Forest biodiversity zones: replaceing or complementing field biodiversity strips and environmental fallows?

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Abstract

When designing agri-environmental policies, proper understanding on the time span, the multiple impacts and the costs of policy measures is vital. This paper attempts to rank agri-environmental measures based on their long-term contribution on biodiversity conservation and ecosystem services as well as on net income received from agriculture and forestry. Three indicators were applied to measure the magnitudes of the following environmental benefits: (1) availability of pollination services described in terms of bumblebee abundance, (2) overall species diversity reflected by the number of flower-visiting insect species and (3) state of species of conservation concern represented by the abundance of habitat-specialist butterflies. The measures compared include a selection of environmental fallows, biodiversity strips on fields and, as a novel measure, a biodiversity zone in a forest on a field-forest border. Our results from boreal agricultural landscapes suggested that the compared measures serve different purposes and thus complement rather than substitute each other. Environmental fallows proved to be a cost-effective measure in promoting bumblebee abundance and, hence, in increasing the availability of pollination services. The composition of seed mixture in field biodiversity strips and environmental fallows was found critical in when enhancing overall species diversity and, despite its poorer effectiveness compared with wildflower seed mixture, the mixture of red clover, timothy and meadow fescue had the highest effectiveness relative to its cost. Forest biodiversity zones offered the cost-effective way to achieve the conservation goals of habitat-specialist butterflies. All compared measures are worth considering when designing future agri-environmental policies, but their optimal combination will depend on the weights the society imposes on enhancing different aspects of biodiversity.

JEL classification: Q57, Q15, Q23

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1. Introduction

Farmland diversity in Europe has drastically declined in the past few decades due to agricultural intensification, concentration and specialisation (Stoate et al., 2009; Kleijn et al., 2011) which have led to the loss and fragmentation of semi-natural grasslands (Öckinger and Smith, 2007; Hooftman and Bullock, 2012) and other non-crop habitats, such as field boundaries and woodland patches (Hietala-Koivu et al., 2004; Carvell et al., 2006). Habitat-specialist species, which depend on specific habitat types, have suffered the most (Ekroos et al., 2010; Öckinger et al., 2010). At the same time, along with the Millennium Ecosystem Assessment (2005), the availability of ecosystem services provided by nature, such as insect pollination of crops, has become a topical issue (Kremen et al., 2002; Garibaldi et al., 2011; Kennedy et al., 2013). As ecosystem services are fundamental to human well-being and their economic value is considerable, there have been concerns on how to maintain them at a sustainable level in degraded agroecoystems (Kremen and Ostfeld, 2005).

Since no markets exist for most ecosystem services, a spectrum of Payments for Ecosystem Services (PES) approaches are being implemented in many countries to mitigate the negative externalities of modern farming practices, including the unfavoured changes in the abundance and diversity of flora and fauna and the associated ecosystem services (Sattler and Matzdorf, 2013). The PES schemes aim to create a market or a contract-like arrangement between people who function as ecosystem service providers, such as farmers and forest owners, and people who are the direct or indirect beneficiaries of these ecosystem services (Sattler and Matzdorf, 2013). In the European Union (EU), voluntary Agri-Environmental Schemes (AES) are the primary instrument to enhance farmland biodiversity via which farmers receive payments for more environmentally-friendly land management practices. The schemes and their poor past performance (Kleijn et al., 2011) have motivated researchers to rank existing measures both in terms of biodiversity gain and socio-economic consequences and to explore new, potentially cost-effective measures.

Recent literature introduces several modelling frameworks developed to analyse the economic and ecological consequences of some specific management alternatives on various scales extending from individual fields to regional or nation-wide analysis. Ekroos et al. (2014) presented a conceptual framework for developing spatially optimal AES for maximising conservation benefits, while maintaining a high level of agricultural production, and demonstrated the trade-offs between agricultural production and conservation benefits through efficiency frontiers. Merckx et al. (2009) investigated the impacts of hedgerow tree and grassy field margin measures on farmer income and the abundance and diversity of larger moths in lowland agricultural landscapes of southern England and demonstrated that efficiency gains can be achieved through careful pricing of different landscape features and by targeting farmers. The need to differentiate prices for conservation improvements in space was also emphasised by Armsworth et al. (2012) who employed an integrated property-level model to assess farmer's marginal private cost of enhancing the density and richness of selected bird species in northern England. Osgathorpe et al. (2011) used an ecological-economic model to assess the impacts and costs of two alternative management options for conserving bumblebees on croft land use in the Outer Hebrides in Scotland and demonstrated that improvements in bumblebee conservation are not necessarily in conflict with maintaining farm income. Polasky et al. (2005) introduced a regional model to investigate trade-offs associated with land-use decisions across agricultural land, forests and protected areas in Oregon USA and demonstrated that a large fraction of conservation objectives may be reached at a rather low cost through thoughtful land-use planning. Mouysset et al. (2011) had an even wider national scope and investigated the community dynamics of 34 bird species together with rational farming decisions in France and demonstrated that simple economic instruments may promote both economic performance and bird population.

Despite the blooming recent literature investigating the costs and impacts of agri-environmental measures, our overall knowledge is scattered geographically, with respect to available measures and biodiversity or ecosystem service indicators. Ex-post analyses suggest that often these measures have proved ineffective considering the amount of funds spent (Kleijn et al., 2006; Pywell et al., 2006). This is also the case in Finland (Herzon et al., 2010; Aakkula et al., 2012). Hence, the aim of this paper is to respond to the demand for cost-effective measures to promote biodiversity conservation and the provision of ecosystem services at the lowest cost. A particular aim of this paper, with potential wider international interest, is to introduce a new candidate measure implemented on a forest border in comparison to measures performed on arable fields.

In our study, we ranked three policy measures applied in boreal agricultural landscapes in southern Finland according to their cost-effectiveness in promoting three aspects of flower-visiting insect diversity: pollination service availability, species diversity and species of conservation concern. The examined measures were: A) a 25-m wide, partly open biodiversity zone in a forest on a field-forest border, B) a 5-m wide, open biodiversity strip on a field on a field-forest border and C) an environmental fallow. Uncropped biodiversity zones and strips as well as fallowing are applied in agri-environment schemes in many EU countries and have been shown to promote flower-visiting insects (Alanen et al., 2011; Haaland et al., 2011; Korpela et al., 2013). In addition to these measures applied on agricultural land, biodiversity zones located in the field-forest ecotone have also been shown to benefit insect diversity and pollination services (Korpela et al., 2014). For this reason, one of the objectives of this study was to find out whether it would be economically feasible to promote flower-visiting insect diversity and the associated ecosystem services by establishing forest biodiversity zones on margins of managed forests abutting to fields.

