Policies for the management of landscape diversity

and collectively managed forests:

the case of Galicia[1]

by

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[1]Draft version

Abstract

Forest management has moved towards a landscape-based approach to manage for social, environmental and economic values. Under collective ownerships, members of a rural community have the rights to the forest resources without parcelling the rights to the forest itself. These forests are managed by integrating multiple forest uses within the decision making process. In this paper, forest landscape management is addressed using a bioeconomic framework, which allows the modelling of optimal clear-cutting strategies for multiple stands. This approach enables an intuitive understanding of the optimal rotational rule in a multiple stand forest managed for an array of timber and non-timber values. The rule suggests that it is the relative contribution of each stand to non-timber benefits from the overall forest landscape that affects the rotation intervals. The empirical analysis explores harvesting decisions using data from Galician collective forests in Spain. The econometric results show that collective holdings' landscape patterns –fragmentation, diversity and clumpiness– are important determinants of rotation periods.

1   Introduction

In recent years, the basis for the management of forest resources has moved towards a landscape-based approach, in which the effect of forest spatial structure on the flow of ecological and economic values is accounted for (Oliver, 1992, Swanson and Franklin, 1993, Swanson, 1993, Baskent and Yolasigmaz, 1999). Managing forests at a landscape level implies thinking beyond individual stands, focusing thus on mosaics of patches and long-term changes in these mosaics (Franklin, 1992). Thus, this approach recognises first that a lack of spatial considerations in management activities may result in unanticipated ecological changes, which can have adverse consequences for ecosystem functioning and biodiversity conservation, and second, that management at a single stand level impedes the assessment of the implications of management strategies at a landscape scale. Landscape structure has been demonstrated to influence the movement and persistence of particular species, the susceptibility and spread of disturbances such as fires, pest outbreaks, etc. (Turner, 1989). For instance, the local rate of extinctions in landscape patches and the rate of movement of the species among these patches influence species survival; and the proportion of disturbance-susceptible patches, and how they are distributed in the landscape affects the spread of disturbances.

Galicia is a Spanish region, located on the western edge of Europe, where forest area covers 68.9% of the territory. In addition, almost 98% of the forest land is in private hands. Individual ownership represents 68% of the forest land, while 30% of the forest land is under common or collective ownership (Consellería de Medio Ambiente, 2001). Collective lands have a mean size of 231 hectares, while individual property plots are very small, with an average size of 2.3 hectares (GEPC, 2002). It is relevant to point out that these collective forest lands are shared private property. The responsibility of managing the ownership is shared by a group of individuals living in the same community. Under this type of ownership, forest resources are therefore managed without the allocation of quotas, and management strategies should be agreed based on the best interests of the whole community. These lands are considered important in the regional policy agenda because of the extension they cover and the adequacy of their size for forest use. In addition, they often have scrublands and open areas that are suitable for forest activities. Given that these lands should contribute to the overall welfare of rural communities, their management is essential to guarantee the provision of a mix of forest goods and services.

This paper focuses on the management of forest landscapes. The main objective is to explore optimal harvesting decisions in multiple stand forests in which the dependence among stands in the provision of non-timber benefits enters into the management decision process. This type of analysis has already been studied in the environmental management literature (Bowes and Krutilla, 1985, Swallow et al., 1997, Tahvonen and Salo, 1999, Amacher et al. 2002). However, this paper adds to the existing literature because the modelling approach developed enables exploration of the insights of the dynamic optimisation process. A dynamic optimal cutting rule which explicitly accounts for spatial interactions is derived analytically. In addition, an economic interpretation is also provided. This model adapts previous bioeconomic forest models (Montgomery and Adams, 1995, Termansen, 2001) to include information on the age-class structure of forests.

The paper is organised as follows. Section 2 proposes a bioeconomic model to a multiple stand problem, in which spatial interactions between stands in the provision of forest non-timber benefits, are endogenous to the management decisions. Section 3 contains an econometric analysis of harvesting decisions in Galician collective forests. A duration analysis is used to examine the impacts of collective forest-specific variables on the length of the rotations. Section 4 provides policy reflections and concludes the paper.

2 A bioeconomic model for multiple even-aged stands

In this section, the management of a forest landscape is considered. The multiple-stand forest could be hypothesised to be under public or private ownership. Given that this study is motivated by the structure of property rights in Galicia, the multiple stands will be assumed to be collectively owned by a rural community. Notice, however, that this paper is not concerned with the relative merits of the property rights systems and the results are independent of the type of ownership considered.

In this model the forest landscape is composed of n stands. Let $x_i = x_i(t)$ and $F_i(x_i)$ be respectively the biomass volume (m^3) and timber growth functions of stand i. This growth function is assumed to be a concave function, such that $F(0) = F(K) = 0$ and $K > 0$, where K is the maximum volume a given stand can accumulate.

In this model, changes in forest biomass due to harvest activities are represented by jumps

in the state variable, $x_i(\tau_{ij}^+) - x_i(\tau_{ij}^-)$. $x_i(\tau_{ij}^+)$ denotes biomass just after harvest and $x_i(\tau_{ij}^-)$ is biomass just before harvest. τ_{ij} denotes the time at which stand i is clear-cut within the planning period $[0, T]$ for the time j, where $i = 1...n$ represents the number of stands in the forest ecosystem, and $j = 1....k$ is the number of harvests carried out throughout the planning period.

The age of the trees, $a_i(t)$, is identified as the calendar or natural time minus the time at planting, i.e. $a_i(t)$ is given by $a_i(t) = t - \tau_{ij}^+$ where $t \; \epsilon \; [\tau_{ij}^+, \tau_{ij+1}^-]$. Note that $a_i(\tau_{ij}^+)$ denotes the age of the trees just after a harvest and $a_i(\tau_{ij}^-)$ is the age just before a harvest.

Harvest activities are restricted to clear-cutting. Therefore, the magnitude of the jumps is constrained to be equal to the state variables before the jump minus their magnitude after planting.

