

Reintroduction of the pine marten

A feasibility study

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feasibility study**

P W Bright & S Harris

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**Reintroduction of the Pine Marten:
feasibility study**

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SUMMARY

(1) The contract asked us to establish the current status of the pine marten in England and to report on the feasibility of reintroductions to southern England. In the light of our survey findings, the contract objectives were modified to include an examination of the research and conservation needs for pine martens in England as a whole.

(2) A field survey of 91 2km transects in northern England found possible evidence of pine martens at only two sites. This, together with a lack of marten sightings by naturalists of known reliability and recent historical records, suggests that pine martens are on the verge of extinction in England. There is no viable population in Cumbria, nor almost certainly in north Yorkshire. A marten population may survive in the Kielder Forest region, though no evidence was found during our necessarily limited survey for this short contract. A more extensive survey of the region is required.

(3) Attributes for 1580 10-km squares of the national grid for England, Wales and southern Scotland were measured from maps. Only 201 (12.7%) of these squares were found to have large blocks of contiguous woodland (>500ha) likely to be suitable for martens. Two way indicator species analysis applied to the 201 squares, resolved nine regions potentially suitable for marten populations. Parts of Northumberland and Thetford Forest were classified as similar to an area of Galloway where martens currently occur. Two regions in southern England, the Weald of Hampshire and Sussex and the New Forest, may have sufficiently extensive woodland to support viable populations. However, detailed field information about habitat suitability in the regions is needed. Our analysis showed that Cumbria, north Yorkshire and some regions to which pine marten reintroductions have been proposed, would not in fact be suitable.

(4) A computer population model, questionnaires to countryside organisations and a review of the literature on carnivore reintroductions were used to assess factors likely to influence the success of a reintroduction or restocking programme. The model showed that marten populations are acutely vulnerable to additional mortality, that might result from road traffic accidents or inadvertently from gamekeeping. Experience overseas suggests that the overwhelming majority of the community in Britain would support marten reintroduction or restocking, but that the attitudes of a minority would be crucial. A majority of organisations (58%) supported the principle of marten reintroductions, but nearly all attached caveats to their support such as safeguarding game-bird rearing interests and further research on marten requirements.

(5) It is argued that intra-sexual territoriality and dependence on woodland provide a behavioural key to successful marten translocations. Three potential translocation scenarios are suggested, involving martens of known or unknown mutual familiarity, releasing martens of one sex before martens of the other and not releasing females until after their young are born.

(6) A timetabled programme of further research and conservation is recommended, beginning with field evaluations of survey methods, marten area requirements and limiting factors. This work would provide the basis for a restocking programme to northern England, which should be preceded by habitat surveys and public awareness campaigns in release areas. We believe that once northern populations are secure, reintroductions to southern England could go ahead. However it would first be essential to examine the impact and interaction of martens with game-bird rearing interests and fully understand marten habitat requirements in southern England.

CONTENTS

Summary	2
Introduction	4
Part 1: Current status of the pine marten in England	5
Part 2: Potential regions for reintroductions and restockings	10
Part 3: Factors affecting the success of a reintroduction or restocking programme	17
Part 4: A potential methodology for translocations	27
Part 5: Recommendations for further research and practical conservation in England	32
Acknowledgements	35
References	35

INTRODUCTION

The contract had six objectives, all of which we have addressed. Some of the objectives overlapped each other so we have not reported separately on each, but grouped our report into five logical self-contained parts. In the light of our survey results and after discussion with English Nature, some of the objectives were slightly modified from those in the original contract. The contract was short and anticipated that most objectives would be met through a desk study. Nevertheless, eight weeks of field survey were completed. The objectives and parts of the report in which they are addressed are given below.

Objective 1

Determine the current status of the pine marten in England, with reference to the factors that caused its decline and may be preventing the spread of current populations. Document previous attempts at reintroduction (restocking) and the reasons for success or failure. Marten status is dealt with in Part 1. Past reintroductions are discussed in Parts 3 and 4.

Objective 2

Identify needs for further research on martens in lowland England and research priorities to help bolster the relict populations of martens in northern England. This is addressed in Part 5.

Objective 3

Propose a short list of regions south of the rivers Humber and Mersey, that appear to provide the general conditions necessary for the long-term survival of pine marten populations. This is covered in Part 2.

Objective 4

Identify the factors likely to influence the success of a pine marten reintroduction or restocking programme and quantify these, where possible, for the short list of regions. This is dealt with in Part 2, but mostly in Part 3.

Objective 5

Locate potential sources of pine martens, wild or captive bred, for reintroduction or restocking. This is included in Part 4.

Objective 6

Propose a list of potential methods for carrying out a trial reintroduction or restocking project, followed by a full programme of monitoring. This is addressed in Part 4.

