

FOREST MANAGEMENT AND BIODIVERSITY CONSERVATION LANDSCAPE ECOLOGICAL ANALYSIS OF WOODED LANDS IN SOUTHERN TOSCANA (ITALY)

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ABSTRACT

The research presented addresses the question of sustainability of coppice management for biodiversity at the large scale. Landscape pattern was analysed at different spatial scales and the scale-dependent relationship between habitat distribution (pattern) and birds habitat selection (process) was explored, by means of already available data. Hypotheses were derived on the effects of coppice management on real landscapes pattern, both by generating management scenarios according to different constraints and by projecting future outcomes of a real management plan. In the latter case also an attempt was made to infer the possible effects on birds habitat availability. Coppice management seems to enhance structural heterogeneity in the forest landscape studied, however this appear to affect birds (indicators of habitat quality) in a contradictory way.

Keywords: Biodiversity, Forest management, Landscape ecology, Grain, Extent.

INTRODUCTION

Ecosystem approach to forest management and cultivation (Hunter 2001, de Philippis 1961, Susmel 1990) not only widens the scope of forestry studies to components other than trees and site features, but puts forests within the context of the landscapes they belong. Such an approach is steadily gaining momentum both in the scientific and the technical communities in Italy too.

This research springs from the precise request of answering to an applicative question rather than testing scientific hypotheses. Such a question was that of organising and interpreting available data so to assess the sustainability for biodiversity of coppice management. The data set, mainly comprised of cartographic data and suffering from the lack of analytical information on bird distribution, life traits and population dynamics, which is chronic for Mediterranean environments, represents however the best possible knowledge base available to the majority of Italian forest technicians taking planning, management and silvicultural choices.

The work as a whole was articulated within a series of independent studies, linked by the idea that if forests production function ought to conciliate other functions (Pavari 1933, Patrone 1970, de Philippis, 1970, Simberloff 1999, Hunter 2001), then the need arises for objectively assess the impact of forestry activities on various ecosystem processes. Among such functions biodiversity maintenance, which in the past was only invoked by forest ecologists and naturalists, is now one of the crucial issues on the agenda of the Pan European Process for sustainable forest management. The first two studies of this series, more speculative in their character and presented in detail in Mairota *et al.* (2006), will only be briefly outlined here as they are preliminary to the third study of which a complete account is given in this paper.

According to hierarchy theory (Allen and Starr 1982, O'Neill *et al.* 1986, Holling, 1992) resource pattern at each level of scale depends on factors with both larger and narrower space-time domains, individual landscape element's both structure and properties depend on those of its components (that can be detected at larger scales, high resolution) and on those of the landscape context (at a smaller scale), and individual species relationship with habitat components depends on factors that are different at each scale. Moreover habitat selection by animal organisms implies responses to the patch structure within a number of hierarchical levels (Wiens, 1985). Therefore, in the first study a hierarchical set of spatial scales (Kotliar and Wiens, 1990) was identified that was relevant to forest managers perspective (figure 1). Resource pattern was described at each level of scale using appropriate attributes and paying attention to their mutual consistency, and implications were highlighted that are critical to the maintenance of biodiversity in the landscape. This description has shown that socio-economic processes attaining to relatively high levels of the hierarchy (regional, land management) have resulted in spatial explicit landscape changes at lower levels (vegetation, forest stand). Such changes take the form of the loss of compositional and structural heterogeneity and of the lowering in the degree of contrast of forest landscape matrix, at the silvicultural level. They ultimately reverberate at the large scale in terms of decline of environmental quality, as confirmed by the relatively low values of rarity and environmental quality indices relevant to the avian component of biotic community, which instead are higher in more heterogeneous parts of the study area. In addition forest managers' and birds' landscape perspective were compared and an attempt was made to assess whether forest managers' perception limits (grain and extent) of landscape heterogeneity (on which management is based) encompasses the limits of birds' resource-habitat perception. This appear to be true, as long as a composite set of species is considered rather than a single species (table 1). Moreover, landscape configuration features selected at different scales appear to be different by different bird category. Thus it was inferred that coppice reinstatement might be a viable strategical planning option for the long-term biodiversity maintenance for this area.