Figure 1 shows the dynamic of the timber stock of a stand i within the forest landscape for a given time period using the notation just described. Notice that the sequence of jump points (τ_{ij}) determines the stand rotation periods within the planning period.
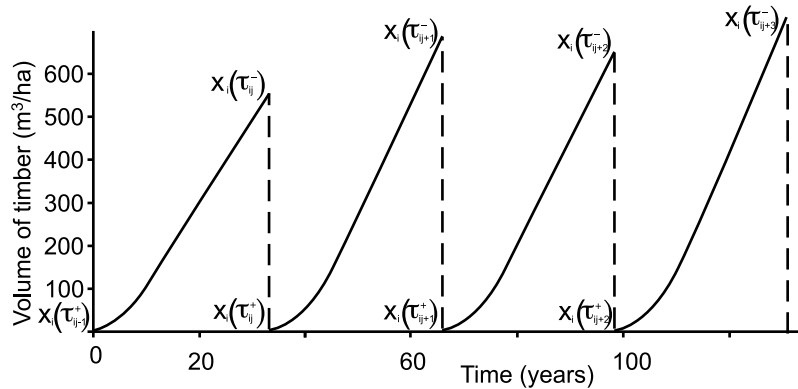

Figure 1: *Illustration of the dynamic of a stand-volume of timber (m^3).*

The planning period starts with the youngest plot in the forest landscape as bare land or immediately after being planted and re-planting activities follow immediately after clear-cutting. The timber price, the cost of planting and the interest rate are p_i, c_{ip} and δ, respectively. These variables are assumed constant following the Faustmann framework. This dynamic model is easily generalised to consider alternative assumptions, i.e. variability of the economic or biological parameters with time (see Léonard and Van Long, 1992, pp. $310 - 325$).

It is assumed that the community problem is to maximise the welfare of the community by the choice of harvesting strategy, taking into account both timber and non-timber benefits (livestock maintenance, hunting, wild fruits, recreation, etc.). Therefore treatment of each stand is decided by the community on the basis of the timber rewards plus the effects of harvest on the provision of non-timber benefits at a forest level.

The net timber benefits after harvesting one stand are the returns associated with each jump. These are the gross timber benefits from the cutting, $p_i x_i(\tau_{ij}^-)$, minus the costs of planting, $c_{ip} x_{ip}$. Let x_{ip} and a_{ip} represent the biomass and the age of the seedlings. The community non-timber benefits depend on the characteristics (the biological attributes, s_i, and the trees' age, a_i) of all the stands and how neighbouring stands interact to influence forest conditions. Harvesting any one stand therefore depends on a vector of characteristics of all stands as well as on their linkages.

The forest owner's problem is to choose the optimal harvest sequence, $\tau_{i1}, ..., \tau_{ik}$, for the multiple stands, $i = 1, ..., n$, over a planning period $[0, T]$ which maximises the forest timber and non-timber values. Thus the maximisation problem for the management of a forest landscape is as follows[3]

$$\max_{\tau_{ij}} \int_0^T \pi(s_1[a_1(t)], ..., s_i[a_i(t)], ..., s_n[a_n(t)]) e^{-\delta t} dt$$

$$+ \sum_{i=1}^n \sum_{j=1}^k [p_i x_i(\tau_{ij}^-) - c_{ip} x_{ip}] e^{-\delta \tau_{ij}} \quad (1)$$

subject to

$$\dot{x}_i = F_i(x_i(t)) \quad except \ at \ \tau_{ij}, \ j = 1...k \ i = 1...n \tag{2}$$

$$\dot{a}_i = 1 \quad except \ at \ \tau_{ij}, \ j = 1...k \ i = 1...n \tag{3}$$

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[3]Note that the non-timber benefit function at the forest level is discontinuous. This is because the values of this function will jump at the harvest points, τ_{ij}, i.e. when any of the stand in the forest is being cut. The maximisation function is thus expressed as,

$$\sum_{i=1}^n \sum_{j=1}^k \int_{\tau_{ij-1}^+}^{\tau_{i+u,j+v}^-} \pi[s_1(t - \tau_{1j+v}^+), ..., s_i(t - \tau_{ij+v}^+), ..., s_n(t - \tau_{nj+v}^+)] e^{-\delta t} dt + \sum_{i=1}^n \sum_{j=1}^k [p_i x_i(\tau_{ij}^-) - c_{ip} x_{ip}] e^{-\delta \tau_{ij}}$$

where u and v are integers. However, as the number of stands approaches infinity, the forest non-timber benefits along the planning period can be approximated by,
$\int_0^T \pi(s_1[a_1(t)], ..., s_i[a_i(t)], ..., s_n[a_n(t)]) e^{-\delta t} dt$. For notational simplicity this approximation is used in the representation of the model.

$$x_i(\tau_{ij}^+) - x_i(\tau_{ij}^-) = -x_i(\tau_{ij}^-) + x_{ip} \quad \forall \tau_{ij}, \quad j = 1...k \quad i = 1...n \tag{4}$$

$$a_i(\tau_{ij}^+) - a_i(\tau_{ij}^-) = -a_i(\tau_{ij}^-) + a_{ip} \quad \forall \tau_{ij}, \quad j = 1...k \quad i = 1...n \tag{5}$$

$$x_i(0) = x_i^0 \tag{6}$$

Equation (2) implies that between harvests the dynamics of the biomass volume of the stands is given by their natural growth. Equation (3) indicates the dynamics of the age of the stands between harvest instants. Equations (4) and (5) relate to the magnitude of the jumps in the state variables, $x_i(t)$ and $a_i(t)$, at the moment of harvest. Equation (6) is the initial stock constraint. This problem is a special case of the theory of optimal control model with jumps (Seierstad and Sydsaeter, 1987 Chapter 3, Theorem 7, Section 4).

The costate variables, indicating the present-value shadow price or imputed value of stand timber stock and age are denoted as $\lambda_i(t)$ and $\theta_i(t)$, respectively. This means they capture the value that a marginal increase in the state variables at time t would contribute to the total forest returns.

The present-value Hamiltonian of this problem is defined by

$$H = \pi(s_1[a_1(t)], ..., s_i[a_i(t)], ..., s_n[a_n(t)])e^{-\delta t} + \sum_{i=1}^{n} \lambda_i(t) F_i(x_i(t)) + \sum_{i=1}^{n} \theta_i(t) \tag{7}$$

The first order necessary conditions for the optimal solution include the dynamics of the costate variables between harvests plus the conditions to be met at optimal harvest moments.

Between harvests points, the following conditions must be satisfied

$$\dot{\lambda}_i = -\frac{\delta H}{\delta x_i} = -\lambda_i F_i'(x_i(t)) \tag{8}$$

$$\dot{\theta}_i = -\frac{\delta H}{\delta a_i} = -\pi'(s_1[a_1(t)], ..., s_i[a_i(t)], ..., s_n[a_n(t)])e^{-\delta t} \tag{9}$$

These conditions state that the imputed value of a unit of the state variables should be changing at a rate equal to their marginal contribution to the forest returns. Thus, condition (8) indicates that the rate at which the value of a unit of stock is decreasing

should equal its marginal impact on the future value of the capital stock. Condition (9) states that the rate at which a marginal increment in age changes the economic return is decreasing at the same rate as the forest non-timber benefits are increasing.

