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Flexible Climate Adaptation Can Substantially Reduce Conservation Costs and Mitigate Risk

Frankie H. T. Cho^{1,2,3,4}  | Brooke A. Williams^{1,2,3}  | Carla L. Archibald⁵  | James Brazill-Boast¹⁰ | Michael J. Drielsma^{6,7} | Daniel Lunney^{8,9} | Jonathan R. Rhodes^{1,2,3} 

¹School of the Environment, The University of Queensland, Brisbane, Queensland, Australia | ²Centre for Biodiversity and Conservation Science, The University of Queensland, Brisbane, Queensland, Australia | ³School of Biology and Environmental Science, Queensland University of Technology, Brisbane, Queensland, Australia | ⁴Land, Environment, Economics and Policy Institute (LEEP), Department of Economics, University of Exeter, Exeter, UK | ⁵School of Life and Environmental Sciences, Deakin University, Burwood, Victoria, Australia | ⁶New South Wales Department of Climate Change, Energy, the Environment and Water, Parramatta, New South Wales, Australia | ⁷University of New England, Armidale, New South Wales, Australia | ⁸School of Life and Environmental Sciences, University of Sydney, Sydney, NSW, Australia | ⁹Australian Museum, Sydney, New South Wales, Australia | ¹⁰New South Wales Biodiversity Conservation Trust

Correspondence: Frankie H. T. Cho (f.cho@exeter.ac.uk)

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ABSTRACT

Climate change will have profound and unexpected impacts on biodiversity in the future. These impacts could potentially be mitigated through adaptive and responsive conservation planning, but it remains unclear how adaptation opportunities can be harnessed through careful planning of present-day activities. Here, we show that the use of flexible conservation strategies that exploit opportunities for climate adaptation can mitigate climate risks without increasing total conservation costs. We estimate the value of allowing flexible delays of conservation investments for protecting habitats of the iconic and threatened koala (*Phascolarctos cinereus*) in eastern Australia. Conservation strategies that have no option to strategically delay investments face significant trade-offs between minimizing conservation costs and reducing risks in conservation outcomes. These trade-offs are substantially mitigated by flexible strategies that strategically delay investments into the future when the effects of climate change are likely to be better understood. Strategic delays are shown to mitigate climate risks in inflexible conservation strategies without even increasing conservation costs. These results show that conservation planning that strategically allocates present-day conservation resources while also allowing the flexibility to shift these resources in the future is much more likely to achieve cost-effective conservation outcomes in the face of uncertain climate change impacts.

1 | Introduction

Climate change is profoundly restructuring ecological dynamics and ecosystems (Pinsky et al. 2018; Scheffers and Pecl 2019; Hanson et al. 2020). If targets such as the Global Biodiversity

Framework's target to protect 30% of the Earth's ecosystems by 2030 are to successfully secure biodiversity for the long term, they must account for climate change (CBD 2013). Achieving these goals requires strategic targeting of conservation investments across space (CBD 2022), often informed by systematic conserva-

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tion planning, a structured decision-support process to identify cost-effective conservation investments (Margules and Pressey 2000). Yet, uncertainties over how climate change will impact conservation outcomes compromise this task (Ando and Mallory 2012; Scheffers and Pecl 2019; Drechsler 2020). Conservation planning strategies that are fixed in time (e.g., Beyer et al. 2018; Strassburg et al. 2020; Jung et al. 2021) could fail to achieve their objectives if those plans cannot continually adapt to ongoing climate change. We therefore urgently need conservation planning strategies that deal explicitly with climate risks to ensure positive outcomes for biodiversity (Dobrowski et al. 2021).

Climate risks to conservation success could be mitigated through strategic flexibility, the act of planning present-day activities that keep future options open for responding to uncertain events (Rhodes et al. 2022). One way strategic flexibility can help reduce climate risks in conservation is through strategically delaying investments into the future. In economics, the theory of option value allows decision-makers to make better decisions by helping them decide whether to invest now or delay decision-making and only commit to irreversible decisions when uncertainties are resolved (Dixit and Pindyck 1994; Arrow and Fisher 1974). Because biodiversity projections used to inform planning are highly sensitive to the trajectory of future climate change (Buisson et al. 2010; Reside et al. 2018; Thuiller et al. 2019), strategic delays could be one approach to keeping conservation agencies' options open, enabling them to adapt actions as new information about climate and ecological systems emerges (Drechsler 2020; Drechsler et al. 2021; Rhodes et al. 2022).

Private land conservation presents an opportunity to plan conservation flexibly in response to climate risks. A common way to conserve biodiversity on private land is through voluntary conservation covenants or easements (Rissman et al. 2007; Adams and Moon 2013). These are usually legal agreements between a conservation agency and private landholders that restrict land clearing or promote other conservation actions (Fitzsimons 2015). In many cases, these agreements are incentivized through payments to landholders to offset opportunity costs or support management actions that incur costs (Iftexhar et al. 2014; Selinske et al. 2022). Although a majority of conservation organizations view climate change as a risk to conservation, few conservation agreements include provisions for flexible adaptation under climate change (Rissman et al. 2015), underscoring a critical gap in the existing practice of private land conservation. If organizations can flexibly choose when to create conservation covenants, it represents an opportunity for them to implement conservation actions that are flexible under climate change.

