosystem services but

to do it in a way that also improves people's access to these services (Iwamura et al., 2018; Palomo et al., 2014). In many cases, protected areas can be seen as an elitist protection policy, reserving desirable conditions for those sectors of society with sufficient resources to enjoy them (O'Keeffe, 2013). However, experiences with nature through protected areas visits and the benefits for human wellbeing that ensue could be more accessible to every person. Conservation efforts targeting social accessibility can bring protected areas closer to all socioeconomic segments of the population (Allan et al., 2015; Daniel et al., 2012). However, despite its importance, social accessibility has been largely ignored in spatial conservation planning.

Conservation efforts bringing social accessibility into the design of the protected area network are also extremely important as high levels of inequality in accessibility exist in Central Chile, with 20% of the population making 87% of the visits to protected areas (Martinez-Harms et al., 2018). Wealthier people can travel further to visit protected areas while people with lower incomes tend to visit protected areas that are closer to home. Therefore, there is an urgent need to expand the protected area network, especially in areas that are closer to lower-income communities, to increase social accessibility to protected areas. Moreover, improving the effectiveness of the protected area network is particularly urgent for the Mediterranean-type climate region of Chile. While this region is a globally important hotspot of plant biodiversity endemism (Myers et al., 2000), the protected area system only covers a small proportion of the region and is largely biased to the Andean range (Arroyo & Cavieres, 1997; Marquet et al., 2004; Plischoff & Fuentes-Castillo, 2011). Alaniz et al. (2016) reported that the ecosystems of Central Chile are highly threatened, with 23% falling under the IUCN Red List of Ecosystems threat categories.

In this study, we address this challenge by strategically identifying spatial priority areas which meet biodiversity conservation targets while minimising land acquisition cost and increasing social accessibility. We

FIGURE 1 Representation of the conservation prioritisation to optimise the spatial configuration of the expansion of protected area networks for conserving biodiversity and increasing social accessibility at the minimum cost. The baseline scenario was compared against a: **minimise land cost** scenario which prioritises the selection of less expensive planning units minimising the land acquisition cost, **the maximum penalty for social access** which penalised social inequality access to cultural ecosystem services, favouring the selection of priority areas closest to municipalities that currently have low access. The **combined land cost and social access** scenario that seeks to reduce land cost and maximise social accessibility at the same time



explore four conservation scenarios in Mediterranean-type climate region of Chile representing: (a) the baseline representing the current conservation network, (b) minimise land cost, (c) maximum penalty for social access scenario that maximised social accessibility to protected areas and (d) a combined land cost and social access scenario reducing the trade-off between cost and social accessibility. We compare the four scenarios (see Figure 1) for biodiversity performance, land acquisition cost and social accessibility and discuss the implications for protected area selection for both people and nature in Chile and more broadly.

2 | METHODS

2.1 | Study area

The study region comprises the central zone of Chile (32°S and 40°S, Figure 2) covers approximately 148,000 km², with elevation ranging

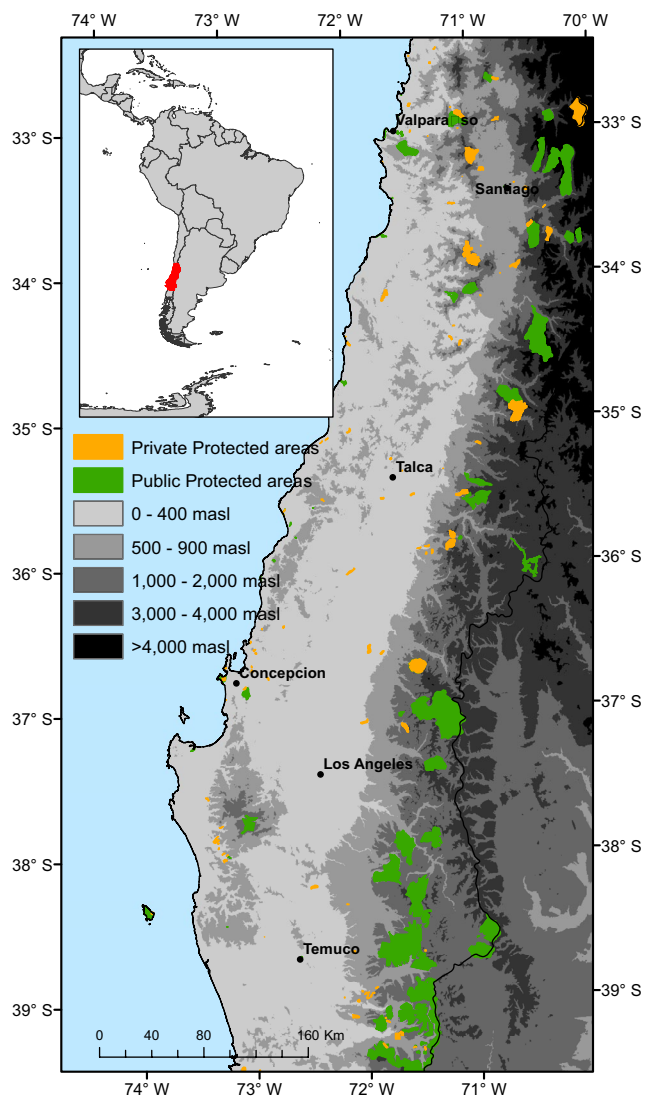


FIGURE 2 The study area highlighting the protected area system (public and private) and the elevation in metres above sea level (m a.s.l.)