PART 1: CURRENT STATUS OF THE PINE MARTEN IN ENGLAND

Introduction

Since the mid nineteenth century the pine marten appears to have been present in England and Wales only in small, isolated, relict populations (Langley & Yalden, 1977). In the last twenty years a series of unconfirmed local reports have suggested that these populations still persist (*e.g.* Clinging & Whiteley, 1980; Howes, 1985; Varty, 1990). A survey conducted in 1980-1982 by searching for distinctive marten faeces (scats) along transects, found no direct evidence of martens in England or Wales. However, based on interviews with local people and museum records, this survey concluded that martens were still present, though at low population density (Velandar, 1983).

Using similar methods a more intensive survey of England and Wales was conducted in 1987-1988 by R. Strachan, D.J. Jefferies and P.R.F. Chanin (D.J. Jefferies, *pers. comm.*), during which marten scats were found in Northumberland, Cumbria, north Yorkshire and north Wales. However, scats were discovered at only 8% of the 896 sites surveyed and a partial resurvey of these sites did not yield consistent results. Nevertheless, interviews with local people and museum records also suggested that martens were present. D.J. Jefferies (*pers. comm.*) interpreted these combined data as indicating marten presence at very low density. He is currently analysing a large collection of earlier records to assess the trends of these English and Welsh populations.

In 1991 PWB, while Mammal Society Conservation Officer, visited Cumbria to explore the feasibility of conservation measures for pine martens there. The 1987-1988 survey had found marten scats at 20 sites in Cumbria (D.J. Jefferies, *pers. comm.*), but two days of searching likely sites for scats and conversations with well-informed local naturalists produced no evidence of pine martens. However at low population density martens and their scats might be easily overlooked, as might a few road casualties (a frequent source of data on marten distribution elsewhere).

Thus considerable uncertainty surrounded the presence of pine martens in England (and Wales) and by 1993 five years had elapsed since a survey had been conducted on populations that appeared to have been declining in recent decades (D.J. Jefferies, *pers. comm.*). Consequently there was a need to determine the present status of martens in England, prior to initiating reintroductions or other conservation measures.

Methods

Survey area

The contract was short, so only a few weeks were available for fieldwork and not all sites visited during the 1987-1988 survey could be resurveyed. Instead surveys were concentrated in areas of Cumbria, the Kielder Forest region of Northumberland and County Durham from which most marten scat records for England came during the previous survey. Fieldwork was not conducted in other parts of Northumberland or North Yorkshire as the 1987-1988 survey recorded only a small number of scats sites from these areas, where marten presence was regarded as unconfirmed (D. Yalden; D. Whitely, *pers. comm.*). Surveys were conducted during October and November 1993.

Survey protocol

A methodology was adopted that would maximise the probability of detecting pine martens if they were present, while also being directly comparable with previous surveys. As in the 1987-1988 survey, 2km transects along woodland paths were walked slowly, searching for marten scats. Marten scats were recognised by their distinctive sweet odour (to PWB they smell like cranberry sauce) and frequent characteristic long, twisted shape (see Lawrence & Brown, 1973); they were not recognised on the basis of shape alone.

Martens mark paths with their scats, particularly where these intersect with their own trails (Lockie, 1964; Pulliainen, 1982; Velander, 1983;). Recent work on another mustelid, the badger *Meles meles*, has suggested that linear features which form a barrier may strongly influence marking behaviour (White, Brown & Harris, 1993). Many mature woodlands, in Cumbria particularly, are sparsely vegetated at ground level; martens might not mark intensively along tracks in such open habitat. Consequently woodland edges were also surveyed, although steep, rocky terrain often made this difficult. Surveys were halted in low light levels or during heavy rain, as scats might have been overlooked in such conditions.

Transects were usually (>90% of transects) grouped three or four together, with each about 1km apart. This search pattern should have minimised the potential for all transects in an local area falling in the interstices between marten territories, which may not be marked with scats (D. Balharry, *pers. comm.*). Transects were walked in areas where marten scats were found during the 1987-1988 survey, but often extended beyond these areas when there appeared to be better habitat for martens nearby (especially pre-canopy closure plantations which are vole *Microtus agrestis* rich patches where martens often hunt; Balharry, 1993) or when there had been clear felling of forests around 1987-1988 survey sites.

Tests of survey protocol

Methods for surveying martens by searching for scats have not been tested; it is not known for instance whether walking 2km transects is a reliable way to detect martens. We had intended to determine detection functions (Buckland *et al.*, 1993) for marten scats in different habitats, as this would allow survey effort to be optimised and enable statistical prediction of marten distribution (c.f. Bright, Mitchell & Morris, 1994). This was not possible due to lack of marten scats, but is an important priority for the future (see Part 5). Instead we applied two other tests to the survey methods: firstly, the method was tested in Galloway where martens are known to be present; secondly, the number of fox *Vulpes vulpes* scats along transects were counted. If fox densities in all survey areas are assumed to be roughly similar, the ratio of fox:marten scats found in Galloway and the number of fox scats found elsewhere should have provided a crude indication as to whether the survey method was able to detect marten scats (D. Balharry, *pers. comm.*).