Here, we develop a strategically-flexible planning framework and apply it to a case study in New South Wales (NSW), Australia, to identify private properties for the conservation of the endemic koala (*Phascolarctos cinereus*). The koala is a charismatic species that has experienced dramatic population declines in eastern Australia where its conservation on private land is critical, with 77% of the population occurring on private land (DAWE 2022a, 2022b; Kearney et al. 2022; Williams et al. 2023). Habitat loss and human-caused mortality continue to be the biggest existing threats to koalas (McAlpine et al. 2015). However, climate change is an emerging threat to koalas (Lunney et al. 2012; Lunney et al. 2014; Ward et al. 2020; Phillips et al. 2021; State of NSW

and DCCEEW 2023), emphasizing the need for effective climate adaptation measures.

2 | Methods

We used a spatially explicit model of landholder preferences (Williams et al. 2024) that predicts how likely will landholders bid to participate in a conservation covenant program and the financial compensation they request based on socioeconomic, demographic, and geographic covariates of their property. This model allowed us to simulate the outcomes of a reverse auction where landholders can bid to participate in a conservation covenant program in exchange for financial payment. Based on these bids, the decision-maker then formulates a conservation planning strategy by choosing which properties are protected. To formulate the strategies, the decision-maker uses projections of the koala habitat quality in each of those properties across several climate scenarios, as quantified through a Koala Landscape Capacity Model (State of NSW and DCCEEW, 2023, and Extended Methods (d)). However, decisions made at present have to be made while being uncertain about which climate scenario will best characterize the magnitude of future impacts of climate change on koala habitats.

We examine four hypothetical conservation planning strategies identified by solving a systematic conservation planning problem using a stochastic programming approach (Extended Methods). The stochastic programming approach minimizes total conservation costs by selecting which landholders' bids are accepted at present and in the future. Although these strategies do not represent official policy, they can be used to quantify the potential outcomes of strategically-flexible conservation. We assume that a decision-maker plans investments in covenants on private land to meet a conservation target for koala habitat protection for all years up to 2070 (Figure 1) and receives no additional benefit from exceeding it. Two of our strategies are inflexible over time, where decision-makers can only make investments in a first time-period (2020–2049): (i) “Inflexible—Ignore Risk,” in which the decision-maker assumes koala habitat conditions (to 2070) will follow average predictions under climate change (thus ignoring the risk that climate outcomes may differ from the average prediction), and (ii) “Inflexible—Robust,” in which the decision-maker again accounts for the effect of climate change (to 2070), but the target is met in all projected climate scenarios. Two of our strategies are fully flexible over time, where the decision-maker in the first time-period is also presented with an option to delay funding to the start of a second time-period (2050–2070). We assume that although the decision-maker can only act while knowing several possible outcomes in the first time-period, in the future, the decision-maker can act based on observations of these outcomes. The two flexible strategies we considered are as follows: (i) “Flexible,” where the decision-maker in the second time-period still faces uncertainty over the true climate scenarios between 2050 and 2070, and (ii) “Flexible & Learning,” where the decision-maker in the second time-period has resolved climate uncertainty and knows the true climate scenario between 2050 and 2070. This comparison provides important insights on how flexible strategies can help conservation agencies achieve targets more cost-effectively.