In addition, at the optimal harvest points, $\tau_{i1}, ..., \tau_{ik}$, conditions (10), (11), (12) must be satisfied.

$$\lambda_i(\tau_{ij}^+) - \lambda_i(\tau_{ij}^-) = -\frac{\partial[(p_i x_i(\tau_{ij}^-) - c_{ip} x_{ip})e^{-\delta\tau_{ij}}]}{\partial x_i} - \lambda_i(\tau_{ij}^+)\frac{\partial[-x_i(\tau_{ij}^-) + x_{ip}]}{\partial x_i} \quad (10)$$

$$\theta_i(\tau_{ij}^+) - \theta_i(\tau_{ij}^-) = -\frac{\partial[(p_i x_i(\tau_{ij}^-) - c_{ip} x_{ip})e^{-\delta\tau_{ij}}]}{\partial a_i} - \theta_i(\tau_{ij}^+)\frac{\partial[-a_i(\tau_{ij}^-) + a_{ip}]}{\partial a_i} \quad (11)$$

and

$$H(\tau_{ij}^+) - H(\tau_{ij}^-) - \frac{\partial[(p_i x_i(\tau_{ij}^-) - c_{ip} x_{ip})e^{-\delta\tau_{ij}}]}{\partial\tau_{ij}} = 0 \quad (12)$$

Equations (10) and (11) can be rearranged to produce, respectively

$$\lambda_i(\tau_{ij}^-) = p_i e^{-\delta\tau_{ij}^-} \quad (13)$$

$$\theta_i(\tau_{ij}^-) = 0 \quad (14)$$

Condition (13) indicates that, along the optimal path, harvests of any stand i will occur only when the internal price of its timber stock equals the outside timber price. Condition (14) states that at the harvest instants, the internal price of the age of the trees at stand i should be equal to zero.

Furthermore, applying the Hamiltonian function shown in equation (7) and solving the first-order differential equations for the timber stock and age costate variable (i.e. equations (8) and (9)), the condition expressed by equation (12), is now (see appendix A for details)

$$\pi(s_1[a_1(\tau_{ij}^-)], .., s_i[a_i(\tau_{ij}^-)], .., s_n[a_n(\tau_{ij}^-)])e^{-\delta\tau_{1j}^-}$$

$$-\pi(s_1[a_1(\tau_{ij}^+)], .., s_i[a_i(\tau_{ij}^+)], .., s_n[a_n(\tau_{ij}^+)])e^{-\delta\tau_{ij}^+} + p_i e^{\delta\tau_{ij}^-} F_i(x_i(\tau_{ij}^-))$$

$$= \delta[p_i x_i(\tau_{ij}^-) - c_{ip} x_{ip}]e^{-\delta\tau_{ij}} + p_i e^{-\delta\tau_{ij+1}^-} F_i(x_i(\tau_{ij+1}^-)) + \theta_i(\tau_{ij}^+) \quad (15)$$

This cutting condition generates the rotation length for any stand in the forest along the planning period that optimises management of the entire forest landscape, i.e. maximizes the forest timber and non-timber returns.

This cutting condition has an intuitive interpretation. The left-hand side of equation (15) is the increase in the value of the forest if the clear-cutting of stand i is delayed over a unit time interval. The right-hand side of equation (15) is the forest marginal costs of postponing the harvest of stand i. These are the opportunity cost of investment of timber revenues plus the opportunity cost of postponing future forest benefits.

Therefore this cutting condition shows that the optimal harvest age of any stand i in the forest should balance the forest marginal benefits of delaying the stand harvest with the forest marginal costs of waiting (i.e. forest MB = forest MOC).

The marginal benefits of postponing the harvest of stand i (left hand side, equation (15)) in the forest includes timber and non-timber values. In particular, the marginal value of the forest non-timber benefits obtained by postponing the stand harvest is determined by the first two terms in equation (15), i.e. $\pi(\tau_{ij}^-) - \pi(\tau_{ij}^+)$.

This is denoted here as the 'stand net contribution' of stand i to the non-timber benefits of the whole forest. The first term is the forest non-timber benefits just before the harvest of stand i; while the second term is the forest non-timber benefits just after the harvest of stand i. The 'stand net contribution' indicates that the optimal harvest age of any stand i depends not only on the provision of forest non-timber benefits if the harvest of stand i is delayed, but also on how the forest non-timber revenues would be affected if harvest had occurred. Therefore, it represents the difference between forest non-timber benefits with and without the harvest of stand i.

Furthermore, this term captures the nature of the interdependence that exists between stands in the forest landscape, both in space and time. Particularly in relation to whether the stands are substitutes or complements in the provision of non-timber goods and services. Stands could be considered as substitutes if they provide substitutable conditions for livestock maintenance; or they could be interpreted as complementary because some animals require a minimum area of forest cover at a similar successional stage (Hunter, 1990).

Thus, when the stands are defined as substitutes in the provision of the non-timber benefits, this term is expected to have a relatively smaller value if other stands are acting as substitute sources of non-timber benefits at the harvest instant (i.e. they have similar ages) than if they are not. Similarly, when the stands are complementary, this term would be higher when the other stands are acting as good complementary sources of non-timber revenues at the harvest instant.

Notice that the nature of the interactions among stands is dynamic. Therefore, the cutting condition of individual stands will not only be affected by whether the adjacent stands are able to generate substitutive or complementary goods and services, but also how their relationship –i.e. their substitutivity and complementarity– evolves over time.

The first term on the right-hand side of (15) is the income that could be earned if revenue from cutting stand i is invested at an interest rate δ. The second and third terms represent the opportunity cost of postponing the harvest of stand i on the forest timber and non-timber returns of the following rotation. It is analoguous to the concept of 'site value' in the traditional forestry framework.

Note that the age costate variable $\theta_i(\tau_{ij}^+)$ represents the flow of non-timber benefits derived from the whole forest during stand i's next rotation (see appendix A). This value depends on the age structure existing in the forest landscape during the following rotation of stand i. Therefore the impact of postponing the harvest is not only the opportunity cost of a delay in future benefits but also the value of altering the age of stand i relative to the age of other stands in the forest landscape. Delaying the harvest decision therefore may cause a shift in the distribution of ages in the forest, altering the interactions between the stands and affecting timber and non-timber benefits in the future.

3   A case study from Galician collective forests

This section presents an empirical examination of the impact of the landscape patterns on harvesting activities using data from Galician collective forests. The analysis focuses on an area known as Baixo-Miño, located in South-West Galicia. It covers $32,441$ hectares, 67.7% of which are formally described as forest land (DGCN, 2001, DGCN, 2002). The most abundant tree species are maritime pine (*Pinus pinaster*) and eucalyptus (*Eucalyptus*

globulus). Classification[4] of the wooded area by dominant tree species (i.e. those species which cover more than 70% of the canopy) provides the following results. Areas dominated by maritime pine or eucalyptus represent 38% and 17% of the wooded-land, respectively. In addition, mixed forests dominated by conifers and eucalyptus represent 21% of the wooded-land. The proportion of wooded area with native species such as oaks (*Quecus robur*, *Quercus suber*) and other broadleaves as dominant tree species is 9%.

