Towards a Woodland Habitat Network for Wales

Report No 686

A collaborative project between CCW and Forestry Commission, Wales

Kevin Watts, Matthew Griffiths, Chris Quine,
Duncan Ray & Jonathan Humphrey

2005

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RHAGAIR

Darnio cynefinoedd yw un o'r ffactorau mwyaf difrifol sy'n effeithio ar ein coetiroedd. Mae gorchudd fforestydd Cymru wedi'i leihau'n ddybryd gan filoedd o flynyddoedd o weithgareddau pobl, ac erbyn heddiw cwta 4% o'r wlad sydd o dan goetir lled-naturiol wedi'i addasu. Mae llawer o rywogaethau wedi ymaddasu at gynefin anarddwys a chysylltiedig iawn y gallan nhw symud yn rhydd o'i fewn, ac mae darnio yn golygu bod poblogaethau wedi darfod ac wedi mynd yn llai cynaliadwy. Mae'r effeithiau'n cael eu gwaethygu gan newid yn yr hinsawdd, gan ei bod yn bosibl na all rhywogaethau symud ar draws y tirlun i ddilyn yr hinsawdd y mae arnyn nhw ei angen.

Ers peth amser mae cylchoedd gwyddonol wedi bod yn trafod *rhwydweithiau o gynefinoedd* - strategaeth i ehangu ac adfer cynefinoedd er mwyn gwrthweithio effeithiau darnio. Yn y blynyddoedd diwethaf, mae'r pwnc wedi denu sylw'r gwleidyddion, ac mae yna gyfeiriadau at rwydweithiau yng nghyfarwyddebau Ewrop, Cynllun Gweithredu Bioamrywiaeth Llywodraeth y Deyrnas Unedig, a Strategaeth Goetir Llywodraeth Cynulliad Cymru. Mewn ymateb i hyn, mae'r Cyngor Cefn gwlad a Chomisiwn Coedwigaeth Cymru yn cydweithio i ddatblygu rhwydweithiau o gynefinoedd coetir yng Nghymru, fel project sydd wedi'i nodi mewn Memorandwm Cytundeb sy'n rhedeg o 2003 i 2007. Mae'r project yn un eang, ac mae'n cynnwys ymchwil bur a chymwysedig ar rwydweithiau cynefinoedd a chymhwyso'r canlyniadau at bolisi coedwigo.

Mae'r adroddiad yma'n disgrifio cyfnod cyntaf y project o ymchwil gomisiwn. Cafodd hwn ei gynnal er mwyn mireinio'r sylfaen ddamcaniaethol ac edrych ar y rhwydweithiau cynefinoedd coetir sydd ar gael yng Nghymru ar hyn o bryd, drwy ddefnyddio modelau cyfrifiadur. Cafodd y gwaith ei wneud gan asiantaeth *Forest Research*; cafodd ei ariannu gan y Cyngor Cefn Gwlad a Chomisiwn Coedwigaeth Cymru a'i oruchwylio gan bwyllgor llywio ehangach. Cafodd y contract ei weinyddu gan y Comisiwn ar ran y Cyngor Cefn Gwlad, ac mae'r adroddiad sy'n deillio o'r gwaith ar gael ar ffurf adroddiad gan y Comisiwn (Cyfeirnod CT-W.H.N.S.W - 0303) ac ar ffurf Adroddiad Gwyddoniaeth gan y Cyngor Cefn Gwlad, sydd wedi'i atgynhyrchu yma. Mae'r project yn parhau, a chaiff rhagor o ganlyniadau eu cyflwyno mewn adroddiadau dilynol.

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Gorffennaf 2005

PREFACE

Habitat fragmentation is one of the most serious factors affecting our woodlands. The forest cover of Wales has been greatly reduced by thousands of years of human activity, and today only about 4% of the country is covered by modified, semi-natural woodland. Many species are adapted to an extensive and highly connected habitat within which they can freely move, and fragmentation has resulted in extinctions and reduced the sustainability of populations. The effects are compounded by climate change, as species may not be able to move across the landscape to follow their climatic requirements.

For some time there has been discussion within scientific circles of *habitat networks* – the strategic expansion and restoration of habitat to counter the impacts of fragmentation. In recent years the subject has gained political attention, and networks are referred to in European directives, the UK Government's Biodiversity Action Plan, and the Wales Assembly Government's Wales Woodland Strategy. In response, CCW and Forestry Commission Wales (FCW) are working together to develop woodland habitats networks in Wales, as a project set out within a Memorandum of Agreement currently running from 2003 to 2007. The project is broad ranging, involving pure and applied research into habitat networks, and application of the results to forestry policy.

This report describes the project's first stage of commissioned research. This was to refine the theoretical basis and to explore existing woodland habitat networks in Wales using computer models. The work was carried out by Forest Research Agency; it was jointly funded by CCW and FCW and overseen by a wider steering committee. The contract was administered by FCW on CCW's behalf, and the resulting report is available as a FC report (Reference CT-W.H.N.S.W – 0303) and as the CCW Science Report reproduced here. The project is continuing, and further results will presented in subsequent reports.

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July 2005

Towards a Woodland Habitat Network for Wales

Contract Report to the Countryside Council for Wales and the Forestry Commission, Wales

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CRYNODEB GWEITHREDOL

Mae darnio cynefinoedd ar amrywiaeth o raddfeydd wedi'i gysylltu'n eang â dirywiad llawer o rywogaethau ledled y byd. Mae hyn yn arbennig o amlwg yng nghoetiroedd Cymru, sydd wedi'u darnio dros gyfnod maith o amser. Mae hyfywedd bioamrywiaeth hirdymor coetiroedd sydd wedi esblygu o fewn cynefin anarddwys a chysylltiedig iawn yn cael ei fygwth wrth i'r coetiroedd gael eu darnio, gan fod hynny'n arwain at goetiroedd llai a'r rheiny'n fwy gwasgaredig. Oherwydd hyn, mae llawer o ecolegwyr a chadwraethwyr wedi dadlau o blaid cynnal a gwella'r cysylltedd rhwng poblogaethau ar goetiroedd sydd wedi'u darnio. Erbyn hyn mae yna ddiddordeb cynyddol mewn defnyddio rhwydweithiau cynefinoedd i wrth-droi effeithiau darnio drwy ehangu cynefinoedd sydd wedi'u hynysu a chreu cysylltiadau rhyngddyn nhw.

Mae Cyngor Cefn Gwlad Cymru a Chomisiwn Coedwigaeth Cymru yn cydweithredu i ddatblygu rhwydwaith o gynefinoedd coetir a'i roi ar waith yng Nghymru. Nod cyffredinol y gwaith ymchwil yw:

Dylunio ac adeiladu fframwaith gofodol a dadansoddiad ategol er mwyn cynghori'r Cyngor a'r Comisiwn, a'u partneriaid, am y potensial ar gyfer datblygu rhwydweithiau o gynefinoedd coetir yng Nghymru

Y bwriad yw y bydd y gwaith ymchwil yma yn bwydo cynllun **strategol** ar gyfer cynnal, gwella ac adfer coetiroedd a'r cynefinoedd perthynol gan anelu at fynd i'r afael ag effeithiau darnio cynefinoedd.

Ar sail y nod ymchwil cyffredinol yma, cafodd methodoleg tri cham ei ddatblygu, ynghyd â rhesymeg i'r ategu'r fethodoleg honno:

- **Cam 1 – Yr egwyddorion y tu ôl i ddatblygu strategaeth rhwydweithiau cynefinoedd coetir**

Er mwyn cynnig sylfaen wyddonol gadarn ar gyfer deall a datblygu'r strategaeth, mae'r cam yma'n edrych ar yr egwyddorion y tu ôl i rwydweithiau o gynefinoedd. Mae'n diffinio ystyr fforestydd, coetiroedd a rhwydweithiau, gan nodi'r cysylltiad pwysig rhwng cynefinoedd coetir a chynefinoedd agored lled-naturiol. Mae'n edrych hefyd ar gwestiwn darnio a chysyniad cysylltedd, sy'n cael ei ddiffinio yn ôl swyddogaeth ecolegol, megis symudiadau a gwasgariad rhywogaethau rhwng clytiau o gynefin, yn hytrach na'i ddiffinio yn ôl pellter ffisegol. Mae'n amlinellu'r damcaniaethau ecolegol allweddol a'r dulliau gwyddonol sy'n sail i rwydweithiau o gynefinoedd, gan gynnwys y berthynas rhwng rhywogaethau ac ardaloedd, ecoleg y tirlun, bioddaearyddaieth ynysoedd, cysyniad SLOSS (*un o rai mawr neu sawl un o rai bach*) a metaboblogaethau. Mae metaboblogaeth yn set o is-boblogaethau y mae cysylltiad deinamig rhyngddyn nhw yn sgil mewnfudo ac allfudo. Mae llawer o rywogaethau a oedd o'r blaen wedi'u dosbarthu dros ardal ddi-dor bellach yn gweithredu fel metaboblogaethau o ganlyniad i ddarnio cynefinoedd.

Mae cysyniadau newydd rhwydweithiau ecolegol a ffyrdd glas yn cael eu cyflwyno fel dulliau i helpu i ddatblygu tirluniau cynaliadwy aml-amcan. Serch hynny, mae'r dulliau hyn wedi'u seilio yn aml ar egwyddorion tirlun syml, y gall fod yn anodd eu rhoi ar waith ar y raddfa strategol yng Nghymru ac sy'n ymwneud ag elfennau penodol ar fioamrywiaeth coetiroedd. Mae'r syniad o fynd ati drwy ganolbwyntio ar rywogaethau penodol i ddiffinio rhwydweithiau o gynefinoedd yn cael ei gyflwyno fel fframwaith mwy effeithiol ar gyfer hoelio'r sylw ar gadw bioamrywiaeth. Byddai'r dull yma'n gwneud cysylltiad pendant rhwng cysylltedd tirluniau ac elfennau penodol o fioamrywiaeth coetiroedd.

Mae'r cam yma'n cau gydag adolygiad o'r ffyrdd allweddol o ddatblygu rhwydweithiau cynefinoedd yn y DU.

Mae defnyddio cysylltedd strwythurol (*wedi'i seilio ar ardaloedd craidd a chysylltiadau*), rhywogaethau penodol, rhwydweithiau o swyddogaethau, trothwyon gorchudd tir, a phwysigrwydd y matrics tirluniau wedi bod yn amlwg iawn yn y gwaith ymchwil diweddar.

- **Cam 2 – Edrych ar drothwyon gorchudd tir**

Mae trothwyon gorchudd tir wedi chwarae rhan ddylanwadol mewn esbonio a datblygu rhwydweithiau cynefinoedd yn y DU. Mae cam 2 yn adolygu egwyddorion trothwyon gorchudd tir, yn enwedig felly rheol gorchuddio 30%, ac yn edrych arnyn nhw er mwyn asesu pa mor ddefnyddiol ydyn nhw o ran datblygu rhwydweithiau cynefinoedd.

Cafodd nifer o fatricsau tirluniau (*nifer y clytiau, cyfanswm yr ymyl, y clwt mwyaf, cyfanswm yr ardal graidd*) sy'n amlygu trothwyon gorchudd tir eu defnyddio gydag amrywiaeth o fodelau tirlun niwtral, a oedd yn amrywio o ran eu clystyru gofodol a'u tirluniau coetir Cymreig 'gwirioneddol'.

Mae cysyniad trothwyon tirlun syml, sy'n deillio o dirluniau amrywiol, yn apelio'n fawr fel cyfrwng i helpu i ddatblygu cynlluniau a strategaethau o'r fath. Serch hynny, mae'n canlyniadau ni'n awgrymu bod gwahaniaethau sylweddol rhwng tirluniau amrywiol a thirluniau Cymreig, sy'n tanlinellu'r problemau tebygol a geir wrth fynd ati'n ymarferol i ddefnyddio trothwyon syml sy'n deillio o dirluniau amrywiol. Mae'r canlyniadau'n cadarnhau bod dosbarthiad coetiroedd Cymru'n un sydd wedi'i glystyru'n ofodol, yn hytrach nag un amrywiol, gyda chyfuniad o ffactorau sy'n cynnwys topograffi, hydroleg a defnyddio'r tir. Mae coetiroedd Cymru'n debycach i fodelau tirlun clystyraidd iawn. Mae'n ddiddorol sylwi nad yw'r modelau hyn yn amlygu'r un trothwyon clir â'r tirluniau amrywiol.

- **Cam 3 – Diffinio Rhwydweithiau a Chysylltiadau**

Nod y cam terfynol oedd defnyddio dull wedi'i seilio ar rywogaethau er mwyn datblygu a diffinio rhwydweithiau o gynefinoedd coetir. Cafodd model pwrpasol ei ddatblygu ar sail cyfres o ddulliau prototeip wedi'u seilio ar GIS, o'r enw BEETLE *(Dulliau Cloriannau Biolegol ac Amgylcheddol ar gyfer Ecoleg Tirluniau)* sydd wedi'i seilio ar ddefnyddio rhywogaethau penodol. Cafodd y model o rwydweithiau cynefinoedd coetir ei seilio ar y strwythur canlynol:

- **MEWNBWN** – Mae'r mewnbwn sylfaenol wedi'i seilio ar fodel statig o orchudd tir sy'n deillio o amryw byd o setiau data, a detholiad o broffiliau o rywogaethau penodol, sydd wedi'u dylunio i gynrychioli nifer ehangach o grwpiau o rywogaethau, cynefinoedd blaenoriaeth a phrosesau ecolegol allweddol. Cafodd y proffiliau eu seilio ar ofynion y tirluniau a gallu rhywogaethau i ymledu.

- **PROSES** – Nod yr elfen sy’n ymwneud â phrosesau yw modelu cysylltedd swyddogaethau. Mae hyn yn cael ei bennu gan allu rhywogaeth benodol i ymledu a pha mor hawdd yw hi iddi symud drwy’r tirlun o’i hamgylch. Bernir bod y matrics amgylchynol yn creu effaith arwyddocaol ar gysylltedd llawer o rywogaethau coetir. Bernir bod cynefinoedd lled-naturiol ac anarddwys yn caniatáu neu yn derbyn symudiadau rhywogaethau yn well, ond rhagwelir y bydd tir sy’n cael ei ddefnyddio’n arddwys yn llai parod i’w derbyn, gan leihau felly ar gysylltedd a chynyddu arwahanrwydd ecolegol.

- **ALLBWN** – Canlyniad y dadansoddi oedd cynhyrchu cyfres o fapiau a oedd yn dangos hyd a lled y rhwydweithiau cynefinoedd posibl ar gyfer coetir hynafol a llydanddail, y bernir eu bod yn flaenoriaeth uchel o ran cadwraeth yng Nghymru. Mae’r rhwydweithiau wedi’u rhannu’n ***Rhwydweithiau Craidd*** (*clytiau mawr o goetir y mae’n hawdd eu cysylltu*) a ***Rhwydweithiau Swyddogaeth*** (*sy’n cynnwys clytiau llai o gynefin a rhwydwaith mwy anarddwys*). Mae camau rheoli at y dyfodol wedi’u cynnig er mwyn cysylltu'n ôl â’r cydrannau rhwydwaith yma. Mae’r camau hyn yn adlewyrchu’r angen i ehangu’r gweithredu o’r Rhwydweithiau Craidd sydd eisoes yn bod i mewn i Rwydweithiau Penodol.

I gloi, dangosodd y gwaith fod potensial ar gyfer defnyddio dull sydd wedi’i seilio ar rywogaethau penodol mewn ardal yr un faint â Chymru, gan gynnig golwg newydd ar sut y gallai coetiroedd Cymru gael eu troi’n rhwydweithiau pendant. Gallai hyn fod yn ategiad buddiol ar gyfer cynlluniau tirlun fel rhan o ddatblygiad cynaliadwy Cymru yn y dyfodol a helpu i’w roi ar waith yn llwyddiannus.

EXECUTIVE SUMMARY

Habitat fragmentation at a variety of scales has been widely linked with the decline of many species globally. This is particularly apparent in the woodlands of Wales, which has undergone a sustained period of fragmentation. The long-term viability of woodland biodiversity, which have evolved within a highly connected and extensive habitat, is threatened by woodland fragmentation as it leads to smaller and more isolated woodlands. Due to this many ecologists and conservationists have advocated the maintenance and improvement of connectivity between fragmented woodland populations. There is now growing interest in the use of habitat networks to reverse the effects of fragmentation by expanding and linking isolated habitats.

