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Integrating ecological uncertainty and farm-scale economics when planning restoration

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Summary

1. Many ecological management problems involve assessing competing options based on the trade-off between economic costs and short- and long-term probabilities of success. In many cases the time to success is crucial, and opportunity costs may be greater than direct costs of implementation. We analyse the problem of how to choose between options when risks of failure vary systematically.

2. Ecological uncertainty propagates through to uncertainty about economic outcomes. We used an ecological model of tree recruitment that accounted for uncertainty surrounding the effects of climate and seed fall, coupled with a farm economics model, to examine how a land manager should act when deciding between active and passive revegetation (planting seed/seedlings or relying on natural recruitment, respectively) for restoration purposes on a farm managed for livestock production.

3. The outcome of the analysis was driven by the relative sizes of up-front costs and opportunity costs, which were a function of potential productivity and the time until successful revegetation was achieved. Active revegetation was less costly than passive revegetation in high-productivity situations, because there was less risk of long periods without production and the associated opportunity costs. At low productivity, passive revegetation was less costly than active revegetation. However, because the probability of a successful outcome increased over time, passive revegetation is only likely to be preferred over medium time-frames (> 5 years) and the strategy may not be chosen by risk-averse farmers.

4. *Synthesis and applications.* This analysis has implications for (i) decision-making by individual land managers and regional planners and (ii) the design of policies for delivery of incentive schemes targeted at revegetation. Risk-averse individual land managers are likely to select active regeneration scenarios, particularly when costs of capital works are shared with the community. For a regional planner, the analysis aids thinking about the probable balance of financial assistance schemes for attaining regional objectives: over high-productivity areas, capital works programmes and short-term opportunity cost incentives (< 5 years) are cheaper; at low productivity, incentive schemes for medium- to long-term land retirement will be cheaper. This analysis provides a starting point for devising the mix of approaches required to achieve broad-scale revegetation targets, which would include greater investment in uncertain, long-term strategies.

Key-words: agriculture, Australia, biodiversity conservation, conservation incentives, cost–benefit analysis, ecological–economic modelling, revegetation, tree recruitment.

Introduction

Identifying and solving conservation management problems is rarely the sole domain of ecology. In many cases, development of strategies and solutions requires the integration of knowledge of both ecological and economic systems (Naidoo *et al.* 2006; Watzold *et al.* 2006). Often there are distinct options for action, e.g. habitat creation vs. restocking populations, active vs. passive revegetation and restoring natural flows vs. engineering solutions. Decisions can then be made by balancing the trade-off between the cost and the risk of failure of a particular option (Newburn *et al.* 2005; Naidoo *et al.* 2006). The more expensive, high-input option does not necessarily provide a better outcome every time, but it may be

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more likely to provide some positive outcome rather than outright failure. In contrast, an inexpensive low-input option may fail in many cases, but occasional successes may be considerable. Clearly, strategies that are inexpensive yet assure success should be adopted universally, whereas strategies that are expensive and are unlikely to achieve their objective will rarely be favoured. Competing options are likely to be arrayed along this trade-off matrix, yet we often know little about the nature of this trade-off, which may vary systematically across situations (Naidoo *et al*. 2006).

In many conservation and restoration problems, the relevant costs are the direct costs of implementation, e.g. purchase of land or property rights, purchase of seed or seedlings and ongoing management costs (e.g. weed control). Yet in some cases, typically where private financial gains are foregone, opportunity costs may be at least as important (Main, Roka & Noss 1999; Pannell 2004; Naidoo & Adamowicz 2006). Examples include fishing moratoriums to enable fish stocks to recover or the case we consider here, resting land from agricultural use to allow revegetation. Risk aversion and short-term focus on the part of managers, combined with uncertainty about if and when ecological benefits may be realized, could lead to selection of suboptimal strategies with high cost but offering high probability of short-term success ahead of low-cost options that have similar probability of success, but over the long term. Our purpose in this paper is to understand the nature of the trade-off between cost and risk of failure of ecological restoration activities and how to make better ecological management decisions.

Making sensible decisions about allocation of resources between alternative restoration actions requires a systematic approach (Possingham *et al*. 2001). The probable outcomes and decisions between them are dependent upon an interaction between the ecological and economic systems, thus requiring a coupled economic and ecological model. Ecological uncertainties resulting from spatial and temporal variation in environmental factors will flow through to economic consequences.