from 0 to 6,500 m a.s.l. Characterised by a Mediterranean-type climate (i.e. warm, dry summers and cool, wet winters), mean daily maximum temperatures range from 20°C in summer to 8°C in winter, and annual precipitation ranges from 250 mm (January–December) to 700 mm (June–August), increasing with altitude and latitude (Luebert & Plischoff, 2018). The region is one of 35 global biodiversity hotspots with more than 1,600 endemic species (Myers et al., 2000). The current system of public parks comprises 65 protected areas, including natural monuments (IUCN category III), national parks (IUCN category II), national reserves and natural sanctuaries (IUCN category IV). The size of the 65 protected areas varies from <1 to 785 km², with 27 protected areas smaller than 10 km² (Figure 2).

2.2 | Conservation features

Biodiversity surrogates are assumed to represent spatial patterns in the distribution of biodiversity (Ware et al., 2018). As a surrogate for biodiversity, we used a potential vegetation type definition (Luebert & Plischoff, 2018). Vegetation types are suitable surrogates for biodiversity because these represent various combinations of species and its interactions and thus can also incorporate ecosystem processes and functions, as well as species richness. Conspicuous organisms such as plants interact with, and are linked spatially to, smaller organisms thus protecting vegetation types might protect the habitat of many more inconspicuous species (Sarkar & Margules, 2002). In Central Chile there is evidence of a positive relation between the number of vegetation types represented and number of species represented by the protected areas (Urbina-Casanova et al., 2016).

This is the most detailed vegetation classification system covering mainland Chile (1:100,000 scale). This system describes vegetation types in the region, defined by the authors using the ‘vegetation belts’ concept. A vegetation belt is a group of zonal vegetation communities with uniform structure and physiognomy, located under similar meso-climatic conditions that occupy a determined position along an elevation gradient, at a specific spatial-temporal scale (Luebert & Plischoff, 2018). Its combination of detail and coverage facilitates a regional representativeness assessment (Plischoff & Fuentes-Castillo, 2011). We considered 34 forest ecosystem types presented in the study area (Luebert & Plischoff, 2018), excluding areas where the native forest had been cleared according to a country-level updated land cover map (CONAF-CONAMA-BIRF, 2015). This potential vegetation map has been identified as the official ecosystem type classification by the Chilean Ministry of Environment (Figure 3d).

2.3 | Conservation scenarios and costs

We took as a baseline scenario the existing protected area system inclusive of both public and private protected areas as derived from the Chilean Ministry of Environment database (ide.mma.gob.cl). We included all existing public reserves (65 public protected areas) and