The Countryside Council for Wales (CCW) and the Forestry Commission Wales (FCW) are collaborating to develop and implement a woodland habitat network in Wales. The overall research aim is to:

Design and build a spatial framework and supporting analysis to advise the CCW and FCW, and partners, on the potential for the development woodland habitat networks in Wales

This research is intended to inform a **strategic** plan for the maintenance, improvement and restoration of woodland and associated habitats with the aim of combating the effects of habitat fragmentation.

A three stage methodology was developed from this overall research aim and supporting rationale:

- **Stage 1 – Principles behind the development of a woodland habitat network strategy**

In order to provide a scientifically robust basis for understanding and developing the strategy, this stage explores the principles behind habitat networks. It defines the meaning of forests, woodlands and networks, identifying the important link between woodland and semi-natural open habitats. It further explores the issue of fragmentation and the concept of connectivity, which is defined by an ecological function such as species movement and dispersal between habitat patches, rather than by physical distance. It outlines the key ecological theories and scientific approaches underlying habitat networks, including the species-area relationship, landscape ecology, island biogeography, the SLOSS (*single large or several small*) concept and metapopulations. A metapopulation is a set of sub-populations which are dynamically connected by immigration and emigration. Many species with a formerly continuous distribution now function as metapopulations as a result of habitat fragmentation.

The emerging concepts of ecological networks and greenways are introduced as tools to aid the development of multi-objective sustainable landscapes. However, these approaches are often based on simple landscape principles, which may difficult to implement at the strategic scale in Wales and relate to specific elements of woodland biodiversity. The use of a focal species approach to define habitat networks is introduced as a more effective framework to focus on biodiversity conservation. This approach would explicitly make the connection between landscape connectivity and specific elements of woodland biodiversity.

This stage concludes with a review of key approaches to the development of habitat networks within the UK. The use of structural connectivity (*based on core areas and linkages*), focal species, functional networks, land cover thresholds, and the importance of the landscape matrix have been at the forefront of recent research.

- **Stage 2 – An exploration of land cover thresholds**

Land cover thresholds have played an influential role in explaining and developing habitat networks within the UK. Stage 2 reviews the principles of land cover thresholds, particularly the 30% cover rule, and explores them to assess their usefulness in the development of habitat networks.

A number of landscape metrics (*number of patches, total edge, largest patch, total core area*) which exhibit land cover thresholds were applied to a range of neutral landscape models, which varied in their degree of spatial clustering and 'actual' Welsh woodland landscapes.

The concept of simple landscape thresholds, derived from random landscapes, is very appealing to aid the development of such plans and strategies. However, our results indicate there are considerable differences between random and Welsh landscapes, highlighting the likely problems of practically applying simple thresholds derived from the former. The results confirm that the distribution of Welsh woodland is spatially clustered, rather than random, with a combination of factors including topography, hydrology and land use. Welsh woodland has greater similarity with the highly clustered landscape models. Interestingly, such models do not exhibit the same clear thresholds as the random landscapes.

- **Stage 3 – Defining Networks and Linkages**

The aim of the final stage was to use a species-based approach to develop and define woodland habitat networks. A custom model was developed from a prototype GIS-based suite of tools called BEETLE *(Biological and Environmental Evaluation Tools for Landscape Ecology)*, which is based on a focal species approach. The woodland habitat network model was based on the following structure:

- **INPUT -** The basic input is based on a static model of land cover derived from various data sets, and a selection of focal species profiles, which are designed to be representative of a wider number of species groups, priority habitats and key ecological processes. The profiles were based around habitat requirements and dispersal ability.

- **PROCESS** – The process element aims to model functional connectivity. This is determined by the dispersal ability of a focal species and the ease of movement through the surrounding landscape. The surrounding matrix is deemed to have a significant impact on connectivity for many woodland species. Semi-natural and extensive habitats are considered to be more conducive, or permeable, to species movement whereas intensive land uses are predicted to be less permeable, thereby reducing connectivity and increasing ecological isolation

- **OUTPUT -** The result of the analysis was the production of a series of maps that showed the potential extent of habitat networks for ancient and broadleaf woodland, which are considered a high priority for conservation in Wales. The networks are divided into ***Core Networks*** (*large woodland patches which are closely connected*) and ***Functional Networks*** (*containing smaller habitat patches and a more extensive network*). Future management actions are proposed to link back to these network components. The actions reflect the need to expand action from existing Core Networks, into Focal Networks.

In conclusion the work showed the potential for applying a focal species approach to an area the size of Wales and provided new insights into how the woodlands of Wales could be potentially formed into discrete networks. This can provide useful support to landscape planning as part of the future sustainable development of Wales and aid its successful implementation.

1 BACKGROUND

1.1 HABITAT FRAGMENTATION – THE PROBLEM

In common with many countries, forests originally covered a large proportion of the land surface of Wales, and formed the matrix within which other habitats occurred. Human influence has been profound, and centuries of clearance and intensive management have reduced forest cover to only a few percent of the land surface: forest fragments, or woods as they have become known, are now islands within a matrix of non-woodland habitats (Figure 1-1). 20th century afforestation with coniferous species accounts for the majority of the larger woodland patches currently existing in Wales; conifer woodlands account for well over half of the total woodland cover in Wales (Forestry Commission, 2003).

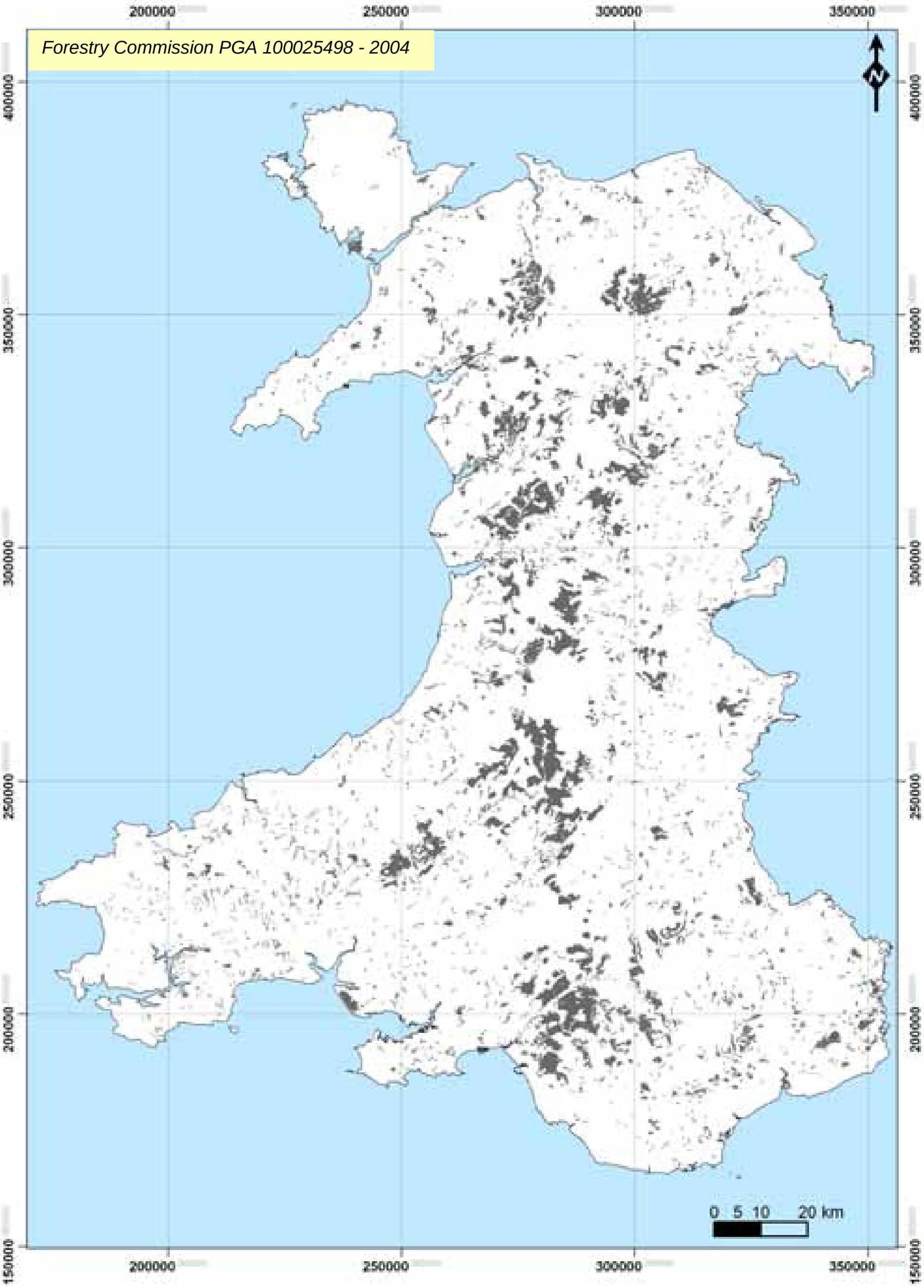


Figure 1-1 – Distribution map of broadleaf, conifer and mixed woodland in Wales

Source: (Countryside Council for Wales – Phase 1 Survey)

The basic fragmentation process involves the break up of a few large patches of habitat into an increased number of smaller patches. This process poses three challenges for biodiversity: firstly, there is a reduction in the area of available habitat; secondly, the remaining patches suffer from increased isolation; and finally, there is a reduction in the amount of core habitat area due to edge effects.

> **Habitat fragmentation** reduces the amount of habitat ***area*** and ***core habitat*** and increases patch ***isolation*** posing a major threat to biodiversity conservation

The reduction in area (or core area) may lead to increased local extinctions, whilst increased isolation may cause a reduction in the exchange of individuals between isolated patches, threatening their long-term viability.

Many forest species have evolved within a highly connected and extensive habitat, and fragmentation has inevitably had a major impact on them. Species with a very large home-range may become extinct rapidly, whilst the chronic interruption of dispersal, migration and metapopulation dynamics of many species will cause a slow attrition of biodiversity. There are concerns that climate change will compound these effects, as species will not be able to track the movement of their climatic niches across landscapes and will become more susceptible to extinction.

1.1.1 The impact of fragmentation on biodiversity in Wales

Habitat fragmentation has been identified as a process leading to a reduction in biodiversity in the UK, and is widely considered as one of the principal threats to biodiversity conservation (UK Biodiversity Group, 1995a; b). Table 1-1 illustrates the impact of fragmentation on woodland biodiversity within a Welsh context with reference to a number of priority woodland species (Spittle and Jenkins, 2001). Extracts from individual Species Action Plans (SAPs), citied within Table 1-1, specifically mention habitat fragmentation as a current factor causing loss or decline (UK Biodiversity Group, 1995a; b; 1998a; c; 1999).

Table 1-1 – Extracts from Species Action Plans (SAPs) for selected high priority, woodland-related species in Wales, which cite fragmentation as a current factor causing loss or decline

Species	Threats related to habitat fragmentation
Black grouse *(Tetrao tetrix)*	▪ Fragmentation of black grouse habitat often leads to small populations which are unlikely to persist
Nightjar *(Caprimulgus europaeus)*	▪ Nightjars require extensive areas of suitable feeding habitat…the loss of such habitats within a few kilometres of the nesting area may result in a decline in the number of birds ▪ In commercial forests, nightjars nest in the young stages of plantations…local population declines could occur as the recently planted blocks mature
Barbastelle Bat *(Barbastella barbastellus)*	▪ Threats to this species are poorly understood, but its low population density and slow population growth make it particularly vulnerable to factors such as loss and fragmentation of ancient deciduous woodland habitat
Bechstein's Bat (*Myotis bechsteinii*)	▪ Threats to this species are poorly understood, but its low population density, exacting habitat requirements and low rates of reproduction make this species particularly vulnerable to factors such as further loss and fragmentation of open ancient deciduous woodland habitat

Dormouse (*Muscardinus avellanarius*)	▪ Fragmentation of woodland, leaving isolated, non-viable populations. (Short distances, possibly as little as 100m, form absolute barriers to dispersal, unless arboreal routes are available)
Red Squirrel (*Sciurus vulgaris*)	▪ Habitat fragmentation making some areas less suitable for red squirrels, increasing their vulnerability to displacement by grey squirrels
Lesser Horseshoe Bat (*Rhinolophus hipposideros*)	▪ Further loss, damage and fragmentation of woodland foraging habitat, old hedgerows and tree lines, and other appropriate habitat
Water Vole *(Arvicola terrestris*)	▪ Loss and fragmentation of habitats
Silver-studded Blue *(Plebejus argus)*	▪ Fragmentation and isolation of habitat
Sand Lizard (*Lacerta agilis*)	▪ Loss, deterioration and fragmentation of heathland and dune habitat to a wide range of competing uses and pressures, for example development, forestry, mineral extraction, etc.

Source: (UK Biodiversity Group, 1995a; b; 1998a; c; 1999)

1.2 HABITAT NETWORKS – A POTENTIAL SOLUTION

The negative impacts of fragmentation are increasingly recognised within the nature conservation community, and consequently there is much interest in developing habitat networks to provide a solution. Habitat networks are intended to reverse the deleterious effects of fragmentation by linking existing habitat to provide large connected areas of habitat, which are capable of sustaining a greater biodiversity. It is now becoming apparent that isolated conservation measures taken at the local, often site-based, scale may be inadequate in tackling the wider problems caused by habitat fragmentation. Habitat network strategies place particular emphasis on the development of strategic plans for the creation of large-scale habitat networks, to provide a framework for the maintenance, improvement and restoration of biodiversity.

Habitat networks are intended to **reverse** the effects of **fragmentation** by expanding and linking isolated habitats

1.2.1 Drivers for habitat networks

An appreciation of the potential of habitat and ecological networks to contribute to the conservation of biodiversity has developed rapidly since the signing of the Convention on Biological Diversity (UNCED, 1992), and has led to their proposal at international, European, national and local scales.

At the international/European scale, the development of the Pan-European Ecological Network (PEEN) (Bennett, 1994; Foppen *et al.*, 2000; Bouwma *et al.*, 2002) seeks to ensure that (Council of Europe, 1998):

- *a full range of ecosystems, habitats, species and their genetic diversity and landscapes of European importance are conserved*
- *habitats are large enough to place species in a favourable conservation status*
- *there are sufficient opportunities for the dispersal and migrations of species*

- *and damaged elements of the key systems are restored and the systems are buffered from potential threats*

It is intended that the PEEN will be developed from core areas, corridors and buffer zones. Restoration areas will be identified, where it will be necessary to improve the ecological status of parts of the potential network. Although the development of PEEN, and similar habitat network strategies, represents a new approach to biodiversity conservation, their establishment will build on, and benefit from, many agreements, programmes and initiatives that have been adopted over the past decades, as outlined in Table 1-2. For example, the core areas of a habitat network will incorporate and help protect the areas and species designated and protected under existing mechanisms.

Table 1-2 - The main international mechanisms contributing to the establishment of the Pan-European Ecological Network (PEEN)

Global
▪ Ramsar Convention on Wetlands of International Importance as Waterfowl Habitat
▪ Paris Convention concerning the Protection of the World Cultural and Natural Heritage
▪ Man and Biosphere Programme (MAB)
▪ Bonn Convention on the Conservation of Migratory Species of Wild Animals
▪ Convention on Biological Diversity
European
▪ Bern Convention on the Conservation of European Wildlife and Natural Habitats
▪ European Diploma for Protected Areas
▪ European Network of Biogenetic Reserves
▪ Convention on the Protection and Use of Transboundary Watercourses and International Lakes
Regional
▪ Barcelona Protocol concerning specially protected areas and biological diversity in the Mediterranean
▪ Helsinki Convention on the protection of the marine environment of the Baltic Sea area
European Union
▪ Council Directive on the conservation of wild birds
▪ Council Directive on the conservation of natural habitats and of wild fauna and flora

Source: (Council of Europe, 1998)

Within the European Union the need for habitat networks has been identified under article 10 of the Habitats Directive (European Commission, 1992). Habitat networks are recognised as important for the long-term sustainability of the condition of Natura 2000 sites and to deliver Favourable Conservation Status to endangered habitats and species. The Directive states:

> *Member States shall endeavour, where they consider it necessary, in their land-use planning and development policies and, in particular, with a view to improving the ecological coherence of the Natura 2000 network, to encourage the management of features of the landscape which are of major importance for wild fauna and flora. Such features are those which, by virtue of their linear and continuous structure…..are essential for the migration, dispersal and genetic exchange of wild species.*

Habitat networks are also formally recognised within the UK through a number of nature conservation programmes and forestry strategies. Of particular relevance are the UK Biodiversity Action Plan (BAP) (UK Government, 1994) and the Welsh Assembly woodland strategy (Forestry Commission, 2001).