Results

In total 91 2km transects were walked (further transects were walked in Galloway, see below). These covered 38 of 47 sites (80%) where marten scats were found in Cumbria and Northumberland in the 1987-1988 survey, plus 53 other sites in areas surrounding 1987-1988 ones. The latter were surveyed to ensure marten presence was not missed (see Methods), particularly if activity had shifted as a result of forest clear-felling, which had recently taken place at 18 (38%) of the 1987-1988 sites. Nine sites where marten scats were found in 1987-1988 were not visited during the present survey. These constituted scattered records mostly away from the large forests, which

were the source of most 1987-1988 records. We felt it was very unlikely that martens would be present at these sites, if not present in the areas where 1987-1988 records were concentrated.

Only two scats were found which had the distinctive marten odour, though neither had the shape which may also be characteristic of martens. These were at Thirlmere and Thelkeld, near Keswick in north Cumbria. A few scats (<20) that had a twisted shape and were small enough to be those of martens were found, but these had distinctive, pungent odours and were clearly those of fox or polecat *Mustela putorius*. No marten scats were found in Northumberland.

Near Glen Trool, Galloway, marten scats were found on four of six transects, with a mean number of scats of 1.83/2km SE 0.65. The mean number of fox scats on these transects was 3.33/2km SE 0.49 and the mean fox:marten scats ratio was 0.86 SE 0.37. On 62 transects walked in England where fox scats were counted, the mean number of fox scats was 5.54/2km SE 0.32. The large number of fox scats found and the ease with which marten scats were located in Galloway, both suggest that the transect protocol would have been an effective way to detect marten scats if they had been present.

Discussion

The survey depended on finding and identifying pine marten scats. PWB was fully familiar with the morphology and odour of marten scats and the range of scats that other carnivores produce, including polecats, that might be confused with those of martens. The rapid location of scats during surveys in Galloway suggests that the transect protocol could be used to detect marten scats, even when these were the product of a population that may be at low population density (PWB, *pers. obs.*: martens having been introduced to Galloway only in 1981). However it would have been preferable, but was not possible due to lack of scats, to determine detection functions (Buckland *et al.*, 1993) for marten scats, as their detectability probably varies between habitat types and with marten population density (Part 5).

Carnivore marking behaviour is known to vary with a number of factors, especially population density (*e.g.* Kruuk & Conroy, 1987), and thus using scats to indicate density or even presence/absence may be misleading. One way in which we attempted to address this potential problem was by surveying woodland edges, barriers where scats might preferentially be deposited (*c.f.* White *et al.*, 1993), but marten scats were still not found. We also ensured transects did not fall only in the interstices between potential marten territories where marten scats would not have been deposited; the 1987-1988 survey (D.J.Jefferies, *pers. comm.*) might have missed marten sites because transects were mostly spaced much more than one territory diameter apart. These caveats aside, studies of marten behaviour in Scotland, continental Europe and North American all suggest that wherever they are present martens leave scats conspicuously on paths (O'Sullivan, 1983; Velander, 1983). Lockie (1964) showed that scat deposition rates were approximately three fold less during autumn and winter, but that marking using scats continued year round. This suggests that surveys should preferably be conducted during spring and summer, but that surveys in autumn and winter, when ours had to be conducted, should still find scats.

Both Velander (1983) and the 1987-1988 survey used reported sightings and museum records to indicate marten presence. However such records, unless based on marten corpses, may be unreliable, as polecats, mink or otters may easily be confused with martens by inexperienced observers. PWB's interviews with Mammal Society members and Forest Enterprise conservation personnel who had considerable field expertise produced no evidence of pine martens, other than acknowledged hearsay.

William Burton of Forest Enterprise in Kielder (*pers. comm.*) reported that Forest Enterprise workers had seen an animal described as a pine marten to the north of Kielder Water on at least two occasions in 1992. But he also suggested that it was strange that there had been no other reported sightings if martens were indeed present.

John Webster (*pers. comm.*), a very experienced mammalogist and Mammal Society member, could find no evidence of martens after more than 20 field days searching at sites in Cumbria where marten scats were found during the 1987-1988 survey. John Cobby (with Forest Enterprise in Grizedale for more than 15 years) had no knowledge of pine martens in Grizedale Forest (the largest in Cumbria), even though he and his colleagues spend long hours in the field.

Marten sightings collated by both previous surveys (Velandar, 1983; D.J. Jefferies, *pers. comm.*) appear to be sporadic, with only about 10-15 records per region (eg north west England) over a 10-20 year period. This sighting frequency is only about one-third of that recently reported in a much smaller area in Galloway (Shaw & Livingstone, 1994). Even where they are present at low density, as probably in Galloway (PWB, *pers. obs.*), martens seem to be frequently observed crossing roads, foraging at dusk, denning in buildings during winter and using large nestboxes put up for birds. Martens may also make their presence felt by raiding chicken houses. We suggest that the frequency of marten sightings in England in the last decade, at least, may be insufficient to indicate the presence of marten *populations*. A fuller analysis of the recent records in England and Wales will be provided by R. Strachan, D.J. Jefferies and P.R.F. Chanin when the report on the 1987-1988 survey is completed. Until then, it is difficult to know how much credence should be attached to anecdotal evidence of martens collected in recent years. However, D.J. Jefferies (*pers. comm.*) has collated records of martens (sightings, scats, corpses) dating from 1850. In each of three areas, north west England, north east England and north Wales, there was a decrease in the number of such records to present times. And, perhaps significantly, there have apparently been no records of martens breeding (cubs sighted or corpses of lactating females found) in north east or north west England since the period 1960-1976 (D.J. Jefferies, *pers. comm.*). Taken at face value these records clearly suggest a decline of marten populations in England this century, and that they are probably close to extinction at the present time.