The study area contains 40 parishes and all except one of these parishes have collective forest lands. Thus, collective forests cover about 49% of the Baixo-Miño and compromise 73% of its forest land. 36% of the forest communities have a management agreement with the public forest administration for the whole or part of their forest area. The public administration tends to focus on the largest forests, and consequently manages more than half (56%) of the collective lands in this area. Timber production is the main use of the collective lands. Traditional uses, such as support for cattle raising and agriculture are relevant secondary uses (Vence et al., 1995). The amenities provided by forests are increasingly recognised. Thus, during the last few decades an increasing number of communities have set aside wood plots for recreational use.

3.1   Data sources and methodology

The data come from the regional forest administration database, which contains information from harvesting undertaken on collective forests managed under agreement with the public forest administration. Before harvest the civil servants of the regional forest organisation report details of the harvest to inform the timber auctions carried out by administration.

This sample includes the harvests carried out in collective forests in the study area from 1995 to 2001[5] All harvests undertaken involve eucalyptus and conifers. This is not surprising given the tree species in the study area. The average number of stems per harvesting report is small, around two thousand. Information on the age at which the stand was

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[4]Calculations are based on Digital Forest Map of Spain, 1 : 50.000 (DGCN, 2002) using Arc/Info software.

[5]Harvests undertaken for 'extraordinary' reasons were excluded. These include harvests of land affected by fire, or harvests to enable the conversion of land to other uses - e.g. to build community facilities.

clear-cut was unavailable in 14% of official reports. Since the goal is to examine the determinants of the rotation intervals, these observations were excluded from the analysis. Sixteen reports include harvests containing both eucalyptus and conifer trees. When one of these tree species contributed less than 10% to the reported total volume of harvest, it was deleted from the sample (this reduced the sample size from 108 to 94 harvests). Nevertheless, the econometric results will be presented for both sample sizes.

Notice that the data do not contain stands that have not been cut when the harvesting data were collected. Therefore there are no censored observations in this analysis. Information was also collected on the following: the year of harvesting, the name of the collective forest in which the harvest took place, existing tree species in the stand, number of stems harvested, timber volume harvested, and timber prices.

Table 1 presents descriptive statistics for the variables used. A dummy variable was created to represent tree species, thus this takes values equal to one if the harvested trees are conifers and zero otherwise. Foresters from the administration are the ones mainly involved in deciding the intensity of harvesting and the selection of the stands to be harvested, based on professional and market considerations. However, the community members may also affect the intensity of harvesting. Stumpage prices and interest rates are thus expected to influence the rotation intervals. The stumpage price variable used here corresponds to the reserve net price detailed in the administration reports, which takes into account quality, location and potential uses. In addition, a regional annual stumpage price index for pine and eucalyptus was also constructed as an average of the prices in the wood industries based on the Galician Forest Association Reports. These provide a time series of regional net prices for pine and eucalyptus saw, board and pulp wood between 1994 and 2001. There is annual and per species variation in this proxy of stumpage price. As a proxy for the alternative rates of return affecting the cutting decisions, this study used the annual real interest rate on long term loans (10-15 years). These data were provided by the Capital Market Department of the Regional Bank Caixanova. Annual difference in the real interest rate (i.e. real interest rate this year minus the value of last year) was used to account for the impact of short-term variation in this variable.

Differences in landscape patterns between collective forests, which are expected to have an influence on rotation intervals, are controlled by including a set of landscape metrics to assess the level of fragmentation, diversity and clumpiness in the wooded part of these

Table 1: Descriptive statistics of the data used in the estimation

Variable	Mean	Std. Dev.	Min.	Max.	N
Rotation period	31.14	10.77	15	60	94
Species DV = one if conifer, zero otherwise	0.48	0.50	0	1	94
Reported reserve net price per m^3 (Euros)	31.98	6.44	12.14	46.16	94
Market stumpage price index per m^3 (Euros)	49.48	7.49	31.25	64.28	94
Annual difference in interest rate ($IR_t - IR_{t-1}$)	$-.40$	1.01	-2.45	1.08	94
Mean wooded patch size index	0.04	.06	.01	.33	94
Percentage of 'mixed' patches	0.35	0.15	0.01	0.55	94
Habitat contagion metric	0.26	0.14	0.09	0.58	94

forests (O'Neill et al., 1988, Turner, 1990, Botequilha-Leitao and Ahern, 2002). The calculation of these metrics is based in a forest inventory and 1 : 10.000 paper maps of collective forests in Baixo-Miño compiled in 1995 (Vence et al., 1995). Note that these maps have a polygonal format which provides a series of vectors describing the boundaries enclosing a patch (i.e. area under a single land cover category). They contain neither geographical information (such as latitude/longitude data) nor information on areas and perimeters. Therefore, these paper maps were digitised using Arc/Info software. The digitisation process produced the areas and perimeters for digital patch data for each of the collective lands. The associated holding's uses/vegetation characteristics were tabulated and linked to the digital patches to create a GIS polygon formatted data base.

Fragmentation is evaluated by the mean wooded patch size index. This index indicates the percentage that the mean size of the wooded patches occupy in the total wooded area of the holding. Lower values of mean patch size index reflects a more fragmented landscape. As an indicator of forest diversity, the percentage of wooded area not occupied by monoculture stands is used. The Spanish Forest Inventory defines this as percentage of wooded lands occupied by at least two species, i.e. areas in which neither tree species covered more than 90% of the canopy. This criterion is proposed in the forest inventory as an indicator of biodiversity of forestry plantations (DGCN, 2001). This index is used here to assess the probability that the harvested trees are located in mixed tree-species forest patches. In order to control for the spatial configuration of the forests, the habitat contagion metric was used. First, collective forest patches were classified per habitat type. Seven forest habitat categories were considered following the classification established by the Forest National Inventory in the area of study (DGCN, 2001) (see appendix B). Then,

the habitat contagion index was calculated to assess the existence of clusters of patches of identical habitats, i.e. to measure the extent to which patches of the same habitat are aggregated (O'Neill et al., 1988, Li and Reynolds, 1993). See appendix B for details on the calculations of this index. Large values of this index indicate high levels of aggregation of patches of identical habitats.

The variable of interest is the length of time t that elapses from the planting of the trees until they are harvested. Therefore, a duration analysis approach is applied to deal with these data. In duration analysis the key notion is the hazard function which gives the probability that the stand is clear-cut after an interval of t, conditional upon it remaining uncut to that point. The hazard function, $\lambda(t) = \frac{f(t)}{S(t)}$, can be written in terms of the density function –the probability that a stand is harvested at time t– and the survival function– the probability that the rotation is of length at least t– (Cox and Oakes, 1984, Greene, 2003).