The second study attempted to exemplify a possible way of reasoning for tactical and operational planning purposes starting from management issues emerging from larger scale considerations. The feasibility of coppice reinstatement as an option was tested confronting it, via hypothetical scenario building, with the issue of sustainability of forest management, based on the consideration of spatial requirements (e.g., adjacency constraints, corridors and patches of mature habitat, accessibility) derived from bioecological, socio-economical and technical instances. Scenario hypotheses were formulated relevant to different forest management tactics by means of an iterative rule incorporation process, based upon a number of criteria, some of which (e.g., coupes size and spatial arrangement) are brought into force by current laws. The exercise carried out demonstrates that a certain degree of heterogeneity of landscape pattern can be obtained as the rules become more restrictive. Finally, the need has emerged for the gathering, within management plans, of quantitative information on the actual distribution of animal species selected as indicators of habitat quality, and/or rare ones, as well as to their breeding performances in those habitat.

Moving from the consideration emerged from the previous studies, a posterior analysis of a forest plan (tactical and operational levels) was carried out in order to assess whether the spatial arrangement of different forest land uses (coppices, old coppices, that is coppices on the way to be transformed to high forest, high forests) resulting from the implementation of a real forest management plan, as well as the space-time succession of interventions, would take into an account the need for securing a diverse forest landscape mosaic, assuming that spatial heterogeneity, as defined by Kotliar and Wiens (1990) and Wiens (1995), directly affects the probability of survival for animal populations at the landscape scale.

METHODOLOGY

The analysis was applied to a “section” (i.e., a territorial unit formally defined by the forest management plan - FMP) of the Complesso forestale “Bandite di Follonica”, Colline Metallifere, southern Toscana, Italy (figure 1), mainly comprised of vegetations dominated by Turkey oak (*Quercus cerris* L.). It was extended in the future up to the year 2042, when the interventions, as scheduled and implemented by 2005, are likely to influence both single stand development and the resultant spatial mosaic, and was intentionally limited to a single time step as at this time the provisions of a new FMP should come into force, that would identify and implement spatially explicit adjustments to account for the drawbacks of the previous plan.

The same set of spatial scale was adopted (figure 1), even though the focus was on the lower three levels of the hierarchy of the patchiness. At the lower level (larger scale, as previously defined), the forest is comprised of a number of elements (patch I) corresponding to the intervention units of the FMP and therefore to the forester's grain. By definition (Kotliar and Wiens 1990) they are internally homogeneous with respect to the attributes used for their identification on the ground. Having been identified by means of qualitative criteria, patch I can be considered as statistically independent. However, they are not independent with respect to space and time, as the state of the *i* patch I at t_1 is influenced by its state at t_0 . This conditions the applicability of statistical dependence tests between variables, which may be misleading. Among the attributes used for patch I identification, structure type (S), land use type (LU) and age (A) were chosen based on birds criteria for habitat selection. In the FMP patches I were ascribed to structure type according to different criteria, such as age in the case of coppices (coppices C1, old coppices C2) and development stage in the case of tall forests (thicket F2, pole F3, adult F4, mature F5). As the implementation of the FMP, *per se*, does not lead to changes at patch level (i.e. patches I do not change their size or shape). Patches I, however, can be classified according to those attribute, forming spatial clusters. Thus FMP produces changes in patches I aggregation (size, shape and clusters spatial pattern) by changing their attributes. At the intermediate level of scale (intermediate resolution) each cluster can thus be seen as a patch (patch II), internally homogeneous as far as one classificatory attribute is concerned (e.g., S), yet heterogeneous as for the others (e.g., LU and A). At the upper level of scale (low resolution) the entire set of groups of patch II forms the landscape. This corresponds to the whole section of the FMP and is located in the middle of the range of spatial scales relevant to the hierarchy of patchiness of forest management (figure 1). To this level (Kotliar and Wiens 1990), two components of patchiness attain, that of patch I (determining heterogeneity at level II) and that within patch II. Thus, at the landscape level as defined, heterogeneity is determined by the combination of aggregation and contrast (Wiens 1995) between clusters of patch II.