In the light of these records it would appear that the present survey may have been conducted when marten populations in England were verging on extinction, when few, if any, marten scats might have been found. Our results can thus be interpreted as entirely consistent with those from the 1987-1988 survey, and as the culmination of a long-term decline.

It is, of course, impossible to prove that pine martens are absent from an area. However, our results strongly suggest that there are no marten populations in Cumbria. This conclusion is based not only on lack of scats, but also on a lack of marten sightings in an area very heavily used for outdoor recreation. There may also be insufficient woodland in north Cumbria to support a viable population of martens (see Part 2). There may be a few individual martens in Cumbria, which could be long-term survivors from a former population, or, more likely in our view, martens that have been translocated from Scotland or escaped from captivity. Unmonitored, undocumented translocations of pine martens are known to have taken place in north Yorkshire (G. Woodroffe, *pers. comm.*), before martens were legally protected; they have probably been conducted elsewhere in England too. Furthermore there was a captive colony of both beech martens *Martes foina* and pine martens within 20km of the sites in Cumbria where two probable marten scats were found during the present survey.

We are less certain about the status of the pine marten in the Kielder Forest region of Northumberland. In neither the 1987-1988 survey nor the present one was it possible

to survey all areas of this very extensive forest. However, during the 1987-1988 survey marten scats were found and the Hancock Museum in Newcastle-upon-Tyne has two marten specimens from the area (E. Morton, *pers. comm.*). One (of which the skull remains) was a road casualty collected near Otterburn in 1968. The other (which has been kept deep frozen) was accidentally shot when mistaken for another animal in about 1989 near Bellingham.

Human presence in the Kielder forests, though substantial, is much lower than in Cumbria; there are fewer buildings in which martens might be found during the winter; and fewer roads on which road traffic casualties might occur. Furthermore there has been no evidence of martens in a large number of nestboxes put up for owls in the Kielder forests (W. Burton, *pers. comm.*). The nestboxes cover only a small fraction of the forest area however; martens might therefore still be present elsewhere. It is thus possible that a small marten population is present in a secluded part the Kielder Forest region, where marten surveys have not yet been conducted. A more detailed survey of Kielder is an important research priority for the future (Part 5).

The origin of a Kielder pine marten population, if there is or has been one, is unclear. It is unlikely that a population has been continuously present there, the area having only really become suitable for martens with the growth of forest cover in the last 50 years. Martens might have dispersed to Kielder a few decades ago from the relict areas of distribution in Cumbria. They may have dispersed from the reintroduced population in Galloway. Both dispersal routes, though long, are almost certainly within the range of a species as mobile as the pine marten. Martens, taken from Scotland or captivity, might also have been translocated to Kielder.

If martens have been present in the Kielder region but now disappeared, it is clearly vital to determine why (Part 5). Comparison with Galloway and elsewhere in Scotland showed that habitats in Kielder are likely to be capable of supporting marten populations (Part 2), though PWB's surveys suggested that den sites may be lacking (there are few rock out-crops and few tree hollows, a matter that warrants further investigation; Part 5). If martens dispersed or were translocated to Kielder the founding population was almost certainly small. It would thus have been acutely vulnerable to the stochastic events that may pull small populations into extinction vortices (Soule, 1987; Burgman, Ferson & Akcakaya, 1993). Such travails might have lead to a recent decline, or demise, of martens in Kielder.

If marten presence is, at best, uncertain in northern England, it seems very unlikely that martens have persisted in North Yorkshire, as reported by the 1987-1988 survey. There is less contiguous woodland there than in Northumberland (only 56km² in total; Part 2) and two very experienced Mammal Society members, Gordon Woodroffe and Charles Chritchley who spend a great deal of time in the field, have not found marten scats and report no reliable sightings (G. Woodroffe, *pers. comm.*).

PART 2: POTENTIAL REGIONS FOR REINTRODUCTIONS & RESTOCKINGS

Introduction

According to Langley & Yalden (1977) the pine marten was found virtually throughout Britain in 1800, though was probably scarce in parts of southern England. However, the paucity of distribution records at this time (Langley & Yalden, 1977) and earlier large scale clearances of forests on which martens depend, suggests that martens were rare in parts of lowland Britain (e.g. Norfolk) well before 1800 (Millais, 1905). Thus much of lowland Britain may not have supported marten populations for 200 and perhaps for as much as 400 years. Since this time there have been large changes in lowland habitats, the reduction and fragmentation of tree cover (Spencer & Kirby, 1992) being particularly significant for this woodland species. There have also been large changes in the habitat matrix between woodlands, particularly the addition of roads which might be an important additional factor contributing to mortality.