Notice that the data do not contain stands that have not been cut when the harvesting data were collected. Therefore there are no censored observations in this analysis, hence in estimating the duration model the density function is used (Greene, 2003). In addition, the earliest age observed in the data at which the trees are clear-cut is 15 (see Table 1). This means that the sample is restricted to stands which have not being cut at or before the age of 14. Based on Hammar and Martinsson (2001), the duration variable to be estimated in this analysis was defined as 'rotation age-14'. This implies that the analysis is conditional on the stands not being harvested up to age 14.

There are several parametric models that assume a given distribution function for the hazard rate, and so for the density function and the survival function. Non-parametric estimates of the survival and hazard rates (as the Kaplan-Meier estimates) were used to provide some guidance on the distribution of the hazard function.

3.2   Results

The Kaplan-Meier estimates of the survival and hazard functions are shown in Figure 2. The shape of the hazard function suggests that the probability of a stand being cut at time t, conditional on its duration up to time t, is monotonically increasing in t. The Weibull and the generalized Gamma models allow for this type of behaviour. The Gamma model

encompasses the Weibull function. Thus, if the extra parameter of the Gamma model, Θ, equals 1 then the Weibull model results. Given that these distributions are nested, the log likelihood ratio can therefore be used to search for the preferred model. The extension of the Weibull model to the gamma generalisation (Greene, 2002, E271-1-E27-6) provided no estimates for the additional parameter, Θ, (absence of convergence). A grip search over Θ showed that the log likelihood was still increasing at values of this parameter equal to forty, suggesting that the data do not support a gamma generalisation. The Weibull model was thus chosen as the preferred specification. Note that this model defines the hazard function as: $\lambda(t) = \lambda p t^{p-1}.exp(\beta'x)$, where λ and p are the parameters to be estimated and x is a vector comprising the covariates. The value of p indicates whether the hazard rate is increasing, decreasing or constant.

Kaplan-Meier estimate for the hazard function   Kaplan-Meier estimate for the survival function
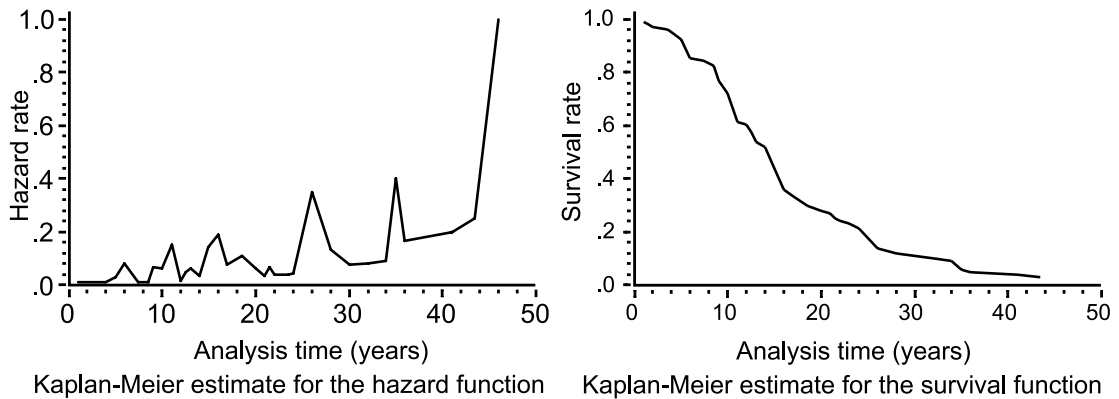
Figure 2: Non-parametric hazard and survival functions for harvesting

Table 2 presents parameter estimates for the determinants of rotation length. As expected, the results show that the dummy for tree species is statistically significant and conifers are expected to have longer rotations (compared to the reference observations: eucalyptus stands). Turning now to the effect of the logarithm of the net reserved prices, the results show that prices have a positive effect, which is fairly significant (10% level) even with the smaller sample. The sign of the coefficient indicates that higher stumpage prices imply longer rotation periods.

Note that this reserved timber price variable may be acting as a proxy for the percentage of harvested logs with high thin-end diameter. It is reasonable to expect that longer rotations produce a higher percentage of logs with high thin-end diameters. A similar estimation in which the reserved price variable is substituted for a regional annual stumpage price index

Table 2: Parameter estimates from the Weibull distribution

Covariate	Coefficient	p-value	Coefficient	p-value
	N=108[a]		N=94	
DV Conifer	0.543***	0.000	0.580***	0.000
Log of reserved timber prices	0.582***	0.003	0.607*	0.060
Annual difference in interest rate	−0.132**	0.006	−0.119**	0.032
Log of mean wooded patch size index	0.465***	0.005	0.427**	0.018
Log of percentage of 'mixed' patches	0.436***	0.000	0.401***	0.001
Log of habitat contagion metric	−0.192**	0.033	−0.206**	0.044
Constant	2.528	0.020	2.215	0.106
λ	0.059	0.000	0.058	0.000
p	2.788	0.000	2.663	0.000
Log Likelihood	−61.799		−57.417	
Wald test (p-value)	0.764		0.766	
p-value[b]	0.000		0.000	

*** Significant at 1% level; ** Significant at 5% level; * Significant at 10% level.

(a): This estimation was computed with several dummy variables for those harvesting reports which contained several tree species but the p-values suggested omitting them from the model.

(b): p-value is from a test of the null hypothesis that the coefficients of the three landscape metrics are jointly zero.

was also computed. Recall that this index was constructed as an average of the regional prices in the different wood processing industries. The coefficient for this variable was also positive, and significant at the 1% level. This suggests some responsiveness of harvesting behaviour to timber price dynamics in the market.

The estimation suggests that higher stumpage prices are related to longer rotation durations. This result does not follow the expectations from the theoretical model. However, Binkley (1981) and Dennis (1989) stated that the sign of the price variable in the harvest decisions is ambiguous. This is because of the trade-offs between income and the non-timber values of the land. An increase in the prices increases the opportunity costs of reserving the stand for non-timber outputs, which may lead to an increased harvest and shorter rotations. However, the higher income derived from increased stumpage prices may imply a higher demand of non-timber outputs and so a reduction in harvest and longer rotations. The results here seem to suggest that as stumpage prices increase, an increased timber income for the rural communities implies less pressure on the forest resources, which allows the public foresters to use longer rotations. In Galicia, where rotation pe-

riods are shorter than in other European countries (harvesting ages of $12-14$ years for the eucalyptus and less than 30 years for conifers are common) the application of longer rotation intervals is necessary to improve the quality of timber (Bermúdez and Touza, 2000).

The coefficient for the annual difference in the interest rates was negative and significant at the 5% level. This is consistent with theory. An increased rate of interest would increase the opportunity costs of delaying the harvest, hence lower harvesting ages are expected.