A key aim of the UK BAP is the reversal of habitat fragmentation, which is implemented through a number of Species and Habitat Action Plans (SAPs and HAPs). For example, the Upland Ashwood Habitat Action Plan (UK Biodiversity Group, 1998b) includes the action to:

> *Encourage the development of forestry/landscape strategies to provide a context for and to promote expansion and positive management of upland mixed ash woodland.*

Woodland habitat networks are an aim of the current strategy for Welsh woodland (Forestry Commission, 2001), which states:

> *The success of this strategy (in part) will be shown if we can improve the quality of these woodlands, linking and expanding their habitat networks….The prospect of global climate change demands that we consider how robust our woodland habitats are, so that we concentrate our conservation efforts on habitats that will be sustainable in the long term.*

It also includes the commitments:

> *We will increase the quality of native woodlands for wildlife and implement the Biodiversity Action Plan targets for their restoration and extension, creating links between fragmented woodlands...We will increase the area of native woodlands, targeting extension and connection of existing woods and incorporating the concept of increasing the core area of native woodland habitats.*

Habitat networks are increasingly recognised as an important mechanism to tackle biodiversity conservation and combat the impacts of habitat fragmentation. Networks are being established at a range of scales from the local to the international, and their significance is supported by many policies, strategies and plans.

1.3 RESEARCH AIM AND APPROACH

1.3.1 Research aim

The Countryside Council for Wales (CCW) and the Forestry Commission Wales (FCW) are collaborating to develop and implement a woodland habitat network in Wales. The overall research aim is to:

> ***Design and build a spatial framework and supporting analysis to advise the CCW and FCW, and partners, on the potential for the development woodland habitat networks in Wales***

This research is intended to inform a **'strategic'** plan for the maintenance, improvement and restoration of woodland and associated habitats with the aim of combating the effects of habitat fragmentation. The ecological focus of this research was developed through consultation with a pre-defined, project-based 'woodland habitat network steering group'. The group established that the rationale for the creation of a woodland habitat network was to **combat the effects of habitat fragmentation, in order to produce an ecologically functional woodland landscape**.

Although beyond the scope of this current project, it is acknowledged that habitat networks are set within the wider context of sustainable development. In addition to ecological benefits, networks can yield wider economic and social benefits. There is a belief that many features of ecological networks, such as riparian corridors, will assist other key environmental functions (e.g. species dispersal, hydrological processes such as improved water quality and flood attenuation) and also impact on associated factors (e.g. recreation, countryside character, visual, buffering) (e.g. Smith and Helmund, 1993). It has been suggested that the wider non-ecological benefits may considerably strengthen the case for the development of habitat networks (Dover, 2000).

The implementation of this strategic plan will inevitably take place at a finer, more **'local'** scale in which many of the associated non-ecological elements can be properly considered, along with additional data, such as habitat quality, suitability and constraints, and with involvement of local stakeholders. There is also a need to understand open-ground habitat networks, to ensure that the expansion of one does not cause a detrimental impact on others. However, the implementation of a comprehensive habitat network strategy is currently beyond the scope of this strategic study.

1.3.2 Research approach

A three stage methodology was agreed and developed from this overall research aim and supporting rationale

- **Stage 1 – Principles behind the development of a woodland habitat network strategy**

In order to provide a scientifically robust basis for understanding and developing the strategy, this stage explores the principles behind habitat networks. It defines the meaning of forests, woodlands and networks; further explores the issue of fragmentation and the concept of connectivity; and outlines the key ecological theories and scientific approaches underlying habitat networks. The emerging concepts of ecological networks and greenways are introduced, and the use of focal species to define habitat networks is discussed. This stage concludes with a review of key approaches to the development of habitat networks within the UK.

- **Stage 2 – An exploration of land cover thresholds**

Land cover thresholds have played an influential role in explaining and developing habitat networks within the UK. This stage introduces the principles of land cover thresholds and explores them within random and 'actual' landscapes to assess their usefulness in the development of habitat networks.

- **Stage 3 – Defining Networks and Linkages**

Stage 3 introduces the focal species-based element of the BEETLE model *(Biological and Environmental Evaluation Tools for Landscape Ecology),* and the development of a suite of focal species. It then examines the use of the BEETLE model to identify Core Networks, Focal Networks and Large-Scale Linkages in the development of woodland habitat networks in Wales.

2 STAGE 1 - PRINCIPLES BEHIND THE DEVELOPMENT OF A WOODLAND HABITAT NETWORK STRATEGY

2.1 DEFINING FORESTS, WOODLANDS AND NETWORKS

Forests are strictly defined as “a plant formation that is composed of trees the crowns of which touch, so forming a continuous canopy” (Allaby, 1994, p.165). Rackham (1986, p.129) suggests “the mysterious word forest may, in its Germanic origin, have meant a tract of trees. In Western Europe it came to mean land on which deer were protected by special byelaws. The word and the laws were introduced to England from the Continent by William the Conqueror”.

“The word ‘forest’ has been much abused in its history…a Forest is land on which the king (or some other magnate) has the right to keep deer. This is the original sense of the word: to the medievals a Forest was place of deer, not a place of trees” (Rackham, 1986, p.65). Within this context forests are not necessarily tree-covered and might include considerable areas of open habitat such as heatlhland, grassland and bog.

Similarly, woodlands are defined as a vegetation community that includes widely spaced, mature tress. In contrast with the strict definition of forest, the trees in woodlands do not form a closed canopy, and “woodland is often defined as having 40 percent canopy cover or less” (Allaby, 1994p.430). However, in line with the broader definition of forests, woodlands can contain substantial areas of open habitats such as grassland, heathland, or scrub communities.

In Britain, the management origin could be used to further define forests as extensive areas of trees often with a plantation focus. Rackham (1986, p.65) uses the word “forestry in the modern sense as the art of managing plantations”. In contrast, woodlands can be seen as smaller areas of trees with a more semi-natural origin. Spatial scale may also be important in defining forests and woodland, with the process of habitat fragmentation reducing extensive forest areas into smaller, isolated woodlands. Allaby (1994) suggests the terms forest and woodland are often used interchangeably within Britain, and Rackham (1986, p.130) re-emphasizes “that the word forest does not imply woodland”.

The key point from this definition is that forests and woodlands consist of not only of trees but substantial areas of associated open, semi-natural habitats. Therefore, a woodland habitat network should reflect this balance between trees and open habitats.

2.2 UNDERSTANDING FRAGMENTATION AND CONNECTIVITY

As previously noted in Section 1.1, one of the fundamental threats of habitat fragmentation to biodiversity conservation arises from the increased isolation of fragmented habitat patches. Increased isolation may threaten the long-term viability of some elements of biodiversity, through the interruption of dispersal, migration and metapopulation dynamics for many species. However, to understand the impact of habitat fragmentation on biodiversity, and particularly isolation, we need to make the fundamental distinction between structural ‘connectedness’ and functional ‘connectivity’ (e.g. Farina, 1998). Connectedness is based on the degree of physical connection between elements of the same type, whilst connectivity is defined by an ecological function such as species movement and dispersal between habitat patches.

> **Connectedness** is a physical attribute of the landscape based on physical distance

Connectivity is not based on a physical measurement between discrete habitat patches, but is related to the species specific use of the landscape. It is difficult to infer the ecological function of a landscape from measurements of physical landscape structure. Consequently, it is possible to have high connectivity in an apparently highly fragmented landscape, with low connectedness, as long as the wider matrix supports the ecological function for a particular species (Farina, 1998). Hobbs claims that if landscape ecology is to provide useful input into land use and conservation issues, greater effort needs to be expended in understanding the functional aspects of landscapes; however, he suggests landscape function is still poorly understood.

> **Connectivity** is a functional attribute of the landscape related to ecological processes

The Council of Europe (1998) consider that the challenge of developing habitat networks is to find ways in which biodiversity can continue to function in landscapes that are also used for human activities. They believe ecological networks meet this challenge because they provide a model for functionally conserving biodiversity, based on sound ecological principles and maintain a degree of human use of the landscape.

2.3 ECOLOGICAL THEORIES AND SCIENTIFIC APPROACHES UNDERLYING HABITAT NETWORKS

A number of key ecological theories and scientific approaches have influenced our understanding of the impacts of habitat fragmentation and the relationship between habitat area, patch isolation and species viability. This body of science forms the building blocks in the understanding and design of habitat networks.

The **species-area** relationship is a formalisation of the observation that large areas usually contain more species than small areas of comparable habitat, and that the benefits of additional unit area declines with increasing size. Plant ecologists first attempted to elucidate the exact form of the curvilinear relationship early in the 20th century (Arrhenius, 1921; Gleason, 1922). The relationship between species and area has an extensive literature; indeed, Connor and McCoy (1979) suggest an awareness of the basic species-area relationship dates back to 1835. Shafer (1994) stresses that the basic idea of the species-area curve predated the theory of island biogeography by over 120 years.

Landscape ecology is defined as "the study of the interactions between the temporal and spatial aspects of a landscape and its flora and fauna" (Dover and Bunce, 1998, p.xx). The term landscape ecology was first coined by the German biogeographer Carl Troll at the end of the 1930s (Farina, 1998). Troll hoped that a new science could be developed that would combine the spatial, 'horizontal' approach of geographers with the functional, 'vertical' approach of ecologists. Landscape ecology also occupies an important bridge between pure and applied ecology, with great potential for the integration of emerging theories (e.g. island biogeography, metapopulation models).

> **Landscape ecology** is the study of the interactions between the temporal and spatial aspects of a landscape and its flora and fauna

Landscape ecology provides a basis for understanding the nature and dynamics of the landscape, based on the key principle that landscapes contain an inherent ecological infrastructure or network (*often based on elements such as patch, corridor, matrix*) that is conducive to different levels of species diversity (e.g. Forman and Godron, 1986; 1995). Landscape ecology appears to be able to help us explain, predict and plan change in the landscape by focussing on the wider ecological structures and functions. Land use plans and indicative strategies based on these ecological principles are finding increasing application, especially in Europe and the USA, and more recently the UK. This reflects a growing maturity in landscape ecology, enabling it not only to inform theory, but also offer solutions to 'real world' planning problems (Hawkins and Selman, 2002).

The theory of **island biogeography** (MacArthur and Wilson, 1967), which attempted to explain the variation in species diversity on oceanic islands, was especially important. Simply stated, the theory holds that the number of species and the species composition of an island is dynamic, and is determined by the equilibrium between the immigration of new species and the extinction of those already present. According to the model, rates of immigration and extinction depend on the size of an island and its distance from a mainland species reservoir, which allows the construction of a general equilibrium model (Figure 2-1). Four equilibrium points are shown on the model representing different combinations of large and small islands near and far from continental shores. In this illustration, point 1 is the worst scenario and point 4 is the best.

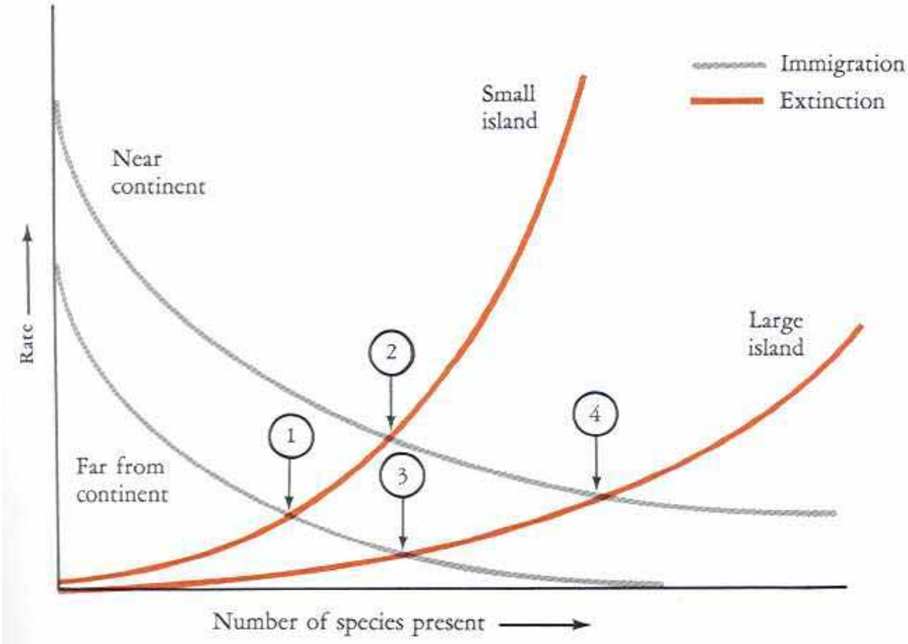


Figure 2-1 - Theory of island biogeography

(Four equilibrium points are shown on the model representing different combinations of large and small islands near and far from continental shores. In this illustration, point 1 is the worst scenario and point 4 is the best)

Source: After (MacArthur and Wilson, 1967; in Odum, 1993)

Owing to the continuing fragmentation and isolation of habitats, an analogy soon formed between 'oceanic islands', upon which the theory of island biogeography is based, and 'terrestrial habitat islands' which were surrounded by an apparent 'sea' of intensively managed or urbanised landscapes. The theory of island biogeography enabled ecologists to relate island size to the range and viability of species, indicating how larger habitat islands would be more likely to sustain a larger number of species.

The idea that such habitat islands could be treated by the same theories as oceanic islands was initially very popular and led to several suggestions as to how such theories could aid conservation, culminating in proposals for designing and acquiring nature reserves (Diamond, 1975). Selman (2000, p.161) describes how the theory of island biogeography was "highly influential on nature conservation policy, where it led scientists to debate the respective merits of protecting several small sites as opposed to a large single one within a particular area" (the **SLOSS concept -** 'single large or several small'). Diamond (1975) used the theory of island biogeography and species-area relationships to propose certain optimal design principles for nature reserves in order to maximise their species richness and viability (Figure 2-2).

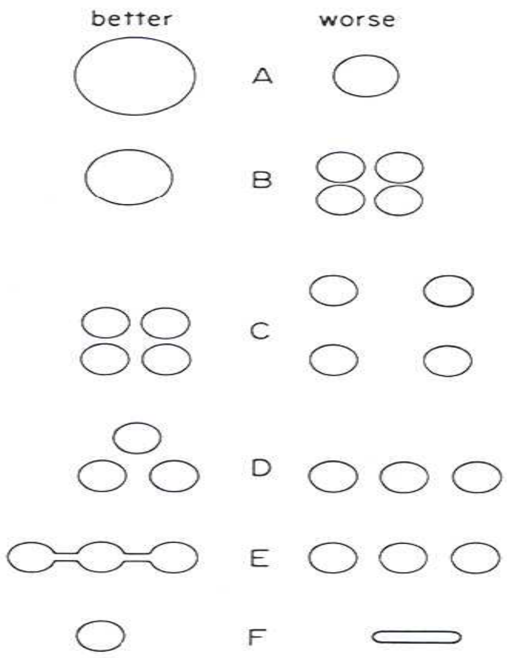


Figure 2-2 - Nature reserve design principles based on island biogeography theory

Source: (Diamond, 1975)

The principles behind the six designs were:

- **A -** A large reserve is better than a small reserve, as the large reserve can hold more species at equilibrium, and it will have lower extinction rates.
- **B -** The reserve should generally be divided into as few disjunctive pieces as possible, for essentially the reasons underlying principle A.
- **C -** If the reserve is broken up, the pieces should be as close to each other as possible, to increase immigration rates.
- **D -** The reserve pieces should be grouped equidistant from each other, rather than grouped linearly, as in linear arrangement the terminal sites become isolated with reduced re-colonisation.
- **E -** Connect several disjunct reserves with strips of protective habitats, which will increase the ability to disperse between reserves.
- **F -** Reserves should be as nearly circular in shape as possible, to minimise dispersal distances within the reserve.