To understand landscape changes deriving from the implementation of the FMP both class-level and landscape-level (*sensu* McGarigal *et al.* 2002) metrics were computed using both patch I (i.e., stratifying observation by attributes but with no reference to spatial clusters) and patch II data (i.e., considering their proximity in space). Only a few indices of landscape pattern were selected from the whole arsenal found in the literature (O'Neill *et al.* 1988, Turner and Gardner 1991, Gustafson 1998) and organised into computing packages (Baker and Cai 1992, McGarigal and Marks 1995), such as number of patches (NP), patch area (PA), class area (CA), total landscape area (TA), percentage of landscape occupied by each class (PLAND) although mathematically related to CA, mean (median) patch size (MPS) and the largest patch index (LPI). In addition, diversity indices were computed, Shannon diversity index - SHDI at the first level, and an index capable of accounting for the distribution of LU within each S type which was calculated according to the modification of the SHDI proposed by Pretzsch (1996, cited in Pignatti, 1998). At the second level also a compactness index (Bosch 1978 - K) and an aggregation index (Clark and Evans 1954, R) were computed. At the third level, also the average segment length (ASL) was used as an index of contrast (Forman 1995). As for the statistical comparison between the values of the indices in the two situations, besides the

considerations on space-time dependence of statistical units, it has to be remembered that this is still an open issue (Wu and Hobbs 2002, Rempel and Csillag 2003).

The attempt to assess the effects of forest management on biodiversity was done here by means of a comparison between nesting and feeding habitat availability in the breeding phenological phase of a set of bird species specialising or dependent on forest habitat types, in both situations. Eight bird species (four of which already used in the previous study) were selected among those known to be present in the area that are of interest for conservation, either at the international (Directive 79/709/CE), national (LIPU and WWF 1999), and/or regional level (Sposimo and Tellini Florenzano 1995). These were assigned to the ecological categories of *area limited* and *resource limited* (Carignan and Villard 2002) and then to those of migrant/non migrant according to the dedicated literature, both general (Hagemeyer and Blair 1997) and specific for the area (Tellini Florenzano et al. 1997). The latter also served as a source of information for the creation of the tables of both nesting and feeding habitat needs (Neave et al., 2000) on which the assessment of the changes in habitat availability (SxLU) was based. To infer the impact on bird species presence the assumption was made that this would only be affected by local factors (i.e., FMP). Even though it is well known that this depends on complex relations between different hierarchical levels of organisation in the landscape (Guisan and Zimmermann 2000; Lehmann et al. 2002, Rushton et al. 2004), it was not possible to take into account other factors (e.g., climate change, landscape change at scales lower than that of the FMP section).

RESULTS

As expected, a rearrangement of patches I among classes occurs as an effect of FMP. NP computed as the median class_S NP (i.e. integrated at the landscape level) and the relative IQR, both increase from t_0 to t_1 (median _{t_0} 26, IQR _{t_0} 38; median _{t_1} 38, IQR _{t_1} 64). The matrix of change for NP by class_S (not shown due to space limitations), which allows for the appreciation of both importance change for all classes and their direct dynamic relationships, indicates a decrease in class number, as both F2 and F3 disappear (F3 mainly enter into F5) and that both C1 and F5 gain from C2 (43% and 33% respectively). Importance-diversity curves (Whittaker 1965) drawn with CA values for both situation (figure 2) are effective in confirming such a rearrangement that ultimately leads to a decrease in diversity (SHDI _{t_0} 1,44, SHDI _{t_1} 1,25). Despite the large dominance of C2, a more equal distribution of total area among classes can be observed at t_0 , as well as a greater number of classes. When integrated at the landscape level, class_S patch density (ratio between class NP and CA, i.e. reciprocal of class MPS) decreases from t_0 to t_1 (median _{t_0} 0,31, IQR _{t_0} 0,224; median _{t_1} 0,16, IQR _{t_1} 0,440), thus indicating an overall increase in MPS. This is mainly due to MPS increase for C1 as for both F4 and F5 this index sensibly decreases and stays nearly the same for C2 (figure 3). LPI does not change, as obvious, at the landscape level (LPI = 3,76), at the class level, however the largest patch moves from F4 to F5.

When the LU attribute is used in patch I classification, the matrix of change (not shown) reveals that, both in terms of NP and of CA, the main part of C1 at t_1 derives from Turkey oak both former coppices and old coppices, whilst C2 at t_1 is mainly comprised of both mixed broadleaved former coppices and old coppices. F5, in turn receives both tall stands derived from earlier coppice conversion and existing conifer plantations, as well as unmanaged old coppices.

Even more striking changes appear when the age attribute is considered. When patches I are classed by age, median ages for class_A increases from 25 to 68 and the IQR from 9 to 58, clearly indicating a greater age variability. The ageing effect brought about by FMP is also evident from the uncoupling in the relation between age and PA by structure class (figure 4), due to coppice reinstatement on the one hand and both conversion to tall forest and no intervention in old coppices on the other.