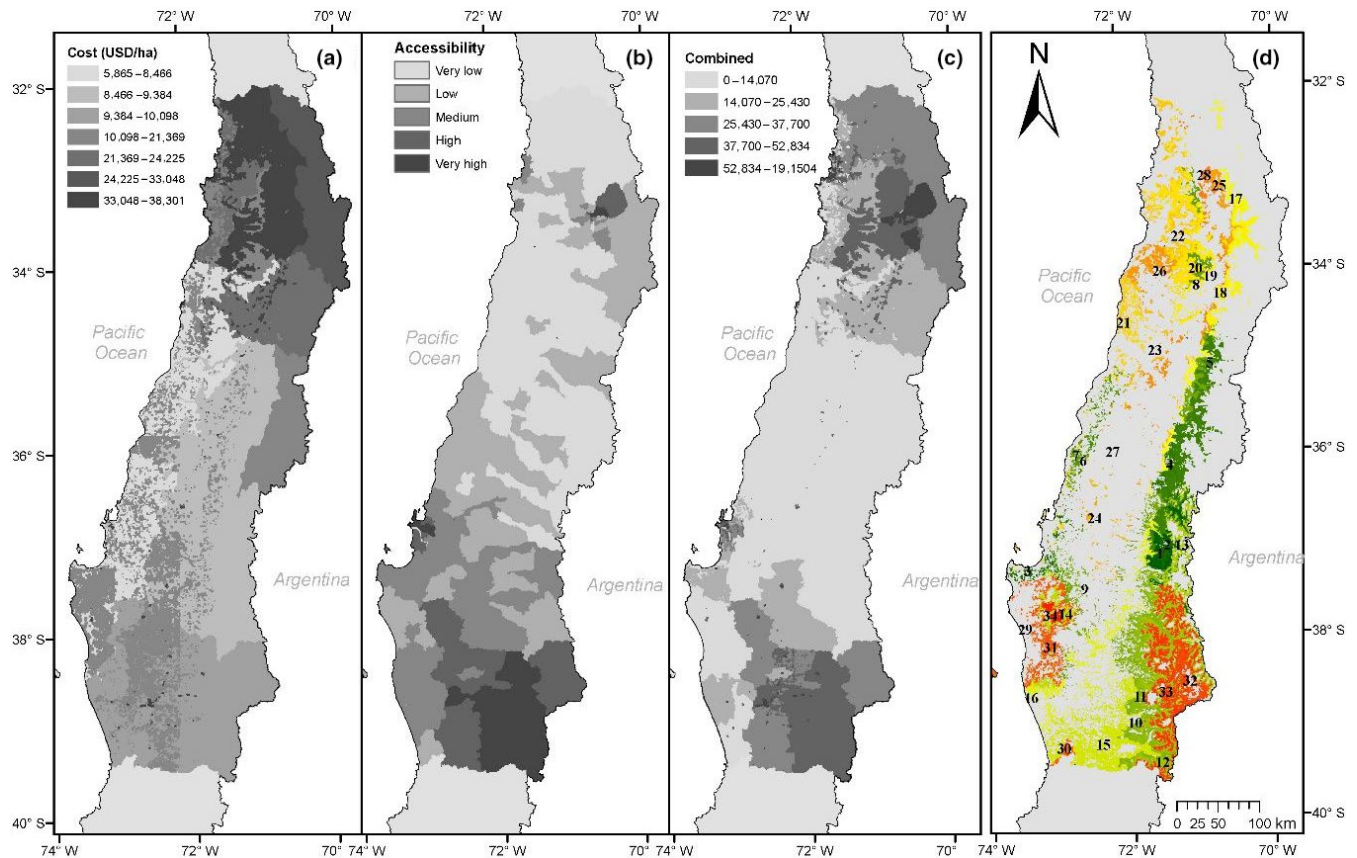


FIGURE 3 Maps of the: (a) Land acquisition cost (USD/ha); (b) Social accessibility penalty index based on the empirical relationship between income of the municipality and the distance travelled from municipalities to protected areas weighted by the popularity or distance travelled from visitors to protected areas (Martinez-Harms et al., 2018); (c) combined land cost and social access resulting from the multiplication of the two spatial layers (social accessibility and land acquisition cost) and (d) map of the 34 remnant forest ecosystem types that represent the conservation features

private conservation areas (95 private protected areas) in every scenario (see Figure 2). We compared the baseline scenario with three different conservation scenarios, the first minimising land acquisition cost (minimise land cost), the second maximising social accessibility (maximum penalty for social access) and the third optimising for both low cost and high accessibility (combined land cost and social access, see Table 1).

For the **minimum land cost scenario**, we developed a map of the average acquisition value of land in USD per hectare (Figure 3). This land acquisition cost proxy was developed based on a look-up table assigning the reported average economic values (ODEPA, 2009) to categories of agricultural productive land. These categories are a combination between the administrative region and geological district (see details in Supporting Information Appendix A).

For the **maximum penalty for social access** scenario, we penalised social inequality favouring the selection of priority areas closest to municipalities that currently have low social access. To reduce the current inequality in social access, the social accessibility layer, that highlights higher and lower access to cultural ecosystem services in existing protected areas, was used as a 'cost' surrogate in Marxan. We aimed to maximise social accessibility from poorer municipalities that are also closer to protected areas that have higher

demand for providing cultural ecosystem services (Martinez-Harms et al., 2018). The social accessibility layer was originally calculated based on a photo-visitation database developed from publicly available geotagged photographs and information of the home municipality of visitors within the photo-visitation database (Martinez-Harms et al., 2018). Socioeconomic information such as the average income for each municipality of the study region (237 municipalities) was also collected. We used the average income of the municipalities because in the study areas there are clear divisions that favour or create opportunities for only a portion of society with higher disposable income that can enjoy greater access to the cultural benefits of protected areas. The municipality is the smallest administrative unit for which socioeconomic data are available from the National Socioeconomic Characterization Survey undertaken by the Chilean Ministry of Planning and made freely available to the public (Ministerio de Desarrollo Social, 2013).

The social accessibility index was calculated for each municipality as the demand for cultural ecosystem services provided by each protected area divided by the distance from the protected area to the municipality, summed over all protected areas, and then multiplied by the average income of the municipality. Demand for cultural ecosystem services of each protected area was calculated as

TABLE 1 Decision framework applied to cost-effectively expand the current conservation network improving biodiversity representation and increasing social accessibility at minimum cost in the Mediterranean region of Chile

Fundamental objective: to cost-effectively expand the current conservation reserve network improving biodiversity and social accessibility at minimum cost				
1. Objectives	Baseline scenario representing current conservation (public and private protected areas)	Minimum cost system achieving biodiversity targets (minimise land cost)	Maximum social accessibility achieving biodiversity targets (maximum penalty for social access)	Minimising cost and maximising social accessibility achieving biodiversity targets (combined land cost and social access)
2. Conservation feature	Biodiversity: 34 native forest ecosystem types			
3. Measurable targets	Representation of the forest ecosystem types in the current conservation network.	Meet 17% of the target. For the forest ecosystems classified as critical and endangered according to the IUCN red list of ecosystems (Alaniz et al., 2016) we increased the target to 30%.		
4. Estimate conservation costs	No cost needed (Baseline scenario to be compared with the other scenarios)	Cost of the land per productive land cover type (USD/km ²)	Social accessibility index (Martinez-Harms et al., in review)	Cost of the land multiplied by social accessibility penalty rescaled
5. Estimate conservation benefit	Area in km ² required to meet the 34 forest ecosystem targets			
6. Review outputs	Selection frequency of solutions (100 repetitions were run and 10 million iterations), to select the best least cost solution.			

the total distance travelled by visitors to the protected area derived from a database of protected area visitation obtained from social media (Martinez-Harms et al., 2018). The layer is calculated using the following equation:

$$\text{Accessibility}_j = \left(\sum_i^n \frac{\text{CES}_i}{\text{Distance}_{ij}} \right) \times \text{Income}_j,$$

where Accessibility_j : Accessibility of each of the 237 municipalities' j to the entire protected area system in the Chilean Mediterranean-type climate region; CES_i : Demand for cultural ecosystem services calculated as the total distance travelled to visit each protected area i summed across all photo-user-days; Distance_{ij} : Distance (km) via the road network from each protected area i to the centroid of each municipality j ; Income_j : Average annual income per capita of each municipality j .