The application of island biogeography theory to terrestrial habitat islands is an appealingly simple idea, but the relationships between the population dynamics of species and the qualities of core and intervening habitats is far more complex. As a result, both the theory of island biogeography and its subsequent applications are often criticised for being too simplistic and not recognising the actual reality of designing and acquiring protected areas (Gilbert, 1980; Margules *et al.*, 1982; Reed, 1983). However, Peck (1998) pointed out that the principles proposed by Diamond (1975) were an important step in the development of the field, identifying several ideas that proved fundamental for reserve design:

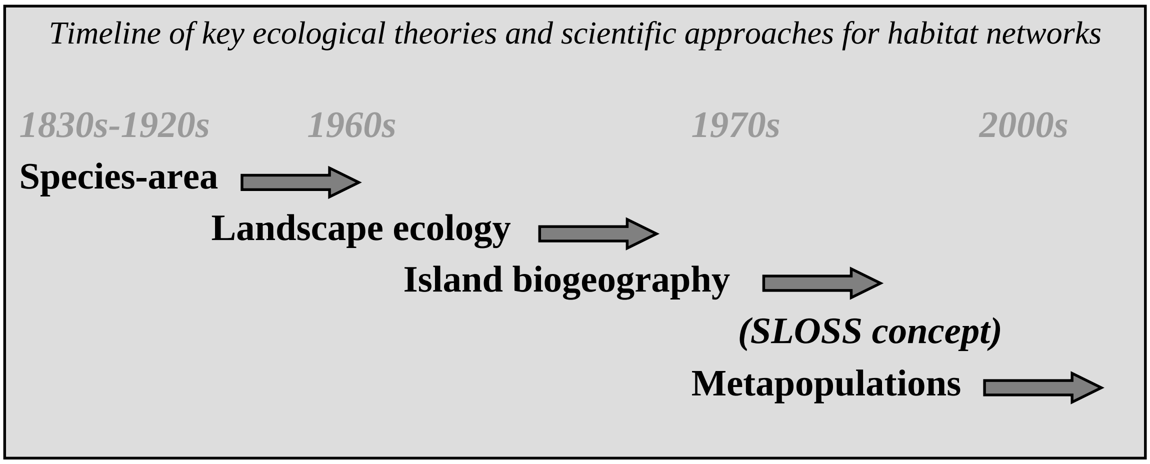
For example, large reserves are clearly valuable for most reserve systems. His principles regarding the size and shape of reserves addressed the impact of edges and the importance of maintaining interior habitat for sensitive species. By advocating reserves located close together, or connected by corridors, he highlighted the value of connectivity for species dispersal (Peck, 1998, p.92).

Metapopulation models (Levins, 1970; Hanski and Gilpin, 1997; Hanski, 1999), which have important conceptual links with the theory of island biogeography, play an increasingly important role in landscape ecology and the study of habitat fragmentation. Levins (1970) first used the term metapopulation to describe a population of populations which are actively in contact with each other. This concept assumes that essential life-cycle processes operate between these dynamically linked sub-populations, with the risk of local extinction and the probability of re-colonisation depending on the ability to maintain an exchange of individuals. When populations living in a heterogeneous environment become isolated by hostile or less favourable conditions, contact between them is ensured only by emigration or immigration. Sub-populations may undergo periodic extinction and colonisation, while the metapopulation as a whole persists.

> A **Metapopulation** is a set of sub-populations which are dynamically connected by immigration and emigration

Within the UK, many species with a formerly continuous distribution now function as metapopulations as a result of habitat fragmentation. The subsequent isolation of these fragmented populations increases the probability of local extinction on small habitat patches, and reduces the exchange of individuals on isolated patches. Metapopulation models are becoming increasingly important in understanding the dynamics of such fragmented populations, and extremely useful when applied to biodiversity conservation in a fragmented environment. Hanski and Gilpin (1991) strongly emphasised the importance of metapopulation models for future biodiversity conservation strategies:

Metapopulation ideas have become vogue in conservation biology, and with most environments becoming increasingly fragmented, it seems clear that much of the metapopulation research in the future will be motivated by and applied to conservation biology (1991, p.13).



2.4 THE DEVELOPMENT OF HABITAT NETWORKS

2.4.1 The emergence of ecological networks and greenways

In recognition of the increased threats from habitat fragmentation, Jongman and Pungetti (2004a) describe how new philosophical directions have emerged, moving from isolation to connection and from a concentric to a peripheral approach. Nature conservation, accordingly, is moving from a local to global scale:

> *If the previous focus was primarily on areas of high nature conservation, e.g. national parks, now the focus is moving towards linkage between them and linkages between nature and the human environment such as greenways, ecosystem coherence and ecological networks. These concepts have become familiar in ecological language at both the scientific and the public level (Jongman and Pungetti, 2004b, p.1).*

Ecological networks provide a framework of ecological components, e.g. core areas, corridors and buffer zones, which comprise the structural elements of a landscape which are deemed necessary to maintain biological and landscape diversity. In a similar fashion, the development of the **greenway** concept is based around the principle that structural components of the landscape, e.g. continuous linear features, will assist key environmental functions such as species dispersal and hydrological processes (Smith and Helmund, 1993; Thorne, 1993; Ahern, 1995; Hawkins and Selman, 2002). However, an important quality of the greenway is that it is essentially a multi-benefit device and, whilst the initial motivation may be ecological, it also supports other objectives such as recreation, visual appreciation, scenic highways and pollution buffering. Jongman and Pungetti (2004a) have suggested that although ecological networks and greenways show a distinction in focus they show a similarity in concept and structure:

> *While greenways came initially from the need to create connections and paths for people to access the American countryside, ecological networks came from the need to conserve European species and habitats. In their later stages, however, the two concepts have come closer, having both been recently recognised as fundamental frameworks for the survival and movement of species populations, including humans (Jongman and Pungetti, 2004a, p.4).*

2.4.2 Habitat networks and focal species

Landscape ecological planning based on the principles of ecological networks and greenways has the potential to provide multiple benefits. One of the main functions of ecological networks and greenways is to protect and enhance biodiversity (Verboom and Pouwels, 2004). However, a significant deficiency of this approach to biodiversity conservation has been its tendency to produce a single optimal network design, principally based upon landscape structure (Hawkins and Selman, 2002). Hawkins and Selman (2002, p.214) suggest that "one of most serious practical difficulties facing landscape ecologists when advising on the re-design of landscape elements is that there is no single optimum design that suits 'biodiversity' generally, as each species has distinctive spatial requirements".

> **Habitat Networks** aim to protect and enhance biodiversity. They are based on ecologically representative focal species

In order to understand and assess the biodiversity conservation function of a network, as opposed to the basic principles of ecological structure that underlie ecological networks and greenways, it is necessary to adopt a species-based approach (Ratcliffe *et al.*, 1998; van Rooij *et al.*, 2001; Verboom *et al.*, 2001; Opdam, 2002;

Opdam *et al.*, 2003; Bolck *et al.*, 2004; Verboom and Pouwels, 2004). **Habitat networks** can be regarded as an ecological, species-based sub-division of ecological networks and greenways, based around the specific landscape requirements of a number of ecologically representative focal species.

Focal species build on the concept of umbrella/flagship species, whose requirements are believed to encapsulate the needs of other species and ecological processes (Lambeck, 1997). Focal species are designed to represent various habitat types and particular ecological processes and vary in their sensitivity to habitat modification and fragmentation (e.g. Bolck *et al.*, 2004). According to the underlying theories (Section 2.3), the sensitivity of a species to habitat fragmentation is basically linked to their area requirements and dispersal ability (Vos *et al.*, 2001).

Rather than promoting a narrow species-based approach, focal species are intended to act as representatives of wider biodiversity and key ecological processes. Indeed, Opdam *et al.* (2003) stress that focal species, or their ecological profiles, should be regarded as part of the evaluation toolkit and not direct targets themselves. Therefore in many cases, it may be desirable, or at least necessary, to create a number of **Generic Focal Species (GFS)** profiles in order to reinforce the focus on landscape processes, and represent the bulk of species for which insufficient autecological knowledge exists, rather than on single species conservation.

> **Focal Species**
> encapsulate the needs of wider biodiversity and key ecological processes

In contrast to ecological networks and greenways, the focal species approach does not advocate an optimal landscape design. The focal species approach is intended to act as an aid to integrated landscape planning by assessing the relative merits of a landscape for particular representative focal species.

2.5 APPROACH TO HABITAT NETWORKS IN THE UK

In the UK work on habitat networks has tended to focus on forest and woodland habitats. Ecological fragmentation of woodland is regarded as a particular problem for biodiversity conservation, even though many woodland fragments are conserved by considerable site-scale conservation measures. The development of habitat networks, in the general sense, has a long history in the UK; however, Peterken (2002, p.5) suggests that this long history of re-afforestation has had limited impact in combating fragmentation:

> *forest habitat network development has effectively been in progress for 200 years or more. New woods and hedges were created in the 18th and 19th centuries. Since 1895, the total forest cover of Britain has increased from about 4 percent to about 11 percent – but these developments have not been efficient at reducing ecological isolation*

The long-term goal for the development of a number of woodland habitat network strategies has been to enlarge and reconnect woodland habitats, in order to combat ecological isolation in a targeted fashion without the need for a large-scale expansion of woodland (e.g. Peterken *et al.*, 1995; Hampson and Peterken, 1998; Peterken, 2003). Such network proposals are often based on targeted action, within a regional framework, on two basic structure elements of the landscape, **core areas (**or **nodes)** and **linkages**. The process suggests that core areas should be retained, expanded and developed within existing clusters, while linear woodlands should be developed into linkages to connect core areas. It has been emphasised that woodland should not take precedence over other scarce or important open habitats. The focus of this early study was on key **structural** elements of the landscape and was aimed at landscape connectedness rather than landscape connectivity.

This initial approach was further developed by Ratcliffe *et al.* (1998) in the development of a forest habitat network for the Cairngorms, Scotland. Ratcliffe *et al.* (1998) recognised the importance of using biodiversity surrogates, or **focal species**, and a limited number of real species to aid the understanding and development of habitat networks. Ratcliffe *et al.* (1998, p. i) stresses that “it is difficult to proceed beyond the theoretical and general in making use of surrogates, or by applying our knowledge of fragmentation, without considering at least some individual species”. The focus of their study is clearly on the development of a **functional**, species-based habitat network strategy rather an ecological network based on landscape structure principles. However, their study revealed a considerable shortage of information for many important species, particularly in terms of habitat requirements and dispersal ability.

Within England, there is a similar imperative to expand the cover of woodland to combat habitat fragmentation. Buckley and Fraser (1998) adopted a comparable focal species approach in order to examine the implications of new woodland planting strategies. They examined strategies based on random, envelope, buffering and linking planting strategies in four contrasting regions of lowland England.

During this initial development of habitat network strategies, Peterken (1995; 1998; 2000) also introduced the influential concept of **land cover thresholds** derived from the analysis of random landscapes (see Franklin and Forman, 1987; Gardner *et al.*, 1987; Gardner and O'Neill, 1991; Andren, 1994). According to this approach there are potentially a large number of small, isolated woods within a landscape with 10-20% woodland cover, edge habitats are relatively minimal and there is little or no core area. As the woodland cover reaches 30% (Figure 2-3a) small woods clump together to form larger woods, ecological isolation is reduced as patches start to coalesce and edge habitat becomes substantial. As 60% cover is reached (Figure 2-3b), edge habitats have reached their maximum, core area increases rapidly and woodland forms the matrix within which other habitats are located.

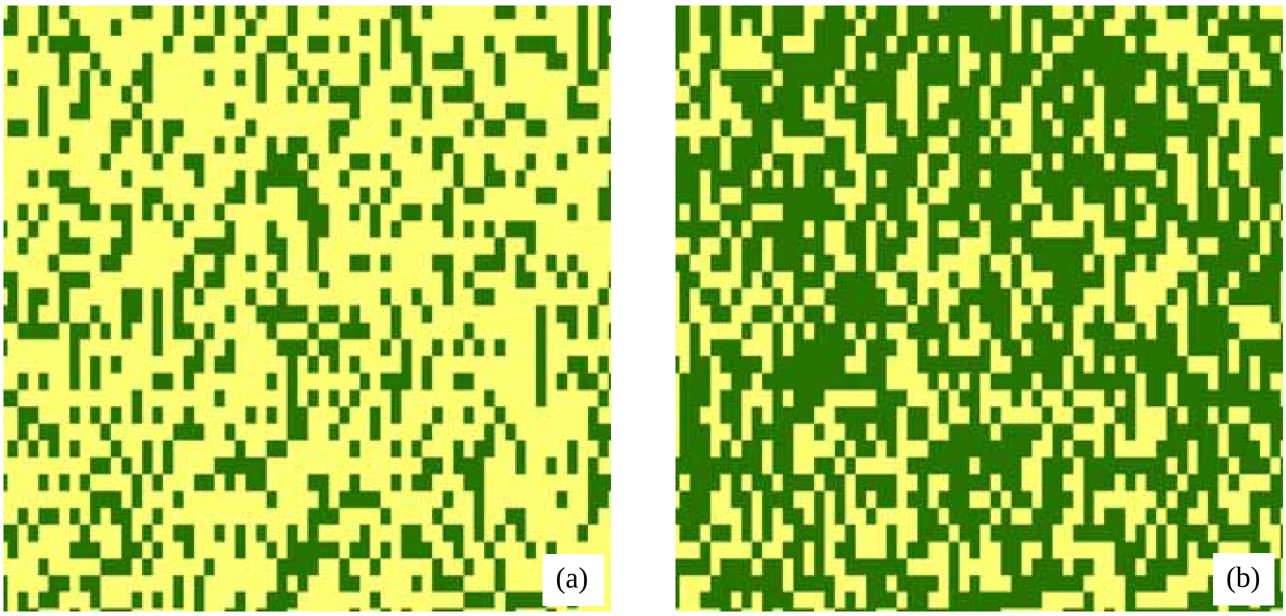


Figure 2-3 – Random landscapes with 30% (a) and 60% (b) woodland cover (green)

The target of 30% for woodland cover has become a widely accepted ‘rule of thumb’ when examining and designing habitat networks (e.g. Peterken, 2002; Woodland Trust, 2002; Forestry Commission Scotland, 2003). The assumption being that "at 30% cover or more, woodlands become more ecologically resilient, i.e., that isolation is so small that woodland species can respond to changes in the pattern of woodland…the areas are functionally one forest" (Peterken, 2000, p. 296).

> The **Matrix** refers to the dominant component of the landscape

The recent Woodland Trust approach to landscape-scale action (Woodland Trust, 2000; 2002) reflects the broader definition of woodlands (see Section 2.1), emphasising the importance of **semi-natural habitats** in the surrounding **matrix**. These associated habitats may improve the quality of woodland habitats and mitigate some of the impacts of ecological isolation for many woodland species. Their aim is to advance beyond the conservation of small, discrete areas for biodiversity, and produce ecologically functional landscapes. This will involve the creation of semi-natural habitats, both woodland and open ground, and modification to agriculture that is more sympathetic to wildlife. They stress "the need for habitat creation to buffer and extend semi-natural habitats to increase their core area and thus their ecological resilience, rather than to simply link them" (Woodland Trust, 2002, p.2). This clearly reflects the wider definition of forests and woodlands as outlined in Section 2.1. Many previous approaches to habitat networks have exaggerated the need to physically link isolated habitats, promoting the impression that habitats have to be structurally connected to combat ecological isolation and improve connectivity (see Section 2.2). Greater emphasis is now being placed on the importance of the surrounding matrix and how many semi-natural habitats can aid woodland connectivity, whilst more intensive land use may impede connectivity (e.g. Ray *et al.*, 2003; Ray *et al.*, 2004a; Ray *et al.*, 2004b).

There is also an emerging need to **balance** the development of woodland habitat networks with the conservation of semi-natural open habitats, which may form their own networks. Humphrey *et al.* (2003) recently adopted a focal species approach to tackle the issue of balancing the development of forest habitat networks with the maintenance of open habitat networks in Scotland.

3 STAGE 2 – AN EXPLORATION OF LAND COVER THRESHOLDS

3.1 INTRODUCTION

Land cover thresholds, particularly the 30% rule (as introduced in Section 2.5), have played an influential role in understanding and developing habitat network strategies within the UK. Although these thresholds have considerable potential, there are increasing concerns over the applicability and appropriateness of such thresholds to aid the conservation of biodiversity within fragmented landscapes. It has been suggested that woodland configuration and landscape context, particularly the spatial arrangement of semi-natural habitats and intensive land use, will play a significant role in determining landscape connectivity in addition to woodland cover. The aim of this initial study is to explore the concept of land cover thresholds within random and 'actual' landscapes and to assess their usefulness in understanding and developing habitat networks.