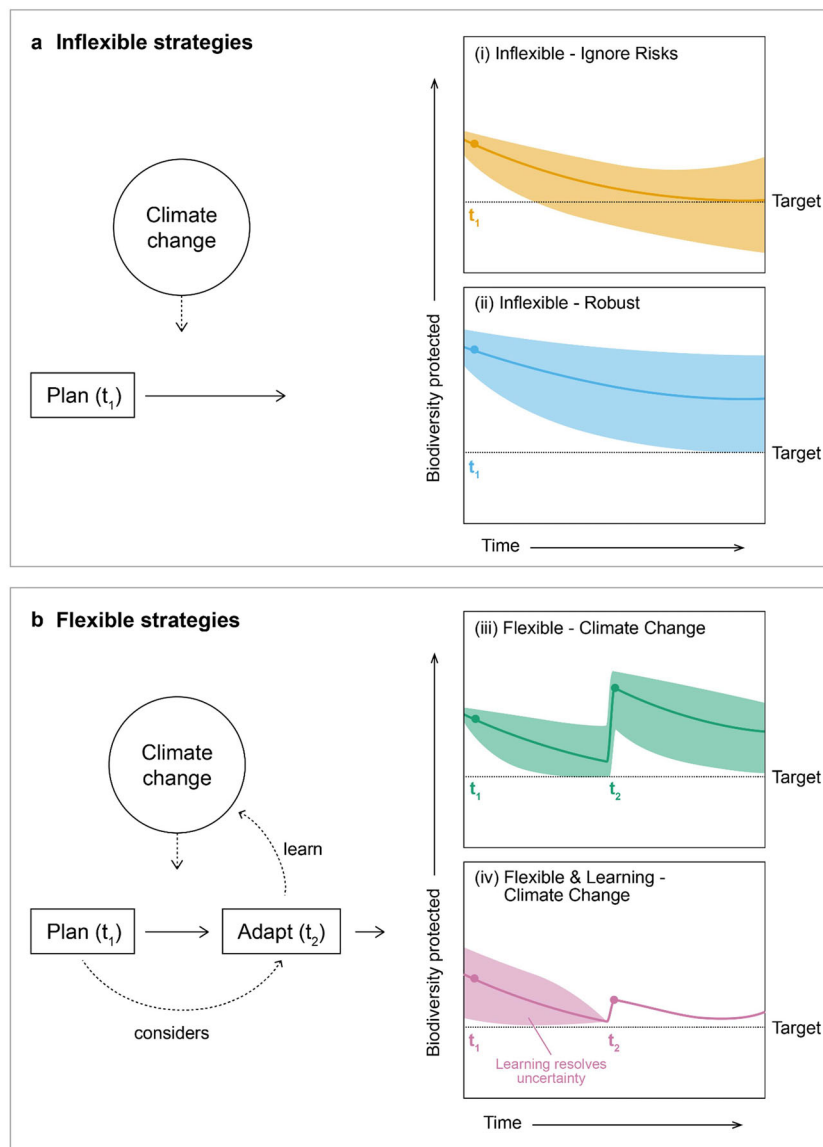


FIGURE 1 | Conceptual diagram of the planning strategies. **(a)** Inflexible strategies, (i) “Inflexible—Ignore Risks,” where the plan for protected areas remains fixed and meets conservation objectives under the expected outcomes across climate scenarios, hence failing to meet objectives under some projected scenarios. (ii), “Inflexible—Robust,” where the plan for protected areas remains fixed as well, but meets conservation objectives across all projected climate scenarios because more areas are protected at the start, thus incurring higher costs. **(b)** Flexible strategies, including: (iii) “Flexible,” where an initial plan is formed and new protected areas added in to adapt to evolving climate change and land clearing outcomes. (iv), “Flexible & Learning,” where an initial plan is formed but new information that resolves climate uncertainty is made available by the start of the second time-period through “learning,” making it possible to adapt conservation plans specifically to precise predictions.

3 | Results

We find that conservation strategies that are not fully flexible in the face of climate change face a substantial risk of failing to meet their objectives. We find that although the “Inflexible—Ignore Risk” strategy meets the conservation target in 2070 if conservation outcomes are assumed to follow the average prediction under climate change (meeting 107% of the target based on the median), it is projected to fail to reach the conservation target in 23% of the climate scenarios (Figure 2b). The consequences of ignoring variabilities across climate scenarios are severe; in 2050, the “Inflexible—Ignore Risk” strategy has the risk (at the 5th percentile of outcomes) of a massive shortfall in conservation outcomes at 72% less than the conservation target

in 2050 (Figure 2a). This could undermine the effectiveness of the new protected areas if proven true. It is feasible to mitigate these risks by scaling up spending in the first time-period, as illustrated by the “Inflexible—Robust” strategy. The “Inflexible—Robust” strategy has the highest median conservation benefits in the first time-period and mitigates risks from undershooting the biodiversity target. However, comparing the “Inflexible—Ignore Risk” strategy to the “Inflexible—Robust” strategy shows that the latter increases conservation costs by 84%, with median costs increasing from AUD \$107 million to AUD \$198 million (Figure 2c).

On the other hand, flexible strategies can mitigate risks from climate change while keeping costs low. Focusing first on comparing