2. Material and methods

2.1. Applied policy measures

We considered three different agri-environmental measures targeted at promoting abundance and diversity of flower-visiting insects and the associated ecosystem services: A) a 25-m wide, partly open biodiversity zone in a forest on a field-forest border, B) a 5-m wide, open biodiversity strip on a field on a field-forest border and C) an environmental fallow. The first measure, the 25-m wide forest biodiversity zone (measure A, Fig. 1a), consisted of two sections: a 5-m wide, open, meadow-like treeless strip at a field-forest ecotone (measure Aa) and a 20-m wide, semi-open transitional zone deeper in the forest (measure Ab). The 5-m wide strip was completely deforested and kept treeless with clearings repeated every 6–7 years. The 20-m wide transitional zone was thinned to the basal area of 8 m^2 ha^{-1} and managed by repeated light selection cuttings every 20 years to create a mixed-species uneven-aged stand structure which was expected to preserve biodiversity in managed forests (Fuller et al., 2004; Pengelly and Cartar, 2010). Control areas of measure A (Fig. 1d) were managed according to the recommended good practices in forestry (even-aged management) (Forestry Development Centre Tapio, 2006).

In the second measure, the 5-m wide sown biodiversity strip on an agricultural field on a forest border (measure B, Fig. 1b) can be established by either one of two wildflower seed mixtures (measures B1 and B2) or by a conventional mixture of red clover, timothy and meadow fescue (measure B3). The composition of the seed mixtures and the thickness of seedlings are described in Table 1. Wildflower seed mixture 1 is equivalent to the one used in the wildflower strip experiment (Korpela et al., 2013; cf. Table 2), whereas wildflower seed mixture 2 (with the removal of plant species having received no bumblebee visits in the field experiment) and the conventional grass seed and red clover mixture are similar to the mixtures used in the environmental fallow experiment (Alanen et al., 2011).

The third compared measure, the environmental fallow (Fig. 1c), refers to biodiversity fields sown with one of two wildflower seed mixtures (measures C1 and C2) or perennial grass fields sown with the conventional grass and red clover seed mixture (measure C3). The use of pesticides and fertilisers is prohibited on biodiversity strips and environmental fallows. In order to impoverish nutrients in the soil and to prevent reforestation, vegetation in the field biodiversity strips and environmental fallows is mown and harvested once a year. Areas sown with wildflower seed mixtures are renewed with the interval of five years. Control treatments of measures B and C (Fig.

1d) were the corresponding field areas in conventional feed-barley production managed according to the rules with which the farmer has to comply (environmental cross-compliance).

2.2. Effectiveness of policy measures

The ecological effectiveness of each measure (A–C) was assessed as an increase in three aspects of flower-visiting insect diversity in comparison with the corresponding control treatment, i.e. the prevailing land-use (see ecological contrast, Kleijn et al., 2011). These aspects were 1) the availability of pollination services, 2) species diversity and 3) species of conservation concern which were measured, respectively, by an increase in 1) bumblebee abundance, 2) total species richness of bumblebees, butterflies and diurnal moths and 3) abundance of habitat-specialist butterflies. Pollination is an ecosystem service with considerable economic value (Gallai et al., 2009) and bumblebees are the most important wild pollinators in northern Europe (Goulson, 2003). Hence, the increase in abundance of bumblebees serves as proxy for the increase in the amount of pollination services. The increase in total species richness of bumblebees, butterflies and diurnal moths measures the increase in the flower-visiting insect diversity of a strip, zone or environmental fallow. Habitat-specialist butterflies have suffered from land-use intensification more than generalist butterflies (Ekroos et al., 2010) and, therefore, they can be considered as species of conservation concern. Hence, the increase in abundance of habitat-specialist butterflies approximates an increase in the conservation value of the studied measures.

The applied measures and their data sources are listed in Table 2. Insect data used in evaluating the effectiveness of the measures were collected in three different field experiments during the years 2003–2011. The line-transect method used for data collection is described in detail in Alanen et al. (2011). Data for forest measures Aa and Ab were collected in a forest border experiment conducted in Vihti and Jokioinen in southern Finland during 2009–2011 (Korpela et al., 2014). The control treatments for the forest measures were located next to the same forest stands as the logged areas and were managed according to the recommended good practices in forestry

(Forestry Development Centre Tapio, 2006). Data on measures B1 and C1 were collected in a wildflower strip experiment in Jokioinen in 2007–2010 (Korpela et al., 2013). Data on measure C1 were obtained from transects located in the middle of the field. Data on measures C2 and C3 were collected in a long-term environmental fallow experiment in Ypäjä in southern Finland in 2003–2008 (Alanen et al., 2011). Since there were no direct field data collected for measures B2 and B3 in the 5-m biodiversity strip, their values were estimated based on comparable datasets of B1, C1, C2 and C3. The control treatments of measures B and C were corresponding areas of a feed-barley field in conventional production the data of which were collected in the forest border and in the wildflower strip experiments.

The number of counts and the lengths of the transect lines differed between the experiments. In the long-term environmental fallow experiment, there were four counts during the summer and the length of the transect line was 250 m, while in the other two experiments the number of insects and species were counted seven times during the summer and the length of the transect line was 50 m. Therefore, transformations to the field data collected in the environmental fallow experiment were needed to produce datasets comparable with each other.

To measure of the effectiveness of policy measures, time series were created. The annual observations for the first few years on bumblebee and habitat species butterfly abundances and numbers of flower-visiting insect species on treatments and controls were received from field experiments. Based on the recorded field data and expert opinions, developments in abundances and species richness were first postulated over a period of 20 years, after which, the projections were expanded to infinity. The annual effects of each measure were calculated by subtracting the abundance (or the number of species) in the control area from the abundance (or the number of species) in the treated area. The stream of conservation benefits, described in terms of increased species richness or species abundance, as well as the costs of policy measures were discounted using a conventional 3% real rate of discount as default.

2.3. Costs of policy measures

Fallowing as well as establishing and managing biodiversity zones and strips entail extra costs for a landowner, since land previously used solely for agriculture or forestry is transferred to the joint or sole production of environmental benefits. The costs of measures applied in forests (Aa and Ab) were calculated in the following way: a total of 30 experimental and control plots representing different initial conditions of forest stands in Jokioinen and Vihti were inventoried and two different simulations were performed in order to calculate the present values of net incomes received from forest stands by means of the SIMO forest stand simulator (Rasinmäki et al., 2009). The first simulation represented a situation in which the experimental plots are managed according to current silvicultural recommendations and no biodiversity zones are established. In Finland, the conventional even-aged management regimes typically consist of two or three thinnings and a clear-cutting. The second simulation represented a situation in which the treatments described above are carried out. The difference in the present values of net income obtained as the result of the simulations reveals the cost of each biodiversity zone in the experiment. In the simulations, the stumpage prices of timber species and assortments were assumed to be in accordance with their long-term averages (Table 3).

