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A GIS site-selection process for habitat creation: estimating connectivity of habitat patches

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Abstract

The paper presents a method that addresses the problem of site-selection for habitat creation involving spatial processes on the landscape scale. It interprets landscape ecological principles, with focus on population dynamics, to specific information required to support a particular decision at each stage of the process. The approach focuses on deciduous woodland with the redstart *Phoenicurous phoenicurous* as an umbrella species for woodland birds and is illustrated within the fragmented landscape of the east midlands area of England. The method requires the use of a Geographic Information System (GIS) to estimate the connectivity of habitat patches. Each patch is assigned a "cost" value that represents the cost of dispersal over a friction surface. The sites are ranked accordingly and, in combination with the spatial context and size, are prioritised in terms of their potential for forming cores for habitat creation. Habitat patches with low cost values, a large area of surrounding habitat and small size were identified as potential sites for expansion in order to satisfy the minimum requirements of the species. The approach is generic, applicable to any species, and despite its limitations it can be a useful aid in conservation planning.

Keywords: Birds; Conservation planning; Connectivity; GIS; Habitat fragmentation; Population dynamics

1. Introduction

Human activities such as agricultural development, commercial conifer afforestation and urbanisation have led to habitat fragmentation, namely loss of the original habitat, reduction in habitat patch size and increasing isolation of habitat patches (Andrén, 1994). These processes result in heterogeneous landscapes, which are composed of more or less isolated, smaller patches of suitable habitat within a matrix of less suitable habitat for reproduction or for providing food and shelter for species confined to the original habitat. The process of landscape change as a result of habitat fragmentation has far-reaching consequences for species survival. In particular, for area-sensitive species, the patches of suitable habitat may be too small to support a breeding pair or a functional social group (Lambeck, 1997), whereas species with low dispersal capacity are unable to recolonize the habitat patches following the extinction of their local populations (Collinge, 1996).

Empirical evidence suggests that the population dynamics for a wide range of organisms living in fragmented landscapes, and particularly for small mammals, invertebrates and birds, follow a pattern of stochastic local extinctions and recolonisations, thus occurring as metapopulations (Opdam et al., 1985; Opdam, 1991; Hanski, 1994). Landscape ecology

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provides the context for studying the effects of the modified landscape pattern on species' population dynamics and hence the distribution and survival of organisms. It considers the crucial role that movement plays in the dynamics of many populations and the importance of habitat connectivity as a determinant of conservation value. The degree to which local populations are functionally connected (*connectivity*) has an influence on the persistence of the metapopulation (Fahrig and Merriam, 1985).

Forest fragmentation is regarded as one of the most serious threats to birds today (Willson et al., 1994). The majority of the investigations on specialised woodland birds show lower frequency of occurrence in the smallest and most isolated woods. This paper presents a methodological spatial approach based on a Geographic Information System (GIS) that (1) identifies the optimal habitat patches that have a greater probability of occupancy and (2) identifies the most effective sites for woodland creation, by selecting the least isolated patches with a greater probability of colonisation. Within this context, the method uses the dispersal model COST and estimates the degree of isolation or inversely the degree of connectivity of habitat patches in the landscape. Sites that are located in a high-connectivity landscape are most suited for species occupation and therefore are given priority status for habitat creation. The method interprets landscape ecological principles, with focus on population dynamics, to specific information required to support a particular decision at each stage of the process. The spatial requirements of a locally threatened woodland bird formed the criteria that informed the procedure. The approach can be an effective tool in conservation planning aimed at enhancing habitat for area-sensitive woodland birds.

There has so far been a plethora of advice for new planting at the level of the individual site (Forestry

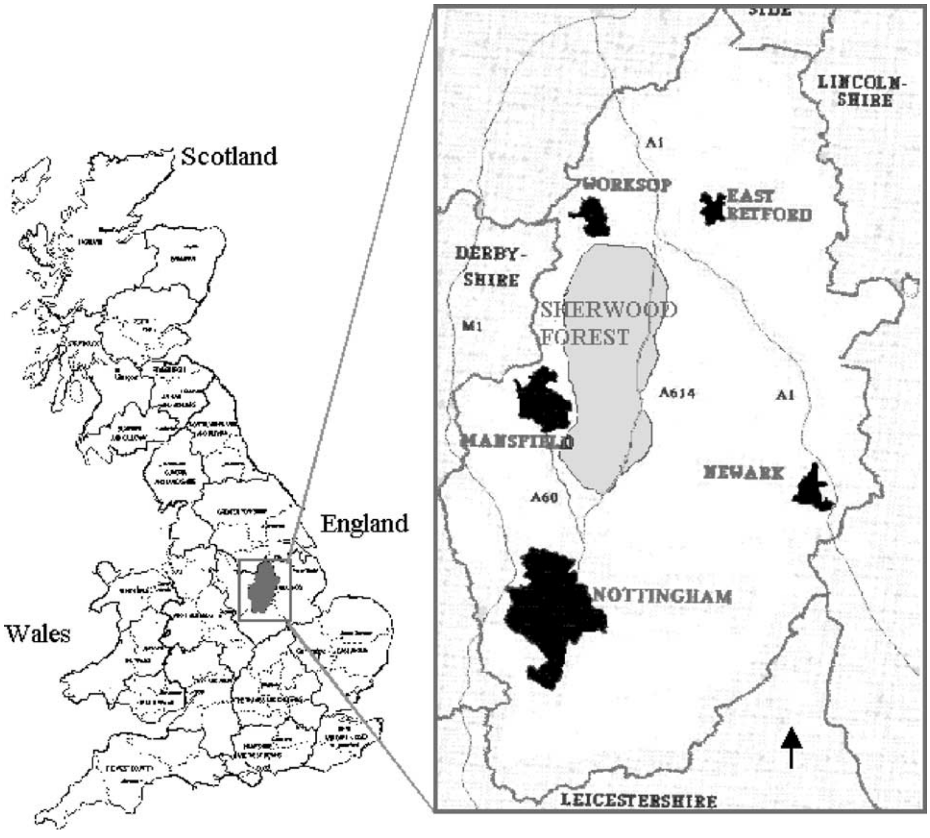

Fig. 1. The Sherwood Forest study area within the boundaries of the County of Nottinghamshire.

Authority, 1994). Little or no account has been taken, in woodland planting schemes in England (e.g. Farm Woodland Premium Scheme), of the wider landscape and spatial parameters such as patch size, differing dispersal distances of species and habitat density in the neighbourhood. This approach employs a large-scale view where habitat patches are not regarded as independent and individual sites, but rather as units connected functionally by spatial processes in a landscape. Site-based physical factors as well as socio-economic constraints were not involved within the remit of this work.

The methodology is discussed using the Sherwood Forest area in England as a case study (Fig. 1). The study area is 101,227 km^2 and much of its native oak-birch woodland is on Sherwood sandstone and acidic sandy soils. Intensification of agriculture, large-scale conifer planting and urban growth have caused fragmentation of the ancient and semi-natural woodland, reducing its total area to 8.7% and leaving 45.5% of the study area entirely as arable land. Although the approach refers to a chosen landscape and to the group of woodland birds, it has general applicability and is flexible. Furthermore, it does not focus on the creation of new patches, but on targeting existing, potential woodland sites for expansion converting arable cropping to deciduous woodland. This would give greater opportunities for local species to disperse into the new woodland and for existing populations to increase.