To calculate the **land cost and social access scenario**, we linearly rescaled the social accessibility penalty index in equal interval values from one to five and multiplied the rescaled layer with the land acquisition cost layer.

2.4 | Measurable targets

The Convention on Biological Diversity's Aichi Target 11 mandates that 17% of terrestrial areas of importance to biodiversity and ecosystem services should be conserved through effectively and equitably managed systems of protected areas and other effective conservation measures by 2020 (CBD, 2010). We aimed to maintain 17% of each conservation feature. However, the Aichi Target 11 acknowledges that such uniform policy-driven targets may not be

appropriate for ensuring the ongoing preservation of conservation features. Hence, we increased the target to 30% (see also Baillie & Zhang, 2018; Dinerstein et al., 2019) for the five ecosystems that are listed as endangered or critical (ecosystems 6, 7, 22, 24 and 25 according to Supporting Information Appendix A) according to the IUCN Red List of Ecosystems criteria (Alaniz et al., 2016). We estimated the cost of achieving the targets with the best solution output (i.e. the network that met all the target at the least cost) and estimated the area needed to achieve it.

2.5 | Spatial prioritisation

To identify conservation priorities, we used the conservation planning tool Marxan to compare the reserve expansion under the three conservation scenarios and in achieving biodiversity targets (see Table 1). Marxan uses a heuristic optimisation algorithm with the help of simulated annealing to develop spatially explicit solutions for conservation problems (Ball et al., 2009). Marxan minimises the total cost of sites in a reserve network while meeting a set of targets for biodiversity features. The problem that Marxan solves is:

$$\text{Minimise } \sum_i^N x_i c_i, \quad (1)$$

$$\text{Subject to } \sum_i^S x_i r_{ij} \geq T_j \text{ for all } j, \quad (2)$$

where x_i is a control variable indicating if a planning unit ($i = 1, \dots, N$) is selected ($x_i = 1$) or not ($x_i = 0$) and c_i is the cost of the planning unit.

Equation (1) is minimised subject to target T_j being met for all conservation features ($j = 1, \dots, S$), where r_{ij} is the conservation benefit for feature j in planning unit i .

We used 1 km² planning units (148,744 planning units) and tested the scenarios for the biodiversity features represented by the 34 native forest types. The Species Penalty Factor (SPF) determined the importance of meeting the target and in this case was kept at 1.0 for all features except those where the target was not met in the first set of runs. In those cases, we increased the SPF to 10.0 to increase the likelihood of the target being met. The boundary length modifier (BLM) is used in Marxan analysis to influence the degree of connectivity between planning units selected as conservation priorities. To encourage some ecological connectivity in the resulting area network, Marxan's BLM was set to the value of 10.0 after testing its sensitivity. We started with a BLM of zero and increased until visual inspection of the results showed the desired degree of clustering (BLM = 10). The calibration of the results was performed to ensure that the set of solutions produced were close to the optimum (lowest cost). Marxan analyses were calibrated iteratively checking the SPF values and the number of iterations needed to achieve that all targets are being met. Then all scenarios were run with 100 repetitions and 10 million iterations.

To explore cost-effective expansion of the conservation reserve network achieving biodiversity targets and increasing social accessibility at the lowest cost, we used the best solution (i.e. that which met targets at the minimum cost from 100 runs) to compare the scenarios in terms of the: area of the reserve, reaching biodiversity targets (number of forest ecosystem types represented <17%), cost and social accessibility measure. We used the selection frequency output (the number of times that a planning unit was selected in the 100 runs) as a measure of the relative priority of each area and for

spatial representation purposes. We compared the spatial distribution of priorities for conservation under each scenario. To quantify if and to what extent the scenarios can be considered correlated or how strong the overlap between them is, we calculated the Jaccard coefficient.

The Jaccard coefficient, is a statistic used for measuring the similarity between finite sample sets, and is defined as the size of the intersection divided by the size of the union of two sample set. In this case the intersection is the number of only those planning units that the two scenarios have in common, in terms of the planning units that were selected >40% of the 100 runs (i.e. the number of matching priority sites). The union is total number of planning units selected >40% belonging to either of the two scenarios. The Jaccard coefficient range from 0 to 1, the higher the coefficient value represents that the two sample sets are more similar. We spatially represented these similarities by comparing the scenarios by pair.

3 | RESULTS

The baseline scenario included a protected area system of 9,642 km² (or 6.5% of the study area), which inadequately represented biodiversity targets (see Table 2). The baseline scenario under-represented 28 forest ecosystem types and achieves only 12% of their total coverage in the conservation network (see Figure 4). There were 19 forest ecosystem types represented by <5% of the coverage (see Supporting Information Appendix A) and forest types such as the sclerophyllous forest types, had 4% of their coverage represented in protected areas (see Figure 4).