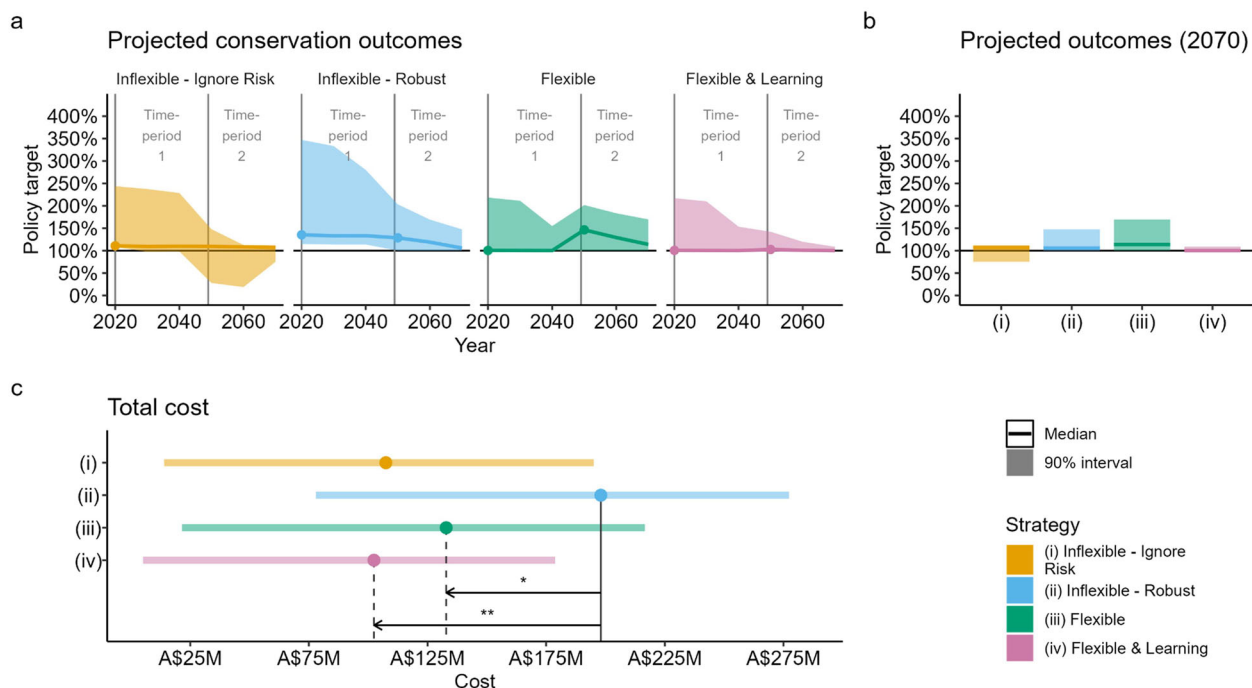


FIGURE 2 | Flexible conservation planning that exploits learning opportunities meets the same conservation objective across climate scenarios at a substantially lower half of the cost. (a) Projected conservation outcomes (solid line and 90% intervals in shaded areas) in terms of percent of the policy target reached by the conservation strategies: “Inflexible—Ignore Risk,” “Inflexible—Robust,” “Flexible” and “Flexible & Learning” planning strategies. (b) median and 90% intervals of conservation outcomes (relative to the policy target) in 2070, and (c) conservation cost of the four strategies with arrows depicting (*) the value of full flexibility, and (**) the value of full flexibility and learning, in net present value (2020 Australian dollar) terms.

the “Inflexible—Robust” with the “Flexible” strategies, we show that the flexible strategy to delay some conservation investments to 2050 is still able to meet the conservation target across all climate scenarios (Figure 2b) while reducing the median costs of meeting conservation targets across all climate scenarios by 32% (Figure 2c, iii), by delaying the spending of operating expenses to the second time-period (Figure 3). These cost reductions are amplified if opportunities to learn and resolve uncertainties at the later date are available to future decision-makers. Contrasting the “Flexible & Learning” strategy with the “Inflexible—Robust” strategy shows that flexibility to climate change and learning of its impacts jointly contribute to a median 44% (90% range: 31%–93%) reduction in total conservation costs (Figure 2c, iv). These results suggest that flexible approaches to conservation planning can mitigate risks inherent in inflexible strategies without increasing conservation costs.

Our sensitivity analyses also show that these flexible strategies consistently deliver robust cost savings relative to inflexible ones repeated across plausible parameter choices, policy targets, and conservation settings (Table S1).

The spatial prioritizations of the strategies depicted in Figure 4a suggest that the benefits of flexible planning can only be effectively harnessed if present-day conservation decisions factor in future adaptation opportunities. Under flexible strategies, conservation decisions made in the first time-step are radically different from priorities of other strategies. Only 45% of the area protected in the first time-step under the “Flexible” strategy overlaps with the “Inflexible—Robust” strategy (Figure 4c). The differences amongst flexible and inflexible strategies are further

amplified when learning opportunities are allowed, where only 34% of the area protected in the first time-step under the “Flexible & Learning” strategy overlaps with that in the “Inflexible—Robust” strategy. Observe that flexible strategies tend not to heavily prioritize properties in the southern parts of the study area for investment in the first time-period. In a minor subset of climate scenarios, these properties could provide high-quality koala habitat. If uncertainty over climate scenarios is resolved in the second time-period through learning, investments into the southern parts of the study area do not have to be made unless the climate turns out to be favorable to koalas in the south. This has not been the case over recent decades (Lunney et al. 2014).

Human-driven habitat loss could, however, potentially undermine strategies that wait before committing investments, because sites potentially suitable for cost-effective conservation could be cleared in the intervening period. Our results show that delaying the creation of new protected areas to a second time-period through flexible strategies is still optimal even when the risk of land clearing is much higher than long-term averages, suggesting uncleared sites will still offer significant conservation opportunities (Figure 5). Assuming historical trends (6% vegetation will be lost to clearing in a 30-year period), this approach of delaying funding is able to achieve reductions in cost, relative to the “Inflexible—Robust” strategy, of 30% (“Flexible”) and 42% (“Flexible & Learning”).

In Figure 6, we show that the amount of budget the decision-maker can save depends on how flexibly they can shift funding into the future. Although achieving the full cost reduction possible through flexible strategies will require decision-makers