2. Aspects of population dynamics in fragmented landscapes

The study is largely based on an extensive literature review of theoretical and empirical landscape ecological studies, which examined the impact of patch size, habitat quality and isolation on the survival of fragmented populations, and of woodland birds in particular. The results of these studies guided decision making during the process of site-selection.

Decreasing rate of recolonization with increasing isolation and decreasing rate of extinction with increasing patch area are very robust findings applying to the population dynamics of the vast majority of species in fragmented landscapes (Hanski, 1994). With respect to avian populations, it is acknowledged from the literature that the assemblages of woodland birds and the dynamics of local populations of many bird species in these woodland fragments are affected by the size of the fragments and their degree of isolation or their degree of connectivity. The two latter attributes are often demonstrated as the distance to other woodland fragments or as their spatial configuration (e.g. the number of corridors and/or the amount of habitat around a patch) (Komdeur and Gabrielsen, 1995; Bellamy et al., 1996a). In particular, the probability of occurrence of many woodland birds is shown to be positively correlated with the distance to an extensive woodland area and with the area of the surrounding suitable habitat, often measured within a 2 or 3 km radius of the boundaries of a woodland patch (Opdam et al., 1985; Harms and Opdam, 1990; Hinsley et al., 1994a,b). Immigration from the surrounding landscape may also benefit local populations by reducing the risk of extinction, known as the “rescue effect” (Brown and Kodric-Brown, 1977; Bellamy et al., 1996b).

Moreover, the number of breeding pairs and woodland area are strongly correlated, and the probability of extinction shows a strong negative relationship with both for most woodland interior birds (Verboom et al., 1991; Bellamy et al., 1996b). In particular, the chance of a local population becoming extinct increases rapidly below a population size of about 3–5 breeding pairs (Bellamy et al., 1996b). The occurrence of most woodland birds is dependent upon a minimal area of critical habitat available in order to satisfy foraging needs and territory size requirements (Moore and Hooper, 1975; Lynch and Whigham, 1984; Opdam et al., 1985). It has been suggested that lack of resources and increased level of predation in small patches may cause high mortality of woodland specialists, whereas poor breeding success would further result in high extinction rates (Sparks et al., 1994). In particular, it is shown that for many area-sensitive woodland species the probability of breeding is strongly positively related to woodland area, approaching 100% when 10 ha or more (Hinsley et al., 1994a,b). McIntyre (1995) also found that there is a threshold of 10 ha, above which interior species are present and avian diversity is high and indistinguishable from that in larger contiguous woodland.

Large habitat patches support large populations that have a very low probability of extinction and can persist for long periods of time, provided there is an exchange of at least a few individuals per generation with other populations (Franklin, 1980; Verboom et al., 1993). These large populations may act as sources of dispersing individuals that colonise neighbouring patches, and thus have a stabilising role for other smaller local populations (Verboom et al., 1993). Source populations should comprise at least 20–50 breeding pairs to have a good chance of surviving any kind of stochastic events in the long term (Franklin, 1980).

3. Selection of an umbrella species

Although the approach aimed at the conservation of a range of woodland birds, in-depth literature review has emphasised the need for a single-species approach to address the problem of site-selection. Species differ in their territory size, their dispersal ability and their perception of the landscape pattern. Consequently, they respond differently to the structure of the landscape even within the same taxonomic group (Wiens et al., 1997). Species whose populations are limited by the pattern of landscape attributes such as habitat area or connectivity are most vulnerable to habitat fragmentation. Therefore, species with the most demanding requirements for these attributes, known as umbrella species, may be selected to define the minimum acceptable value for each landscape parameter (Simberloff, 1998). The umbrella species that was selected has such habitat requirements that many other species with lesser or similar requirements and autecological behaviour were also assumed to benefit from the selected sites.

The migratory passerine redstart (*Phoenicurus phoenicurus*), characteristic of the avian fauna of Sherwood Forest, was chosen. The species favours mature, deciduous woodland but has been experiencing a population decline in recent years as a result of habitat change and loss in the breeding grounds (Carter, 1995). Research shows that populations of redstarts are affected by fragmentation, showing strong effects of area and isolation (Opdam et al., 1985; Cramp, 1988). Loss of woodland habitat has led to the restriction of the species in smaller fragments, where competition for the available tree holes for nesting is higher.

3.1. *Habitat requirements of the redstart*

In addition to the information about spatial processes in avian populations, scientific literature findings and consultation with experts about the behaviour of the species provided the framework for the site-selection procedure. Moore and Hooper (1975), in their study of British woods, found that there was a minimum area of about 2.5 ha, below which there was no likelihood of finding a breeding pair of redstarts. However, the greatest occurrence of redstarts was found between 10 and 100 ha (Winspear, 1991). Furthermore, empirical studies have shown that the spatial structure of the surrounding landscape significantly affects patch occupancy and colonisation by redstarts. In particular, the probability of occurrence of the species increased with an increase in the area of woodland within a 3 km radius of the target wood's perimeter (Opdam et al., 1985). It has also been suggested that the redstart has a short dispersal distance (Wilson, British Trust for Ornithology, personal communication). Taking into account issues of population dynamics in fragmented landscapes and the habitat requirements of the redstart, with regard to area and isolation parameters, a series of decision rules were formulated:

- Provided the predecline population density in British woods is approximately 0.6–0.8 pairs/ha (Cramp, 1988), a minimum size of 5 ha was assumed to be sufficient to support a local population of 3–5 breeding pairs.
- Likewise, habitat patches of 50 ha and over consisting of mature deciduous woodland could support a population of 30–50 pairs that would be viable in the longer term.
- The area of woodland within a 3 km radius of the target wood's perimeter is found to be a good predictor of the degree of isolation.
- During the breeding period, daily movements across arable land for feeding and breeding purposes range from only a few hundred metres up to approximately 700 m.

Identification of suitable sites for habitat expansion on the basis of the above spatial criteria would favour the population persistence of threatened redstarts and prevent them from further decline. Other area-sensitive and sedentary species would also benefit from the suggested sites.

4. Site-selection process

There were three stages involved in the site-selection process. These were based not only on aspects of population dynamics but also on the functionalities of GIS.

1. *Identification of the source populations*: The paper develops a method for identifying the best potentially suitable habitat patches that can support breeding populations of redstarts and other species, and function as permanent sources of dispersal. It translates a considerable amount of literature to clearly articulated selection criteria. Habitat suitability was determined by incorporating the factors of patch size, habitat quality and spatial context. Each of these factors was converted to a GIS map layer. The overlay of the layers composed the feasible area of those habitat patches that met the necessary conditions for the occurrence of the species. The results were also validated by observations of biologists familiar with the area.
2. *Estimation of connectivity*: The model COST was used to simulate dispersal from the set of sources and estimate the potential connectivity of any site in the landscape. It took into account not only the distance from the sources but also barriers and the underlying heterogeneity of the landscape, quantifying their effect on dispersal.
3. *Prioritisation of sites for habitat creation*: The relative patch connectivity formed the basis from which to infer how accessible a woodland patch was from the set of the source populations. The effect of patch size on the extinction probability of local populations as well as the role of dispersal from surrounding suitable habitat were further taken into account to predict the occupancy state of patches, and prioritise them accordingly for habitat creation.