In agricultural landscapes across the world, conservation reserves are limited. Often native species are not restricted to protected areas and their persistence in landscapes depends upon the condition and management of private land (McIntyre & Hobbs 1999; Donald & Evans 2006; Manning *et al*. 2006). In many places, farmers are undertaking restoration activities, both with and without direct financial support from government, to mitigate environmental degradation, such as biodiversity loss and altered ecosystem processes (Abenspeg-Traun *et al*. 2004). An important conflict in conservation decisions in agricultural landscapes is that agriculture is the primary and ongoing land use responsible for income generation and conservation benefits are achievable only within this production context.

A CASE STUDY OF AUSTRALIAN TEMPERATE GRAZING LANDS

In grazing lands of southern Australia, clearing of woodland and forest vegetation underlies widespread declines in biodiversity, soil stability and changes to hydrology that have led to secondary salinization (Yates & Hobbs 1997; Anderies, Ryan & Walker 2006). In most regions little intact remnant woodland or forest persists, although scattered trees, over a native- or exotic-based pasture, are widespread (Manning, Fischer & Lindenmayer 2006) but declining (Ozolins, Brack & Freudenberger 2001). Restoration of tree cover is necessary to minimize, if not reverse, these adverse changes (Vesk & MacNally 2006). Currently the Australian state and federal governments and private landholders invest tens of millions of dollars annually in revegetation and associated activities (Natural Heritage Trust 2005). Despite the scale of investment, at regional scales the ecological outcomes have been limited and poorly assessed (Freudenberger, Harvey & Drew 2004)

Importantly, all restoration occurs within economic constraints. For Australian grazing enterprises, the economic margins are very small, and in any given year up to two-thirds of farms are not profitable (Martin *et al*. 2005). While, in recent years, government assistance for environmental works has been substantial, it is almost exclusively for capital costs, i.e. fencing and tree planting and involves a cost-sharing arrangement. Within Australia assistance for forgone income due to lost opportunity of grazing has been largely ignored (although see below). Because forgone income is potentially large (Crosthwaite & Macleod 2000; Sinden 2004), allocation of land to revegetation and away from grazing has been limited.

Incentive and stewardship schemes have been developed in several countries to offset foregone income. In the United States the Conservation Reserve Program (CRP) was established in 1985 to take croplands out of production by providing payments to landholders, with a reserve price (the minimum acceptable value) based on the rental value of the land (Reichelderfer & Boggess 1988). In most cases CRP lands are also revegetated with native vegetation. In the European Union agri-environment schemes provide fixed-price payments to farmers for activities such as extensive management of grasslands. The payments are, however, not linked to probable conservation outcomes, and assessing the cost-effectiveness of these schemes is problematic (Kleijn & Sutherland 2003). In Australia there is growing use of auctions for conservation outcomes, with selection of successful bids based on estimates of the conservation value of the land, estimated improvement in habitat and the bid price (Stoneham *et al*. 2003; Hajkowicz *et al*. 2007). Conservation auctions have been used for management of existing remnant vegetation and to manage land to increase the likelihood of overstorey tree recruitment.

CONTEXT FOR THE PROBLEM

The problem we consider is of a land manager aiming to restore tree cover on a paddock (field) for the least possible total cost while achieving the greatest success. There are two broad options: active revegetation, which we split further into planting seedlings (tubestock) or direct sowing of seed (direct seeding); and passive revegetation via unassisted recruitment of seedlings resulting from seed dispersed from existing mature trees (also known as natural regeneration). Optimal decisions are likely to differ across farms due to the systematic variation in the probability of successful revegetation and costs of forgone income, which depend upon inherent productivity and stocking capacity.

Active revegetation via tubestock or direct seeding is often recommended, citing high success rates, yet these methods can be expensive and labour-intensive (Schirmer & Field 2001). Natural regeneration is promoted as a cheaper and less labour-intensive form of revegetation (Cluff & Semple 1994) and it has been suggested that it could make considerable contributions to increased landscape tree cover (Cluff & Semple 1994; Dorrough & Moxham 2005). Comparisons of the two methods have only considered direct costs: estimates of foregone income have rarely been examined (Schirmer & Field 2001). The likelihood of achieving the desired outcomes from natural regeneration has been modelled recently (Vesk & Dorrough 2006) and provides the basis for contrasting the options. Here we analyse the problem of how to act in different situations.