The costs of measures on agricultural fields (B and C) of different soil types and productivity were evaluated by means of profit margin calculations utilising data received from experimental field plots situated in Jokioinen and Vihti. The calculation principle between the measures B and C is similar, but the average opportunity cost of field biodiversity strips remains smaller than that of environmental fallows, because we also included the effect of shading on arable land, whereby hectare yields on the border of a field abutting to a forest are smaller than those on the whole field on average (cf. Miettinen et al., 2012). First, the present value of net income received from feed-barley cultivation in each control area was calculated assuming a price of €175 ton^{-1} for feed barley. Next, the present values of net income streams obtained from the biodiversity strips and environmental fallows were calculated. The total of costs and income losses caused by a measure were computed by comparing the difference of the present values of per-hectare profit margins obtained from feed barley and from the biodiversity strip or the environmental fallow.

Wildflower seed mixtures (measures B1, B2, C1, and C2) are more expensive than the conventional mixture of red clover, timothy and meadow fescue (measures B3 and C3), but their positive effect on species richness and abundance of nectar- and pollen-feeding invertebrates may outweigh the costs (Carvell et al., 2004; Carvell et al., 2007; Haaland et al., 2011; Pywell et al., 2005). The seed costs of wildflower seed mixtures 1 and 2 were €1,625 ha^{-1} and €1,917 ha^{-1}, respectively. The conventional mixture was considerably cheaper, its price being €77 ha^{-1}. In addition to seed costs, tilling and sowing costs were taken into account. We assumed that areas sown with the wildflower seed mixtures should be regenerated with the interval of five years. In the wildflower strip study by Korpela et al. (2013) bumblebee abundance clearly decreased in the last year of the experiment, which was associated with decreasing flower coverage in the wildflower strips. This highlights the importance of re-sowing at regular intervals to compensate the decrease of flowers in long-term strips (Carvell et al., 2004). Instead, permanent grassland fields do not require regeneration. It was also assumed that the landowner does not receive any crop income from area sown with wildflowers, because wildflowers cannot be used as livestock feed. The harvest from biodiversity strips and environmental fallows sown with the conventional mixture can be utilised as dry hay but, in this case, annual labour costs as well as tractor fuel and lubricant costs are higher than those which result from areas sown with wildflowers. Since there is no market price for dry hay, we assumed that the price of dry hay is based on the feed unit price. Thus, the computational price of dry hay also changes as the price of feed barley varies. When evaluating variable and labour costs, we utilised the Tuottopehtori e-service (ProAgria Association of Rural Advisory Centres, 2010) along with machine-work costs and statistical contract prices reported by TTS Research (Palva, 2009).

As the viewpoint was that of a private landowner, agricultural subsidies were also included in the calculations. Within the EU, agricultural subsidies are decoupled from production and thus independent of production decisions. Therefore, we assumed that both the control area (feed barley) and the treated area receive the same amount of subsidies per hectare. Thus, the difference in the present values of net income shows the minimum additional compensation required by the landowner for applying the measure. The principles of the cost calculations are described in detail in a study by Miettinen et al. (2012).

2.4. Cost-effectiveness analysis

There are well-known problems in the monetary valuation of non-market goods and services (e.g. Mendelsohn and Binder, 2013). Therefore, the costs and effectiveness of the policy measures were compared employing cost-effectiveness analysis (CEA) (see e.g. Boardman et al., 2006) which avoids the problem of monetising policy effects by measuring them in physical units. We limit our cost-effectiveness analyses to the three indicators and do not try to aggregate different ecological effects of measures to an index.

3. Results

3.1. On effects of measures

This section describes selected results from the effects of biodiversity measures during the first 40 years of implementation in order to give the reader a better understanding on the data which is a mixture of field experiment results and expert assessments. All measures are not included in the same figures because their scales differ considerably from each other. The effectiveness of measures is obtained by subtracting the value of control treatment from the annual observation of the treatment.

When examining development in the bumblebee abundance, the effectiveness of environmental fallows (measure C) was the best of the compared measures. In Fig. 2a, a cycle of five years is visible in the effectiveness of measures C1 and C2, which is due to the fact that growths sown by wildflower seed mixtures are renewed every five years. Annual lacy phacelia (*Phacelia tanacetifolia*) in seed mixture 2 significantly increases the effectiveness of measure C2 in the years it is sown (i.e. years 1, 6, 11,...). The environmental fallow sown by the conventional seed mixture (measure C3) is not renewed after the sowing. The effectiveness of measure C3 increases during the first five years and reaches in the sixth year a level on which the number of bumblebee individuals per hectare will remain.

Fig. 2b shows the development of total species richness of bumblebees, butterflies and diurnal moths on the 5-m wide strip on the border of a field abutting to a forest. If no biodiversity strip has been established but feed barley is grown on the field, there will be about 14 different bumblebee and butterfly species (control treatment) on an area of one hectare on the border of the field (5 m × 2,000 m). The effectiveness of measures sown by wildflower seed mixtures (B1 and B2) follow the five-year cycle. On the grass strip (measure B3), the species richness increases in the first few years after the establishment but becomes stable at the long-term level on the seventh year.

Fig. 2c illustrates the development of the abundance of habitat-specialist butterflies on the 25-m wide biodiversity zone established on the border of a forest. The figure clearly shows the effects of light selection fellings (measure Ab) done every 20 years in the transitional zone and clearings (Measure Aa) done at the interval of 6–7 years in the 5-m strip. The stand grows closed quickly, whereby the abundance of habitat-specialist butterflies returns to the level of the control already on the fourth year after the treatment.

3.2. Cost-effectiveness analyses

The results of the cost-effectiveness analyses are presented in Tables 4–6. When considering the increase in bumblebee abundance and the availability of pollination services (Table 4), we found that the ranking of the examined measures in terms of cost-effectiveness was I) environmental fallow, II) 5-m wide field biodiversity strip and III) forest measures, environmental fallow being the most cost-effective. The better cost-effectiveness of environmental fallows as opposed to biodiversity strips is due to the effectiveness of environmental fallows which might be due to the fact that bumblebees typically concentrate on such patches in the landscape which are most clearly distinguishable from the surrounding vegetation (Heard et al., 2007). Furthermore, this phenomenon is stronger in simple as opposed to complex landscapes (Kleijn et al., 2011) and our set-aside experiment was carried out in a simple landscape on a field situated in an intensively cultivated area far from the nearest forest borders. The ranking of seed mixtures was I) wildflower seed mixture 1, II) wildflower seed mixture 2 and III) conventional grass mixture. The difference between wildflower mixtures was mainly due to differences in their effectiveness. Perennial knapweeds (*Centaurea*) attract a great number of bumblebees and were sown with a higher density in mixture 1 than in mixture 2. The poor effectiveness of the forest measures can be explained by poor flower availability. As no seeds were sown within the forest measures, the emergence of nectar and pollen plants relied solely on the seed bank.