The three landscape metrics included in the estimation capture differences in landscape-level aspects of collective forests. The coefficient of the mean wooded patch size index is positive and significant at the 5% level. This suggests that the smaller the wooded patches in the holding, the longer the rotations. The percentage of area occupied by mixed tree-species patches is also significant at the 1% level and also positively associated with harvesting age. This means that collective forests with a higher percentage of wooded area of at least two tree species have longer rotation intervals. The habitat contagion metric is significant at the 5% level and it has a negative sign. Thus, lower levels of this index, i.e. lower levels of aggregation of patches of identical habitats, imply higher harvesting ages. A test of the null hypothesis that the coefficients on the three landscape metrics are jointly zero shows that they are jointly statistically significantly different from zero at the 1% level and rejects the null hypothesis.

These findings suggest that in collective forests with small patches, and clusters of patches under similar forest conditions –in terms of tree species, occupation and age structure–, the impact of harvesting on forest non-timber benefits is perceived to be small, and shorter rotation periods are used. However, the positive relationship found between the forest diversity indicator and the duration of the rotations indicates that harvesting ages are longer on more diverse collective holdings, i.e. with a higher proportion of area growing multiple tree species. This result seems to indicate that the role of an individual stand in the provision of the holding's total non-timber benefits, or the negative impact of harvesting, is higher.

A RESET test was used to test the null hypothesis of misspecification in the estimation. This involved including the squares of the predicted values as an extra covariate in the Weibull model. The log likelihood ratio and the Wald tests indicate that the null hy-

pothesis can not be rejected (p-values, 0.764 and 0.766, Table 2). The sensitivity of the results to heterogeneity problems was also considered. A Weibull model with heterogeneity can be estimated assuming that the unobservable variables have a gamma distribution (Greene, 2003). In this analysis, the Weibull model with gamma heterogeneity fails to converge. This suggests that it is not a feasible model, hence there are no problems due to unobserved heterogeneity.

Notice that this econometric analysis has used a retrospective data set, which may lead to problems due to rounded-off durations. The fact that in a few cases a range of ages with one, three or five year differences were reported, instead of a certain rotation age, seems to confirm this possibility. Problems of this type may result in 'heaps' of the duration variable at certain values. An analysis of the sensitivity of the results to this issue, with dummy variables coding for those rotations which were, or were suspected of being, rounded off, suggests that the signs and significance of the variables presented above are robust to heaping effects in the data set. This is consistent with the conclusions from previous duration analysis (Foster and Jones, 2001, Lopéz, 2002).

4   Conclusions and policy implications

The paper developed a bioeconomic forest model in which multi-use issues and spatial interactions between stands were investigated. The importance of these issues for managing forest resources at a landscape scale motivated this research. The simplicity of this theoretical framework provides a coherent and tractable analytical understanding of the optimal solution. Its flexibility will enable further developments to study environmental conservation issues in forest management.

It is shown that optimal harvesting ages no longer follow the traditional Faustmann-Hartman rule when spatial interactions between forest stands are endogenous to the harvest decisions. A basic conclusion therefore is that 'optimal' harvesting strategies at a single-stand scale are not necessarily optimal when a larger spatial scale is adopted and spatial interactions are included in the management decisions.

What is the difference between the single-stand and multiple-stand (i.e. forest-level) optimal harvest rules? When a single stand is managed independently, the Faustmann-

Hartman rule indicates that is the flow of the stand's non-timber benefits that influences when the stand should be harvested (Hartman, 1976). The optimal harvesting rule at the forest level derived here indicates that it is the relative contribution of each stand to non-timber benefits from the overall forest landscape that affects the rotation intervals.

Therefore, a stand's optimal harvesting age is a function of the importance of the stand's non-timber benefits relative to the non-timber benefits derived from the entire forest. Hence, evaluating harvest strategies at a forest-level is a complex process, since the role of each stand in determining forest benefits varies over space and time.

The empirical analysis found that fragmentation, diversity and clumpiness are relevant determinants of harvesting behaviour in Galician collective forests managed by the public administration. Forest managers opt for shorter rotation periods in collective forests with smaller stand's sizes and a higher degree of clustering of stands with similar characteristics (i.e. tree species and age structure). In addition, they apply longer rotations in collective forests with a higher percentage of area with multiple species.

This research has various implications. Firstly, non-harvesting policies may be optimal in those areas which contribute highly valuable environmental goods and services to forest landscape benefits. Secondly, if non-timber benefits increase with the age of the stands and are significant with respect to other uses, it may be optimal never to harvest any of the stands in the forest. Thirdly, the ecological and economic consequences of alternative actions taken at small scales (i.e. stands) on a wider spatial context (i.e. forest landscape) must be allowed for in forest management decision making. An understanding of the environmental and economic goals of forest landscape management is also a necessity.

This conclusion emphasises the importance of research on the relationship between sustainability of forest goods and services and landscape spatial patterns which result from management activities. It also suggests the importance of spatial interactions on optimal harvesting strategies, because the weight or value attached to the forest benefits from a particular stand may differ depending on the interdependence between stands. This implies that optimal harvesting strategies at one scale may not be optimal at a broader scale if the nature or intensity of the spatial interdependence between stands varies.

In Galicia where private lands cover about 98% of the forest land and private holdings, with an average size of 2.3 hectares, represent two thirds of these lands, public planning

of forest landscapes is essential to account both for spatial interactions between stands and preferences of society. In addition, public policies, which encourage coordination and cooperation among forest owners, are necessary to ensure that private owners' actions are consistent with environmental and economics goals set at a landscape, or even at a regional, level.

A fundamental problem for public planning is that existing inventories of single and collective forest ownerships are scarce, as is information about socio-economic characteristics of their owners (Marey et al., 2002, Chas et al., 2002). In relation to collective forest, less than 2% of the communities maintain an inventory of their forests and operate a management plan (Consellería de Medio Ambiente, 2001). The regional government has established, a Programme 'Fomento de ordenación de montes' to incentive forest owners to develop management plans for their forest.

The success of this programme in collective forests could be limited for several reasons (Balboa, 1990, Fernández, 1990, Bermúdez and Touza, 2000, Valdés and Gil, 2001). Demographic aging of the rural population, and absence of forest culture and therefore little involvement in forest policies, are some of the reasons. In addition, collective lands were traditionally used to support agricultural activities in the rural economy. More recently, these lands were in hands of municipality authorities for some decades. Rural communities were excluded from their forests. When the traditional users were finally given the property rights to the forest lands (legislation of 1968 and 1989), the former communal institutions were much weakened, and there was no sufficient ability to organise negotiation and cooperation among community members. This still constitutes a problem today. Management administration and the general assembly work reasonable well in only half of the rural communities and 32% of the communities lack any institution whatsoever for the management of their collective forests (GEPC, 2002). Future research should encompass the analysis of organisational issues in the communities, and their relationship to the socio-economic, environmental and institutional factors surrounding the management of community lands.