The minimise land cost scenario required just an extra 3% of the land (4,060 km²) and contributed much better to conservation target

TABLE 2 Comparison of the four scenarios in terms of the area of the reserve, biodiversity performance (number of forest ecosystem types under-represented or represented by <17% in their extent in the conservation network), cost and the average accessibility index. The average accessibility varies from 0% to 100%, the higher index value represents more access of lower income municipalities that are further away from those protected areas highly accessed cultural ecosystem services

Conservation scenarios	Area of the reserve (km ²)	Biodiversity performance	Cost (million USD)	Average social accessibility index
Baseline scenario representing current conservation	9,642	28	139	49
Minimum cost system achieving biodiversity targets (minimise land cost)	13,702	4	186	55
Maximum social accessibility achieving biodiversity targets (maximum penalty for social access)	13,798	5	210	59
Minimising cost and maximising social accessibility achieving biodiversity targets (combined land cost and social access)	13,707	4	186	58

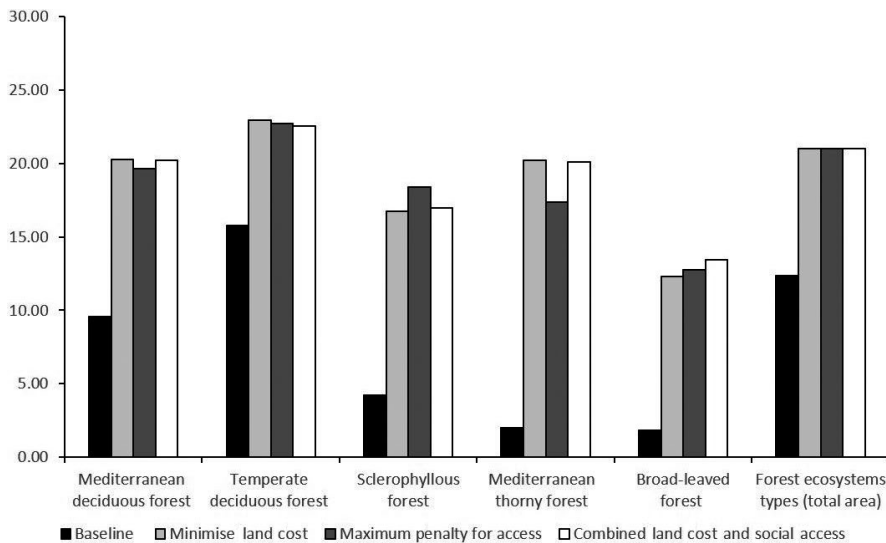


FIGURE 4 Representation targets (%) of the forest ecosystem formations according to (Luebert & Plischoff, 2018) under the baseline scenario and the three conservation scenarios tested

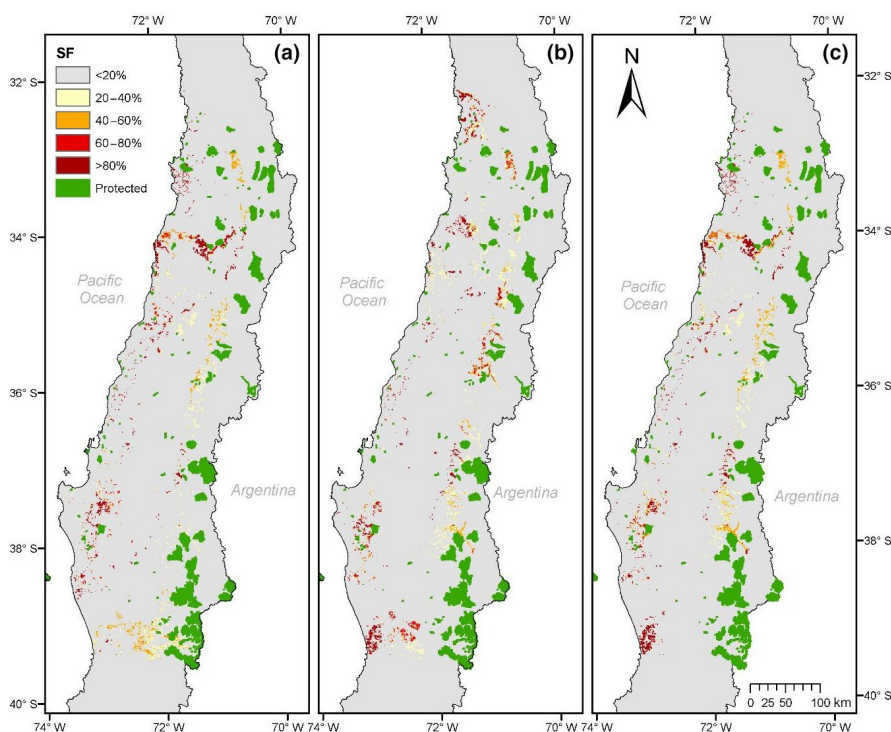


FIGURE 5 Selection frequency (SF) maps of sites achieving a 17% for each of the 34 forest ecosystem types: (a) scenario minimise land cost, (b) the maximum penalty for social access scenario and (c) combined land cost and social access scenario

achievement, under-representing just four forest types (see Table 2). This scenario was nearly 47 million USD more expensive than the baseline, and social accessibility was higher by 12%. The maximum penalty for social access and the combined land cost and social access scenario resulted in similar-sized protected area systems and performance against biodiversity targets as the minimum land cost scenario. The maximum penalty for social access scenario resulted in the most expensive outcome being 71 million USD more expensive than the baseline. The combined land cost and social access scenario cost was similar to the minimum land cost, but the former was more effective with a higher social accessibility index (higher by 18.4% compared to the baseline).