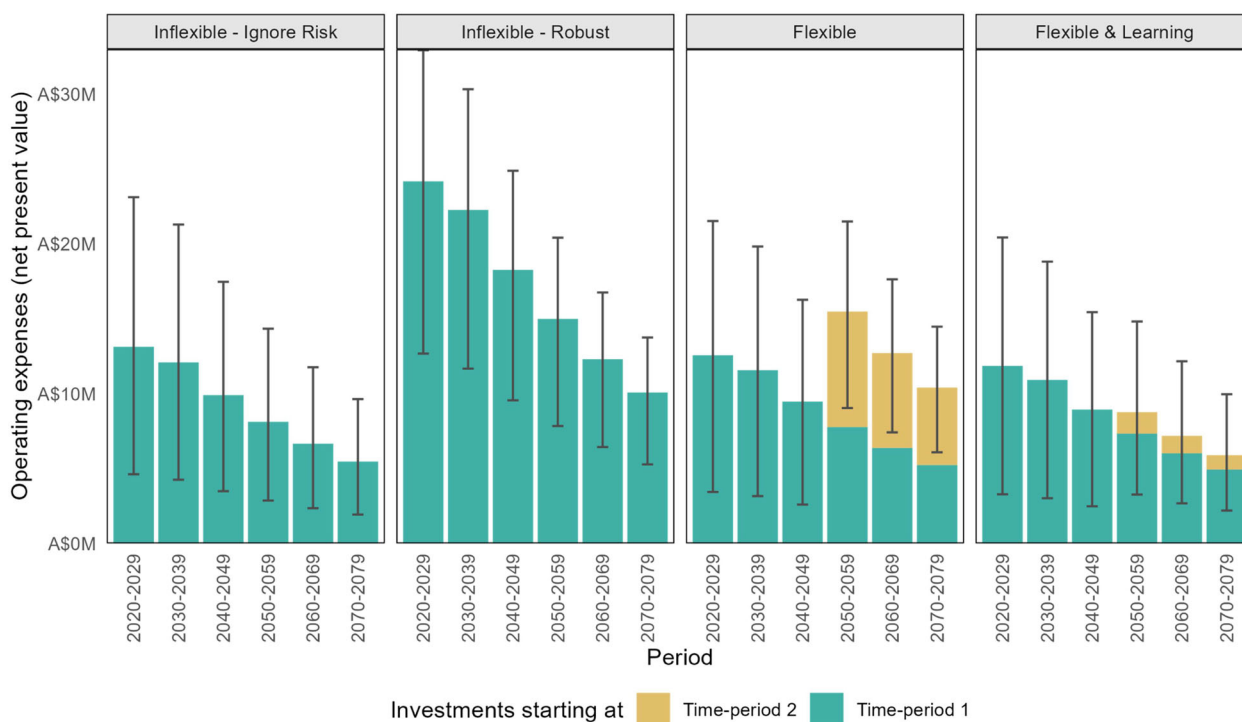


FIGURE 3 | Operating expenses of conservation planning strategies in net present value terms, for the strategies “Inflexible—Ignore Risk,” “Inflexible—Robust,” “Flexible” and “Flexible & Learning,” with a break-down by operating expenses from investments made in time-periods 1 and 2. Values are presented in net present value terms (2020 Australian dollars) with a 2% discount rate. Error bars show 90% confidence intervals of total expenses in those 10-year periods.

to guarantee a budget of AUD \$85 million (in 2050 terms), which is available in the second time-period, a decision-maker can still achieve a 10% and 22% cost reduction by adopting “Flexible” and “Flexible & Learning” strategies, respectively (compared to the “Inflexible-Robust” strategy), by making AUD \$20 million (in 2050 terms) available in the second time-period. Decision-makers can therefore substantially improve their strategies even without being fully flexible. In this instance, we find that a third of the cost reductions achieved by the fully flexible strategies can be achieved by setting aside just a quarter of the budget that is needed for fully flexible strategies in the second time-period.

3.1 | Discussion

Climate change is threatening efforts to reverse global biodiversity loss, making the question of how to make conservation efforts adaptive to climate change key to conservation decision-making. Our work shows that conservation that is strategic about flexible adaptation can mitigate climate change risks without sacrificing cost-effectiveness. However, conservation investments are likely to be most successful when agencies account for potential decisions made in the future when making decisions today and strategically embed flexibility at the beginning of the planning process. This allows for future flexibility at different points in time and reduces the risks of conservation investments across space (Rhodes et al. 2022). Previously, it was shown that strategic delays in conservation investments when they allow conservation agencies to generate more capital through financial interest and alternative investments (Iacona et al. 2017). Our research adds to the literature by showing that delays can also be

beneficial as it keeps options open to facilitate climate adaptation (Golub et al. 2021).

Although it is well-established that planning that overlooks the risk to conservation success due to climate change is a high-risk strategy (Runting et al. 2018), a wide range of planning approaches can be used to tackle climate risks. Modern Portfolio Theory and robust optimization approaches commonly used to tackle conservation planning problems under climate risks find explicit trade-offs between maximizing expected returns and minimizing risks (Ando and Mallory 2012; Ando et al. 2018; Beyer et al. 2018; Runting et al. 2018). This trade-off exists because conservation agencies have to invest in several conservation activities to spread risk and in anticipation that some will fail under climate change. But by delaying some conservation investments, conservation agencies can use new information accumulated over time to target conservation resources more precisely.