The analysis presented here has focused on rotation periods. Investigating the effects on forest management of other practices for maintaining ecological forest values (i.e. enhancing aesthetic values, opening ecological corridors, controlling damaging invasive species, carrying out less systematic thinning, etc.) remains one relevant avenue of research. In

addition, examining restrictions on harvest practices, which could require that a minimum volume remains in the stand or that some trees are left uncut to decay, would also be interesting. Nguyen (1979) and Koskela and Ollikainen (2003) analysed these harvest restrictions in the traditional Faustmann-Hartman static framework. Studying these issues in a dynamic model would allow the implications of adding a temporal dimension to the analysis of environmental incentives for forest owners to be examined. Furthermore, note that management of the forest at an ecologically and economically significant scale involves multiple owners' decisions and frequently operates within a structure of mixed property rights which introduces requirement for coordination and cooperation among adjacent landowners (Sample, 1993, Ellefson, 1997). Therefore, expansion of the analysis here to address these issues is necessary to explore forest policy design at a landscape level.

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Appendix A

Recall that the present-value Hamiltonian and the first order necessary conditions of the theoretical problem are given by equations (7), (8), (9), (12), (13), (14). Applying the Hamiltonian function shown in equation (7), the condition expressed by equation (12), is now

$$\pi(s_1[a_1(\tau_{ij}^+)], ..., s_i[a_i(\tau_{ij}^+)], ..., s_n[a_n(\tau_{ij}^+)])e^{-\delta\tau_{ij}^+} + \lambda_i(\tau_{ij}^+)F_i(x_i(\tau_{ij}^+)) + \theta_i(\tau_{ij}^+) \quad \Rightarrow H(\tau_{ij}^+)$$

$$-\pi(s_1[a_1(\tau_{ij}^-)], ..., s_i[a_i(\tau_{ij}^-)], ..., s_n[a_n(\tau_{ij}^-)])e^{-\delta\tau_{ij}^-} - \lambda_i(\tau_{ij}^-)F_i(x_i(\tau_{ij}^-)) - \theta_i(\tau_{ij}^-) \quad \Rightarrow H(\tau_{ij}^-)$$

$$+\delta[p_i x_i(\tau_{ij}^-) - c_{ip}x_{ip}]e^{-\delta\tau_{ij}} = 0 \tag{16}$$

This cutting condition indicates that the difference in the value of the Hamiltonian just before and just after the cutting of stand i plus the financial opportunity cost of not harvesting this stand should equal to zero. The first-order differential equation associated with the dynamics of the imputed value of timber stock between harvests, equation (8), was derived applying the method of integration by substitution as follows[6]

$$\lambda_i(t) = \lambda_i(\tau_{ij}^+)exp\left\{-\int_{\tau_{ij}^+}^{t} F_i'(x_i(t))dt\right\}$$

$$= \lambda_i(\tau_{ij}^+)exp\left\{-\int_{x_i(\tau_{ij}^+)}^{x_i(t)} \frac{F_i'(x_i(t))}{F_i(x_i(t))}dx\right\}$$

$$= \lambda_i(\tau_{ij}^+)exp\left\{-\int_{F_i[x_i(\tau_{ij}^+)]}^{F_i[x_i(t)]} \frac{1}{F_i(x_i(t))}dF_i(x_i(t))\right\}$$

$$= \lambda_i(\tau_{ij}^+)exp\left\{-ln[F_i(x_i(t))]|_{x_i(\tau_{ij}^+)}^{x_i(t)}\right\}$$

$$= \lambda_i(\tau_{ij}^+)\frac{exp\left\{ln[F_i(x_i(\tau_{ij}^+)]\right\}}{exp\left\{ln[F_i(x_i(t))]\right\}} = \lambda_i(\tau_{ij}^+)\frac{F_i(x_i(\tau_{ij}^+))}{F_i(x_i(t))} \tag{17}$$

At the next rotation harvest point, i.e. at the jump point $t = \tau_{ij+1}^-$, equation (13) implies $\lambda_i(\tau_{ij+1}^-) = p_i e^{-\delta\tau_{ij+1}^-}$. Using this, equation (17), also at $t = \tau_{ij+1}^-$, gives the value of the stock costate variable just after each harvest:

$$\lambda_i(\tau_{ij}^+) = p_i e^{-\delta\tau_{ij+1}^-} \frac{F_i(x_i(\tau_{ij+1}^-))}{F_i(x_i(\tau_{ij}^+))} \tag{18}$$

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[6]If necessary see details in Chapter 3, Section 3.2.1.

The solution of the first-order differential equation for the dynamics of the imputed value of the trees' age, equation (9), at the jump point $t = \tau^-_{ij+1}$, generates,

$$\theta_i(\tau^+_{ij}) = \sum_i^u \sum_j^v \int_{\tau^+_{ij}}^{\tau^-_n} \pi'(s_1[a_1(t)], ..., s_i[a_i(t)], ..., s_n[a_n(t)])e^{-\delta t}dt \tag{19}$$

where u and v are integers, and τ^-_n is the next harvest point in calendar time. Note that τ^-_{uv} equals τ^-_{ij+1}, i.e. stand i following the cutting instant. Therefore, $\theta_i(\tau^+_{ij})$ is related to the non-timber benefits from date τ^+_{ij} to date τ^-_{ij+1} (i.e. stand i's next rotation). There may be points of discontinuity if (an)other stand/s in the forest ecosystem is/are harvested during the following rotation of stand i. For illustrative purposes, an example of how the integral above can be solved in a case in which another stand in the forest, i.e. stand 2, is cut during stand i's following rotation follows. Applying, as previously, the method of integration by parts, the solution is given by[7]

$$\theta_i(\tau^+_{ij}) = \pi[s_1[a_1(\tau^-_{2j})], ..., s_n[a_n(\tau^-_{2j})]]e^{-\delta\tau^-_{2j}} - \pi[s_1[a_1(\tau^+_{ij})], ..., s_n[a_n(\tau^+_{ij})]]e^{-\delta\tau^+_{ij}}$$

$$+ \delta \int_{\tau^+_{ij}}^{\tau^-_{2j}} \pi[s_1[a_1(t)], ..., s_n[a_n(t)]]e^{-\delta t}dt$$

$$+ \pi[s_1[a_1(\tau^-_{ij+1})], ..., s_n[a_n(\tau^-_{ij+1})]]e^{-\delta\tau^-_{ij+1}} - \pi[s_1[a_1(\tau^+_{2j})], ..., s_n[a_n(\tau^+_{2j})]]e^{-\delta\tau^+_{2j}}$$

$$+ \delta \int_{\tau^+_{2j}}^{\tau^-_{ij+1}} \pi[s_1[a_1(t)], ..., s_n[a_n(t)]]e^{-\delta t}dt \tag{20}$$