A number of key land cover thresholds are revealed by examining a number of simple landscape metrics applied to a selection of random landscapes (see Franklin and Forman, 1987; Gardner *et al.*, 1987; Gardner and O'Neill, 1991; Andren, 1994; Peterken, 2000; 2002). The thresholds are illustrated in Figure 3-1 and summarised below:

- *The **number of patches** of woodland within a landscape decreases considerably between 20% and 60% cover as the patches start to coalesce and potential isolation is minimised.*
- *The **total edge** of woodland reaches a maximum at 50% woodland cover and reduces thereafter.*
- *The **largest patch**, as a proportion of the total woodland cover, increases considerably from 30% and contains the majority of the woodland by 50%.*
- *The **total core area** increases slowly depending on the patch size and the edge definition used; a 50m edge is used in this example.*

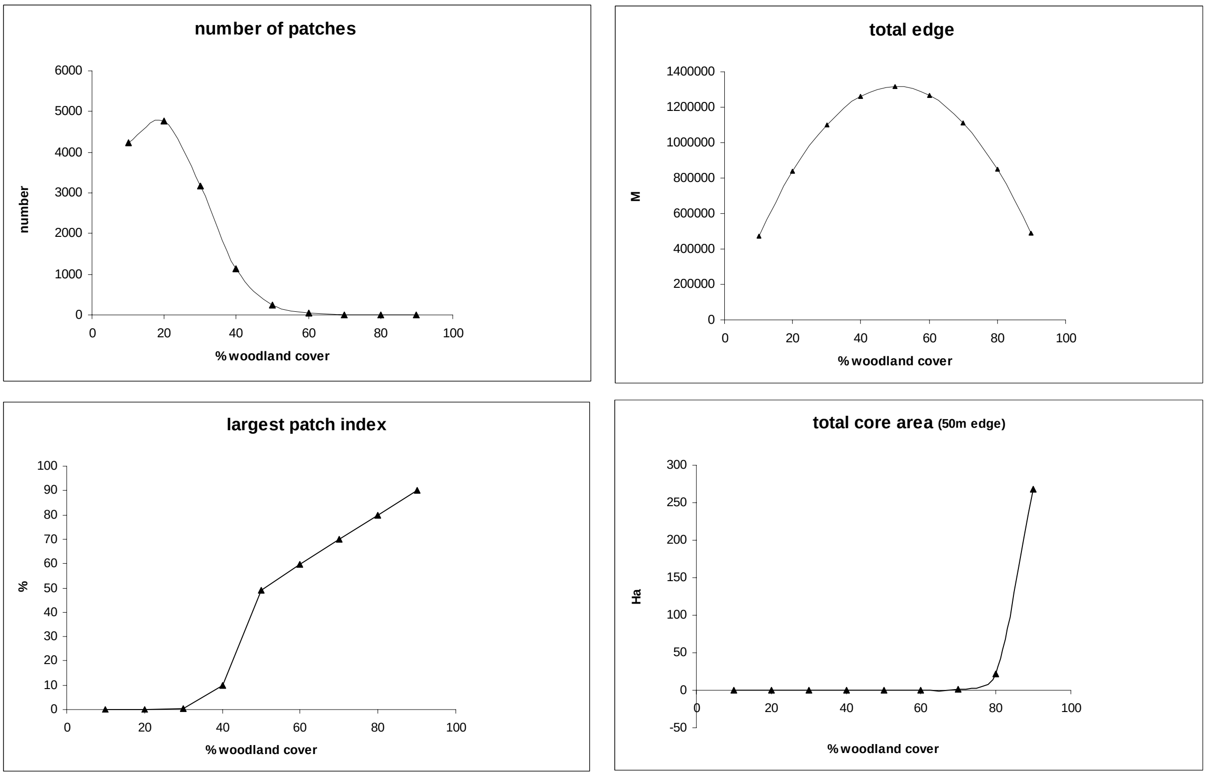


Figure 3-1 – Key land cover thresholds, revealed by simple landscape metrics, derived from the analysis of random landscape models

3.2 METHODS

This investigation of land cover thresholds was achieved through the generation and analysis of a series of random landscapes or neutral landscape models (NLMs), with varying degrees of woodland cover. This method will assess whether the potential thresholds, particularly the 30% and 60% thresholds discussed earlier, occur within a selection of NLMs. Model outputs are compared with a selection of Welsh landscapes with varying percentage of woodland cover to identify relationships with the NLMs and any additional thresholds.

3.2.1 Neutral landscape models

Neutral landscape models (NLMs) allow the production of a wide range of simple, random and more realistic spatially-correlated, or clustered, landscapes (Figure 3-2) with varying degrees of woodland cover (Gardner *et al.*, 1987; With and King, 1997; Turner *et al.*, 2001). The clustered NLMs are generated by an algorithm to produce spatially-correlated patterns of land cover. Clustered NLMs are considered highly relevant to this study, as they are often used by investigators wishing to use neutral, but realistic, landscapes to simulate the movement and dispersal of organisms (With *et al.*, 1997). A key purpose of artificial NLMs is to evaluate the effects of landscape structure on ecological process within a range of theoretical landscapes.

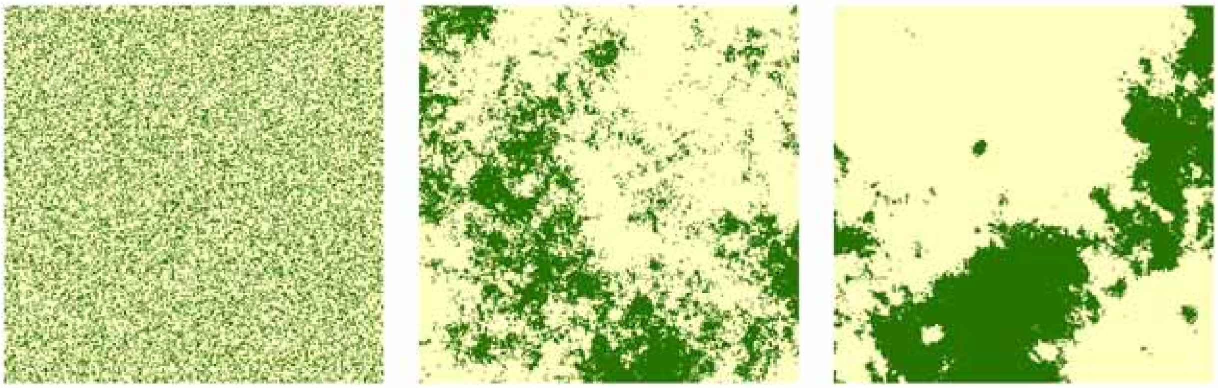


Figure 3-2 – Random, Low and High Clustered neutral landscape models (NLMs) all with 30% woodland cover

Each NLM was based on a grid of 250 x 250 pixels with a resolution of 20m, representing a 5km x 5km landscape unit. Random, Low and High Clustered NLMs were generated with 10-90% cover, at 10% intervals. 10 replicates were generated for each in order to develop a representative sample, resulting in the analysis of 270 NLMs (samples contained within Appendix 1). The mean score for the various landscape metrics, introduced in Section 3.1, were calculated using Fragstats (McGarigal *et al.*, 2002).

3.2.2 Welsh landscape

The whole of the Welsh land area was similarly divided into 5km by 5km squares with a resolution of 20m, thereby creating a 250 x 250 pixel grid of comparable size and resolution to the NLMs. A binary grid (i.e., habitat and non-habitat) was generated from woodland identified within the Countryside Council for Wales Phase 1 Survey; there were over 950 squares with woodland cover ranging from under 1 to over 85% (Figure 3-3).

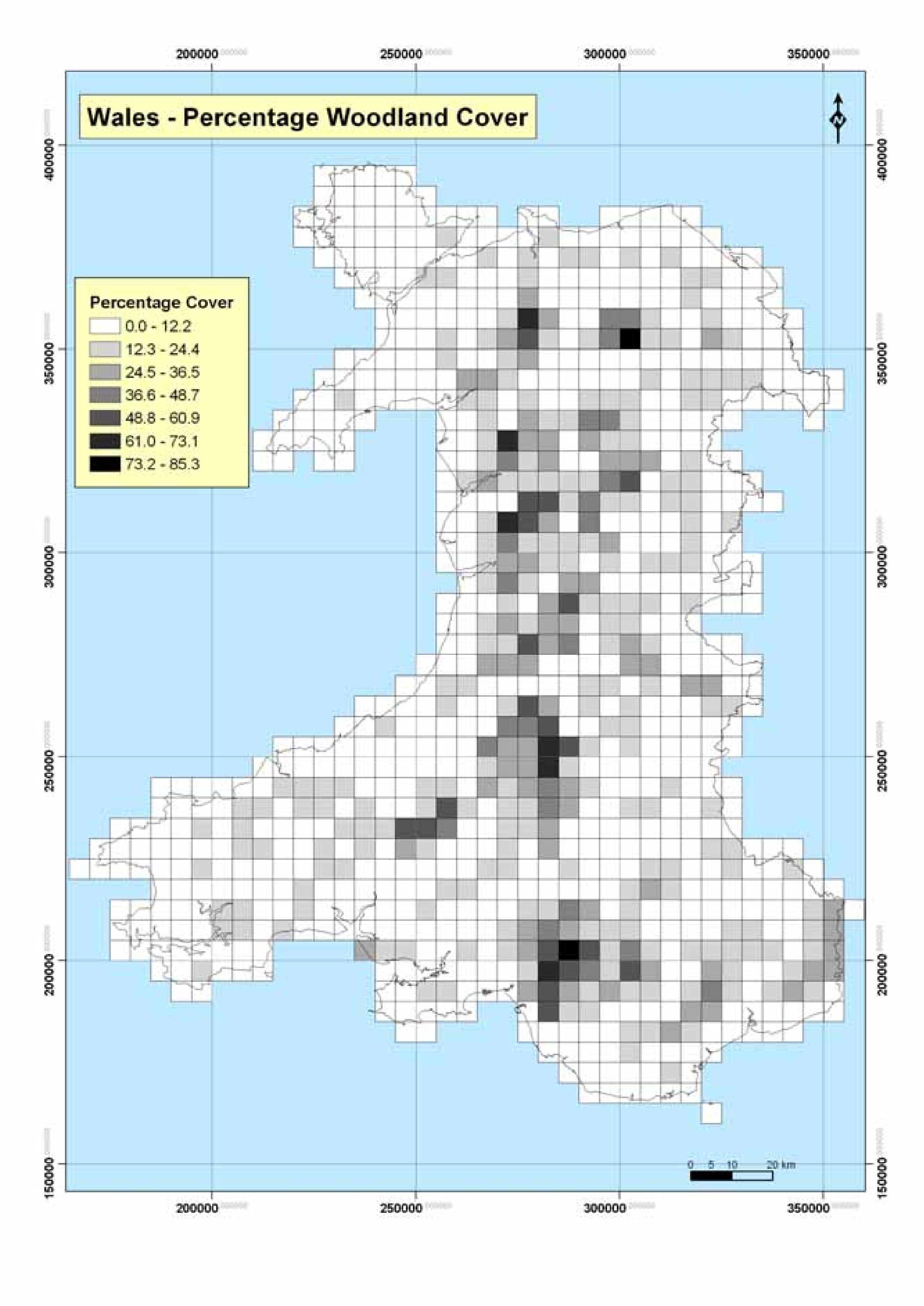


Figure 3-3 - Map of percentage woodland cover (broadleaf, conifer & mixed) within 5km x 5km landscape units of Wales

3.2.3 Neighbourhood rules

Figure 3-4 illustrates three possible neighbourhood rules for defining habitat connectivity based on the surrounding 4, 8 or 12 cells. As the previous land cover thresholds have been linked to landscape connectedness, the landscape analysis was based upon the 8 cell neighbourhood rule. The 8 cell rule permits the formation of habitat clusters from contiguous cells that occur within the surrounding 8 cells, i.e. where there is a physical connection between them.

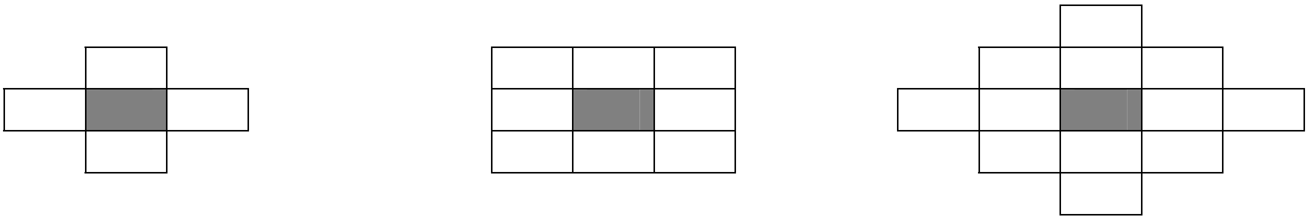


Figure 3-4 – Illustration of the 4, 8 & 12 cell neighbourhood rules

(Neighbourhood rules define the formation of individual habitat clusters from cells that occur within the surrounding 4, 8 or 12. There is a physical connection in the 4 and 8 but not in 12 cell rule)

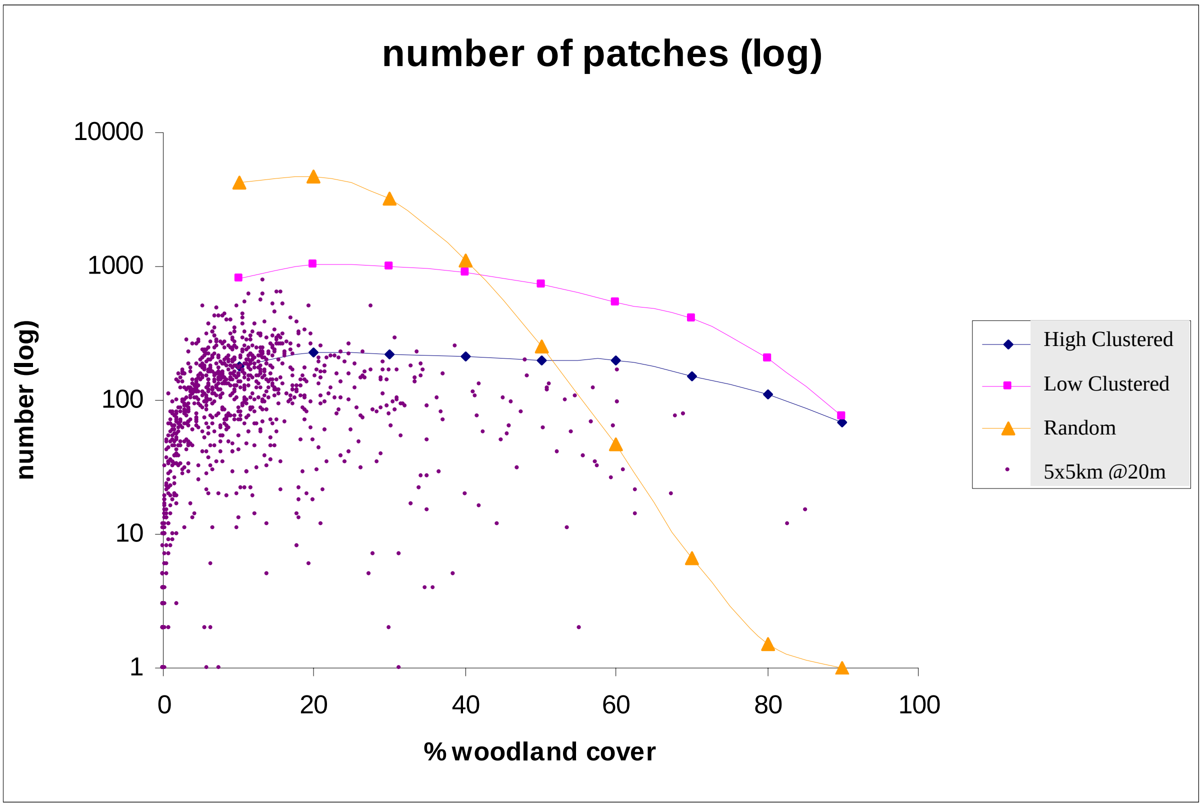
3.2.4 Binary landscapes

This analysis was conducted, and land cover thresholds identified, using binary landscapes (i.e. habitat and non-habitat), which takes no account of habitat quality or the impacts of the wider matrix.

3.3 RESULTS

Results are presented for four simple landscape metrics commonly used in landscape ecology analyses. As detailed below, the Welsh wooded landscapes differed markedly from the random landscapes in the values of the selected landscape metrics. This is consistent with other studies that suggest there is great variation between random NLMs and real landscapes, particularly within the range of 10-50% woodland cover (Turner *et al.*, 2001).

3.3.1 Number of patches



Description:
This metric measures the total number of patches in each landscape unit.

Comments:

1. *Random* neutral landscape models exhibit massive numbers of patches between 10% and 20% cover, with upwards of 8,000 individual patches. The number of patches undergoes an exponential decline with increasing woodland cover. This is not reflected in Welsh Landscapes or the clustered landscape models. The relationship is characteristic of a random landscape; the lack of spatial correlation would mean that at low cover, additional units of woodland have a high probability of forming individual patches. The probability declines as cover increases.
2. *Clustered* landscapes exhibit a decline in the number of individual patches with an increase in woodland cover. The spatially-correlated nature of the woodlands results in a lower probability of forming an individual patch. The probability of a woodland unit forming a new patch would be less dependent with increased cover when compared to random landscapes.
3. There is a large degree of variability in the number of patches of each *Welsh landscape* unit. This appears to be a reflection of the heterogeneity seen within Welsh Landscapes. For example in Figure 3-5, points labelled (a) show the location of extensive conifer plantations, and point (b) shows where areas contain less clustered landscapes.