Revegetation targets may be set at a regional level (appropriate for biodiversity, ecosystem processes). However, the decisions are made by individual land managers at the scale of individual farms or fields. There are important questions about how best to achieve regional scale outcomes when the decisions are made at smaller scales by multiple managers operating somewhat independently, but these are beyond the scope of this paper. Nevertheless, the question of how best to revegetate on a particular farm will be a central part of any regional scale planning. Estimating costs of revegetation will enable development of effective strategies for achieving such regional-scale objectives.

Materials and methods

BACKGROUND

Our objectives were to assess the cost-effectiveness of different modes of revegetation under two plausible production scenarios. Success was estimated by the probability of sapling escape (achieving > 1 m height). Cost was estimated using net cash flow budgets. Annual benefit cost ratios were also calculated, with costs measured in units of $10 000 (AUS) and benefit as the cumulative probability of success. The analyses we present here are for a ‘representative’ wool-producing farm of 1400 hectares (ha) carrying 12090 dry sheep equivalents (dse, a standard measure of animal density where 1 dse is an individual non-lactating sheep) in the central Victorian uplands of south-eastern Australia. The size, stocking rates, management system and financial situation of the representative farm are based on data collected from 17 farms throughout central Victoria (Dorrough, Moll & Crosthwaite 2007).

Information on annual revegetation successes was obtained from a rules-based model of natural regeneration of eucalypts described in Vesk & Dorrough (2006). Although this model was designed for natural regeneration, it can be modified to provide probabilities (with associated uncertainty) of establishment success for situations equivalent to active revegetation via sowing seed and planting tree seedlings (see below).

CONTEXT AND INITIAL ASSUMPTIONS

In each scenario it was assumed that a single, fenced 50-ha field within the farm would be revegetated, thus no additional fencing costs were considered. It was assumed that the field supported scattered mature trees, optimal for the spatial success of natural regeneration. The field was either an unfertilized low-productivity pasture with an average stocking rate of 4 dse ha^{-1}, or a high-productivity sown and fertilized pasture averaging 12 dse ha^{-1}. Productivity is important, in that it not only determines the potential carrying capacity of a field but also affects eucalypt seedling growth rates and the competitive effect from pasture (Vesk & Dorrough 2006).

Revegetation targets were approximately 50–100 stems ha^{-1}, substantially lower than that planted in most revegetation situations but more equivalent to pre-European settlement woodland densities (Lunt *et al.* 2006). Costs of revegetation using direct seeding and tubestock were based on figures reported in Schirmer & Field (2001), but were updated to reflect 2005 values and also adjusted accordingly to account for the reduced target stem densities (direct seeding = $314 ha^{-1}; tube stock = $352 ha^{-1}). The up-front costs of revegetation can be separated into site preparation (estimated at approximately $204 ha^{-1} for both methods) and the materials (primarily seeds and seedlings), labour and fuel required for sowing and planting (direct seeding = $110 ha^{-1}; tube stock = $148 ha^{-1}).

Stem densities from natural regeneration can be high, and in this case we assumed that this could be managed subsequently through mechanical or chemical means but costs were not included. We did not consider incentive payments, which typically cover some of the establishment works and favour direct seeding and tubestock.

We measured opportunity costs of forgone income from managing for increased native tree cover, which is dependent upon the time taken by the trees to reach an escape height (i.e. above the reach of a browsing sheep at about 1 m). The time to reach escape height is dependent upon establishment success and subsequent growth rates which are functions of rainfall, competition and productivity. We assumed that landholders have the choice of either maintaining current stocking rates (with a $20 dse^{-1} gross margin) and effectively eliminating any potential for broad-scale tree establishment, or undertaking revegetation work. We do not consider alternative, intensive options with different opportunity costs, such as landholders investing in crops or pasture improvement. We investigated a range of time-frames (2–15 years) over which landholders were prepared to attempt revegetation. If revegetation was successful before the end of the time-frame, then the landholder received a windfall through returning stock to the field earlier than expected. If revegetation was not successful within the time-frames, stock were returned to the field regardless.