Figure 5 presents the spatial priorities for the minimise land cost scenario (Figure 5a), the maximum penalty for social access scenario

(see Figure 5b) and the combined land cost and social access scenario (see Figure 5c). The subset of candidate priority areas—those always selected regardless of where the selected areas were located in the coastal range of the Mediterranean-type climate region—especially prioritised the protection of sclerophyllous coastal forests. In these landscapes, native vegetation clearing has left few options for meeting biodiversity and access to cultural ecosystem services targets (Figure 5).

The quantitative comparison between scenarios (see Figure 6) showed that the minimise land cost and the combined land cost and social access scenario were more similar and had more matching sites. The minimise land cost scenario and the combined land cost and social access scenario (see Figure 6b) had more matching planning units selected >40% (2,843 km²) and the highest Jaccard

FIGURE 6 Comparison between the scenarios highlighting matching planning units between the scenarios (blue) and those planning units that are different (red) between scenarios: (a) the comparison between the minimum land cost scenario and the maximum social accessibility scenario; (b) the comparison between the minimum land cost scenario and the combined low cost/high access scenario; and (c) the comparison between the maximum penalty for social access scenario and the combined land cost and social access scenario

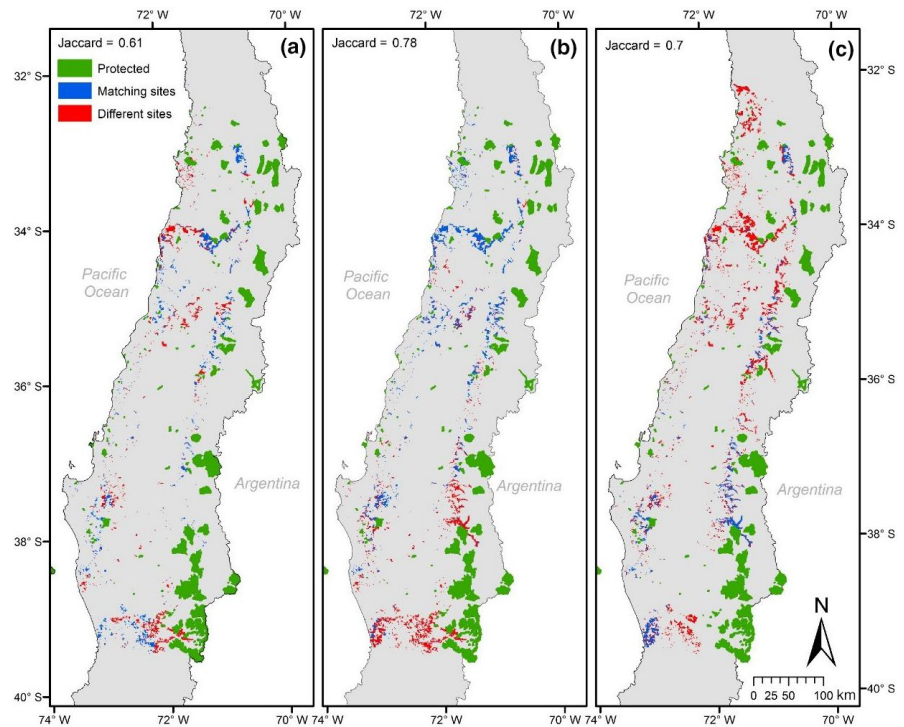
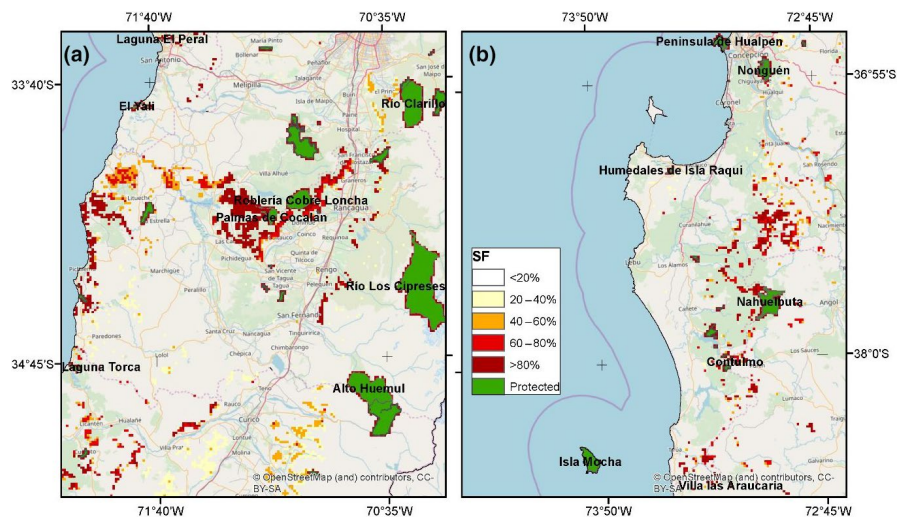


FIGURE 7 The combined land cost and social access scenario (a) highlights a corridor of conservation priority sites at 34°S connecting protected areas located in the northern coastal range and (b) highlights high priorities surrounding the Nahuelbuta coastal range at 37°S



coefficient (0.78). The higher Jaccard coefficient values indicated that these two scenario outputs were the most similar ones. The comparison between the minimise land cost scenario and the maximum penalty for social access scenario (Figure 6a) resulted in the lowest Jaccard coefficient (0.61) but followed in area of matching planning units selected >40%. The comparison between the maximum penalty for access scenario and the combined land cost and social access scenarios (Figure 6c) resulted in a Jaccard coefficient of 0.7 and the lowest area of matching planning units selected >40% (2,239 km²).