In the case of the increase in total species richness (Table 5), the most important factor from the viewpoint of cost-effectiveness was seed mixture composition. We found that an environmental fallow or a biodiversity strip on a field established with the conventional mixture (measures B3 and C3) increased the species richness most effectively compared with its costs. This is due to the lower costs of the grass mixture including the assumption that farmers are able to use dry hay harvested from environmental fallows and biodiversity strips as livestock feed and probably also to the fact that perennial grasses gradually change in a direction favourable for pollinating insects. The structural complexity of vegetation increases and wild plants germinate from the seed bank or disperse from outside the field (Alanen et al., 2011). The poor success of forest measures was mostly due to their poor effectiveness.

Among the measures studied, money invested in biodiversity zones (measure A) in the field-forest ecotone, i.e. forest measures, increased the abundance of habitat-specialist butterflies in the most cost-effective way (Table 6). This can be explained by the fact that many species classified as specialists in this study are associated with forest edges (Korpela et al., 2014). As shown by Korpela et al. (2013), their colonisation of wildflower strips depends on the proportion of forests in the surrounding landscape. Forest borders in boreal agricultural landscape are source habitats for many specialist species. In addition, many specialist species are also forest edge species.

In practice, the choice of agri-environment measures depends on their preferred effects. Therefore, we varied the relative weights given to the three effectiveness indicators and represented our results utilising a ternary plot (Fig. 3) in which every point within the triangle represents a different composition of the relative weights given to the three indicators. When the abundance of habitat-specialist butterflies was given a 100-% weight (the left lower corner of the triangle in Fig. 3), the most effective measure was the forest measure (measure A) consisting of the 5-m wide open strip in the field-forest ecotone at the forest edge and the 20-wide transitional zone deeper in the forest. Measure A remained the most effective one even if some weight was moved from the abundance of habitat-specialist butterflies to the total species richness of bumblebees, butterflies and diurnal moths as long as the abundance of bumblebees was not given any weight in policy-making. When 48% of the relative weight is given to the total species richness and 52% is left to the abundance of habitat-specialist butterflies, the biodiversity strip established by the conventional seed mixture (measure B3) becomes effective. This shift is seen in Fig. 3 between the relative weights of 60% and 50% when moving upwards along the left side of the triangle. We also found that if more than 2% of weight is given to the abundance of bumblebees, the biodiversity field established by the wildflower seed mixture 1 (measure C1) is the one with the highest effectiveness relative to its costs. In other words, if we have to choose just one measure from our toolbox to maximise the impact of money spent without knowing the weights given to the indicators, we would have chosen the right measure in most situations if we chose the biodiversity field established by the wildflower seed mixture 1.

3.3. Sensitivity analyses of feed-barley price and discount rate

Crop prices have varied considerably during the past ten years in Finland. Instead, timber prices have been quite stable. In our framework, feed-barley price affects the production costs of field measures (B and C) and, with its rise, forest measures become relatively less costly for landowners. Miettinen et al. (2012) also demonstrated that a high real discount rate increases the landowner's willingness to establish biodiversity zones in a forest rather than on a field. Therefore, we varied the price of feed barley (€125 ton^{-1}–€225 ton^{-1}) and the real discount rate (1%–5%) and conducted two sensitivity analyses.

The results of the sensitivity analyses generally showed no significant changes in the ranking of the measures, but there were also some interesting exceptions. Fig. 4a illustrates effectiveness cost ratios of the studied measures when the price of feed barley changes. When the feed-barley price is low (€125 ton^{-1}), field measures B3 and C3 are more effective in increasing the abundance of habitat-specialist butterflies than the forest measures because of lower land-use opportunity costs. Fig. 4b indicates that, when the real discount rate increases, the effectiveness cost ratio of forest measures becomes better compared with the field measures. This is in part attributable to the change in the temporal pattern of logging after the establishment of a forest biodiversity zone, because a frequent and even flow of revenues from the forest biodiversity zone is favourable at a high discount rate, as more weight is given to income earned today and in the near future than to that earned at a later date (Miettinen et al., 2012).

3.4. Costs and effectiveness of measures at landscape level

The studied measures are a group of policy instruments the scales of which differ considerably. Therefore, we exemplify the implementation of the measures in a typical landscape setting in southern Finland where the average size of a field parcel is about 3.5 ha and the field abuts from its one side to a forest. In our example, the length of the joint border between the field and the forest is 200 metres. Thus, the area under forest measures is 0.5 ha (25 m × 200 m), the area under field biodiversity strip is 0.1 ha (5 m × 200 m) and the area under environmental fallow is 3.5 ha (175 m × 200 m) making the entire area of our landscape unity 4 ha (200 m × 200 m).

Two main conclusions on the costs and effectiveness of the measures at landscape level are reached with the help of histograms drawn in Figs 5a-c. First according to Fig. 5a, measures A and B will not decrease the landowner's annual net revenues from the forest and the field much compared to the baseline. Then, positive effects for the abundance of flower-visiting insects may be achieved with potentially small economic compensations. Second, if the aim of the policymaker is to have large increases in flower-visiting insect abundances (Figs 5b-c), measures performed for the whole parcel (measures C1-C3) are necessary.

4. Discussion

We examined the cost-effectiveness of three measures A) forest biodiversity zones, B) field biodiversity strips and C) environmental fallows in promoting 1) the availability of pollination services, 2) species diversity of flower-visiting insects and 3) abundance of habitat-specialist butterfly species of conservation concern in boreal agricultural landscapes. Our results suggest that all three agri-environmental measures (A–C) investigated may be economically justified, but that they serve slightly different purposes and aspects of biological diversity when applied in an actual landscape to meet the multiple goals of regional or nation-wide agri-environmental schemes. When considering the availability of pollination services, the most effective measures were environmental fallows sown with wildflower seed mixtures, since they increased bumblebee abundance with the lowest cost. In the case of an increase in total species richness, the composition of the seed mixture was the most important factor for cost-effectiveness. We found that an environmental fallow or a 5-m wide biodiversity strip on an agricultural field established with a conventional mixture increased species richness more effectively than wild flower seed mixtures. Among the measures studied, a 25-m wide biodiversity zone in a forest on a field-forest border promoted the abundance of habitat-specialist butterflies of conservation concern in the most cost-effective way. Our findings indicate that forest biodiversity zones, field biodiversity strips and environmental fallows complement rather than substitute each other. Therefore, a balanced combination of these measures will be case-specific and depended on relative weights given to the policy targets, i.e., promotion of different flower-visiting insect groups.