SCENARIOS AND INCORPORATING ESTABLISHMENT PROBABILITY INTO ECONOMIC MODELS

Three establishment scenarios, natural regeneration, direct seeding and tubestock planting, were considered, each in either a low-productivity or high-productivity field. For each scenario the frequency of annual sapling escapes were estimated over 15 years using the natural regeneration model (Vesk & Dorrough 2006). Briefly, the model is stage-based (seed, small and large seedlings and saplings) and has deterministic (pasture growth, pasture competitive effect) and stochastic elements (seasonal rainfall and effect of rainfall on growth and mortality of trees and pasture growth). High-productivity fields achieve pasture with higher biomass and more quickly than low-productivity fields. Seed supply is known to vary substantially between years, but the process is poorly understood (see Vesk & Dorrough 2006 for review). For this reason seed supply was varied, such that 25% of years received low seed, 50% medium seed and 25% high seed. Natural seed fall was also allowed in the active regeneration scenarios. Direct seeding was modelled using a high level of seed in year 2 and tubestock planting was modelled by beginning simulations with small seedlings in year 2: all ground preparation was carried out in year 1. Each scenario of establishment and productivity was run 3240 times to generate the distribution of escape probabilities for each of the 15 years. Specifically, we tallied the frequency with which saplings first escaped in a given year y, P_y. We also examine how sensitive results were to variation in predicted probabilities of sapling escape, varying median probabilities of escape for natural regeneration by up to 30%.

The costs of revegetation were estimated in an Excel spreadsheet using a deterministic cash flow budget for time-frames up to 15 years. The cash flow budget calculated the annual income forgone due to loss of grazing area and associated stocking rate, assumed to be \$20 dse^{-1} (gross margin). In year 1 it was assumed that livestock were removed from the field to be revegetated and sold at \$40 dse^{-1}. Our assumption here is that the farm is operating at maximum carrying capacity and that displaced stock cannot be retained elsewhere on the farm. Replacement livestock were purchased at the same cost in the year saplings reached escape height or at the end of the time-frame. It was assumed that income could be received from the returned livestock in the year following their purchase.

Future cash flow was discounted at a standard rate of 10% per annum, although outcomes were also compared using rates of 8% and 12%. Discounting provides a means of estimating future costs in terms of current dollar values, enabling comparison of alternative investment strategies in common (real) terms (Malcolm, Makeham & Wright 2005). Both future annual income and future annual costs were discounted to estimate present benefits and present costs:

$$\text{Present value} = \text{future value}/(1 + r)^y \qquad \text{eqn 1}$$

where r = discount rate, 'value' is either costs or income and y is years 1–15. Cash flow for a given year was then estimated by subtracting present costs from present benefits.

The expected net cash flow was calculated for each time-frame between years 2 and 15 as a function of the revegetation scenario and the year at which saplings escaped and livestock returned. Given a certain time-frame, there are three possible outcomes: saplings could first escape in the last year of the time-frame (timely escapes); saplings could first escape before the end of the time-frame with a corresponding early return of stock (early escapes); or saplings do not escape within the time-frame but stock are returned regardless (failures). The expected cash contributions of each of these outcomes are conditional upon their respective probabilities, and are given by: timely escapes, $C_T \times P_T$; early escapes, $\sum_{y=1}^{T-1}(C_y \times P_y)$; and failures, $C_T \times (1 - \sum_{y=1}^{T} P_y)$, where C_y is the deterministic cash flow resulting were stock removed in year 0 and returned in year y. The expected net cash flow over a particular time-frame, T, is the sum of the expected cash flows from each of the three possible outcomes, and simplifies to:

$$Exp\,(NCF_T) = C_T \times \left(1 - \sum_{y=1}^{T-1} P_y\right) + \sum_{y=1}^{T-1}(C_y \times P_y) \qquad \text{eqn 2}$$

To account for uncertainty about when saplings escaped, we calculated the expected net cash flow using the median, 5th and 95th percentiles of escape probabilities.