Before implementing pine marten reintroductions or a restocking programme to areas where they may still occur in England (Part 1), it is thus vital to assess whether habitats south of the Scottish border could now support viable marten populations. This might be accomplished using correlations between current marten presence or absence and habitat parameters, to build predictive models of marten distribution (c.f. Bright, Mitchell & Morris, 1994). Velander (1983) conducted a survey of martens in Scotland and collected data on the habitats in which marten scats were found. However nearly all Velander's survey sites were in "mixed conifer plantations" (Velandar, 1983: Table 3), so her database is not useful for predictive purposes; it would be necessary to examine marten presence or absence in a wider range of habitats.

Hence we adopted an alternative strategy and examined the prevalence and distribution of key habitat attributes known or likely to be correlated with marten population density, mortality or behaviour. Using these attributes, 10-km squares of the national grid throughout England, Wales and southern Scotland (martens are currently present in the latter) were classified into groups of differing potential suitability to martens. From these it was possible to determine which regions might currently support marten populations and thus general areas in which restockings or reintroductions could be conducted in the future. Southern Scotland and Wales were included in the analysis even though they were beyond the remit of the contract, because they provided a valuable comparison for sites in England.

Methods

Attributes for 1580 10-km squares of the national grid were measured from 1:25,000 Ordnance Survey maps for as far north as northing 600 i.e. it included the 100-km squares NW-NZ (southern Scotland). For some areas 1:50,000 maps were used to provide the most up to date information. Attributes were selected on the basis of their correlation or likely correlation with marten abundance in Scotland, continental Europe and north America:

Woodland block size. The total size and fragmentation of local areas of woodland, partly or wholly in a 10-km square. There were three block sizes: (1) >500ha of contiguous woodland (woods <500m apart); (2) >500ha of non-contiguous woodland (woods >500m apart); (3) <500ha of non-contiguous woodland. This was used because martens require at least 230ha of contiguous woodland to establish a breeding territory (Allen, 1984; Balharry, 1993).

Table 1. The frequency of 10-km squares with different sizes of woodland blocks in England, Wales and southern Scotland. Mean percentage cover of woodland per 10-km square for each block size is shown.

Block size	Frequency	Mean % woodland cover/10-km square (SE)
(1) > 500ha of contiguous woodland (woodland <500m apart)	201	19.8 (1.16)
(2) > 500ha of non-contiguous woodland (500m <interwood distance < 2000m)	136	8.8 (0.35)
(3) < 500 ha of non-contiguous woodland	1243	2.2 (0.05)

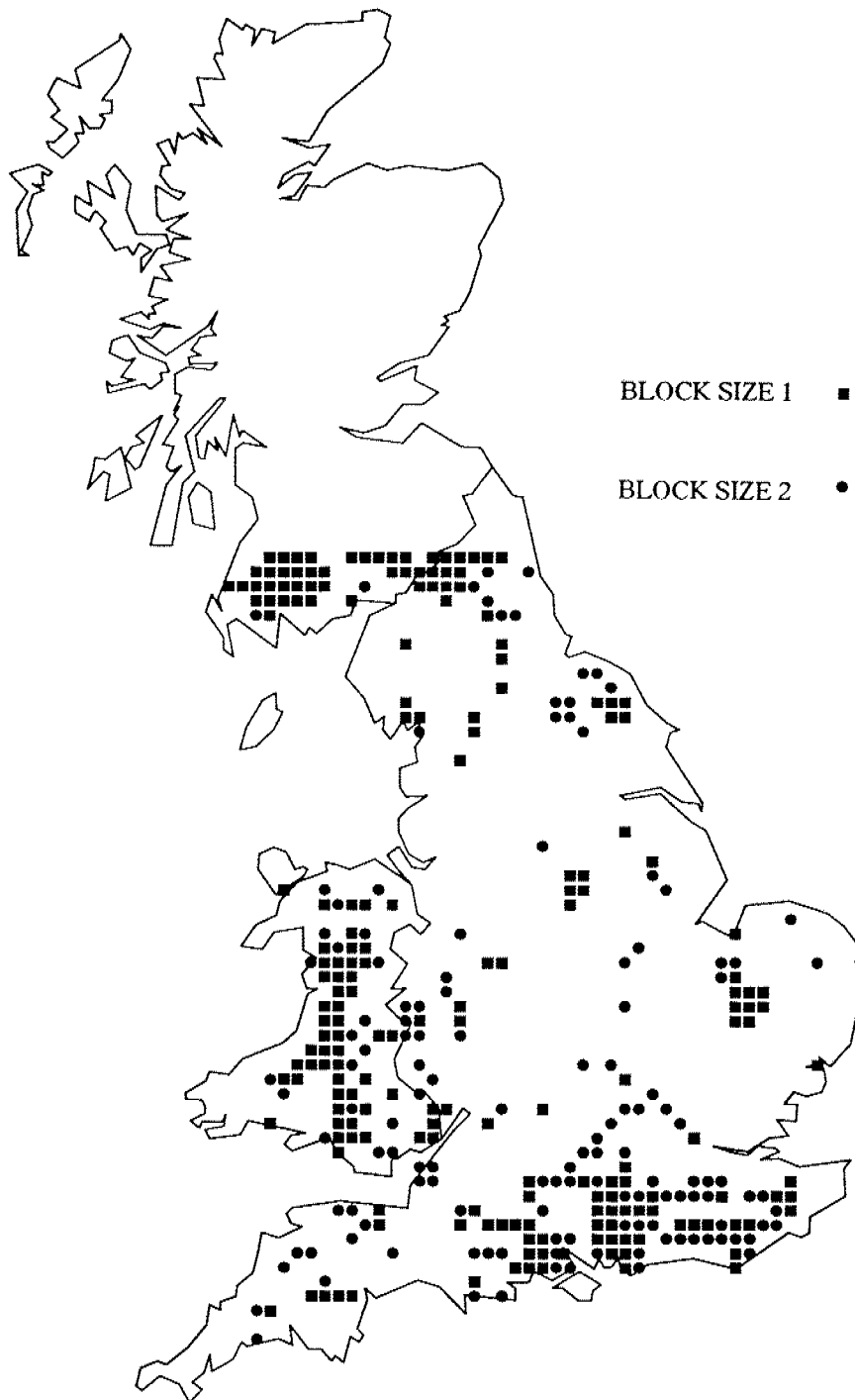
Table 2. Attributes of eight groups of 10-km squares classified using TWINSpan. Means followed are given, followed by standard errors in parentheses.