Considering now the cutting condition given by equation (16). This condition can be evaluated further. Thus, using the expressions for $\lambda_i(\tau^+_{ij})$, $\lambda_i(\tau^-_{ij})$, and $\theta_i(\tau^-_{ij})$, it yields

$$\pi(s_1[a_1(\tau^+_{ij})], .., s_i[a_i(\tau^+_{ij})], .., s_n[a_n(\tau^+_{ij})])e^{-\delta\tau^+_{1j}} + p_i e^{-\delta\tau^-_{ij+1}}F_i(x_i(\tau^-_{ij+1})) + \theta_i(\tau^+_{ij}) \quad \Rightarrow H(\tau^+_{ij})$$

$$-\pi(s_1[a_1(\tau^-_{ij})], .., s_i[a_i(\tau^-_{ij})], .., s_n[a_n(\tau^-_{ij})])e^{-\delta\tau^-_{1j}} - p_i e^{\delta\tau^-_{1j}}F_i(x_i(\tau^-_{ij})) \quad \Rightarrow H(\tau^-_{ij})$$

---

[7]Let's see another example: if forest stand 2 and 3 are harvested during stand i's next rotation, the age costate variable of stand i at τ^+_{ij} is

$$\theta_i(\tau^+_{ij}) = \pi[s_1[a_1(\tau^-_{2j})], ..., s_n[a_n(\tau^-_{2j})]]e^{-\delta\tau^-_{2j}} - \pi[s_1[a_1(\tau^+_{ij})], ..., s_n[a_n(\tau^+_{ij})]]e^{-\delta\tau^+_{ij}}$$

$$+ \delta \int_{\tau^+_{ij}}^{\tau^-_{2j}} \pi[s_1[a_1(t)], ..., s_n[a_n(t)]]e^{-\delta t}dt$$

$$+ \pi[s_1[a_1(\tau^-_{3j})], ..., s_n[a_n(\tau^-_{3j})]]e^{-\delta\tau^-_{3j}} - \pi[s_1[a_1(\tau^+_{2j})], ..., s_n[a_n(\tau^+_{2j})]]e^{-\delta\tau^+_{2j}}$$

$$+ \delta \int_{\tau^+_{2j}}^{\tau^-_{3j}} \pi[s_1[a_1(t)], ..., s_n[a_n(t)]]e^{-\delta t}dt$$

$$+ \pi[s_1[a_1(\tau^-_{ij+1})], ..., s_n[a_n(\tau^-_{ij+1})]]e^{-\delta\tau^-_{ij+1}} - \pi[s_1[a_1(\tau^+_{3j})], ..., s_n[a_n(\tau^+_{3j})]]e^{-\delta\tau^+_{3j}}$$

$$+ \delta \int_{\tau^+_{3j}}^{\tau^-_{ij+1}} \pi[s_1[a_1(t)], ..., s_n[a_n(t)]]e^{-\delta t}dt$$

$$+\delta[p_i x_i(\tau_{ij}^-) - c_{ip} x_{ip}]e^{-\delta\tau_{ij}} = 0 \tag{21}$$

For ease of interpretation, rearranging the terms in the equation above gives

$$\pi(s_1[a_1(\tau_{ij}^-)], .., s_i[a_i(\tau_{ij}^-)], .., s_n[a_n(\tau_{ij}^-)])e^{-\delta\tau_{1j}^-}$$

$$-\pi(s_1[a_1(\tau_{ij}^+)], .., s_i[a_i(\tau_{ij}^+)], .., s_n[a_n(\tau_{ij}^+)])e^{-\delta\tau_{ij}^+} + p_i e^{\delta\tau_{1j}^-} F_i(x_i(\tau_{ij}^-))$$

$$= \delta[p_i x_i(\tau_{ij}^-) - c_{ip} x_{ip}]e^{-\delta\tau_{ij}} + p_i e^{-\delta\tau_{ij+1}^-} F_i(x_i(\tau_{ij+1}^-)) + \theta_i(\tau_{ij}^+) \tag{22}$$

Appendix B

The contagion habitat index is given by (O'Neill et al., 1988, Li and Reynolds, 1993):

$$C = \frac{nln(n) + \sum_{i=1}^{n}\sum_{j=1}^{n} P_{ij}ln(P_{ij})}{nln(n)} = 1 + \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} P_{ij}ln(P_{ij})}{nln(n)} \tag{23}$$

where $P_{ij} = \frac{N_{ij}}{N_i}$ represents the probability of patches of habitat type i being adjacent to patches of habitat type j. This is calculated by dividing the number of patches of habitat type i that are adjacent to patches of habitat type j, N_{ij}, by the total number of adjacencies between patches of habitat type i and all other patch types (including type i itself), N_i. In this equation, $nln(n)$ expresses the maximum possible contagion, when adjacency probabilities between all habitat types are equal (i.e. when, for any random patch in the forest holding, there is an equal probability of any habitat type being adjacent to the patch). The summation, $\sum_{i=1}^{n}\sum_{j=1}^{n} P_{ij}ln(P_{ij})$ is negative, so large values of contagion indicate high levels of aggregation of patches of identical habitats.

Table 3: Habitat classification used in the calculation of landscape metrics

Habitat	Tree species-Occupation-Age structure
Habitat 1: Oak	A pole/mature native deciduous forest of which at least 70% of stems are Quercus and the canopy crown is at least 20%.
Habitat 2: Conifer	A pole (between $16 - 24$ years) or mature (more than 25 years old) conifer forest of which at least 70% of stems are *Pinus Pinaster -Pinus radiata* and the canopy crown is at least 20%.
Habitat 3: Eucalyptus	A pole (between $6 - 9$ years) or mature (more than 10 years old) forest with 70% or more of the canopy as *Eucalyptus globulus* and at least 20% percent tree cover.
Habitat 4: Mixture of oak with conifers, eucalyptus or both; or with chestnuts, acacia or other decidious trees	A mixed forest with *P. pinaster-radiata-Q. robur-E. globulus* or with *Q. robur-Betula spp.-Castanea sativa-E. globulus*, with less than 70% of the canopy under one single species and irregular age structure and canopy crown of at least 20%.
Habitat 5: Mixture of conifers or conifers and eucalyptus	Young conifer (1 to 15 years) or eucalyptus (1 to 5 years) forest; or mixed pole/mature forest of conifers and eucalyptus of which less than 70% of the canopy is *P. pinaster-P. radiata* or *Eucalyptus globulus* and canopy crown is at least 20%.
Habitat 6: Scrub forest	Land with scrubs and disperse trees with crown cover between $5 - 20\%$.
Habitat 7: Riparian trees	Riparian zones with trees species such as alders (*Alnus glutinosa*) grey willow (*Salix atrocinerea*), buckthorn (*Rhamnus frangula*), etc.

Source: DGCN, 2001.