This paper contributes to the design of agri-environmental schemes by providing information on the costs and effects of a set of presently applied measures (biodiversity strips and environmental fallows) and one new, potential measure: a biodiversity zone in a forest on the field-forest border. To our knowledge, this is the first study of its kind and, therefore, there are no direct benchmarks to compare. Still, many of our results are in line with results obtained in the UK and elsewhere in Europe. First, the importance of careful selection of seed mixtures on environmental fallows and biodiversity strips to attract pollinators seems to be a common feature (e.g. Wratten et al., 2012). For example, Osgathorpe et al. (2011) emphasised that the availability and abundance of foraging resources is important for bumblebees throughout the flying season and that the inclusion of wildflower mixtures is costly but highly effective in promoting bumblebee abundance when associated with croft management in Scotland. Second, many an empirical study concluded that different policy measures may serve varied purposes and meet specific goals. Armsworth et al. (2011) reported that individual species abundance and whole community indices differ in their responses to agri-environmental measures.

It is a precondition for ranking the measures and designing cost-effective policies that information on the multiple impacts of agri-environmental measures is available. Unfortunately, such information is often costly and time-consuming to acquire. Preferably, the entire suite of alternative measures (on a forest border, biodiversity strips or farmland) should be assessed in the same landscape over the entire time span of effectiveness. Such experiments, however, require extensive testing procedures and may take decades to accomplish. In this study, we attempted to combine empirical data on the immediate impacts of measures over the first few years and projected the impacts over the remaining part of the time span on the basis of expert opinions based on literature and theoretical understanding. Data were collected from different but relatively closely located and comparable localities. Such simplifications made it possible to utilise data from different surveys but, naturally, the data must be properly accounted for when interpreting the results. Repeated analyses with consistent datasets and accumulation of data may enable modelling the provision of multiple ecosystem services as a function of measures. This would allow the use of simulation and optimisation techniques in identifying cost-effective combinations of the measures (see e.g. Armsworth et al., 2012).

Possibilities to develop the forest measures in creating meadow-like habitats could be further explored. Collection of logging residues after harvesting and sowing wildflower seeds to the opened forest strip would obviously increase the attractiveness of these areas to flower-visiting insects. Such an adjustment would require more frequent removal of bushes and control of underbrush which increases costs but, if applied to poorer soils with smaller competition from existing plant communities, such adjustments would perhaps be worth experimenting.

5. Conclusions

Our findings give support to biodiversity policies which involve a mosaic of measures at landscape level. A balanced combination of these measures in a landscape, together with other biodiversity measures, will be case-specific and depend on the relative weights given to different biodiversity objectives and target insect groups. Altered management of forests bordering the fields and biodiversity strips are both potential measures which belong to a cost-effective combination of measures at landscape level and which can be applied on a limited scale. However, significant improvements in insect populations can be achieved only through sacrificing a larger field area to environmental protection by establishing flower-rich environmental fallows. Modified management of forests bordering the fields is not yet part of AES but, according to our results, it can in a limited manner be an efficient means to widen the habitat area for specific species groups, such as butterflies. Altered forest management next to the field-forest boundary also works as a transition zone by smoothing the steep vertical steps in the landscape and may enhance rural aesthetics (Wratten et al., 2012).

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Figures

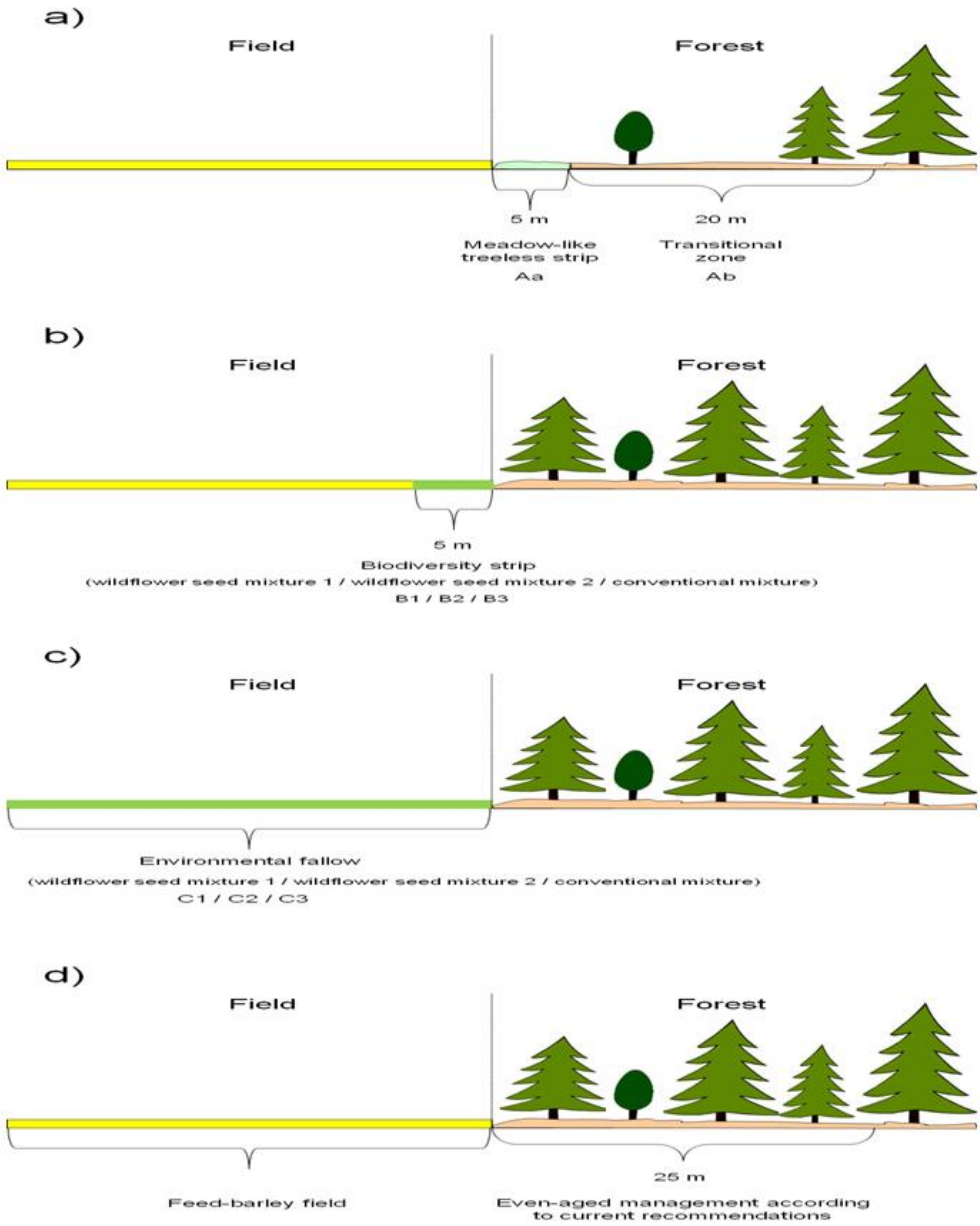


Fig. 1. a) 25-m wide biodiversity zone in forest on field-forest border **b)** 5-m wide biodiversity strip on field on field-forest border **c)** Environmental fallow **d)** Control treatment.