We show specifically that trade-offs can be mitigated when present-day decision-making actively accounts for future adaptation options, informed by the principles of real options (Hildebrandt and Knoke 2011; Chadès et al. 2015; Regan et al. 2015; Shah and Ando 2016; Golub et al. 2021). A real options approach quantifies the value of the option, but not an obligation, to undertake further conservation investments in the future when uncertainties may be resolved (Dixit and Pindyck 1998). The stochastic dynamic programming approach we adopted, analogous to the real options framework, also allows a decision-maker to quantify the value of flexibility as the cost difference between strategies to achieve conservation outcomes with up-front investments versus a strategy with the option to wait before investing. Although our

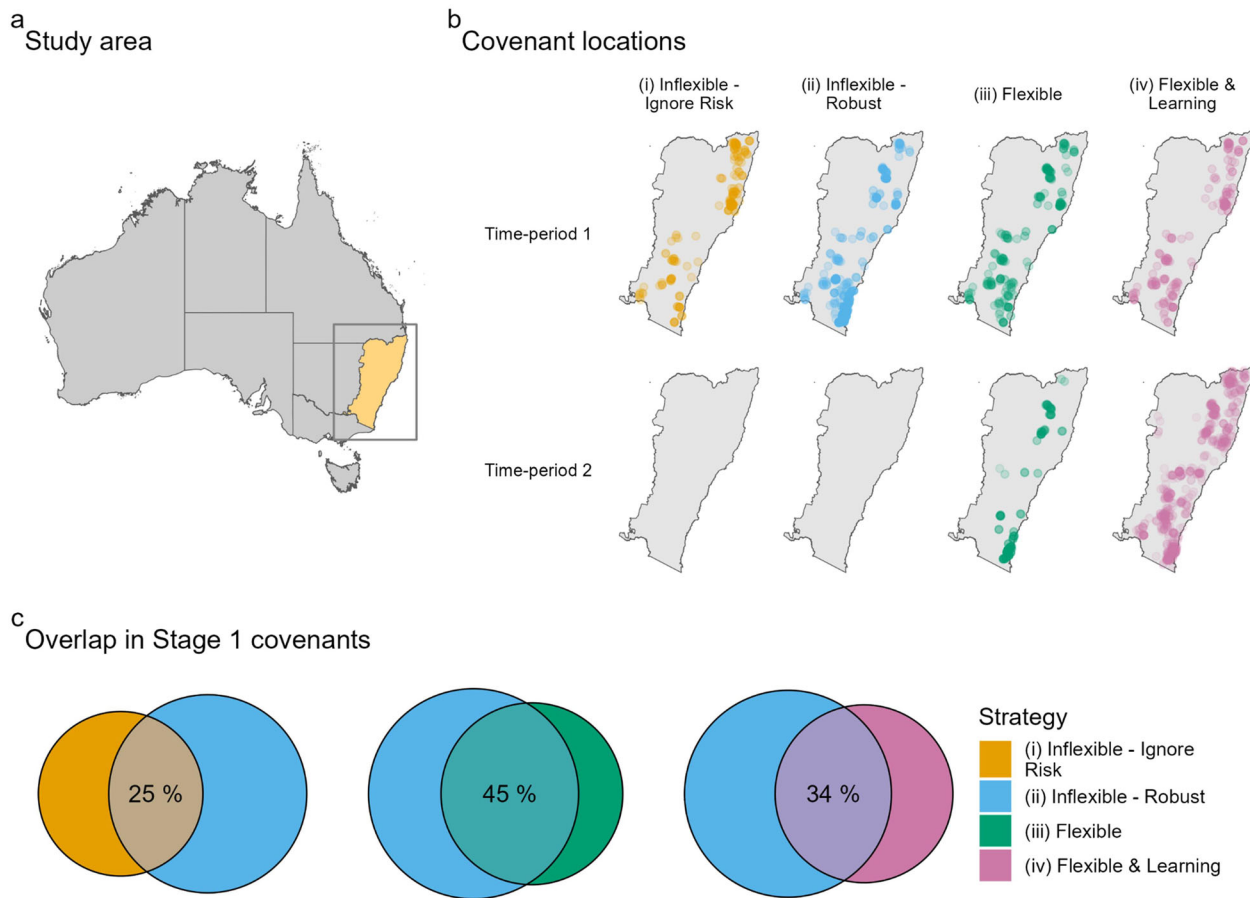


FIGURE 4 | Strategic flexibility alters present-day conservation investment decisions. (a) Map of Australia depicting the study region, (b) Maps showing properties with an accepted covenant agreement larger than 20 ha in 2020 (first time-period) and 2050 (second time-period) under the different planning strategies: (i) “Inflexible—Ignore Risk,” (ii) “Inflexible—Robust,” (iii) “Flexible,” and (iv) “Flexible and Learning,” shaded by the probability it was awarded the covenant agreement, and (c) size of the protected area under covenants in the first time-period overlapping.

approach only allows the decision-makers to adapt actions in one discrete point in time, improvements that enable decision-makers to adapt across several points in time and several options for adaptation will be important next steps to uncovering the full value of preserving options in conservation.