In the face of limited scientific information, particularly about distribution of species, it is essential to provide a rational, explicit basis on which to make decisions in a planning procedure. The strategy in this paper was to incorporate as much credible scientific information as possible to create a model of spatial habitat value in a GIS format. The resulting maps of each stage can support decision-making in local land-use planning. Besides the model COST, GIS overlay and classification operations were the backbone of the analysis. In particular, classifications based on Boolean logic were widely used; areas not fulfilling the required conditions were excluded from further consideration, while the remaining areas that satisfied certain criteria established the suitable locations. In addition, operations for describing the landscape pattern such as estimation of the area of individual patches and measurement of the spatial context were carried out.

IDRISI for Windows (version 1.0), a raster-based software, was used and a 20 m resolution was defined. Digital data of the land uses, ancient woodland and County Wildlife Sites were provided by Nottinghamshire County Council. Of the land uses data, the layer of deciduous woodland was isolated for the purposes of the analysis.

4.1. Identification of the sources

4.1.1. Patch size and isolation

Woodland patches of at least 50 ha were the first to be identified, as they would have a greater likelihood of being occupied by viable breeding populations of redstart and would provide a large number of dispersing colonists for local recolonizations (Urban and Shugart, 1986; Knaapen et al., 1992). Such large woods would most likely support breeding populations of other woodland specialists (e.g. nuthatch, treecreeper, marsh tit and long-tailed tit) that require large patch sizes of woodland habitat (Fuller et al., 1995). Moreover, patches large enough to sustain a viable population of a given specialist species should also have large populations of generalist species (e.g. chaffinch, blackbird and blue-tit) which are less demanding in habitat patch size (Fuller and Warren, 1991). These woods were also assumed to comprise a good habitat, since large patches generally tend to have a greater diversity of habitats (Bellamy et al., 1997).

Although a larger area is less affected by isolation (Harms and Knaapen, 1988), immigration from the surrounding landscape to the sources would still remain important in order to greatly minimise rare cases of local extinctions (Harms and Opdam, 1990). Hence, the area of deciduous woodland within a range of 3 km of the identified large woods was estimated as a variable that determined their degree of isolation. The probability of persistence of these populations was taken proportional to the amount of the surrounding woodland.

4.1.2. Habitat quality and isolation

It has been found that good habitat quality can also improve the chances of population persistence through favouring greater reproductive success, reducing mortality, and/or improving the chance of successful settlement by immigrants (Bellamy et al., 1996b). Research has also shown that habitat quality and area are to a certain degree compensatory in their effects on bird occurrence (Whitcomb et al., 1981). Moreover, the negative impact of a small patch can be offset by good habitat quality and the total area of suitable woodland in the region, providing that the patch size is above a minimum critical area (Lynch and Whigham, 1984). Hence, remnants of ancient oak-birch woodland acquiring a minimum patch size of 10 ha that would ensure a high probability of occurrence of redstarts were also identified as potential sources. Likewise, mature deciduous woods designated as County Wildlife Sites (CWS), due to their structural and floristic characteristics, of minimum 10 ha were also chosen.

Because of the smaller size of these patches, greater importance was given to the spatial context as a compensatory factor. Thus, only CWS and ancient woodland with an amount of surrounding habitat higher than that estimated for the large woods were regarded as sources. A larger amount of neighbouring woodland would further enhance recolonization, ensuring a good prospect for these sites to sustain viable redstart populations.

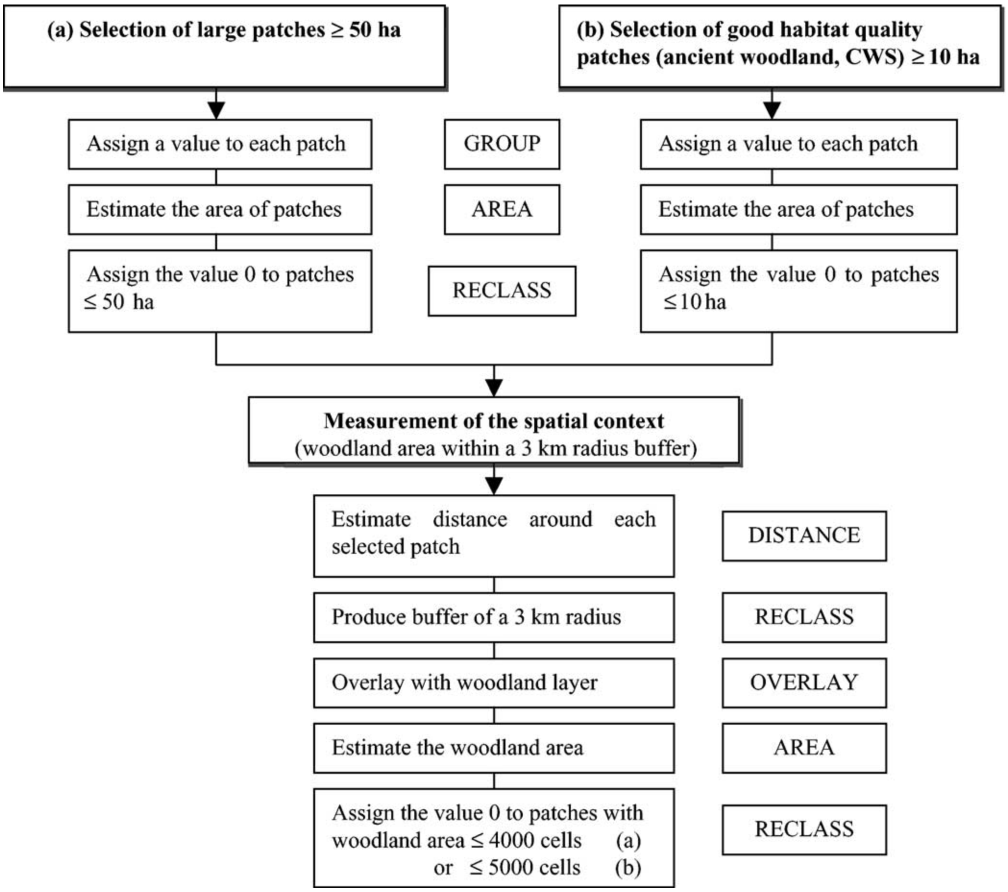

Fig. 2. Steps of the GIS analysis for the identification of the sources.

4.1.3. GIS approach to the identification of the sources

4.1.3.1. Area measures. The GROUP model was used for the layers of deciduous woodland, ancient woodland and CWS in order to estimate the area of individual habitat patches. GROUP finds polygons in a layer by identifying contiguous groups of cells holding the same value, and assigns a unique value to each group. Area analysis gave the size of each woodland patch by measuring the number of cells of each of these groups. Polygons with an area smaller than 50 ha (or 1250 cells) regarding the layer of deciduous woodland, and polygons smaller than 10 ha regarding the layers of ancient woodland and CWS, respectively were eliminated (Fig. 2).

4.1.3.2. Spatial context measures. In order to estimate the amount of woodland within a 3 km radius, the DISTANCE model was initially applied for each of the selected potential sources. DISTANCE calculates the Euclidean distance of each cell to the nearest of a set of target cells as specified in a separate layer. A buffer zone of a 3 km radius was produced around the selected patch in order to measure the area of the surrounding woodland (Fig. 3a–c). In estimating the spatial context, the Euclidean distance was applied rather than a distance operator that integrates frictional effects, because relevant studies used the metric distance in demonstrating the significance of the woodland area within 3 km as a good predictor of isolation.