In summary, the sequence was year 1, ground prepared (for planting tubestock or direct seeding) and stock sold; year 2, planting or seeding (for tubestock or direct seeding); year 3, to $T - 1$, check for sapling escapes, if saplings escape, then stock are purchased and returned to the paddock in that year. In year T, check for sapling escapes, but stock will be purchased and returned to the paddock in year T regardless of the outcome.

DATA PRESENTATION

The proportion of saplings escaping for any given year was presented showing the median, 5th and 95th percentiles. Financial costs, as net cash flow, were presented for years 2–15 as determined from equation 2. To enable assessment of trade-offs between competing management scenarios, financial costs and cumulative probability of establishment success were graphed. Annual benefit–cost ratios and the associated 5th and 95th percentiles were graphed for years 2–15.

Results

SAPLING ESTABLISHMENT

Annual probabilities of sapling escape varied among establishment methods and field productivities. Probabilities of sapling escape were initially much lower for passive than for active revegetation, particularly in high-productivity fields where competition with pasture is important (Fig. 1). Importantly, however, the likelihood of escape via passive revegetation increased over time and, in low-productivity fields, after 15 years was similar to the results of active methods. In contrast, the probability of seedlings reaching escape

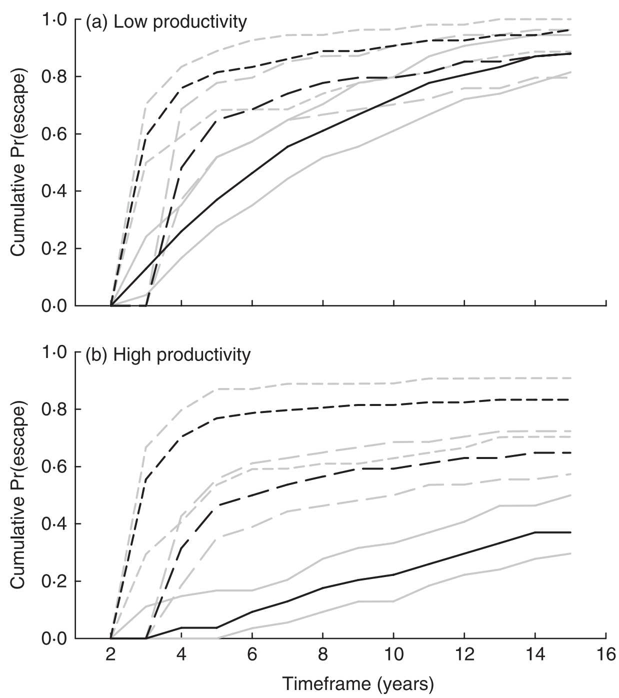

Fig. 1. Cumulative probabilities of sapling escape (when saplings reach > 1 m height) for active [tubestock (short dash), direct seeding (long dash)] and passive revegetation [natural regeneration (solid)] strategies in both a (a) low- and (b) high-productivity pasture. The median (black), 5th and 95th percentiles (grey) are shown for each strategy.

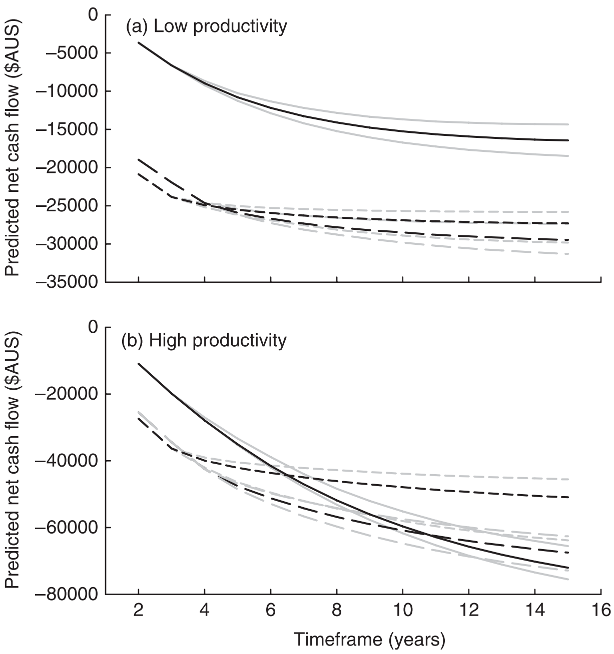

Fig. 2. The relative cost of different revegetation strategies over a 15-year time-period for (a) low-productivity and (b) high-productivity pasture. Costs in any given year take into account the probability of sapling escape in all previous years, the probability of escape or failure in that year and reveal the costs incurred, were stock to be returned in the following year. Short dash: tubestock; long dash: direct seeding; solid: natural regeneration. Median values are black and 5th and 95th percentiles are grey.