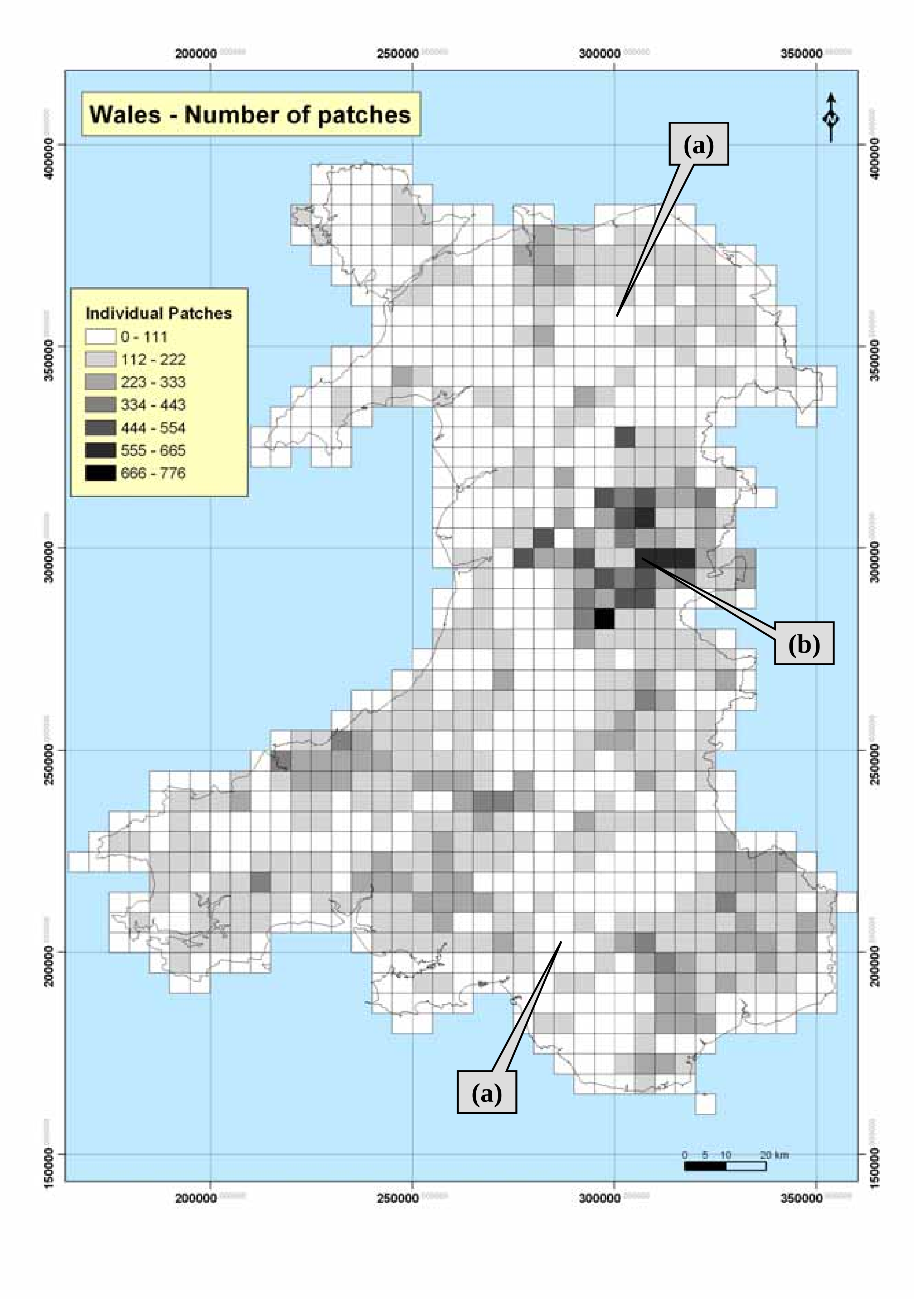
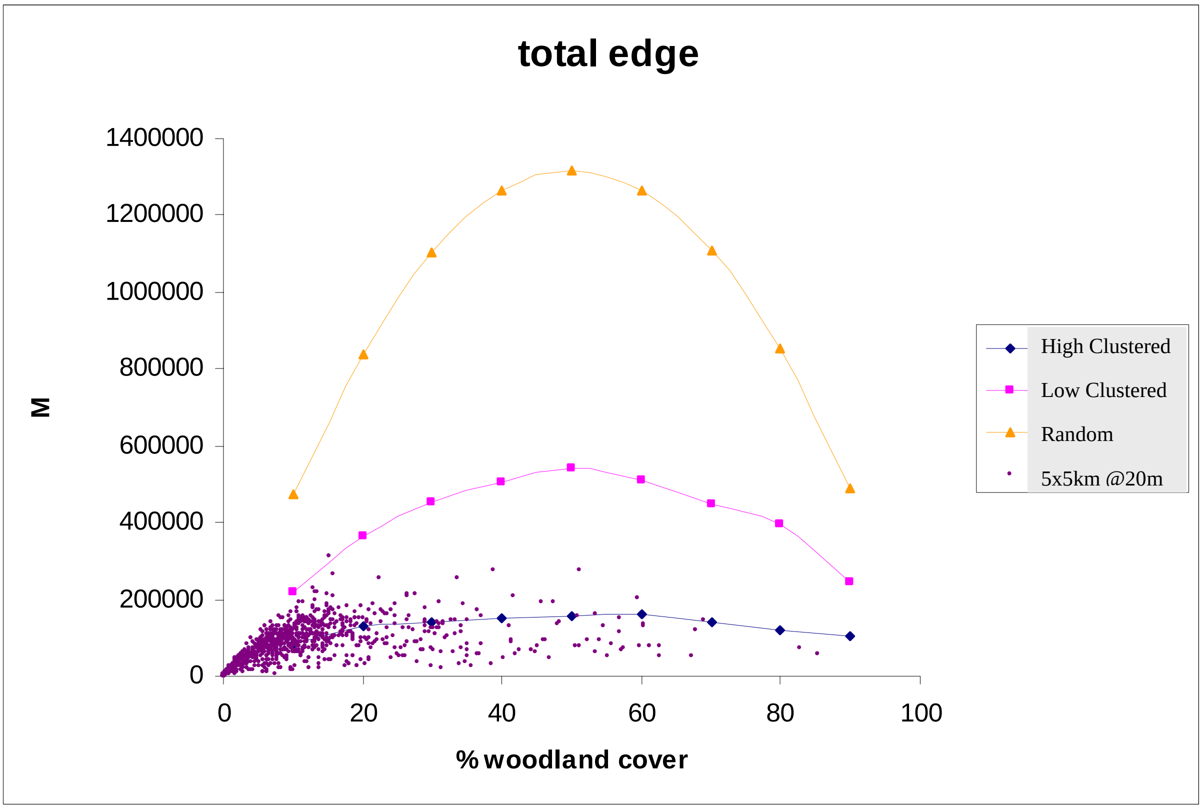


Figure 3-5 - Map of 'number of patches' for Wales

3.3.2 Total edge



Description:
This metric indicates the total perimeter of patches in each landscape unit. The minimum resolution of a woodland unit is 20m with a total edge of 80m.

Comments:
1. When the woodland cover is 10% in the *random* neutral landscapes the total edge approaches the theoretical maximum of 500,000m from 6250 individual patches, i.e. nearly all woodland units are forming individual patches at 10% cover. The maximum total edge is reached at 50% cover when the probability of any new woodland unit forming a new patch is less than the chance of it consolidating the edge of existing patches.
2. *Clustered* neutral landscapes exhibit a similar pattern reflecting the same overall process. But as woodland has a higher likelihood of being near other woodland the process is much less pronounced.
3. In each *Welsh landscape* unit the amount of edge demonstrated in the random and low clustered models is rarely approached. This is likely to be due to the spatially-correlated nature of woodlands in Wales. In addition, the woodland unit size used in the NLM may not be representative of woodlands in Wales.

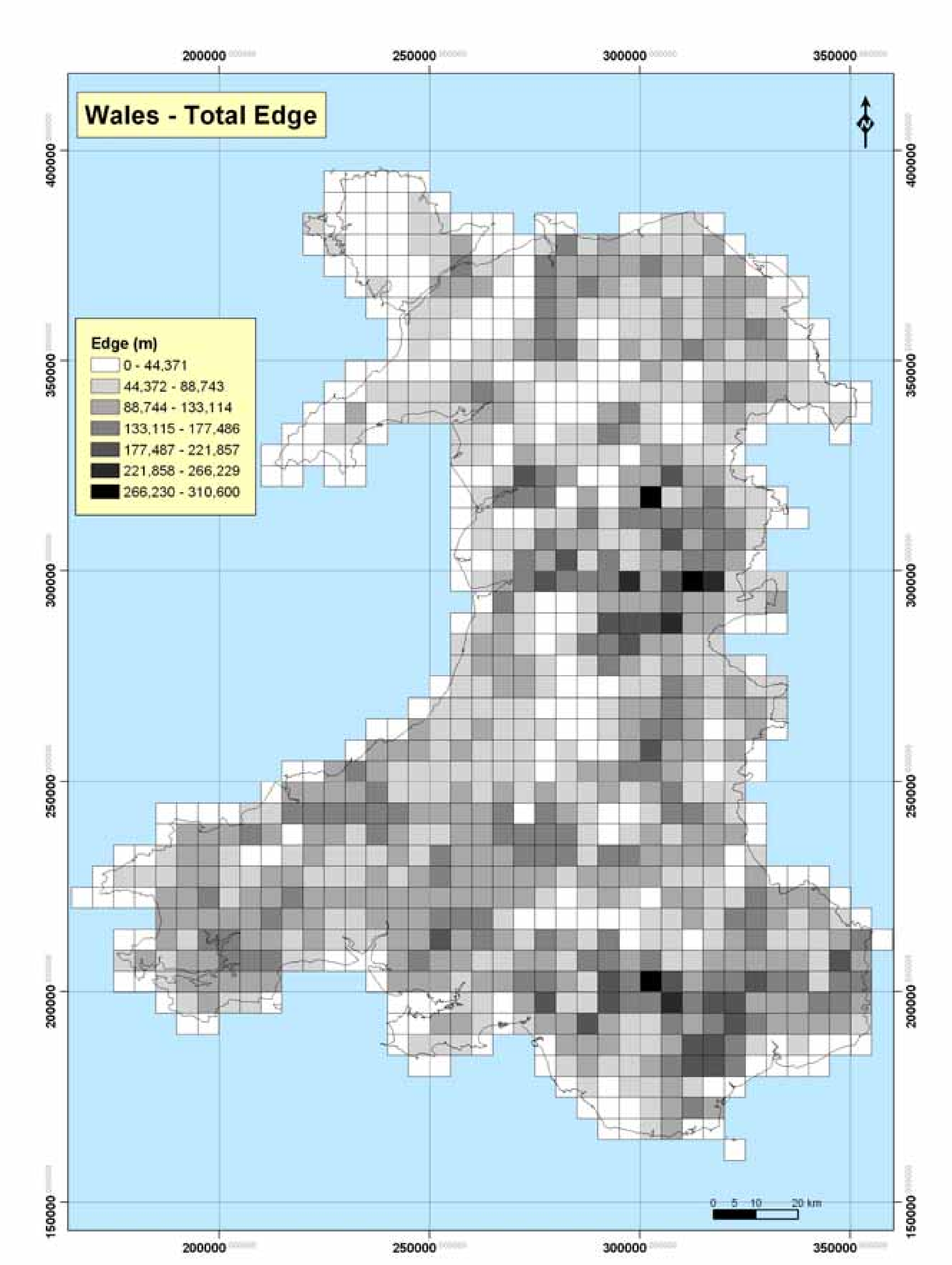
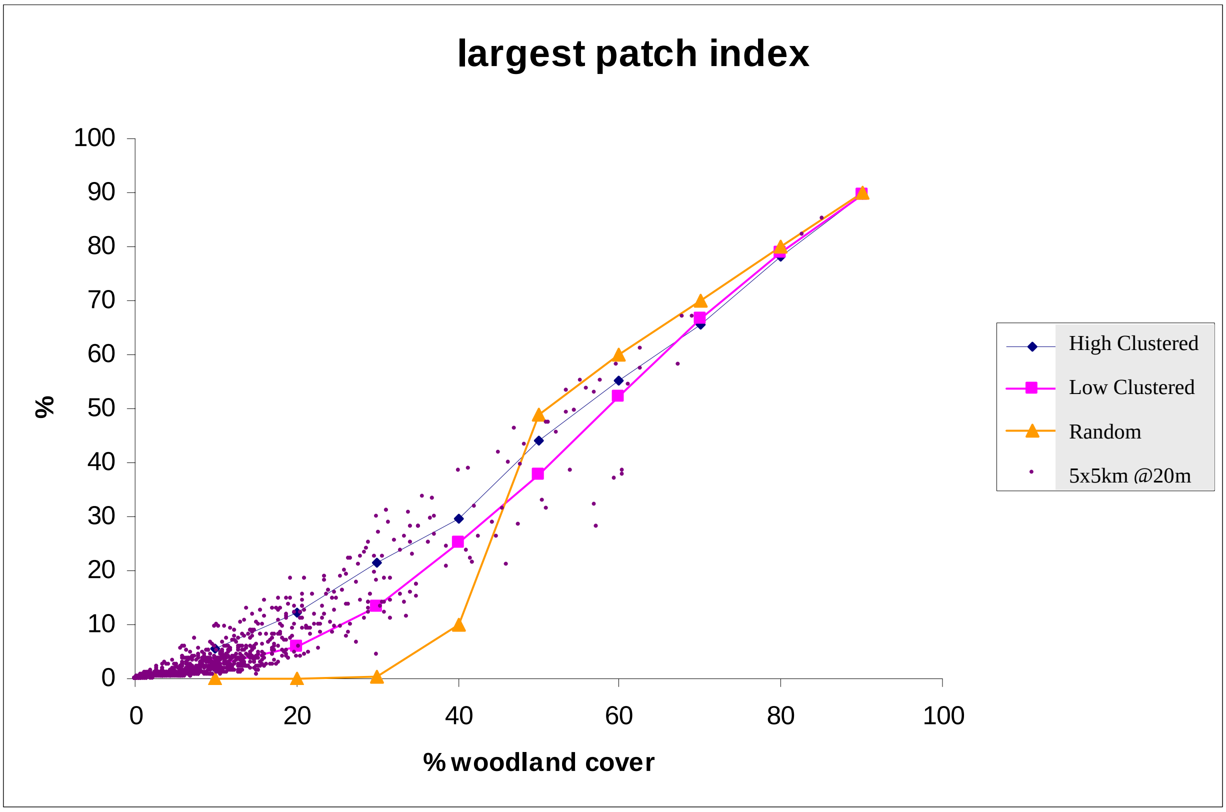


Figure 3-6 - Map of 'total edge' for Wales

3.3.3 Largest patch index



Description:

Largest Patch Index (LPI) equals the area of the largest patch in the landscape expressed as a percentage of the total landscape. The maximum LPI is equal to the % woodland cover.

Comments:

1. *Random* neutral landscapes exhibit a significant increase in the LPI between 30% - 50%. This threshold was very apparent in the model and forms the basis of the '30% rule' (see Section 2.5). Above 50% the woodland cover and LPI are positively correlated; with LPI close to its maximum value.
2. *Clustered* neutral landscapes show a direct relationship between LPI and woodland cover. A clear threshold of woodland cover and LPI is not apparent.
3. In each *Welsh landscape* unit there is a degree of correlation, with wide variation. High LPI values appear to be closely correlated with plantation woodlands as seen in Figure 3-7 (points a).