Our work further finds explicit differences in strategies that rely on future learning opportunities to resolve climate uncertainty from those that do not, both in terms of cost-effectiveness and its spatial prioritizations in the first time-period. Although learning to resolve climate uncertainty leads to cost reductions compared to strategies without learning, these cost reductions may need to rely on investments in learning that improves climate predictions. We do not explicitly consider these costs and who bears these costs in our analysis. In some cases, if learning costs are high enough, a flexible strategy could be less cost-effective than a fixed strategy (Drechsler et al. 2006). Our analytical results depend on the time it takes for updated climate information to be integrated into conservation decision-making and are subject to the assumption that learning completely resolves uncertainty over future climate scenarios. A priority for future research therefore lies in understanding the process and quantifying the time it takes for new information to be integrated into conservation actions and how new scientific information can be integrated to decision-making when it only partially resolves uncertainties.

Our analysis also only considered flexible adaptation through strategically-delayed creation of new covenants and did not consider many other actions that can further reduce species’ vulnerability to climate change, such as the active improvement to the climate resilience of habitats already in the protected area network (Simonson et al. 2021). Specifically, for koala conservation, actions like planting trees that preserve the richness of tree species that koalas feed on can improve the koalas’ climate resilience (Cristescu et al. 2013; Rhind et al. 2014; Reckless et al. 2018). Future work that accounts for the complex landscape-scale spatial interactions of koala populations and how it responds to conservation activities can further improve the prioritization of habitats for conservation.

Conservation investments like these can also create co-benefits in the form of climate change mitigation (Lamba et al. 2023), flood risk control (Johnston et al. 2006), and recreational opportunities (Pelletier et al. 2021), and if done well, have the potential of empowering indigenous communities (Pert et al. 2020). Although we did not expressly quantify the non-biodiversity benefits and trade-offs linked to conservation activities here, we envisage that accounting for these factors could have significant implications to the cost-benefit estimates, spatial priorities, and optimal timing of these conservation investments.

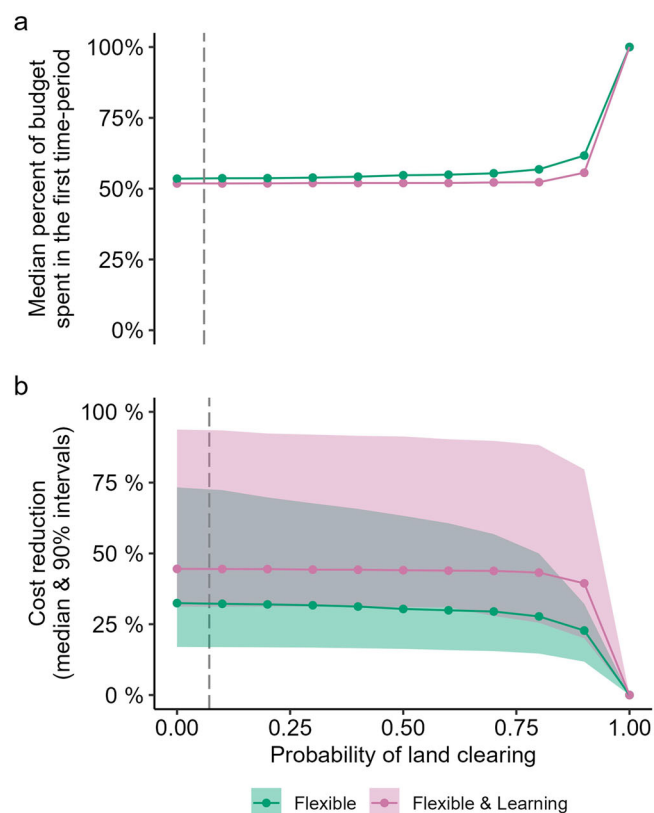


FIGURE 5 | Strategic delays still yield substantial cost reductions even under high future land clearing rates. (a) The median percent of funding allocated in the first time-period (relative to the amount of spending in the first time-period in the “Inflexible—Robust” strategy) under different land clearing risk assumptions. (b) Lines and shaded areas show median and 90% intervals of cost reductions (conservation cost of strategy relative to the “Inflexible—Robust” strategy) under alternative assumptions over future land clearing patterns of properties not protected by covenants in the first time-period, for “Flexible” and “Flexible & Learning” approaches. Dashed line shows 30-year deforestation risk extrapolated from long-term annual average rates of land clearing in the study area (Table S1).

Another way conservation planning can adapt to climate change, but not considered here, is through temporary conservation agreements, which could be used to complement static protected areas to provide dynamic protection to species tracking evolving niches under climate change (Alagador et al. 2014; D’Aloia et al. 2019; Gerling et al. 2022). This can potentially improve outcomes as it gives agencies the flexibility to modify or reverse conservation actions that become unsuitable under climate change (Rissman et al. 2015; Owley et al. 2018; Drechsler 2020; Drechsler and Wätzold 2020; Rhodes et al. 2022). However, as landholders can also voluntarily choose not to renew conservation contracts, the conservation benefits provided by temporary agreement designs could be impermanent. Landholders’ beliefs, preferences, and motivations around conservation could drive their willingness to partake in conservation agreements and the compensation they request (Yasué et al. 2019), but these factors are often poorly understood. Understanding how their motivations are shaped by climate change and other socioeconomic factors can