A range of values of woodland area in the 3 km buffer was found for each of the three groups of sources falling into three categories of low, medium and high values. In order to ensure a high chance of colonisation, only sites greater than 50 ha and surrounded by a comparatively larger amount of woodland within the 3 km radius, larger than 4000 cells or 160.52 ha, were selected and the rest were rejected through a Boolean classification. The threshold value is not an absolute figure, established in the literature, so it was considered necessary to employ a relatively high value of woodland area to further secure the choice of woods as the appropriate ones. The area value of 4000 cells (at 36% of the maximum value) was adopted from a wide range of values with a minimum of 587 cells up to 11,079 cells. However, a higher threshold value, of 5000 cells or 200 ha, was chosen for the smaller patches of the County Wildlife Sites and ancient woodland.

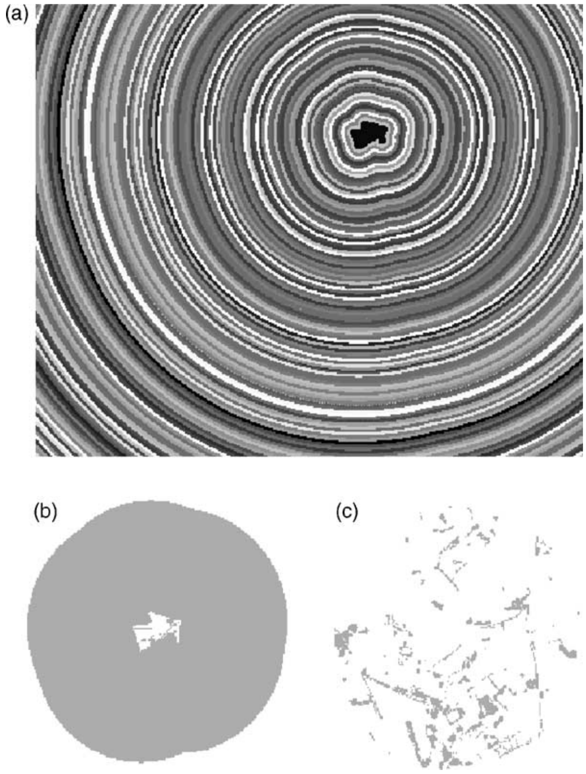

Fig. 3. Stages of estimating the spatial context. (a) Calculation of the distance of all pixels of the image; distance values are estimated radially from the edges of the target wood, shown in black. The rings join areas with the same distance; (b) production of a buffer of a 3 km radius; (c) production of the buffer zone containing the deciduous woodland.

The layers depicting the three kinds of source woods that satisfied the criteria of patch size, habitat quality and spatial context, respectively, were overlaid to produce the final map representing all deciduous woods which could function potentially as permanent sources of dispersing colonists to the surrounding woodland patches (Fig. 4). The potential occupancy of these patches is partly or entirely dependent on the distance from the sources and on the presence of immigrating individuals (Brown and Kodric-Brown, 1977).

4.2. Estimation of connectivity

Landscape ecological research has shown that landscape connectivity should not be expressed solely in

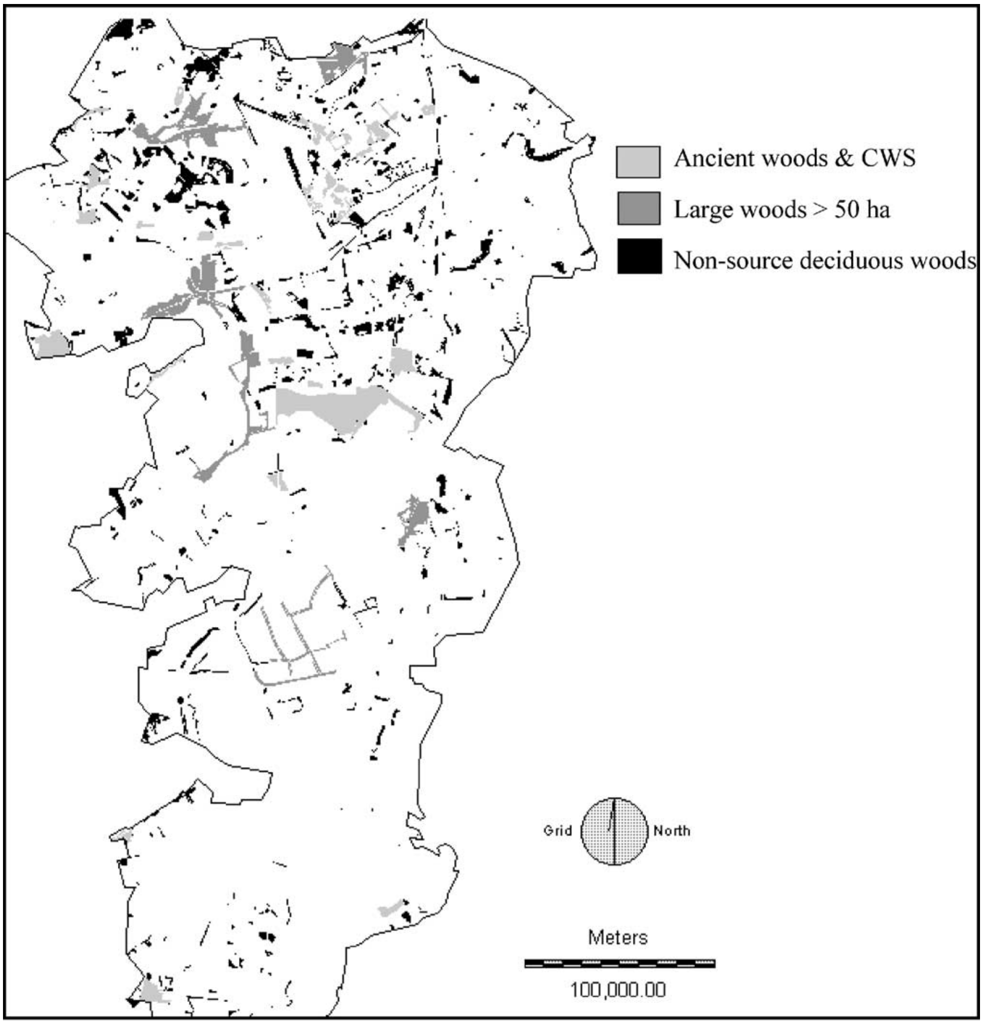

Fig. 4. Deciduous woods of large size and good habitat quality (ancient woods and County Wildlife Sites) were identified as "source" populations of redstart.

terms of physical distance or spatial configuration, but should also incorporate the effect of the landscape matrix on the dispersal of species (Forman and Godron, 1986; Hof and Flather, 1996). This derives from the fact that landscapes are heterogeneous, thus encompassing various types of landscape elements that pose different resistance to the dispersal flow. Thus, the concept of landscape resistance is introduced, which represents the difficulty of crossing a landscape element or land use type for the individuals of a species. In this perspective, connectivity constitutes the degree of ease with which a species moves through the landscape (Taylor, 1997).