The spatial priority map for the combined land cost and social access scenario showed at 34°S a corridor of land parcels recommended for reserve selection because of the high biodiversity value and ability to increase social access in a high-poverty area. This corridor connects land parcels located in the coastal range (e.g.

'Palmas de Cocalan' and 'Roblerias de los Cobres de Loncha') with a protected area ('Rio Clarillo') at the south foothills of Santiago (see Figure 7a). The combined land cost and social access scenario also identified land parcels recommended for selection in the area surrounding the Nahuelbuta coastal range at 37°S (see Figure 7b). These parcels present the last remnants of the coastal temperate forest of *Araucana araucana*, an endangered slow-growing relict conifer poorly represented in the existing protected area system. The minimise land cost scenario and the combined land cost and social access scenario recommended reserve selection in the Andean range from 35°S to 37°S (Figure 5a,c). The maximum penalty for social access scenario (see Figure 5b) identified high conservation priority sites in the coastal range between 32 and 33°S and in the Andean range from 34 to 36°S (from protected area 'Alto Huelmul' to 'Radal siete tazas').

4 | DISCUSSION

Incorporating social accessibility into conservation planning, can bring people closer to protected areas, without compromising costs, however, we do not know that this is without compromising the protection of biodiversity. Increasing social accessibility could also mean that these areas could experience more environmental pressures from visitors (Tverijonaite et al., 2018). There is evidence that even low intensity of presence of visitors might produce an overall loss of biodiversity (Martínez et al., 2020). Planning for social accessibility should be done carefully to protect biodiversity through the development and enforcement of protected area management plans. Although it is outside the scope of this study, it is key to plan and manage the multiple uses within and around each one of the protected areas in the study area to distinguish zones with varying degrees of allowable human impact in order to co-manage low human development and to preserve biodiversity. Currently there is a lack of management plans for the vast majority of the protected areas in the study area (Petit et al., 2018).

Our outputs can assist policymakers and planners to strategically identify suitable new locations for protected areas that could cost-effectively fill the current gaps of the conservation network improving representation of forest ecosystem types, while increasing social accessibility. The current protected area network in the study area is largely deficient, inadequately representing 82% of the forest ecosystem types, as well as plants and vertebrate species (Ramírez de Arellano et al., 2019; Squeo et al., 2012; Tognelli et al., 2008). The network is biased toward high altitudes and lower opportunity cost areas in the region. Species and ecosystems in the Mediterranean region may be lost because of the current inefficiencies in representation of biodiversity features. The use of more flexible approaches targeting ecological and social objectives could help to enhance both biodiversity conservation and human wellbeing through strategic spatial planning resulting in co-benefits based on uncorrelated indicators such as land cost and social accessibility (see Figure 6a).

There are limitations and pitfalls on prioritising sites for conservation just focusing on representation of ecosystems. Framing targets on area-based representation ignores the relative urgency of features' protection because of extensive past reductions or rapid ongoing declines, assuming that all will eventually be adequately represented which is unreliable (Barnes et al., 2018; Pressey et al., 2017). To address this limitation we increased the target of ecosystems listed as endangered or critical according to the IUCN Red List of Ecosystems criteria. However, we acknowledge that sets of proposed conservation areas that represent all features are rarely implemented and partial implementation is likely to focus on least contentious areas.

The scenarios tested represented different conservation alternatives, highlighting a subset of priority areas minimising land acquisition cost and maximising social access. These areas contain examples of biodiversity for which there are few or no substitutes in the region. Our results showed that the most efficient scenario is the one that jointly considers land cost and social access, which

showed that the protected area network could be slightly expanded (3% of the area) to greatly improve biodiversity representation (by 86%) at a minimal land cost. This would also increase the accessibility to protected areas (by 18.4%). This output highlights the most inexpensive areas that are closer to municipalities with low access, which can potentially help meet the demand for cultural services in this region. Further studies eliciting landscape preferences of tourists and local stakeholders are needed to know with certainty if the priority areas selected under this scenario can meet the demand for cultural services.

It is urgent to further understand and account for cultural ecosystem services in terms of its human-wellbeing contributions such as the identities they help frame, the experiences they help enable and the capabilities they help equip (Fish et al., 2016). This requires a relational approach while the evidence on cultural ecosystem services has focused on linear constructions based on the supply (Hutcheson et al., 2018; McGinlay et al., 2018; Nahuelhual et al., 2013) and the demand side of cultural services (Fu et al., 2020). Social accessibility is not just the space that connects supply with demand of cultural services (Yoshimura & Hiura, 2017), but a cultural service itself by enabling experiences with nature and cultural practices derived from human–nature interactions (Fish et al., 2016). Bringing protected areas closer to people better enables the flow of visitors to experience protected areas as environmental spaces in which people interact with each other and the natural environment allowing them to appreciate nature (Allan et al., 2015; Daniel et al., 2012). This has the potential to create a wider set of cultural values for protected areas where these natural spaces accrue meaning and significance for people who end up motivated and supporting nature conservation. Ultimately the likelihood of success of protected areas as a conservation tool can be increased.