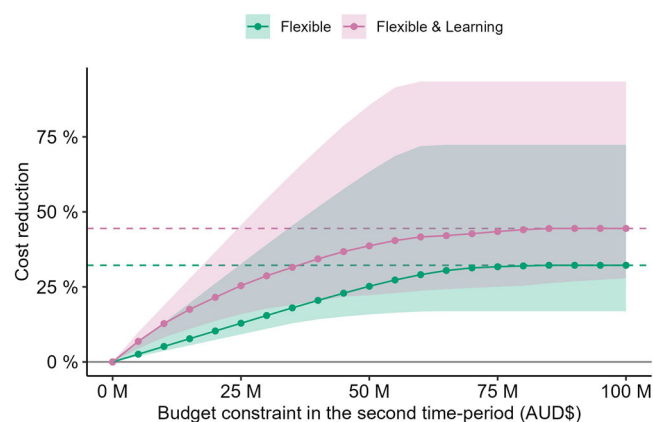


FIGURE 6 | Cost reduction of flexible conservation strategies depends on future budget availability. Percentage of cost reduction of the “Flexible” and “Flexible & Learning” strategies relative to the “Inflexible—Robust” strategy, under the situation where the total budget available in the second time-period (expressed in 2050 terms) is constrained, and dashed lines show the cost reduction achieved by the unconstrained “Flexible” and “Flexible & Learning” strategies.

help improve their participation in conservation (Fitzsimons and Mitchell 2024).

Our analysis also illustrates that flexible strategies that delay conservation investments also need to confront the reality of accelerating global deforestation that continues to contribute to irreversible habitat loss (Bradshaw 2012; Evans 2016). Strategic delays to conservation may not be appropriate in other cases, particularly in cases where the habitat that is at risk of loss is irreplaceable and faces a higher risk of deforestation than other habitats (Pressey 1999; Ferrier et al. 2000; Meir et al. 2004; Baisero et al. 2022).

The flexible strategies are possible in this context because habitats that can support koala populations in the study area are relatively replaceable. Other threatened species across the world could be supported by unique, special ecosystems that are irreplaceable, and its protection is vital to reaching conservation goals (Pressey 1999; Ferrier et al. 2000). Habitat irreplaceability analysis has been applied in several international contexts, from the protection of rangelands in Australia (Pressey and Taffs 2001) to the protection of the Giant Panda and Rhino in Africa (Zhang et al. 2018; Kerley et al. 2003). Our approach and insights can be applied more broadly to land acquisition and easement strategies, and similar tactics were already successfully applied in land-acquisition strategies by The Nature Conservancy (TNC) in the United States and the Royal Society for the Protection of Birds (RSPB) in the United Kingdom (Lennox et al. 2017). Practitioners applying the principles of flexible conservation planning must complement it with habitat irreplaceability analysis to limit the risk that irreplaceable habitats are lost to delayed conservation interventions.

Furthermore, our analysis only considers uncertainty from long-term climate change and covenant costs, and not other uncertainties from ecological tipping points and extreme weather shocks such as wildfires, drought, and flooding. The presence of unforeseen changes to ecosystems further underscores the

need to set aside conservation budgets and preserve options for changing conservation plans when it is needed (Rhodes et al. 2022).

Taken together, these findings highlight the need for conservation organizations to incorporate flexible climate adaptation into its strategy and overcome the numerous constraints that hinder its adoption. Constraints such as the provision to spend budgets within a given timeframe, inability to release funding from previously-committed investments (Lennox et al. 2017), and variability in conservation funding available across years (Wintle et al. 2019) can lead to massive inefficiencies (Meir et al. 2004; Barnett et al. 2015; Drechsler and Wätzold 2020). There are growing calls for international conservation policy to be adaptive and flexible as a vital strategy reducing climate change risks and our study re-emphasizes this need (Gross et al. 2015; IPBES and IPCC 2021). These strategies are enabled through flexible institutional arrangements, such as budget borrowing and carry-overs across years (Lennox et al. 2017). Even if organizations cannot develop a governance structure that involves saving budgets over decades as implied in this study, a first step for organizations to operationalize flexible strategies could involve setting aside resources toward a climate adaptation fund that can be mobilized to cope with unexpected threats from global change (Armsworth et al. 2015). New mechanisms in conservation financing, such as accumulating endowment funds, could provide certainty over the availability of future conservation resources (Elton and Fitzsimons 2023) and can potentially be expanded to ensure that future adaptation funding is not affected by shifting political will. As climate change continues to threaten the effectiveness of global area-based targets (Arneth et al. 2020; Jaureguiberry et al. 2022), the careful reflection and redesign of conservation governance to enable flexible and adaptive planning could be the first step toward ensuring that conservation activities effectively contribute to biodiversity under climate change.

Data Availability Statement

The full annotated source code of the optimization model and data processing is available at: <https://github.com/koala-private-land/koala-uncertainty> (based on v1.0.0). Annotated R code for landholder preference models are available here: <https://github.com/koala-private-land/spatial-bid-model> (based on v1.2). The data for the Koala REMP models used to produce koala landscape capacity indicators are available for download at the New South Wales Sharing and Enabling Environmental Data Portal (SEED) at <https://datasets.seed.nsw.gov.au/dataset/adaa5c0c-76b5-4a20-87c8-5f8a3a25bfe8>. The Survey of landholders used to construct the landholder preference models contains sensitive information and is therefore not available for use.

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Supporting Information

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