Habitats that are less suitable for dispersal have a higher resistance value. Birds hesitate to fly over non-habitat, and dispersal mortality can be higher in open landscapes (Verboom et al., 1991). Opdam et al. (1984) argued that a small stretch of open land could restrict the immigration rates of woodland dependent birds far below the actual distance that they could cover according to their flying abilities. Regarding linear landscape elements, Willis (1974) also suggested that the width of a major river could be a barrier to birds; some birds cannot fly even across a small water gap. With respect to roads, Bennett (1991) in his review claimed that a broad highway could constitute a functional barrier to sedentary woodland birds.

The classification of the different types of landscape elements according to their impedance to dispersal was carried out on the basis of existing studies (Knaapen et al., 1992) and knowledge of the ecological requirements and behaviour of the redstart. Thus, the suitability of each land use and the degree of its resemblance to the optimal habitat of redstarts provided the context for assigning landscape resistance values (Table 1). Hence, deciduous woodland, being the most suitable and preferred habitat of the redstart and other woodland birds, was assigned the least resistance value 1, while mixed and conifer woodland were attributed the values 2 and 3, respectively. Arable land was assigned a high resistance value of 10, and urban together with derelict areas, a high resistance value of 20. These landscape elements comprise a significantly more inhospitable habitat for the redstart, thereby impeding its dispersal. Rivers, lakes, roads and railways were regarded as relative barriers to dispersal, i.e. movements between populations on either side of the barrier are infrequent but do occur, and thus they were given the highest resistance value of 25 (Dawson, 1994).

Table 1
Classification of the landscape elements according to expected landscape resistance value

Landscape elements	Landscape resistance value
Deciduous woodland	1
Mixed woodland	2
Conifer woodland	3
New plantations	3
Bracken/grass heath with mature trees	4
Rough grassland with mature trees	4
Permanent pasture/meadow with mature trees	4
Amenity grassland	5
Bracken/grass heath with scrub	5
Bracken/grass heath with heather	5
Bracken and/or grass heathland	5
Rough grassland with scrub	5
Rough grassland including marshland	5
Permanent pasture/meadow with scrub	5
Permanent pasture and meadow	5
New and/or improved grassland	5
Cultivated arable land	10
Allotments	10
Permanent horticultural crops	10
Urban	20
Mineral workings, active pits, tips and spoil heaps	20
Relative barriers	
Open water—lakes, ponds	25
Rivers	25
Roads	25
Rail	25

4.2.1. GIS approach to estimating connectivity

The land use map was reclassified by assigning a new value to each land use according to its suitability as habitat for redstarts and other birds of mature deciduous woodland. In this manner, the original 25 categories were reduced to 8, and the resulting map represented the landscape as a mosaic of various types of landscape resistance, with greatest resistance in areas of inhospitable habitat which also reflected the occurrence of barriers (Fig. 5).

The model COST (Cost Grow) produces a graphical display of the ecological distance between the source populations and the local populations. It requires a map of the core areas "sources" and a friction surface map (Fig. 6). The operational result of COST is to generate a distance/proximity surface (also referred to as a cost surface) where distance is measured as the least cost distance or the least effort in moving over a friction surface. COST uses a growth algorithm that can accommodate complex friction surfaces as well as absolute barriers to movement. The output of COST attributed a value to each cell and in effect to each wood representing the cost of dispersal of an individual to reach that wood. The unit of measurement is "grid cell equivalents" (gce). A grid cell equivalent of 1 indicates the cost of moving through a grid cell when the friction equals 1. A cost of five gce's might arise from a movement through five cells with a friction of 1, or one cell with a friction of 5.

Fig. 7 shows the output of a radial dispersal simulation from each source patch throughout the friction surface. The colour gradation from black to dark and light grey represents a range of cost values from 0 (black) to 1166 (light grey), where the value 0 corresponds to the sources. The cost of a dispersal route increases with the distance travelled and in landscapes with high resistance value. The light grey areas in the south and north-east of the study area have cost values

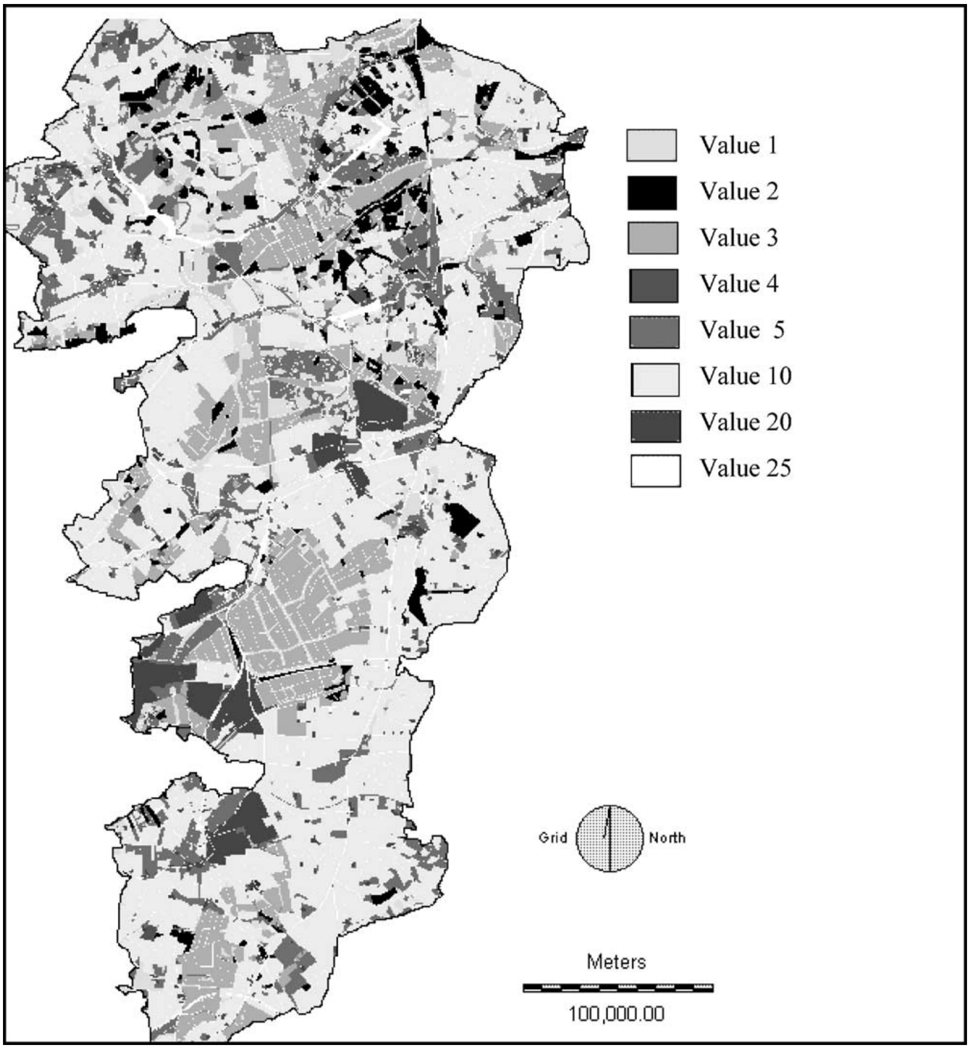

Fig. 5. Friction surface image. The variation in the grey colour shades indicates the different groups of landscape elements with a corresponding landscape resistance value (for the classification of the landscape elements see Table 1).