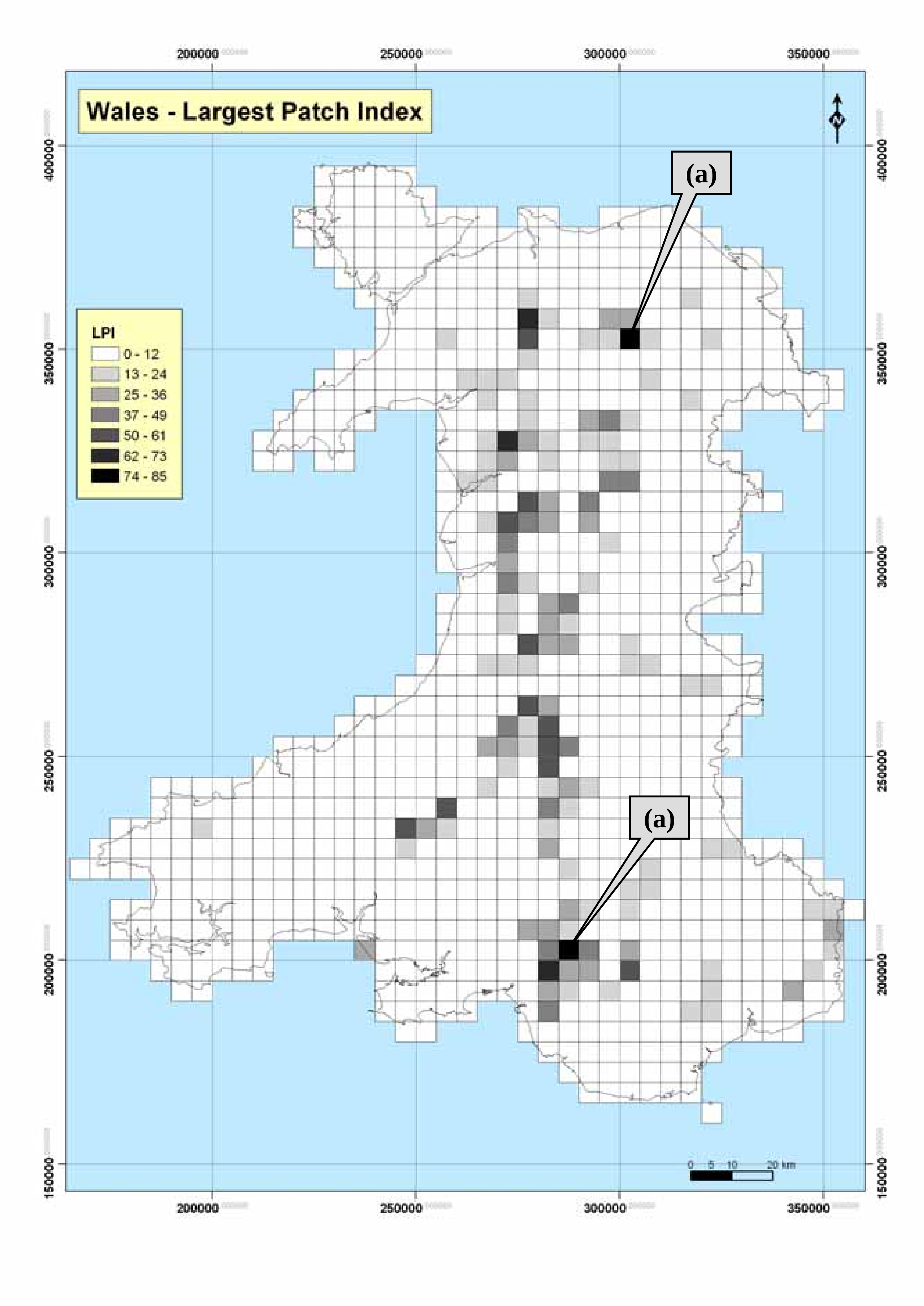
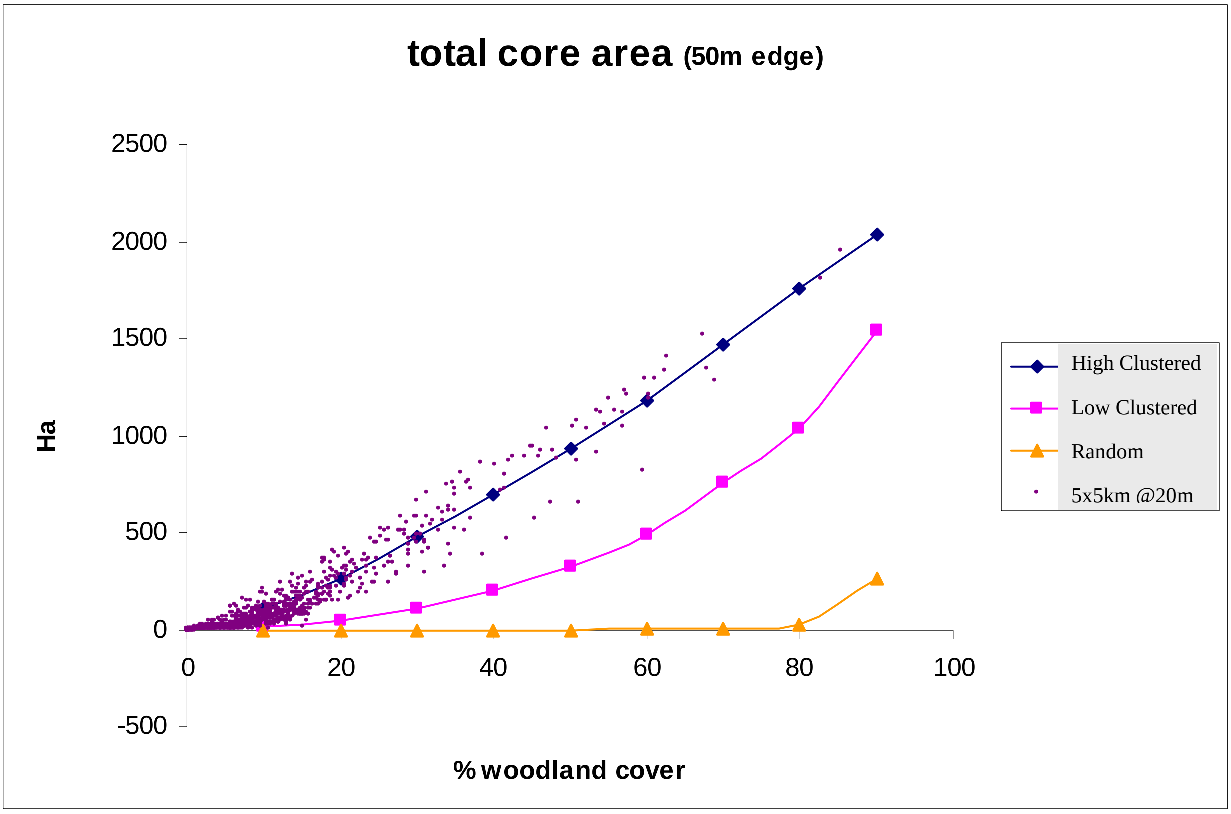


Figure 3-7 - Map of 'largest patch index' for Wales

3.3.4 Total core area



Description:

Total Core Area (TCA) is the sum of the core areas of each patch in a landscape unit. The core area of an individual patche is defined by the area remaining after the removal of a 50m internal buffer.

Comments:

1. Core area in *random* neutral landscapes remains low and is not correlated with increasing woodland cover. There is an apparent threshold at 80% cover when core area starts to increase with increase cover. The low TCA is a reflection of the woodland unit (20m x 20m) relative to the internal buffer (50m).
2. In *Clustered* neutral landscapes TCA is correlated with woodland cover. No clear threshold of woodland cover and LPI exists. There is increased correlation between highly clustered NLMs and woodland cover.
3. The core area of the *Welsh landscape* is positively correlated with woodland cover. Areas with high TCA are shown in Figure 3-8 (points a), and they occur in areas with large plantations.

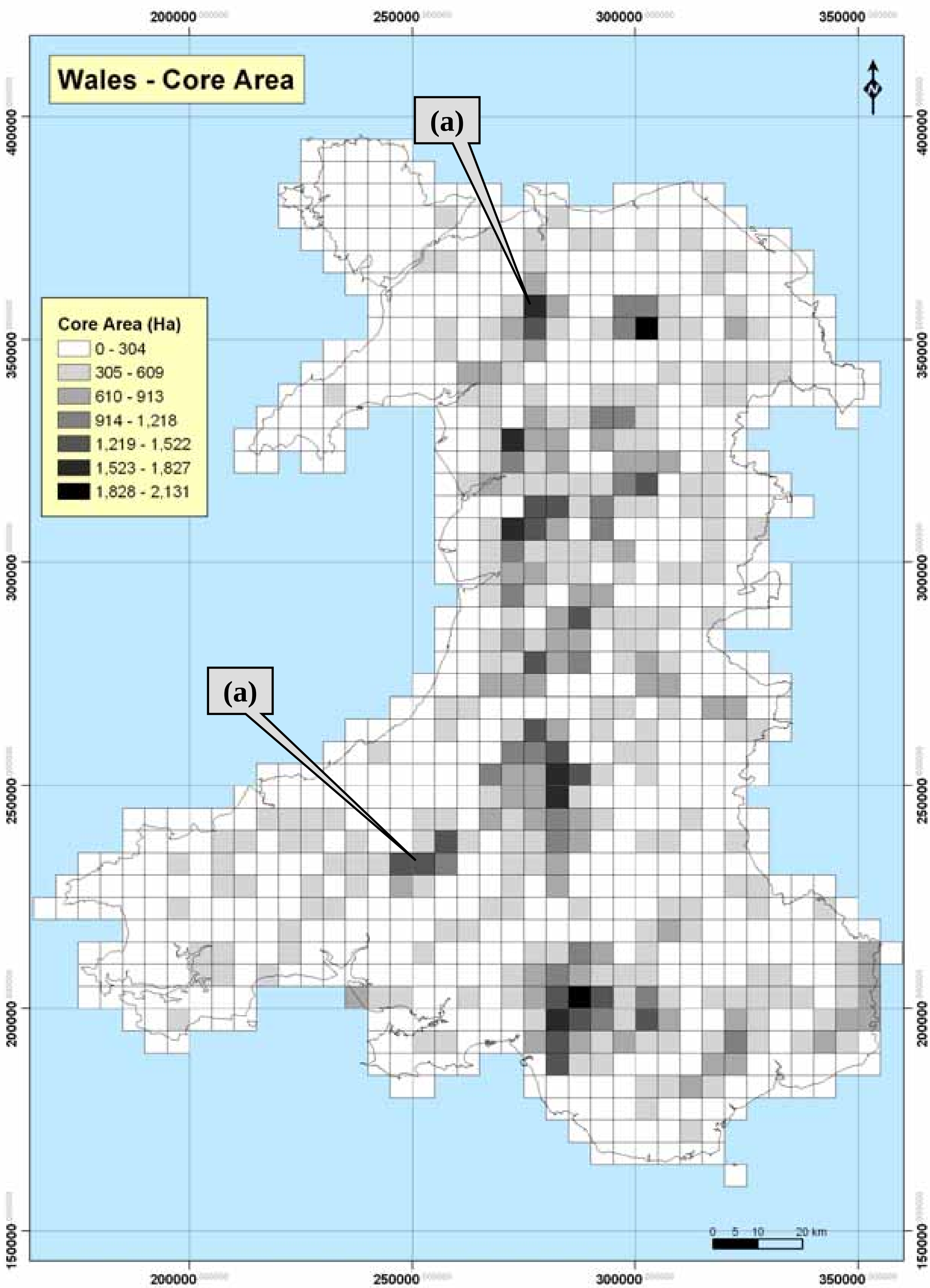


Figure 3-8 - Map of 'total core area' for Wales

3.4 DISCUSSION

Overall, the Welsh woodland landscape differs markedly with the random landscape models, which revealed very clear land cover thresholds. Welsh woodland has greater similarity with the highly clustered NLMs. Interestingly, such NLMs do not exhibit the same clear thresholds as the random landscapes.

3.4.1 Clustered landscapes

The distribution of Welsh woodland (broadleaf, conifer and mixed) is spatially-correlated, rather than random, with a combination of factors including topography, hydrology and land use (agriculture and plantation forestry) (Figure 3-9). It is expected that large, conifer plantations will be particularly highly correlated: whereas small broadleaf woodlands (often ancient) may exhibit a less clustered distribution.

> The distribution of Welsh woodland is **spatially-correlated**, rather than **random**

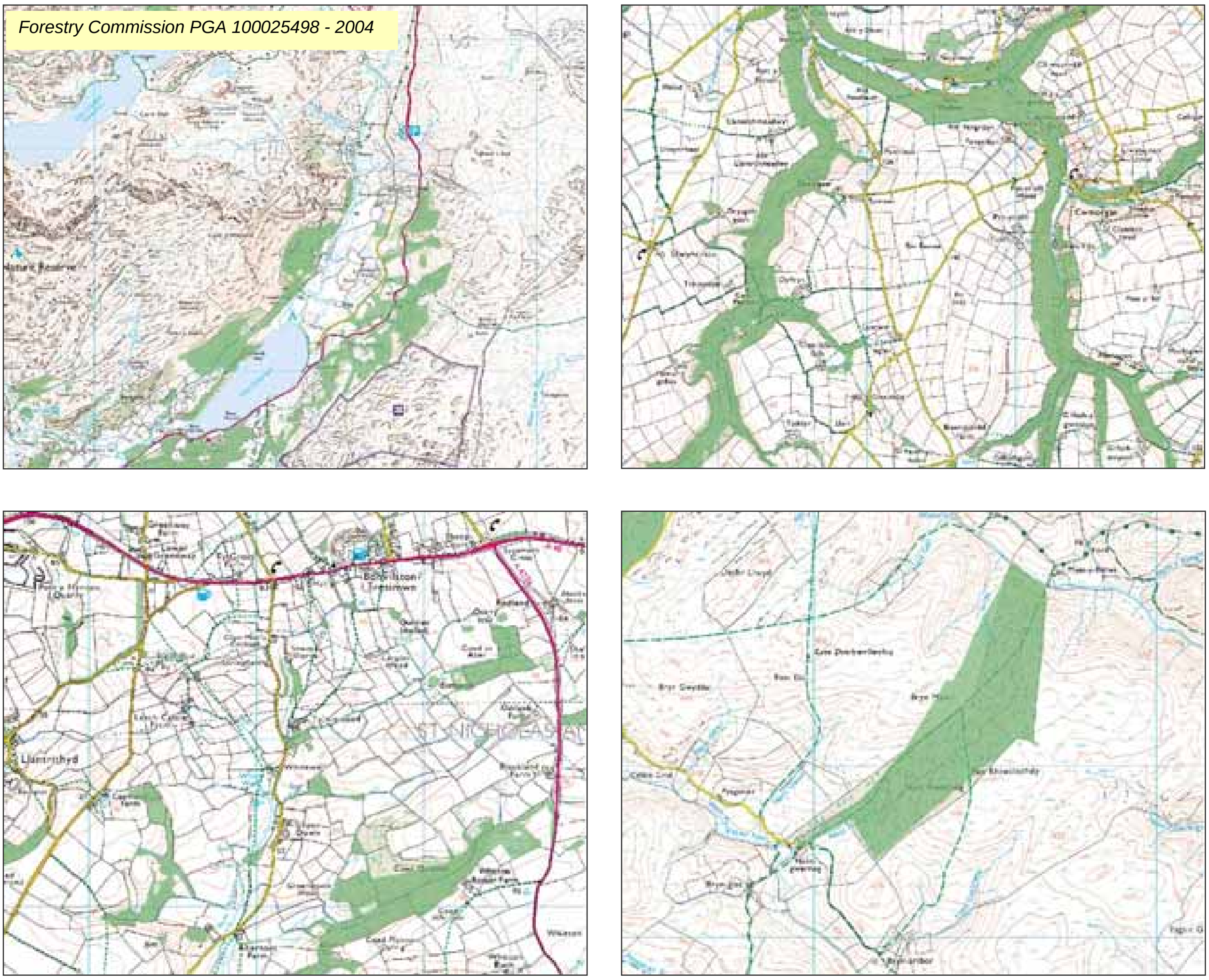


Figure 3-9 – Welsh woodland correlated with a combination of factors including topography, hydrology, agriculture and plantation forestry