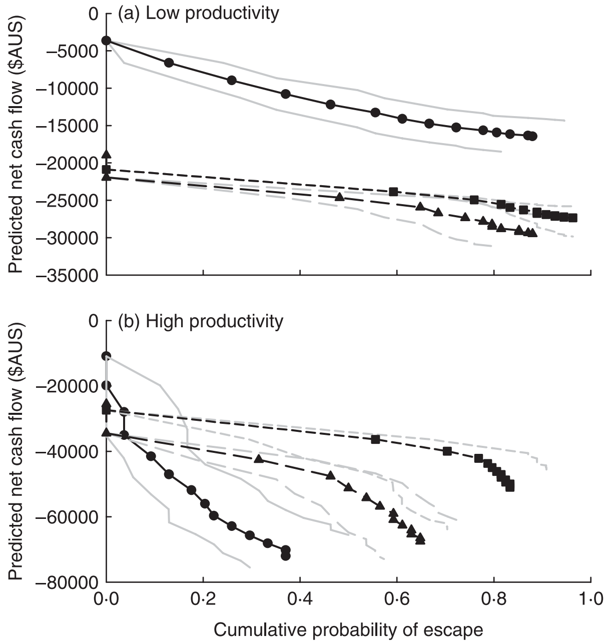

Fig. 3. Trade-offs between the predicted costs of a revegetation strategy and the cumulative probability of successful sapling escape in both (a) low- and (b) high-productivity pasture over 15 years. Symbols indicate successive years. Over time revegetation strategies tend to become more costly, but their probability of success improves. For any given year preferred strategies should have both low cost and high probability of success. Short dash: tubestock; long dash: direct seeding; solid: natural regeneration. Median values are black and 5th and 95th percentiles are grey.

height in actively revegetated fields increased rapidly and then plateaued after 3 (tubestock) or 4–5 (direct seeding) years (Fig. 1).

NET CASH FLOW

Net cash flow varies among the three management options, but the greatest response is to pasture productivity (Fig. 2). In low-productivity pastures, annual foregone income is small and up-front costs are important. Under this scenario passive revegetation is economically attractive compared to the active revegetation strategies. In a high-productivity field, up-front costs of establishment are small relative to opportunity costs, because of a low likelihood of early establishment and high annual costs of land retirement (Fig. 2). Our results suggest that, in high-productivity fields, planting tubestock (the less risky of the active revegetation strategies) will be typically the least-cost method. In contrast, passive revegetation is highly risky and, despite low direct costs, overall economic impacts are predicted to be substantially greater.

TRADE-OFF BETWEEN COST AND ESTABLISHMENT SUCCESS

The revegetation strategies differed markedly in the trajectory of cumulative probability of success against net cash flow (Figs 3 and 4). In low-productivity pastures, active revegetation strategies with high early success rates are most cost-effective over short time-periods, but natural regeneration becomes increasingly cost-effective over time (Fig. 4a).

In high-productivity pastures, where opportunity costs are greater, methods that provide high certainty of success are likely to be most cost-effective (Fig. 3b). Although the probability of successful tree establishment via natural regeneration improves gradually over a 15-year period, it never provides a cost-effective alternative to active revegetation (Fig. 4b).

Although varying the discount rate upwards or downwards by 20% (i.e. 8% to 12%) changes the absolute values for each scenario, their relative magnitude is not sensitive to choice of discount rate. The benefit–cost ratio cross-over point for natural regeneration and tubestock planting at low productivity did not shift in time by more than 1 year across the range of discount values.

The results are also relatively robust to variation in the predicted probabilities of annual sapling escape, particularly in high-productivity pasture (results not shown). In low-productivity pasture median probabilities of sapling escape via natural regeneration need to decline by 20% or more before the median benefit–cost ratio falls between the 5th and 95th percentile for active revegetation (tubestock). In high-productivity pastures median annual escape probabilities via natural regeneration need to more than double before passive regeneration would become competitive over a 15-year time-frame.