Group	Distance east (km)	Distance north (km)	Woodland cover (%)	Surrounding woodland area (km ²)	Field size (ha)	Total road length (km/10-km sq.)
1	306 (17.8)	576 (2.6)	60.2 (4.6)	260 (23.4)	41.8 (22.5)	15.7 (2.9)
2	302 (11.1)	345 (29.0)	22.6 (2.6)	117 (8.6)	53.5 (3.0)	43.5 (3.8)
3	350 (26.7)	441 (32.5)	19.6 (2.8)	158 (10.7)	124.5 (17.4)	50.9 (4.5)
4	351 (19.5)	464 (24.7)	17.0 (3.4)	48 (4.9)	140.2 (19.9)	47.1 (4.3)
5	458 (14.0)	145 (11.5)	21.0 (2.9)	131 (7.8)	72.7 (2.7)	120.3 (7.0)
6	398 (17.7)	204 (18.3)	18.9 (1.6)	98 (8.0)	49.1 (2.0)	120.5 (6.5)
7	368 (15.4)	259 (20.8)	11.3 (7.2)	36 (2.6)	49.3 (2.8)	105.1 (6.9)
8	471 (25.8)	211 (29.9)	10.0 (0.8)	40 (3.5)	104.5 (7.3)	119.2 (8.9)

Table 3. Attributes of nine regions derived from a TWINSpan classification and contiguous 10-km squares. Means followed by standard errors in parentheses and potential total breeding pine marten population sizes are given. Potential population sizes are calculated by assuming that each breeding marten territory contains two animals and 230ha of woodland.

Region	Woodland cover (%)	Field size (ha)	Total road length (km/10-km sq.)	Total area of contiguous woodland (km ²)	Potential total breeding marten population
Galloway	20.5 (2.8)	44.3 (3.0)	64.5 (10.5)	492	214
Northumberland	20.1 (3.7)	49.6 (4.6)	61.5 (8.8)	444	193
Thetford Forest	13.6 (2.4)	58.8 (12.2)	60.5 (11.0)	123	53
Weald	32.0 (5.4)	69.7 (9.2)	80.9 (10.0)	673	292
New Forest	19.8 (2.8)	65.3 (8.7)	90.7 (13.3)	258	112
Forest of Dean	12.8 (2.8)	77.0 (18.7)	93.0 (18.8)	64	28
Central Wales	20.1 (2.8)	56.9 (9.6)	61.0 (6.8)	804	349
North York Moors	11.2 (2.9)	86.0 (28.4)	73.0 (24.9)	56	24
Sherwood Forest	32.2 (14.4)	57.7 (4.8)	117.2 (11.2)	161	70

Fig. 1. Distribution of 10-km squares with: (a) block size 1 [squares] with > 500 ha of contiguous woodland; (b) block size 2 [circles] with > 500 ha of non-contiguous (>500 m apart) woodland; (c) block size 3 [all other areas] with < 500 ha of non-contiguous woodland. The distribution for England, Wales and southern Scotland is shown.



Woodland cover. The percentage total area of woodland/10-km square. This was used because it should describe potential marten population density: marten population density is known to be positively correlated with landscape woodland cover and woodland continuity (Stevenson & Major, 1982; Allen, 1984; Snyder & Bissonette, 1987).