The spatial explicit effect of the changes outlined with reference to patches I becomes evident, which is consistent with those previously shown, when the second and third hierarchical levels are examined. NP_{II} computed at the class_S, shows a remarkable variation and marked appear

changes from t_0 to t_1 when $P_{II}A$ is considered (figure 5), and LP_{III} (ratio between largest patch II for each class and TA), formerly in C1 (LPI_0 22,24), attains to C2 (LPI_1 21,02) also changing at the landscape level. Patch II shape also sensibly changes as shown in figure 6, particularly for patches II of class C1 and for those of class F5. In the latter case this is due to the choice of converting coppices along roads and streams. The indices A, R, ALS which are landscape indices (*sensu* McGarigal *et al.* 2002) for hierarchical level II, are class indices for hierarchical level III. When averaged over the classes they also are landscape indices for hierarchical level III. Variation of such indices (table 2) indicate an overall increase in land use diversity within all structure types but C2, a general trend towards aggregation, with R values that stay (C1 and C2) or drop (F4 and F5) below 1, and an increase in contrast, as shown by the decreased average connectedness of patches II, despite the increased ASL for patches II of C1 and F5 structure types.

FMP determines important changes in habitat availability for all habitat types, for all species and for both nesting and feeding requirements. However some species are more affected than others by these changes (figure 7). For *Caprimulgus europaeus* a loss in suitable nesting forest habitat is observed due to the disappearance of pole stands. For both *Strix aluco* and *Picoides major* suitable nesting sites diminish due to the decrease in old coppices as old trees and dead ones are not necessarily present in still relatively young high forests (F5) even though considered as mature from the silviculture stand point. *Parus palustris* too suffers from the decrease in old coppices as it also loses feeding habitats. For both *Circaetus gallicus* and *Pernis apivorus* instead suitable nesting sites augment due to the increase in high forests. The latter species and *Falco tinnunculus* however lose a great deal of feeding habitats. Non forest areas (AS) within the management unit appear of increased importance for several species. In addition due to the decreased compactness in the shape, F5 forests may become ecological sinks (*sensu* Pulliam 1988) for species nesting in those habitats as nest predation risk appears correlated to the distance from forest margin (Wilcove, 1985).

DISCUSSION

Despite its declared applicative and descriptive imprint, this work finds its theoretical and methodological roots within the wide stream of landscape ecological research aimed at exploring both ecological and planning/management implications of the space-time hierarchical nature of complex ecological systems (O'Neill *et al.* 1986, Wiens 1989, Milne 1991, Levin, 1992), within the outcomes of the debate on the ecological relevance of landscape indices (Tischendorf 2001, Wu and Hobbs, 2002, Li and Wu 2004, Wu 2004), and within the conceptual framework of "spatial forest planning" (see Baskent and Keles 2005 for a comprehensive review). The rationale of the work is consistent with the concept of "hierarchical planning" – i.e., strategic = landscape level; tactical = forest level, operational = stand level - (Session and Bettinger 2004, Baskent and Keles 2005) which appear as a promising approach to forest planning. In the particular case study of a wooded landscape in southern Toscana (Italy), with both evergreen and deciduous broadleaved woods, strategic choices facing the forester were those relevant to the opportunity of reinstating coppicing on vast landscape portions characterised by old coppice woodlands. These are by no means *old-growth* forests (Motta 2002) in a condition of dynamic equilibrium in both space and time, but woodlands for which the cessation of long tradition silvicultural practices may be a treat for stability and biodiversity maintenance (Packham *et al.* 1992, Fuller and Warren 1993). Tactical choices attained the need to regulate coppicing in space and time and that of considering the options of no interventions or of applying different criteria (i.e., conversion to high forest) to selected stands (riparian buffers, green-up for improving visual quality, connectivity). Operational choices were mainly those relevant to the fulfilment of adjacency, *coupes* size and number of standards constraints. The findings of the early studies carried out are in fact preparatory for the third one as from the first the evidence is supported that pattern and process operate in the same domain of spatial

scales and so that they can actually interact (Li and Wu 2004), as well as that different birds categories (area vs. resource limited; migrant vs. non migrant) respond to spatial configuration at different scales; from the second it appears how management criteria at the tactical level ought to be case-specific.