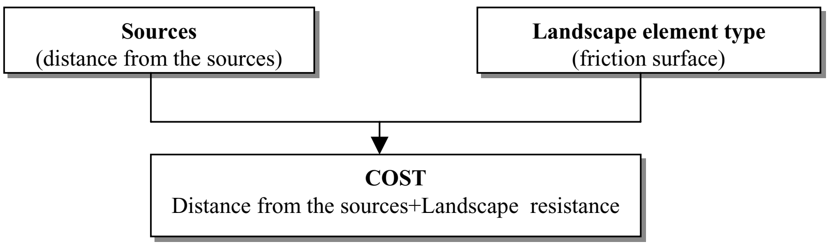

Fig. 6. The cost of each patch is estimated as the sum of the distance from the set of the source patches and of the landscape resistance of the cells in the intervening matrix.

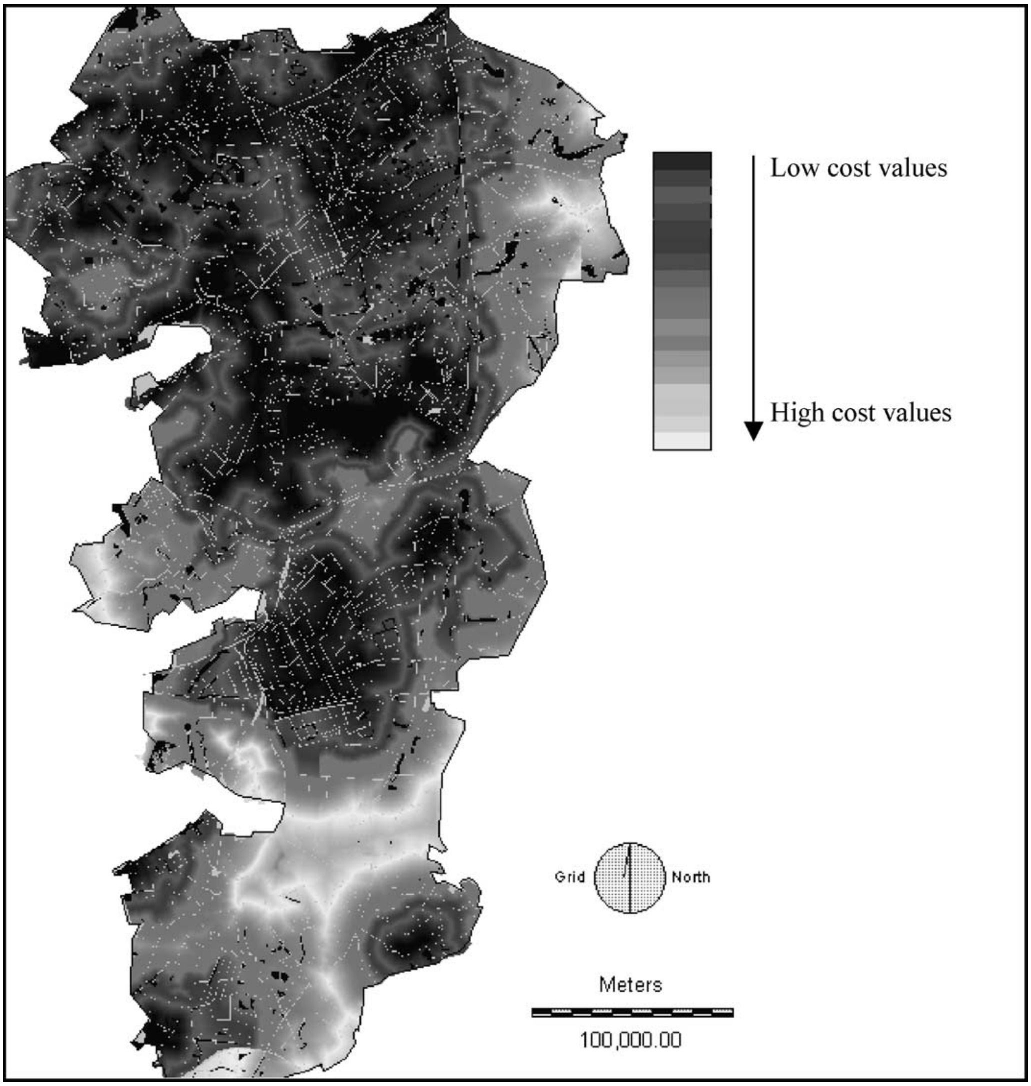

Fig. 7. Cost surface image. Cost values are defined radially from the sources and are demonstrated as concentric rings that enclose the sources (black areas in the centre of the rings). The gradation of the shading from black to dark and light grey indicates the range of cost values from low to high, and the potential of patch occupancy from high to low respectively. Non-source deciduous woods are illustrated as small, distinct, black patches with well-defined boundaries, scattered throughout the cost surface.

greater than 1000. The location in the south, which is dominated by large expanses of treeless arable landscape and built-up areas represents a considerable resistance to species dispersal. This is also shown in the friction surface map where this area corresponds to types of landscape elements with resistance values 10 and 20. The chances of a successful dispersal and subsequently of patch occupancy are expected to be particularly low in this part of the study area.

Fig. 7 also shows the groups of woodland patches connected by areas of similar cost. The difference between ecological and real distance was verified by the fact that some woods, although they were located at the same distance from the sources, were found to have different cost values and vice versa because of the landscape effect (e.g. patches at 40 m distance had cost values 2 and 45, respectively, whereas on the other hand woods with cost value 84 were situated at 720 and 220 m distance from the set of sources).

4.3. Prioritisation of sites for habitat creation

The ranking of all sites by COST determined their degree of connectivity, guiding their prioritisation for woodland creation. Woods with low cost values, being characterised by high connectivity, would be highly accessible to the source populations and therefore would have a high chance of being colonised. Yet, a cost threshold value was considered necessary to be drawn among the lower cost values, in order to identify the least isolated woods and prioritise the sites of the study area accordingly. Connectivity of the potential target woods would also be accomplished by being within the dispersal distance of the redstart from the sources. Therefore, two values were estimated for each site: the cost of the dispersal of an individual to reach that wood and its distance from the sources.

The comparison of the cost and distance values indicated that the physical distance alone could not account for the functional isolation of the habitat patches. Therefore, suitable sites for habitat creation should be identified primarily by their low cost values, and their selection could then be refined by taking into account their metric distance from the sources. It was suggested that woods with small cost values but also with corresponding distance values less than 700 m could be regarded as the least isolated. It was found that all woods with low cost up to the value of (100) were also located within an approximate distance of 700 m from the sources, whereas sites with cost values just above (100) were situated at long distances far beyond the dispersal distance. As a result of employing a threshold cost value rather than a distance value as a primary determinant for isolation, some sites with distance less than 700 m were not selected because of their high cost. The use of the metric distance above was only made to help define the threshold value as opposed to being used as a predictor of isolation on its own right.

After having determined the threshold cost value, two zones of low and high cost for the dispersal of redstarts could be clearly distinguished (Fig. 8). All the sites in the low cost zone, because of their close proximity to the sources and relative low landscape resistance, would be easily accessible to dispersing individuals and thus would mostly benefit from expansion. Therefore, they were targeted as first priority sites for habitat creation. On the other hand, the sites in the high cost zone are characterised by a greater degree of isolation and would thus support local populations with a lower probability of recolonization. These woods were regarded as second priority sites. However, their degree of isolation would still vary depending on the cost values, allowing further refining of their priority status.