The exploration of alternatives and their quantitative comparison for reserve expansion targeting social access to cultural ecosystem services to bring closer the nature benefits derived from protected area people has rarely been addressed in conservation planning (Powers et al., 2013). The comparison of scenarios was useful to quantify where important selected areas are matching between the scenarios. The results showed that the comparison between the minimise land cost scenario and the combined land cost and social access scenarios was more similar with more matching areas (almost 3,000 km²). An important corridor of planning units at 34°S for reserve selection was highlighted because of the high biodiversity value and ability to increase social accessibility.

There is an urgency to improve conservation in this region where the protected area system is inversely proportional to species endemism and richness (Schutz, 2018). The situation of the Mediterranean-type sclerophyllous ecosystems of Chile is especially critical with a current protected area network that only covers a small proportion of the remnant ecosystems. The outputs could help unlock new conservation opportunities in this region, by identifying land parcels that could greatly improve biodiversity and social access to nature and help determine which action to undertake in a given location. For example, our results suggest that land acquisition is

better targeted away from the costly land around cities, particularly away from cities such as Santiago, Valparaíso and Concepción. While social accessibility targeted areas on the northern coast of Valparaíso region such as areas near localities like Zapallar and Papudo, where there is mediterranean coastal forest left and currently there are few protected areas.

Effective conservation actions must achieve maximum conservation benefit within the limits of available funding. Cost-effective conservation plans are ideal to maximise ecological and social outcomes, while not placing an ever-growing burden on taxpayers or relying on donations (Schöttker & Santos, 2019). Easements or other public–private partnerships have been suggested because some ecosystems only occur in current private land not available for sale (Nolte, 2018). In the study region most of the remaining area with high conservation value remains on private land. In 2016, a new conservation policy has been established in Chile (In Rem Right of conservation law 20930) enabling private landowners to take long-term action to protect the conservation attributes of their land, without losing the property title. Through voluntary agreements between landowners and a third party (e.g. Landtrust), landowners can protect their properties and establish certain restrictions to the real estate incentivising a market of economic transactions for private conservation (MMA, 2016). Our study can be useful as one of the key strategic activities in the implementation of this law is to cost-effectively identify strategic sites and landowners to enable private land conservation in the region.

The current inefficiencies in the representation of biodiversity features and social access make evident the urgent need for conservation initiatives in the region such as the implementation of easements or other public–private partnerships (Nolte, 2018). In Chile there are high levels of inequality affecting all dimensions of human well-being such as access to education, health and social security and also access to nature. The social accessibility cost layer used in this study can allow conservation policy to address social inequality of access to nature by identifying alternatives that improve people's access to protected areas without compromising economic costs.

Private conservation initiatives can play an important role in the region as a long-term biodiversity conservation strategy covering protection gaps, favouring territorial and biological connectivity in the current protected area system and creating opportunities for nature recreation. In Chile, private conservation has had an extensive impact with many national and international non-governmental and civil organisations pushing an environmental agenda for promoting legal reforms to support private conservation (Di Giminiani & Fonck, 2018). Low-impact tourism and environmental education are activities that are being prioritised by private conservation initiatives in Chile (Nuñez-Avila et al., 2013). Private conservation could help provide social access for nature recreation through voluntary or incentivised programs. For example, there are industries in the region such as the forestry and wine industry that are increasingly interested in the conservation of native forest and ecotourism to give an added value to their products (Merelender et al., 2014).

Immediate action is needed to engage landowners, where unrepresented remnant forest ecosystem types occur and provide them with targeted incentives for conservation. Conservation planning targeting social accessibility provides important opportunities for conservation and improving human well-being. As such, payments for ecosystem services to offset the opportunity costs of conservation might be an important incentive for the conservation of native forests on private land (Alix-Garcia & Wolff, 2014). We applied an approach that can be adapted in collaboration with national conservation stakeholders to respond to international conservation policy commitments.

5 | CONCLUSION

Conservation planning that cost-effectively improve biodiversity conservation and access to cultural ecosystem services by reducing inequality in social accessibility, could help increase the success of protected areas as a conservation tool by bringing people closer to nature. In this study we strategically identified priority areas that reach biodiversity targets while minimising land acquisition cost and social inequality of access to cultural ecosystem services. The exploration of conservation scenarios and their comparison showed that it is possible to improve social accessibility while minimising land cost, highlighting the most inexpensive areas that are closer to municipalities with low social access to protected areas. Private conservation initiatives and new conservation policy in Chile facilitating private conservation in the long term, can play an important role in this region helping offset conservation costs through novel public–private partnerships. Our results can provide specific guidance to conservation decision making for the cost-effective expansion of the conservation network.

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CONFLICT OF INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

AUTHORS' CONTRIBUTIONS

M.J.M.-H. and B.A.B. conceived the idea of the manuscript; M.J.M.-H. collected and analysed the data; M.J.M.-H. and B.A.B. led the writing; M.J.M.-H., K.A.W., M.D.P.C., H.P.P., S.G., A.C., P.P., P.A.M. and B.A.B. provided important feedback, contributed in the writing of the manuscript, review and approve the final manuscript.

DATA AVAILABILITY STATEMENT

The dataset generated in this publication will be embargoed until 21 February 2022. The files and description will be available to download and view from 21 February 2022 onwards. This dataset will be discoverable and citable immediately afterwards via Mendeley Data <https://doi.org/10.17632/pwrzhp6jpk.1> (Martinez Harms, 2021).

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section.

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