The choice of a posterior analysis rather than a model simulation in the third study was mainly due to the lack of a cognitive base on the actual animal species distribution and their reproductive performance in each habitat type, needed (Harrison and Fahrig 1995) for the design of a spatially explicit and dynamic simulation model. Moreover, since no optimisation of spatial configuration (both in space and time) was sought, the recourse to a formal landscape model (*sensu* Baskent and Keles, 2005), either mathematical optimisation, simulation or meta-heuristic, was beyond the scope of this research, and the GIS sufficed the needs for organising and calculating, both *ex ante* and *ex post*, landscape pattern metrics.

Even though not all of the metrics used show consistent and relatively robust scaling relations with respect to changing grain size (Wu 2004), never the less these appeared as appropriate to the purposes of the present research due to their simplicity and as they seem to relate to habitat availability and quality (*sensu* Directive 92/43/CE, art. 6), which are crucial for maintenance of biodiversity. Moreover, it is known that the distribution of a great deal of animal species (area limited species) depend both on a minimum habitat availability and on the minimum patch size of the given habitat (for a review see Forman 1995).

Computation of landscape indices at both class and landscape level also proved to be appropriate to reveal changes in the landscape pattern. Yet, the results point at the need for complementing the standard analysis at hierarchical level I, i.e., by means of the sole stratification of observations by attributes, regardless of their proximity in space, with those at higher hierarchical levels. The expected increase in landscape heterogeneity (due to the increase of both aggregation and contrast), could only be appreciated by examining hierarchical levels II and III, whereas hierarchical level I, somewhat deceiving as for the decrease of structure type diversity at the landscape level, provided information on the age pattern, which affects landscape functioning in a more subtle way. However, such complementarities can only be achieved if, differently than in standard landscape pattern analysis, an appropriate set of attributes is associated to each patch I rather than a single one (usually land use). To this regard operating with FMP intervention units also helps in avoiding the risk of misinterpretation deriving from the analysis of other (than land use) attributes (including topography) “neutral” landscapes (see Dorner *et al.* 2002). These indeed are more *ecotopes* (*sensu* Zonneveld 1995) than *patches*, and as such implicitly carry information on a number of attributes.

The contradictory results relative to habitat availability, in addition show how different the impact of FMP could be on different species and indeed on the same species. This corroborates the choice of using a set rather than a single species, and yet contributes to the discussion (Simberloff 1999) on the opportunity of using “umbrella” species and “indicator” species as their requirements might be indifferent or divergent from those of other species. Moreover, such results indicate that population viability of a few among the bird species examined can be only secured if suitable habitat persist outside the management unit. Thus calling for the need of an analysis at hierarchical level IV in order to keep into account such concurrent changes.

The approach adopted is consistent with both the principles of “wise forest management in Europe” (Andersson, 2003) and of “adaptative management” (FEMAT), which however are not alien from the Italian (sylvi-)cultural tradition (Pavari 1933, Patrone, 1970, de Philippis, 1970) concerned of the different values of forests.

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Figure 1 – Range of spatial scales and perception limits.

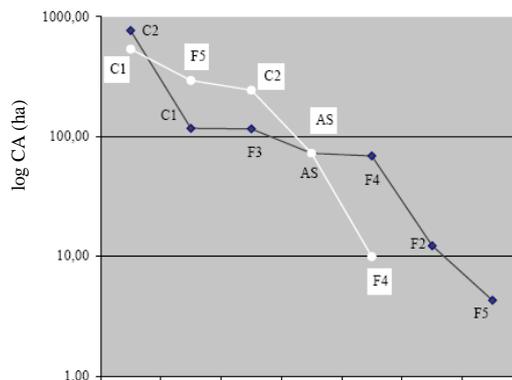


Figure 2 – Importance-diversity curves for structure type classes by extension (t_0 black line, t_1 white line).

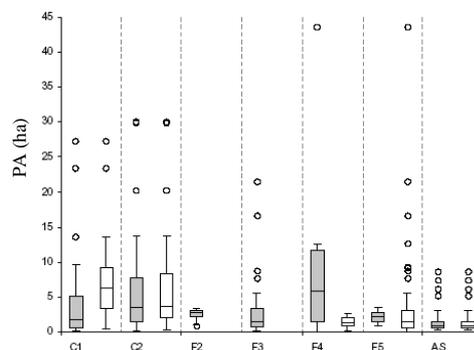


Figure 3 – Boxplots for patch I size by structure type class (t_0 grey, t_1 white).