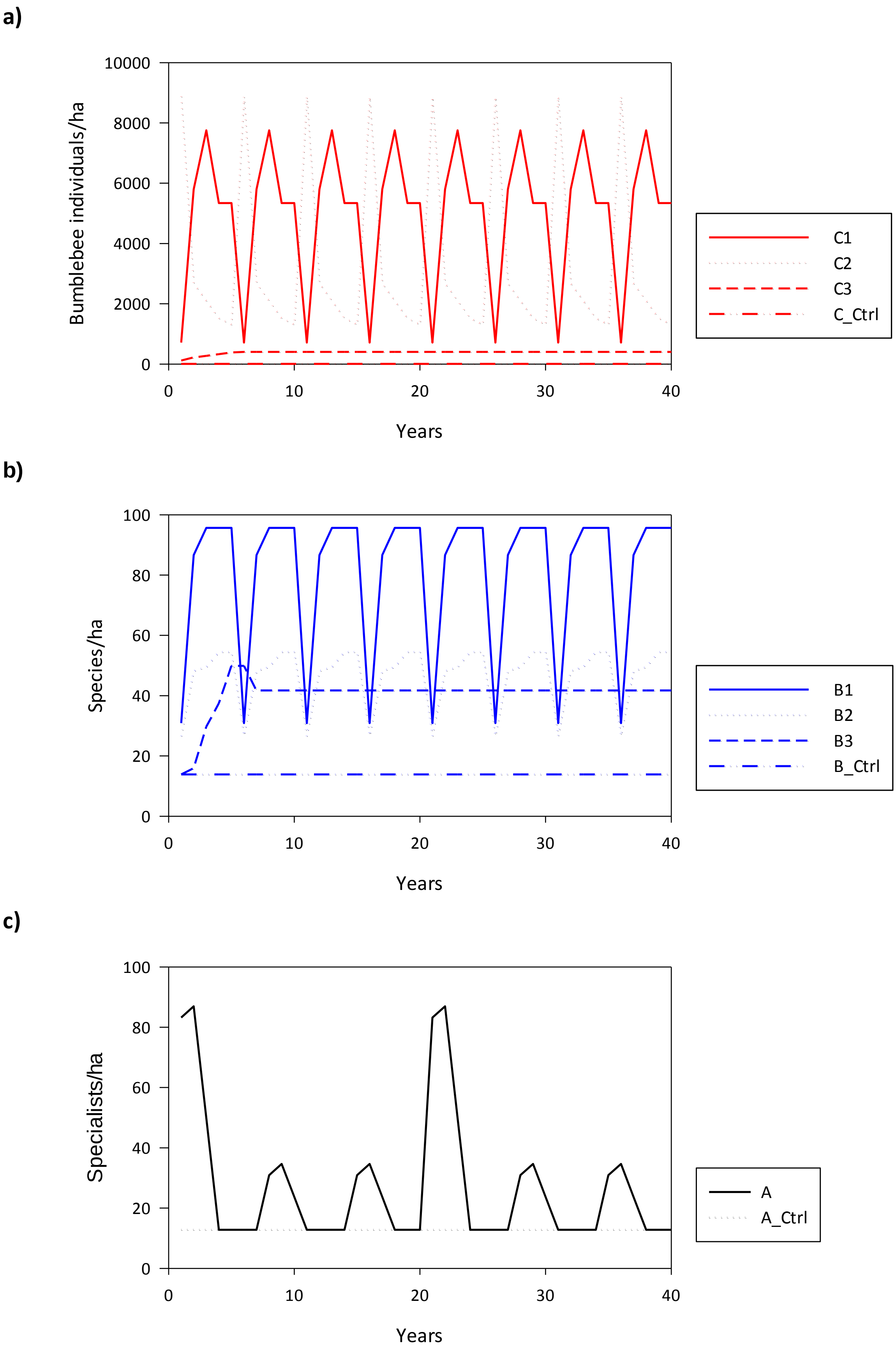


Fig. 2. a) Abundance of bumblebees on environmental fallow **b)** Total species richness of bumblebees, butterflies and diurnal moths on biodiversity strip on border of field **c)** Abundance of habitat-specialist butterflies on border of forest abutting to field.