4.3.1. High priority sites

Patches of the low cost zone, larger than 5 ha and managed for good habitat quality, may support local populations of sufficient size (of at least 3–5 breeding pairs) that have low extinction rate. Thus, further enlargement of these sites was not regarded as necessary for the persistence of these populations. On the other hand, patches less than 5 ha can accommodate only small local populations of redstarts and other woodland birds that have a high extinction rate due to stochastic events (Urban and Shugart, 1986; Verboom et al., 1991). The survival of these populations is highly dependent on dispersal from the surrounding habitat and therefore the need to enhance these vulnerable populations is much greater. Therefore, among patches with low cost only those smaller than 5 ha were selected for expansion at an initial stage.

Because the colonisation probability and the occurrence of woodland birds and redstarts is positively related to the spatial configuration of habitat patches, the amount of deciduous woodland within a 3 km radius of the selected woods shaped the next rule in the selection process. The application of this criterion would further reinforce the assumption that the identified woods which fulfilled all the above criteria, being also located in a high-value neighbourhood, would support local populations that have a greater chance of recolonization. Immigration of individuals to these target populations could take place not only from the identified permanent sources but also from neighbouring populations. Thus, once the species has settled in these woods, enhanced species recruitment through frequent recolonization into the sites, would

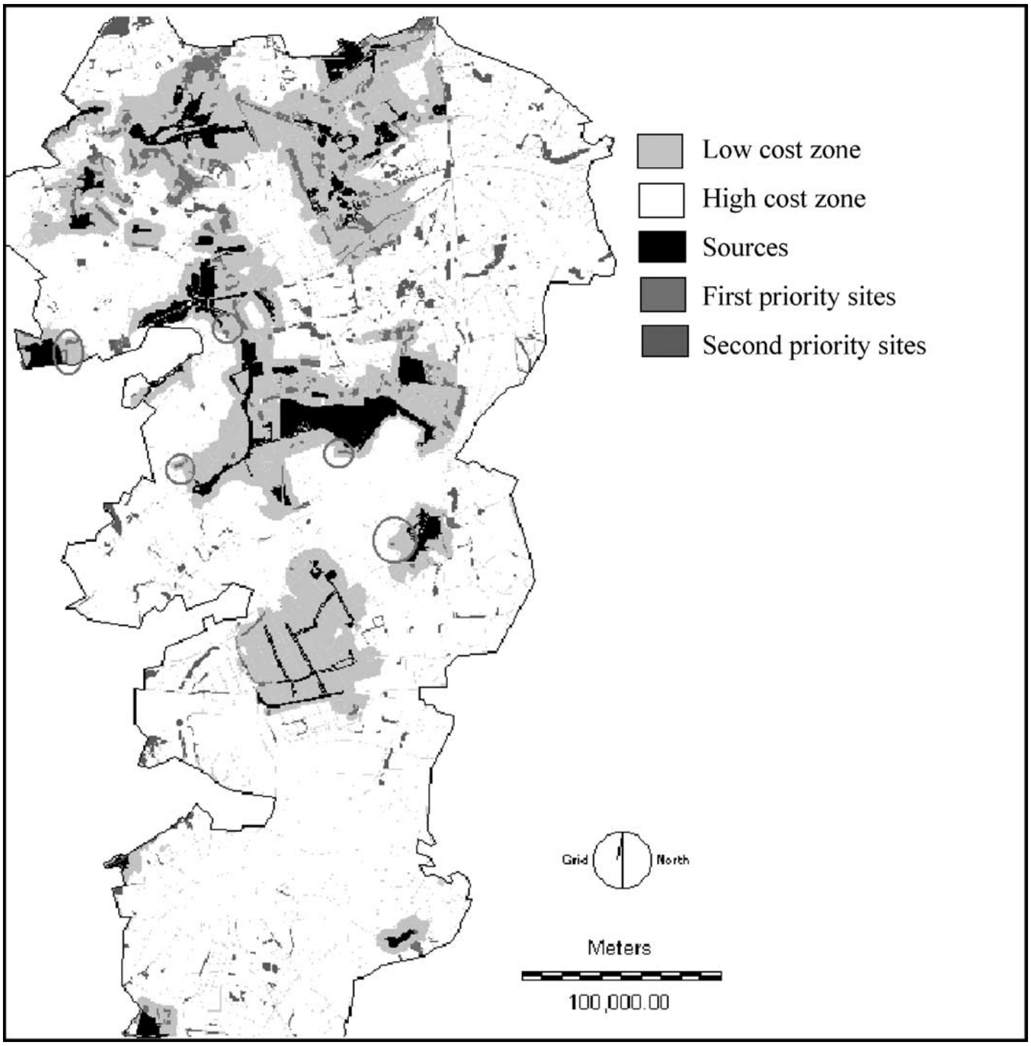

Fig. 8. Prioritization of sites for new planting. Sources are shown in black; the grey area around the sources indicates the low cost zone and the white area the high cost zone. The darker grey patches within the low cost zone are the first priority sites for habitat creation; those in circles represent the high priority sites. The patches within the high cost zone are the second priority sites.

buffer possible local extinctions ("rescue effect"). The greater the area of suitable woodland within the 3 km buffer, the lower the probability of local redstart populations becoming extinct. Those patches, which were found to be surrounded by a large amount of deciduous woodland (larger than 4000 cells) were finally selected and were identified as high priority sites for habitat creation. It is expected that by enlarging these sites to the minimum size required maximum benefits might be gained for the persistence of the local populations.

5. Discussion

This paper presents the development of a methodology for identifying and prioritising potential sites for habitat creation, using GIS technology (Fig. 9). It describes a system that can support local land-use decision making by structuring the best available knowledge about habitat processes and species response in a fragmented landscape into the quantification of spatial parameters. The method identifies