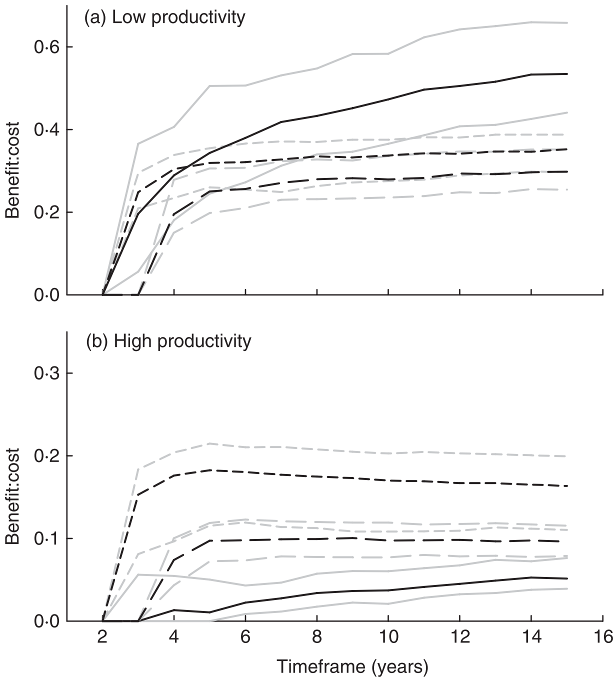

Fig. 4. The benefit–cost ratio for establishing trees in (a) low- and (b) high-productivity pasture over a 15-year period. Benefit is measured as the cumulative probability of sapling escape and cost is the lost income calculated from expected net cash flow. For the purposes of calculating the benefit–cost, income lost is measured in units of $10 000 (AUS). Short dash: tubestock; long dash: direct seeding; solid: natural regeneration. Median values are black and 5th and 95th percentiles are grey.

Discussion

Opportunity costs can be a significant barrier to conservation and restoration activities on private lands. Here we have shown how systematic variation in those costs (relative to direct costs), driven by the economic productivity of the land and ecological processes that influence eucalypt recruitment, determines the suitability of alternative activities (here passive vs. active revegetation). Uncertainty in ecological, and hence economic, outcomes makes decisions about which strategy to implement difficult, but its effects can be incorporated when solving the problem. Where temporal uncertainty of success is considerable longer time-frames need to be considered, with implications for the design of assistance schemes. In the specific case study here, productivity or stocking rate affects systematically the decision of which strategy to implement.

If sapling escape is achieved before 15 years the land manager can restock early, thus reducing the opportunity costs of forgone income. This will impel the land manager to manage for increasing the probability of sapling escape. Clever management to increase the probability of sapling escape, e.g. preparing a seedbed or controlling competitive effects through biomass removal by grazing or fire, will reduce the risks of passive revegetation failing but will also increase the direct costs substantially, making it more equivalent to direct seeding. However, we must not ignore that the weather plays an overwhelming role and management unsupported by suitable rainfall will be wasted (Vesk & Dorrough 2006). An increased understanding of the relative likelihoods of different revegetation strategies will be important in guiding the decision-making process, particularly in low productivity situations.

The analysis presented here considers the problem of an individual land manager choosing the least-cost revegetation strategy on a given field. This question is central to problems faced by regional planners thinking about the probable balance of financial assistance schemes for attaining regional objectives: over high-productivity areas capital works programmes, in conjunction with incentives for foregone income, are cheaper, whereas in low-productivity areas incentive schemes for land retirement will be cheaper. To achieve regional revegetation goals a regional planner may need to invest in a mix of both short-term low-risk, high-cost activities in productive landscapes and extensive, low-cost, long-term strategies in less productive areas.