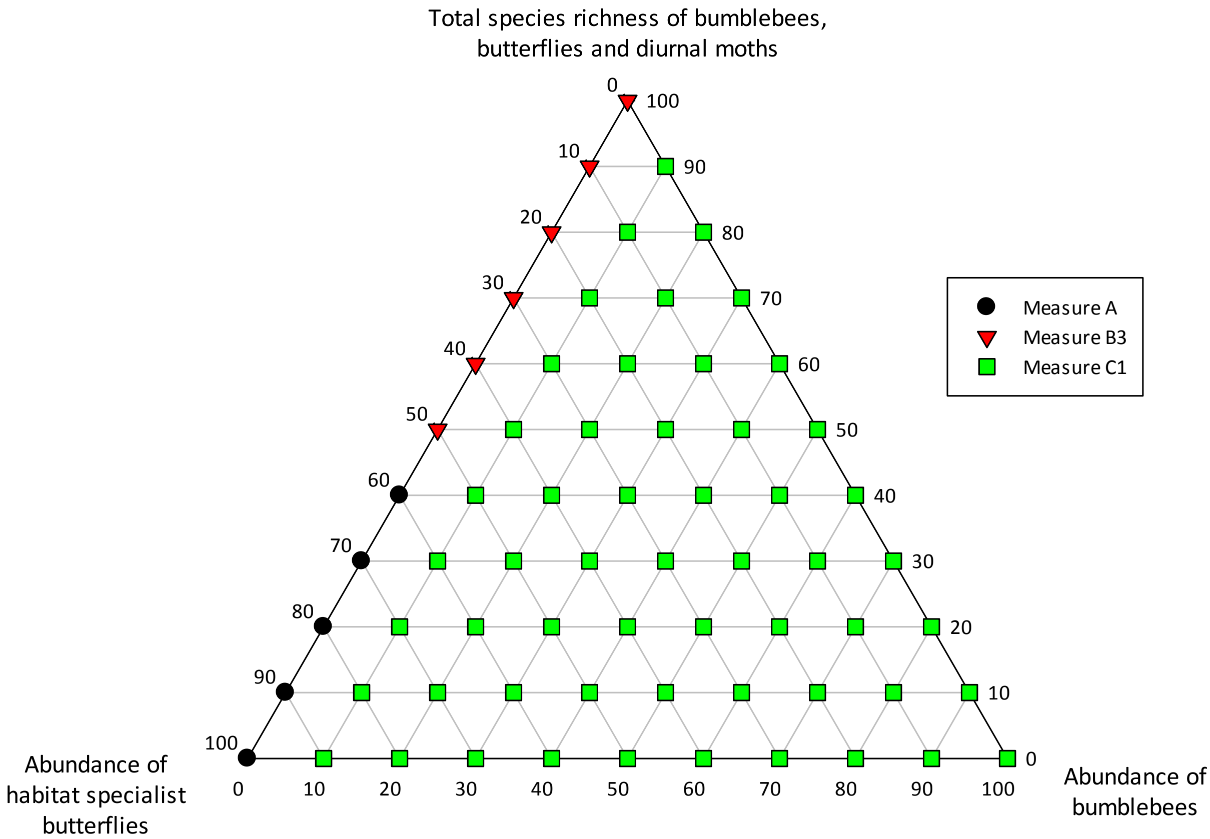
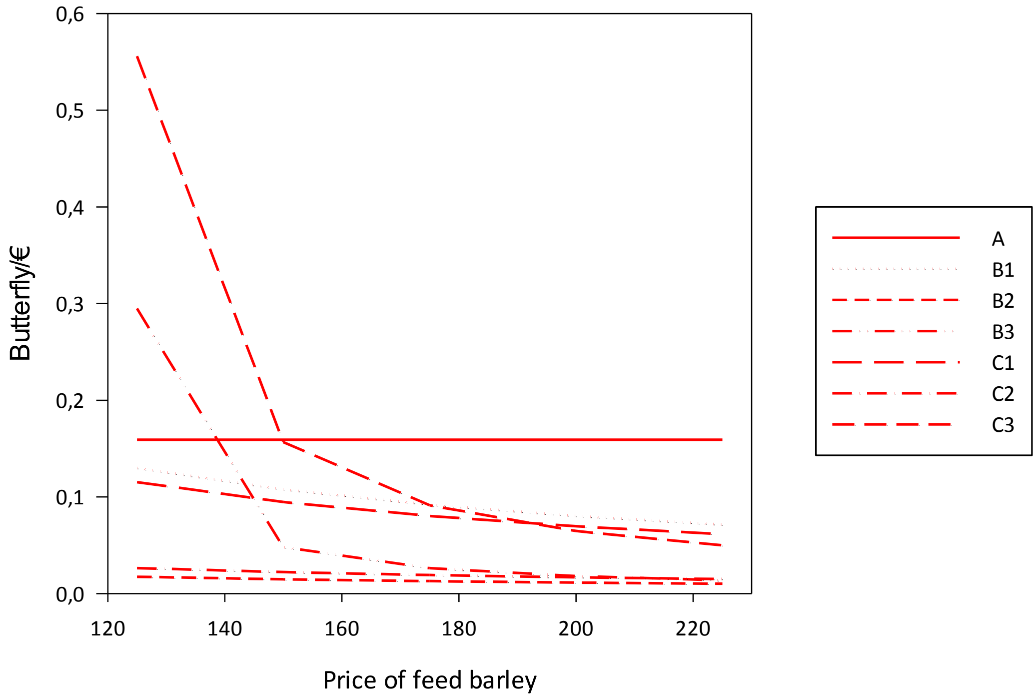


Fig. 3. Most cost-effective measures when biodiversity indicators are weighted.

a)



b)

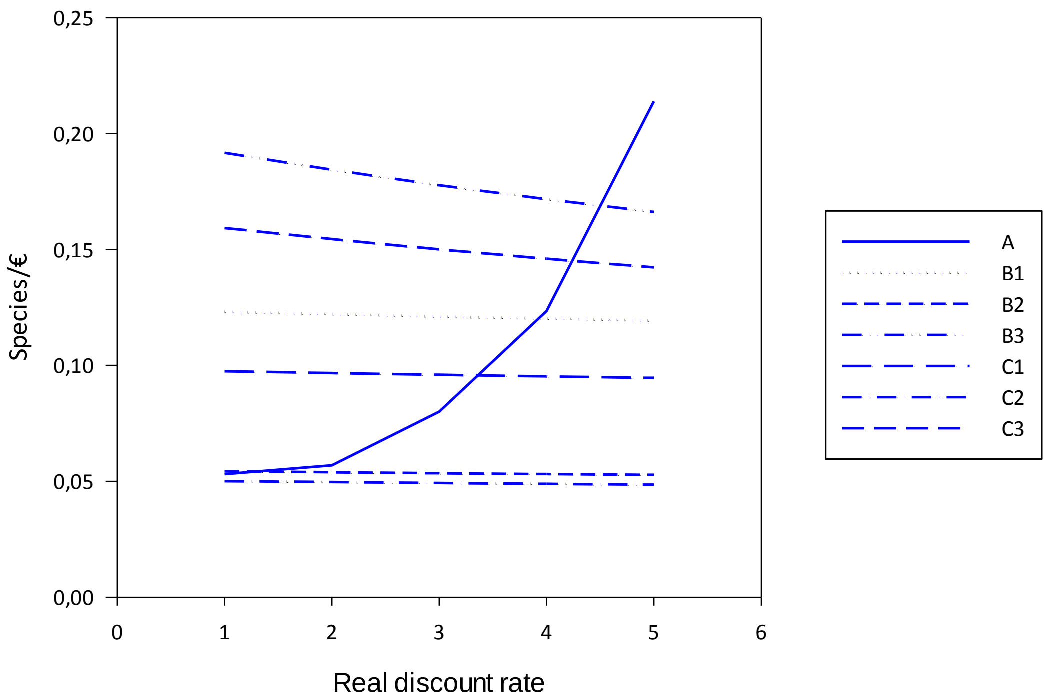


Fig. 4. a) Cost-effectiveness of measures enhancing abundance of habitat-specialist butterflies when price of feed barley varies **b)** Cost-effectiveness of measures enhancing total species richness of bumblebees, butterflies and diurnal moths when real discount rate varies.