Surrounding woodland cover. The percentage total area of woodland in the eight 10-km squares adjacent to a focal 10-km square, calculated from *woodland cover*. This was used as a measure of habitat availability adjacent to a focal 10-km square.

Field size. The mean size of fields (ha), measured in a sub-sample of 10 randomly chosen 1-km squares within a 10-km square. Field size was used as a surrogate variable to describe potential habitat suitability for martens, on the assumption that smaller field sizes represent more enclosed landscapes (Rackham, 1986) which have a greater diversity and biomass of the pine martens principal foods (e.g. Village, 1990).

Road length. The total length of motorway, A, B and C class roads in a 10-km square. This was used because road traffic accidents are a frequent source of recorded mortality of pine martens in Scotland (Velandar, 1983).

These attributes, plus the east-north coordinates of grid squares, were used to classify each 10-km square using two-way indicator species analysis (TWINSPAN: Hill, 1979). Pseudo-species cut levels at 15, 30, 60 and 90 were used to match the scale of the attributes. The two upper cut levels were double-weighted, as particularly high values of the attributes would be strong positive or negative indicators of a 10-km square suitability for pine martens.

Persecution was the direct cause of past marten extinctions and inadvertent capture in snares and traps remains a significant cause of mortality in Scotland (Langley & Yalden, 1977; Velandar, 1983; D. Balharry, *pers. comm.*). The Game Conservancy records of gamekeeper density (Tapper, 1993), were used to estimate current levels of inadvertent trapping to which martens might be accidentally subjected in different regions; these are at best only a crude measure, but more precise data would have required lengthy field surveys.

Groups of 10-km square classified by TWINSPAN were compared using one-way ANOVAs. We tested attributes for normality, applying arcsin transformations (Sokal & Rohlf, 1981) to percentage-scale attributes where appropriate, and ensured that group variances were homogeneous prior to ANOVAs.

Results

Only 201 (12.7%) of 10-km squares covered large contiguous blocks of woodland (>500ha), where there was a mean woodland cover of 19.8%/10-km squares, SE 1.16%. The vast majority of 10-km squares had scattered blocks of woodland and a mean woodland cover of only 2.5%/10-km squares, SE 0.07% (Fig. 1; Table 1: block sizes 2 & 3). These latter areas were considered unlikely to support viable marten populations in England due to low woodland cover and were not considered further (see Discussion).

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TWINSPAN applied to the 201 10-km squares where block size=1, produced eight groups and a final miss-classification rate on 4% (Fig. 2). One way ANOVAs showed that there were significant differences between groups in terms of the five attributes (Table 2); the groups clearly represented distinct landscape types. There is a gradient

from group 1 to group 8 of decreasing woodland area, surrounding woodland, field size and distance north, and increasing road length and distance east. We suggest that groups 1 to 8 also represent a decreasing gradient in potential pine marten population density, assuming constant mortality due to persecution. Group 1 covers the area where pine martens first became established after reintroduction in Galloway (Shaw & Livingstone, 1994) and the Kielder Forest region where they may also be present (Part 1). Groups 5-8 are mostly in southern England where pine marten populations first became extinct (Langley & Yalden, 1977).

Figure 3 shows the geographical distribution of the TWINSPAN groups, which form discrete regions of contiguous 10-km squares. These regions have significantly different attributes (Table 3; Fig. 4) and thus differ in their potential suitability for pine martens:

Region 1 Galloway. This region has a low density of roads and relatively small field size. It is comprised of TWINSPAN groups 1, 3 and 4, contains 600km² of land with more than 50% woodland cover, a large total area of woodland (49 km²), and a mean woodland cover of 20.1%.

Region 2 Northumberland, is similar to Galloway. There is a low density of roads and 700km² of land with more than 50% woodland, though the mean woodland cover is 20.5%. There is a large total woodland area (444km²). Most of the region was classified as groups 1 or 2.

Region 3 Thetford, has similar attributes to Galloway and Northumberland, particularly a low density of roads, and is mostly classified as group 3. However mean woodland cover is low (13.6%), the total area of woodland is only 123km² and gamekeeper density is high (0.6/km²).

Region 4 Weald. This region, like the others in the south of England, has a significantly higher density of roads than the preceding ones. Gamekeeper density is moderate to high (0.3-0.6/km²). Mean woodland cover is high (32%) and the total area of wooded land is very large (674km²).

Region 5 New Forest. This region has similar attributes to the Weald, but is more heterogeneous (being comprised of five different TWINSPAN groups) and has a significantly higher density of roads and a lower mean woodland cover (19.8%). Gamekeeper density is high (0.6/km²) and there is a moderately large total area of woodland (258km²).

Region 6 Forest of Dean. A high density of roads, large field sizes and relatively low woodland cover (12.8%) characterise this region, which contains only 64km² of woodland in total.