The case study we describe here also has lessons for the design and delivery of conservation incentive schemes. Certainly a range of approaches will be required to facilitate revegetation across heterogeneous landscapes. The interactive ecological–economic effect of pasture productivity supports the linking of incentive schemes to potential agricultural value of land, although this may need to be balanced with the potential for increased costs and complexity of such an approach. The results also suggest the need for varying management time-frames. At present the majority of government incentives in Australia are in the form of short-term fixed-price schemes, irrespective of the productive capacity of the land, with a cost-sharing arrangement between government and the individual landholder (Pannell 2004). In addition, incentive schemes pay farmers typically for management actions, not outcomes, with the funding agency bearing most risk. This is of lesser concern for active revegetation strategies where success can be achieved rapidly. For passive revegetation, because of the potential for long time-periods without success, contracts may run a greater risk of being broken and additional payments for outcomes may be required.

Even when conservation management activities have the potential to result in long-term economic benefits to the private land manager, a combination of direct costs, negative impacts on net cash flow and uncertain success can be substantial barriers to investment on farms (Goldstein *et al.* 2006). Although we recognize that tree establishment can have local and wider economic and ecosystem service benefits, for example through provision of shelter for stock, increases in the capital value of the asset and lowering of local water tables (Bird *et al.* 1992), we excluded these explicitly from our analyses. For an individual manager, these long-term economic benefits are likely to be small and provide limited additional incentive. Even if a landholder decides to re-vegetate they must then decide which method to apply. Greater understanding of the ecological and economic implications of active and passive revegetation strategies will be important in informing this decision, but other factors could be overwhelming (i.e. past experience, local norms, desired outcomes).

Although the direct and long-term opportunity costs will be a major barrier to investment by individual farmers, the costs we present here could be greater than the incentives required to trigger revegetation on farms (Pannell *et al*. 2006). In Australia much of the cost of revegetation undertaken through government incentive schemes has been shared by private landholders (Pannell 2004; Pannell *et al*. 2006). Recent market-based auction schemes have revealed that while some landholders will bid for the full opportunity costs of conservation activities, many are willing to share costs (Stoneham *et al*. 2003). Other social factors, such as underlying trends in land use, may also contribute to an overestimate. Observations from Europe and North America suggest that passive revegetation is most likely where social, political and economic forces lead to land abandonment (Debussche, Lepart & Dervieux 1999; Eberhardt *et al*. 2003). Low-productivity landscapes, most suited to passive revegetation, are common throughout south-eastern Australia. Land retirement is likely to be a continuing process in these landscapes and opportunity costs to accelerate such change could be less than we estimate here.

Natural regeneration requires that live mature trees are retained in agricultural landscapes. In southern Australia, where broad-scale vegetation clearing has ceased, the loss of scattered mature trees is still occurring (Ozolins, Brack & Freudenberger 2001; Saunders *et al*. 2003). While some loss is a function of natural mortality rates currently exceeding recruitment, scattered tree loss has been accelerated due to poor health resulting from pathogens, herbivory and changes in abiotic factors (e.g. salinity) (Landsberg, Morse & Khanna 1990; Reid & Landsberg 2000) and direct removal for agriculture and timber (Maron & Fitzsimons 2007). Although scattered trees in high-productivity landscapes provide considerable ecological functions (Manning, Fischer & Lindenmayer 2006), the results we present here suggest that their persistence in this agricultural context will depend most probably on direct revegetation rather than facilitating natural recruitment processes. Even then the high costs of implementing active revegetation at the scales required to maintain a scattered tree landscape may be restrictive. Current patterns of active revegetation in productive landscapes resemble narrow linear woodlots rather than scattered tree woodlands, arguably to minimize, in part, opportunity costs. In contrast, the loss of mature trees in low productivity pastures will have a substantial economic cost if future options for restoration are restricted to direct seeding or planting of seedlings. The likelihood of retaining a woodland vegetation structure in low productivity landscapes seems greater.

Conclusions

Retaining and increasing woodland tree cover in agricultural landscapes of southern Australia will require a mix of investment and planning strategies. The ecological processes that underlie recruitment probabilities and the productive capacity of the pastures vary systematically, and so strategies to encourage conservation management practices will need to consider such variation explicitly. The approaches we applied here to uncover the probable costs of conservation management could have broad application to restoration problems elsewhere. We suggest that more attention be paid to uncovering the opportunity costs of conservation activities. This necessitates evaluation of the time–course of recovery of desired ecological processes or structures and their uncertainty. Without such work we believe that decisions will continue to be made on short-term priorities, often to poor cost-efficiencies.

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