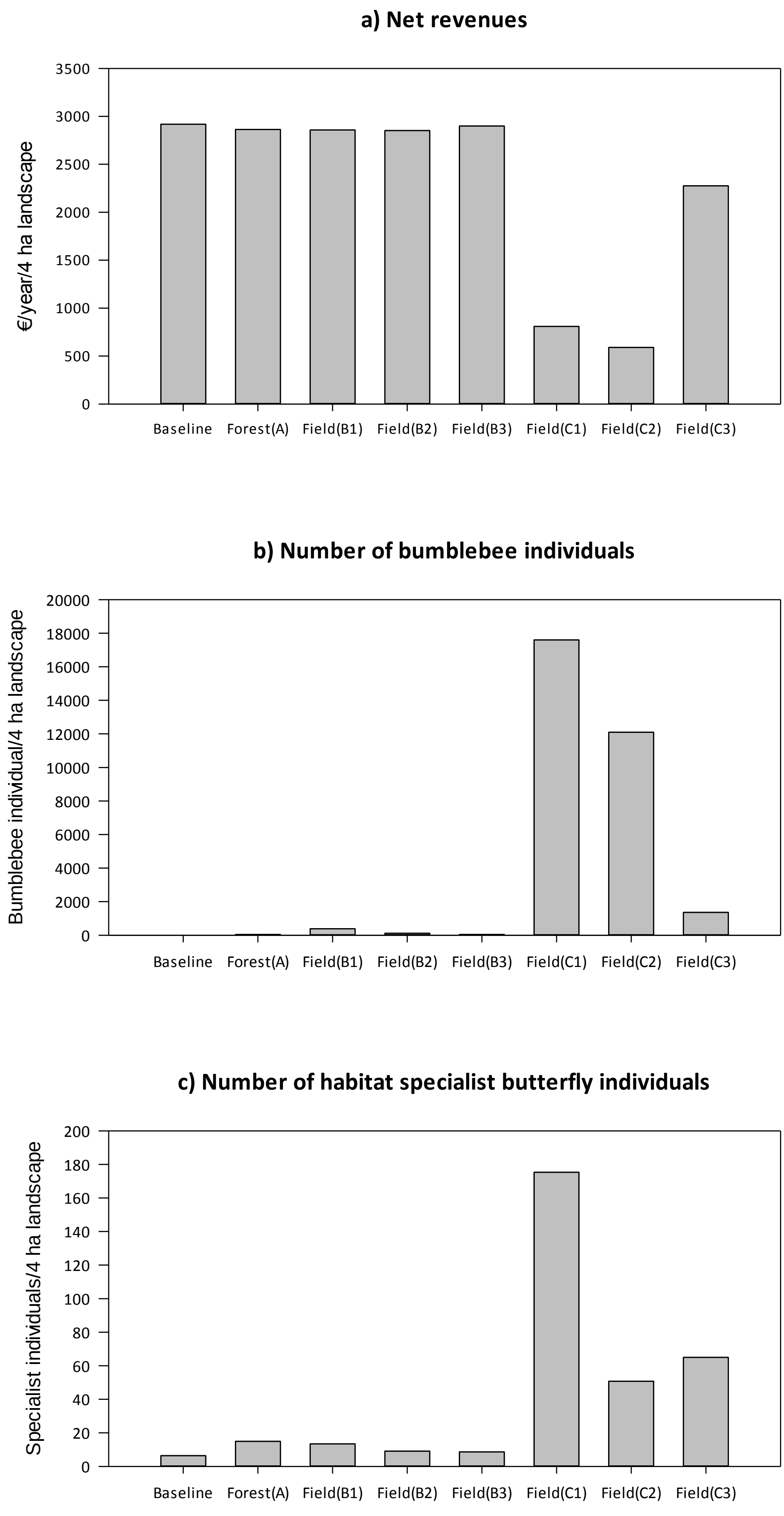


Fig. 5. Net revenues and effectiveness of measures at landscape level.

Tables

Table 1

Seed mixtures and thicknesses of seedling used in measures B and C.

Wildflower seed mixture 1	Wildflower seed mixture 2	Grass seed mixture
Centaurea jacea 10 seeds/m^2	*Phacelia tanacetifolia* 5 kg/ha	*Trifolium pratense* 4 kg/ha
Centaurea phrygia 5 seeds/m^2	*Vicia villosa* 15 kg/ha	*Phleum pratense* 5 kg/ha
Leucanthemum vulgare 10 seeds/m^2	*Silene latifolia* 10 seeds/m^2	*Festuca pratensis* 5 kg/ha
Trifolium repens 0,5 kg/ha	*Centaurea jacea* 5 seeds/m^2	
Agrostis capillaris 1 kg/ha	*Anthemis tinctoria* 10 seeds/m^2	
	Leucanthemum vulgare 10 seeds/m^2	
	Knautia arvensis 1 seed/m^2	
	Festuca ovina 7 kg/ha	
	Agrostis capillaris 7 kg/ha	

Table 2

Measures examined and their primary data sources.

A	*25-m wide biodiversity zone on forest border*	Forest border experiment[1]
Aa	5-m wide open strip in field-forest ecotone on forest border	Forest border experiment[1]
Ab	20-m wide transitional zone managed by light selection cuttings behind 5-m wide strip	Forest border experiment[1]
Control	Forest managed according to recommended good practices in forestry	Forest border experiment[1]
B	*5-m wide biodiversity strip established on field on forest border*	
B1	Biodiversity strip established by wildflower seed mixture 1	Wildflower strip experiment[2]
B2	Biodiversity strip established by wildflower seed mixture 2	Environmental fallow experiment[3]
B3	Biodiversity strip established by grass seed mixture	Environmental fallow experiment[3]
Control	Feed-barley strip in conventional production	Forest border experiment[1]
C	*Environmental fallow*	
C1	Biodiversity field established by wildflower seed mixture 1	Wildflower strip experiment[2]
C2	Biodiversity field established by wildflower seed mixture 2	Environmental fallow experiment[3]
C3	Perennial grass field established by grass seed mixture	Environmental fallow experiment[3]
Control	Feed-barley field in conventional production	Wildflower strip experiment[2]

Results of field experiments are reported in separate publications: [1] Korpela et al. (2014), [2] Korpela et al. (2013) and [3] Alanen et al. (2011).

Table 3

Assortment prices of timber species.

	€ m^{-3}
Pine logs	55
Pine pulp	17
Spruce logs	55
Spruce pulp	25
Birch logs	43
Birch pulp	15
Other wood species	10

Table 4

Cost-effectiveness of measures enhancing bumblebee abundance.

Measures	Effectiveness, E (bumblebee individuals/ha)	Cost, C (€/ha)	C/E (€/bumblebee)	E/C (bumblebees/€)
A	18	107	5.93	0.17
B1	3,582	559	0.16	6.41
B2	820	622	0.76	1.32
B3	80	149	1.87	0.53
C1	5,019	602	0.12	8.34
C2	3,447	665	0.19	5.18
C3	380	184	0.48	2.07

Table 5

Cost-effectiveness of measures enhancing total species richness of bumblebees, butterflies and diurnal moths.

Measures	Effectiveness, E (species/ha)	Cost, C (€/ha)	C/E (€/species)	E/C (species/€)
A	9	107	12.49	0.08
B1	68	559	8.26	0.12
B2	33	622	18.71	0.05
B3	26	149	5.63	0.18
C1	58	602	10.43	0.10
C2	33	665	20.30	0.05
C3	28	184	6.67	0.15

Table 6

Cost-effectiveness of measures enhancing abundance of habitat-specialist butterflies of conservation concern.

Measures	Effectiveness, E (butterfly individuals/ha)	Cost, C (€/ha)	C/E (€/butterfly individual)	E/C (butterfly individual/€)
A	17	107	6.29	0.16
B1	51	559	10.88	0.09
B2	8	622	78.33	0.01
B3	4	149	38.25	0.03
C1	48	602	12.48	0.08
C2	13	665	52.51	0.02
C3	17	184	10.96	0.09