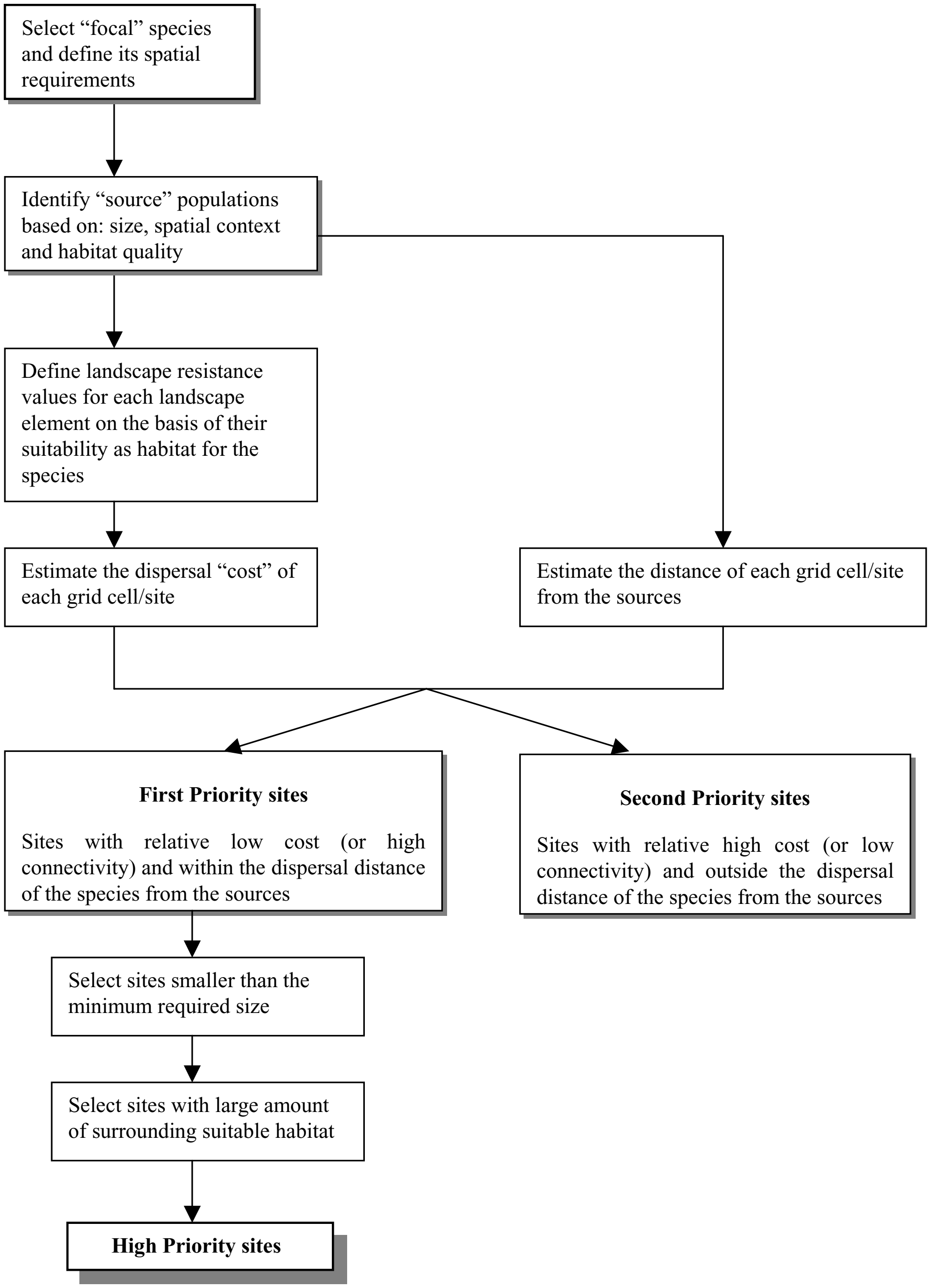

Fig. 9. Process overview.

the best potential habitats ("sources") and also sites for new habitat considering ecological guidelines of minimum patch, maximum threshold distance, certain landscape configuration and the suitability of the landscape to species dispersal. It adopts a target species with well-known requirements since the above issues can only be addressed with the available knowledge as a single-species approach. Population dynamics were introduced by the spatial requirements of the redstart and were translated into specific conservation objectives that governed the selection of the sites.

Estimating connectivity is an important part of the site-selection process. In viewing landscape connectivity in either empirical or theoretical studies, the effect of the distance between populations on dispersal as well as the amount of habitat around a patch (or number of corridors) is usually taken into account but rarely the effect of the landscape mosaic on the dispersal of individuals. The strength of this approach in estimating connectivity lies in the premise that the landscape is heterogeneous; namely, it is not regarded as a binary mosaic where habitat patches are embedded within an ecologically neutral matrix but comprises a variety of habitats and barriers of varying degrees of suitability to different species. The concept of landscape resistance reflects the heterogeneity of a landscape and is applied as a friction parameter that decreases or enhances connectivity.

New planting at the suggested sites as well as enhancing breeding populations of redstarts by decreasing the rate of extinction, would also favour other area-sensitive woodland interior birds that may someday be at risk. Woodland generalist species, not typically confined to the edges of small woods, would also benefit. Moreover, enlargement of the woodland sites that are located at a short distance from the species pool should also increase the probability of initial colonisation in the establishment phase of a range of woodland specialists which have relatively short dispersal distances (Opdam et al., 1985).

The method can also be applied to species other than woodland birds. Sufficient existing knowledge of the autecological characteristics of an umbrella species will be necessary. It should also be possible to formulate its spatial requirements in terms of threshold distances and minimum area. Generalisation of its spatial requirements into guidelines for site-selection depends on the spatial scale and on the species group that can be represented by the species concerned. The approach can be applied to each scale level depending on the species; the grid size must be selected according to its dispersal distance. The flexibility of the GIS system enables precisely such a change to take place.

5.1. The role of GIS in site-selection

The process applied is systematic, flexible and reproducible. Moreover, the study has demonstrated the utility and feasibility of using GIS for addressing the issue of site-selection for habitat creation. The use of GIS enhanced the capability to view woodland conservation within a broader landscape context, rather than just on individual sites (Nikolakaki and Dunnett, 1998). The easy and quick implementation of overlay and Boolean operations made it a very useful tool in the process. Landscape and habitat requirements were fed in as GIS layers and were overlaid accordingly. GIS was also capable of calculating attributes by means of spatial analysis, such as area of individual patches and their distance from other woodland patches.

One of the major advantages of using GIS was the application of the model COST for estimating landscape connectivity without relying explicitly on the physical distance. Moreover, COST, by estimating the potential cost of dispersal for each cell, produces a wide range of values, and the outcome map represents the potential connectivity of any site in the landscape. This gradation of COST values allows the comparison among sites, and thus ranks the potential suitability of all sites for woodland creation within the study area prioritising them accordingly. Moreover, the spatial context constitutes an additional criterion for identifying the most potentially suitable sites among those fulfilling the criteria. In this way, the approach does not adopt a classification based on the classical Boolean logic, where an area is either accepted or rejected given a threshold value. Regarding the second priority sites, they could constitute part of an ecological network where creation of corridors could reduce their isolation. The exploration of this scenario formed part of a later work.

In relation to the threshold cost value, although there was a clear distinction in this study, with cost values below 100 also corresponding to very low distance values (<700 m), this might not have been the case for a different cost outcome. In such a case, the amount of available funding for implementing such a project could determine the threshold value, above which sites could be disregarded. Habitat creation could start at the sites with the lowest cost values continuing at patches with relatively higher cost values in ascending order, until the full expenditure of the funding.

A point that should also be made is that extending habitat patches alters the mosaic around the woodlands resulting in changing values of the variables (such as area of woodland within 3 km). These alterations should be included in the modelling and the computation should ideally be an iterative process. With regard to landscape resistance, because it is a theoretical variable, which thus far has not been studied or measured as such, its estimation was based on sensible assumptions and literature findings for woodland birds. Given that the difficulty to cross a landscape element depends on the species concerned, it is possible to modify the landscape resistance values. A more precise definition of the resistances requires collecting field data on the dispersal rate of the studied species between habitat patches. However, it would be beneficial if the results could be generalised and applied to "ecological groups" of organisms with a common ecological profile.

Though the approach is based on assumptions, it allows the selection of the core areas that can represent the backbone of a strategic ecological network as well as the identification of those patches that are more likely to receive colonists from the sources. The identification of these areas could direct mitigation conservation funds. The method can be used as an initial step in the process of site-selection on a large scale that can then guide more detailed field-based assessments. Adding other factors as a series of overlays such as soils, soil moisture or aspect constraints could further refine the prioritisation procedure. Moreover, overlay with data layers of zoning and pending projects could be used to assess future threats for the identified habitats. In general, the model provides a simple approach that can be a useful tool in nature conservation and landscape planning, integrating population dynamics and spatial relations in GIS facilities for site-selection endeavours.

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