Table 1 – Perception limits of forest manager and birds.

hierarchical level	forest manager	resource limited		area limited	
		migrant C. europaeus	non migrant P. maior	migrant C. gallicus	non migrant F. tinnunculus
sub-continent				extent	
region					extent
watershed		extent			
forest management			extent	grain	
vegetation					grain
sylviculture					
infra-sylviculture		grain	grain		

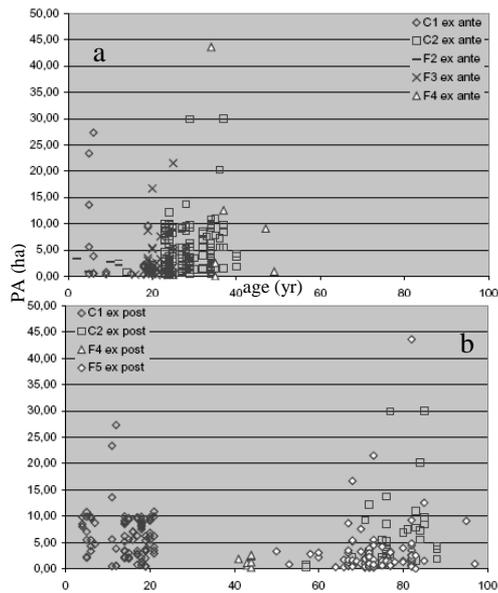


Figure 4 - Relation between stand age and patch I size by structure type class (a- t_0 ; b- t_1). For legibility two outliers for class F5 are not plotted.

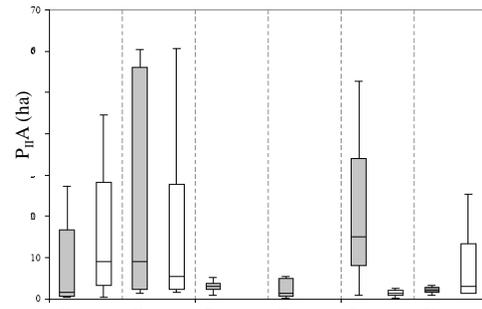


Figure 5 – Boxplots for patch II size by structure type class (t_0 grey, t_1 white).

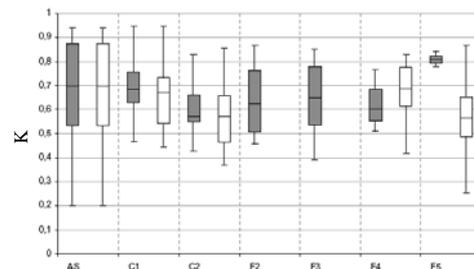


Figure 6 - Boxplots for patch II K index by structure type (t_0 grey, t_1 white).

Table 2 - Changes of A, R and ASL indices by structure type at the class and landscape level for hierarchical level III.

	A		R*		ASL(m)**	
	t_0	t_1	t_0	t_1	t_0	t_1
C1	0,630	0,713	0,619	0,834	204	285
C2	1,280	0,977	0,753	0,767	351	255
F4	0,034	0,064	1,210	0,248	298	61
F5	0,301	1,802	1,748	0,616	96	179
mean	0,561	0,889	1,083	0,616	315	230

*Reference values: $0 < R < 2,1491$; $R=0$ maximum aggregation; $R=2,1491$ maximum dispersion; $R < 1$ tendency towards aggregation; $R \sim 1$ random aggregation; $R > 1$ tendency towards dispersion.
 ** Computed over all ASL.

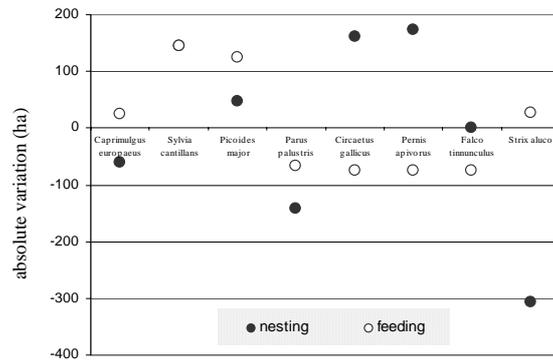


Figure 7 – Nesting and feeding habitat availability absolute variation by species.