Region 7 Central Wales has similar attributes to the Galloway and Northumberland regions. Road density is low and mean woodland cover is 20.1%. At 804km², the total area of contiguous woodland is the largest in any of the regions.

Region 8 North York Moors. This region is characterised by large field sizes (ie semi-enclosed, marginal upland), similar to peripheral parts of the Galloway region. However, it also has a high density of roads, a moderately high density of gamekeepers (0.3/km²) and a relatively low mean woodland cover (11.2%). The total woodland area is only 56km².

Region 9 Sherwood Forest has the highest road density of any of the regions, but also a high woodland cover (32.2%) and small field sizes. This small distinct region has a total woodland area of 161km².

Fig. 2. Classification of 201 10-km squares with a block size of 1 (> 500 ha of contiguous woodland), using TWINSpan. Each square was classified on the basis of six attributes: woodland cover; surrounding woodland cover; field size; road length; easting; and northing (see text for definitions). The annotations on the classification tree below, refer to the group on the right branch of each dichotomy.

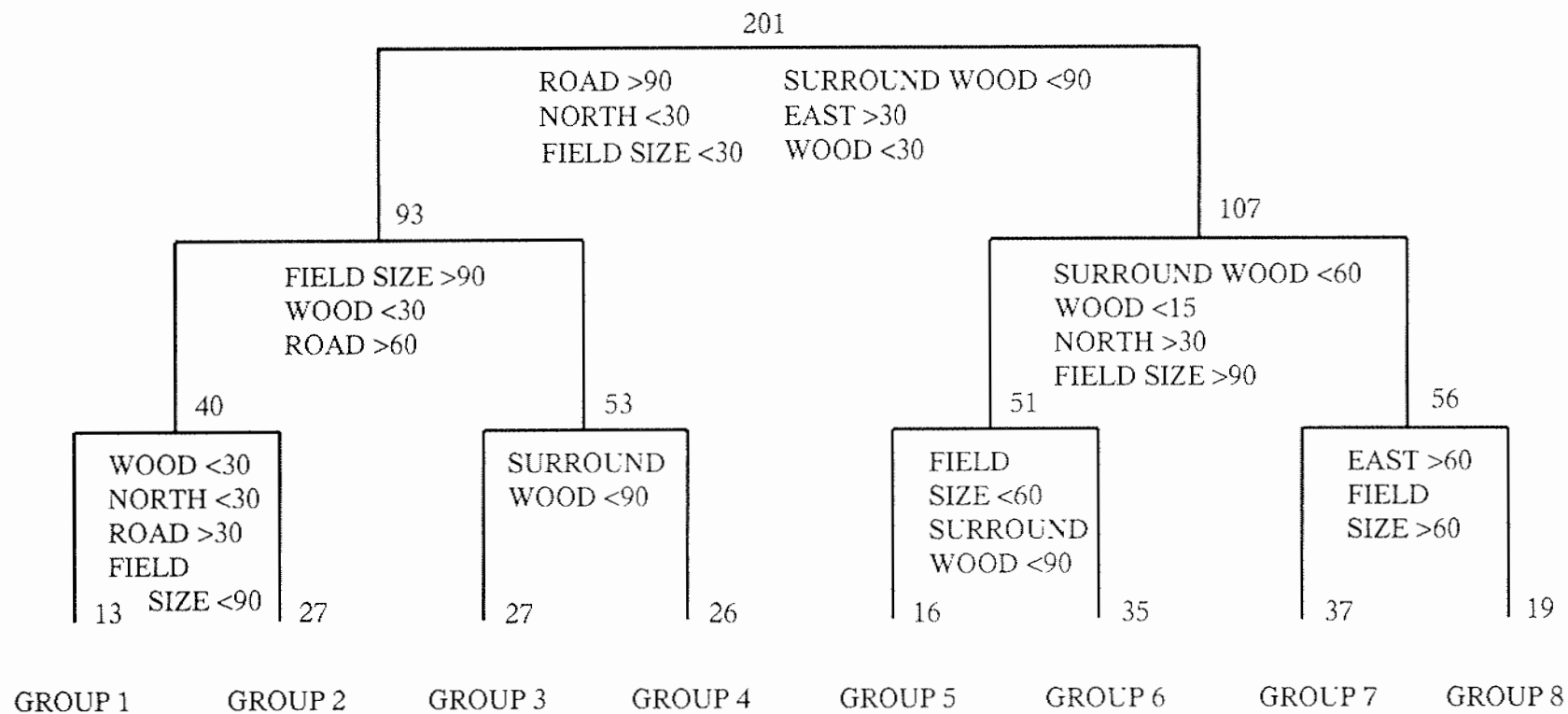


Fig. 3. Distribution of eight groups of 10-km squares, all with a woodland block size of 3, classified by TWINSpan. Contiguous 10-km squares form nine discrete regions, which are referred to as: (1) Galloway; (2) Northumberland; (3) Thetford; (4) Weald; (5) New Forest; (6) Forest of Dean; (7) Central Wales; (8) North York Moors; (9) Sherwood Forest.