3.4.2 Neutral landscape model theory

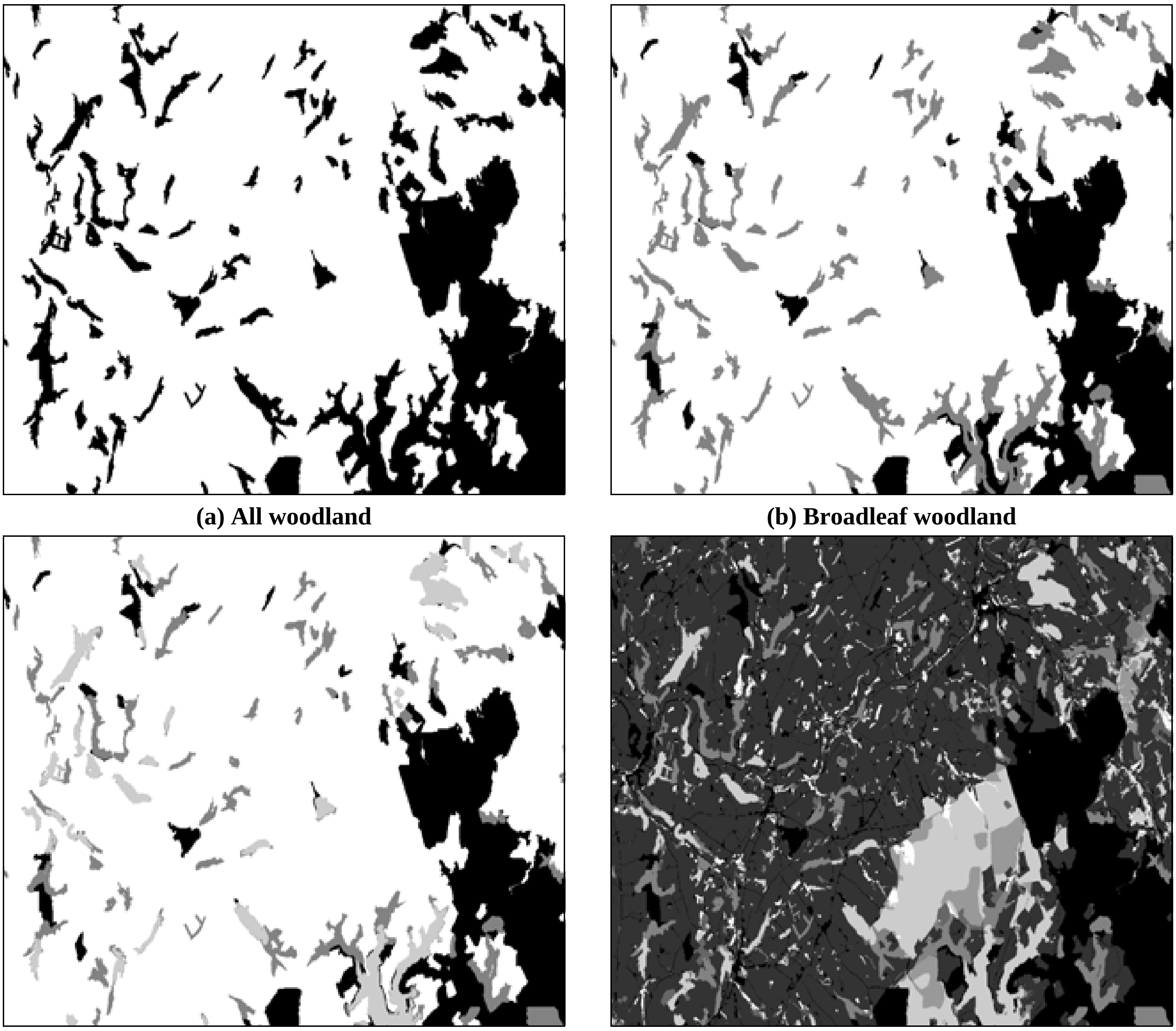
With and King (1997, p.219) state that the purpose of NLMs is "to provide null models of landscape structure as a baseline for comparison with real landscape patterns, or for evaluating the effects of landscape structure on ecological processes". Use of NLMs has now expanded beyond the domain of theoretical landscape ecology, for which they were originally developed, to applications in other areas of ecology. However, there is concern that such models may be used inappropriately, or that their function may be misunderstood or misinterpreted. Indeed, With and King (1997, p.224) have emphasised "it would be a misuse of NLMs to assume that the results from simulations on neutral landscapes can be applied directly to real landscapes…it would also be naive to assume that real landscapes percolate [*are traversable using adjacent cells*] when at least 59.28% of the landscape is habitat".

3.4.3 Neighbourhood rules

Previous work has shown that the connectivity threshold can be moved simply by adjusting the neighbourhood rules for identifying habitat clusters, as outlined in Figure 3-4. For instance, a percolating cluster, i.e. a group of connected habitat patches that span the whole landscape, occur at about 60% habitat cover for the 4 cell rule and 30% for the 12 cell rule.

3.4.4 Binary landscapes

Binary approaches to landscape analysis do not account for habitat quality or the impacts of the wider landscape, raising doubt over the applicability of thresholds derived from random models in binary landscapes. Landscapes will inevitably vary in habitat quality and the surrounding matrix. Figure 3-10 illustrates how a binary landscape comprised of woodland (a) can be subdivided into areas of broadleaf woodland (b), which may represent sub-optimal habitat, and areas of ancient woodland (c), representing optimal habitat. The surrounding landscape matrix may also vary greatly in its degree of hostility or permeability to species movement (d). Real landscapes should be represented as 'shades of grey' in terms of habitat quality and landscape permeability rather than black and white.



(a) All woodland **(b) Broadleaf woodland**

(c) Ancient woodland **(d) Landscape matrix**

Figure 3-10 – Illustration of the subdivision of a binary landscape in terms of habitat quality and landscape permeability

(supporting text above)

3.4.5 Implications of scale

The scale of analysis (extent of 5km x 5km and a resolution of 20m, giving a 250 x 250 landscape unit) can have impacts on the results (Wu, 2004). Further analysis of the influence of extent and resolution of scale are being undertaken but are not considered to have implications for the development of a habitat network, as Welsh landscapes are clearly spatially-correlated at a range of scales. Landscapes at 5 x 5km and 20km x 20km extent, with a resolution of 20m, 50m and 200m have been provisionally investigated. Preliminary results revealed that the number of patches and the total edge decreases with decreasing resolution, whilst the total core area increases as complex shapes are simplified.

3.5 CONCLUSIONS

Maintaining landscape connectivity in a fragmented landscape, through the use of habitat networks, has now become a management imperative for many agencies. The concept of simple landscape thresholds, derived from random landscapes, is very appealing to aid the development of such plans and strategies. However, our results indicate there are considerable differences between random NLMs and Welsh landscapes, highlighting the likely problems of practically applying simple thresholds derived from the former. This reinforces the need for an alternative more functional approach, possibly utilising focal species, in order to determine landscape connectivity and aid biodiversity conservation. With (2002, p.105) has stated "landscape connectivity is far more complex than is implied by the notion of habitat corridors linking fragments". Clearly, it is possible to have high connectivity in a structurally fragmented landscape. Therefore, a more functional perspective is necessary if we are to develop meaningful and effective conservation strategies.

4 STAGE 3 - DEFINING NETWORKS AND LINKAGES

4.1 INTRODUCTION

In Stage 1 a woodland habitat network was defined as areas of woodland and associated open semi-natural habitats. The importance of connectivity, as opposed to connectedness, has been established; and semi-natural habitats have been identified as having the potential to promote connectivity for woodland species. This has resulted in the emergence of functional, species-based approaches to habitat networks. Stage 2 examined the use of land cover thresholds, and identified limitations to their use in understanding and developing habitat networks. There is a need to develop a strategy which incorporates a functional approach to habitat networks and acknowledges the importance of semi-natural habitats in the wider matrix.

4.2 METHODS

4.2.1 The modelling approach

The approach is based on the prototype GIS-based model 'BEETLE' *(Biological and Environmental Evaluation Tools for Landscape Ecology)* being developed by Forest Research (Humphrey *et al.*, 2003; Watts, 2003; Latham *et al.*, 2004; Ray *et al.*, 2004b). Part of this model is a focal species (see Lambeck, 1997; Brooker, 2002) tool that utilises habitat area requirements and dispersal characteristics to identify functional habitat networks for a given species. The basic principles of this tool are similar to the LARCH model developed in the Netherlands, which has also been used to examine habitat networks (van Rooij *et al.*, 2001; Opdam, 2002; Bolck *et al.*, 2004; Verboom and Pouwels, 2004). The BEETLE tool takes into account the probability of movement across the wider landscape matrix, and so does not require woodland to be contiguous to be functionally connected. This enables investigation of the implications of habitat fragmentation, in particular alterations to habitat area, ecological isolation and matrix quality; explicitly making the distinction between connectedness and connectivity. It is therefore likely to generate recommendations for relatively discrete new areas of woodland and extensification of other land uses, which may be more socially acceptable and compatible with the conservation of other habitats than application of thresholds.

BEETLE - Biological and Environmental Evaluation Tools for Landscape Ecology

There are inherent assumptions within this modelling approach, such as habitat preference, area requirements, dispersal distance and matrix permeability. The assumptions undoubtedly have an impact on the outputs; however, they are based on sound ecological theories and have been developed through consultation with a pre-defined, project-based 'woodland habitat network steering group' and are explicit within the modelling approach. The BEETLE tool is designed to be an adaptive management tool to guide and support management action, based on sound theories, principles and assumptions, rather than a tool to model and predict actual species dispersal and viability.

4.2.2 Implementing the BEETLE model

The BEETLE model is implemented through a set of modules that represent and process input data. The use of modules allows a flexible framework allowing the incorporation of a range of data inputs, and providing an analysis varying in complexity and landscape ecology focus. The modules used within the woodland habitat networks analysis are outlined below and their elements and interactions are identified in Figure 4-1.

- **Land cover module**
- **Focal species module**
- **Connectivity module**
- **Network analysis module**

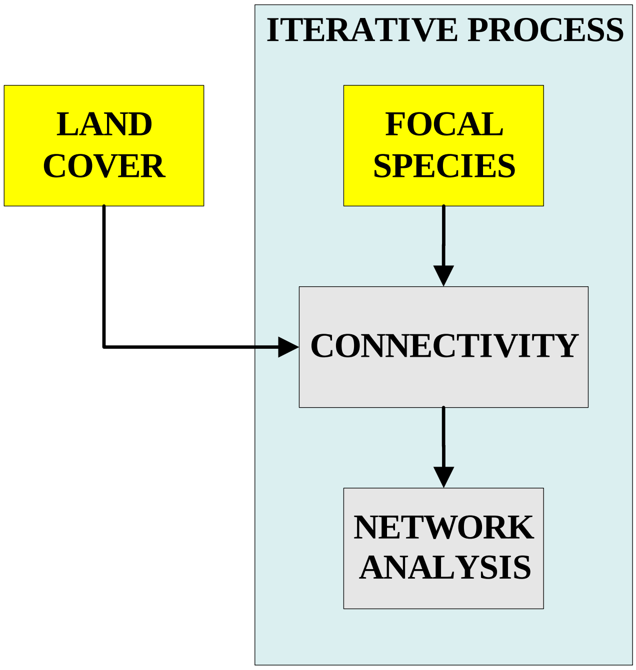


Figure 4-1 – Key modules of the BEETLE model

The implementation of the model is tightly coupled to a geographical information system (GIS), using raster processing within ArcView (ESRI, Redlands, California). The BEETLE model has two input data elements: a **land cover module** and a **focal species module**; in this analysis the land cover module remained constant, while the parameters of the focal species module control the model behaviour. The **connectivity module** handles the interaction between land cover and focal species. This module outputs areas which are considered as habitat and indicates the probability of movement across the landscape. The analysis allows the **network analysis module** to identify habitat patches within potential networks, within an iterative environment. These four modules are described in further detail in the following sections.

4.2.2.1 Land cover module

Land cover data for Wales and part of England were needed. Two datasets contained the required information and were sufficiently detailed for this analysis: the Countryside Council for Wales Phase 1 survey and the Centre for Ecology and Hydrology Land Cover Map 2000. Further information was also obtained and incorporated from datasets on ancient woodland and topography. Figure 4-2 to Figure 4-6 illustrate the various data sets for a small area of the Gower Peninsula.

***The Welsh Phase 1* survey** (Phase 1) is held by the Countryside Council for Wales. The data set holds habitat cover data for all of Wales, based on an Upland Vegetation Survey between 1979 and 1989 (Ratcliffe and Birks, 1980) and a Phase 1 field survey undertaken between 1987 and 1997 (Nature Conservancy Council, 1990). The survey was mapped at a scale of 1:10,000, and the minimum mapping unit was undefined, but is held to be between 0.1 to 2.5ha. Survey methodology details are available in Day (1989) and Howe and Blackstock (1991). A digitised version of the survey was produced between 2000 and 2002. Boundaries were clipped to Ordnance Survey Land-Line data. A section of Phase 1 is illustrated in Figure 4-2.

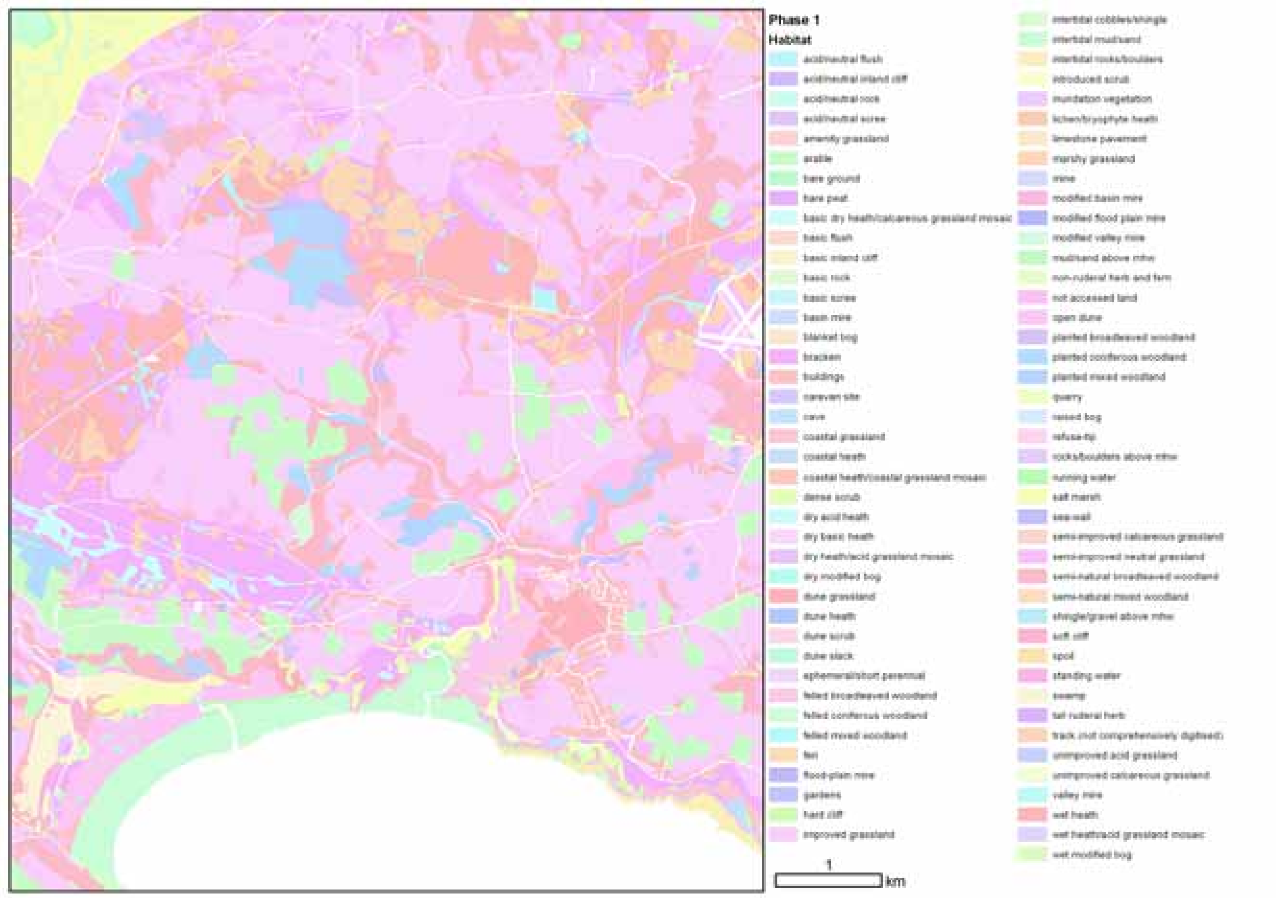


Figure 4-2 – Section of the Phase 1 survey of Wales

Land Cover Map 2000 (LCM), as described in Haines-Young *et al.*(2000), is a remotely-sensed land cover data set of Great Britain, which is commercially available from the Centre for Ecology and Hydrology. Data resolution is 25m and a section of LCM is illustrated in Figure 4-3. Integration with Phase 1 requires the use of LCM sub-class components level-3 classification. This is the classification with the highest degree of uncertainty in LCM, but is roughly comparable to the Phase 1 classes in Figure 4-2. LCM has been related to land parcels, but there is an inherent grid base to the survey process, e.g. each pixel may contain a number of land cover classes, when this occurs it aims to classify the largest cover type. This data set was particularly necessary to incorporate a 15km land cover buffer into England, due to an absence of a Phase 1 survey.

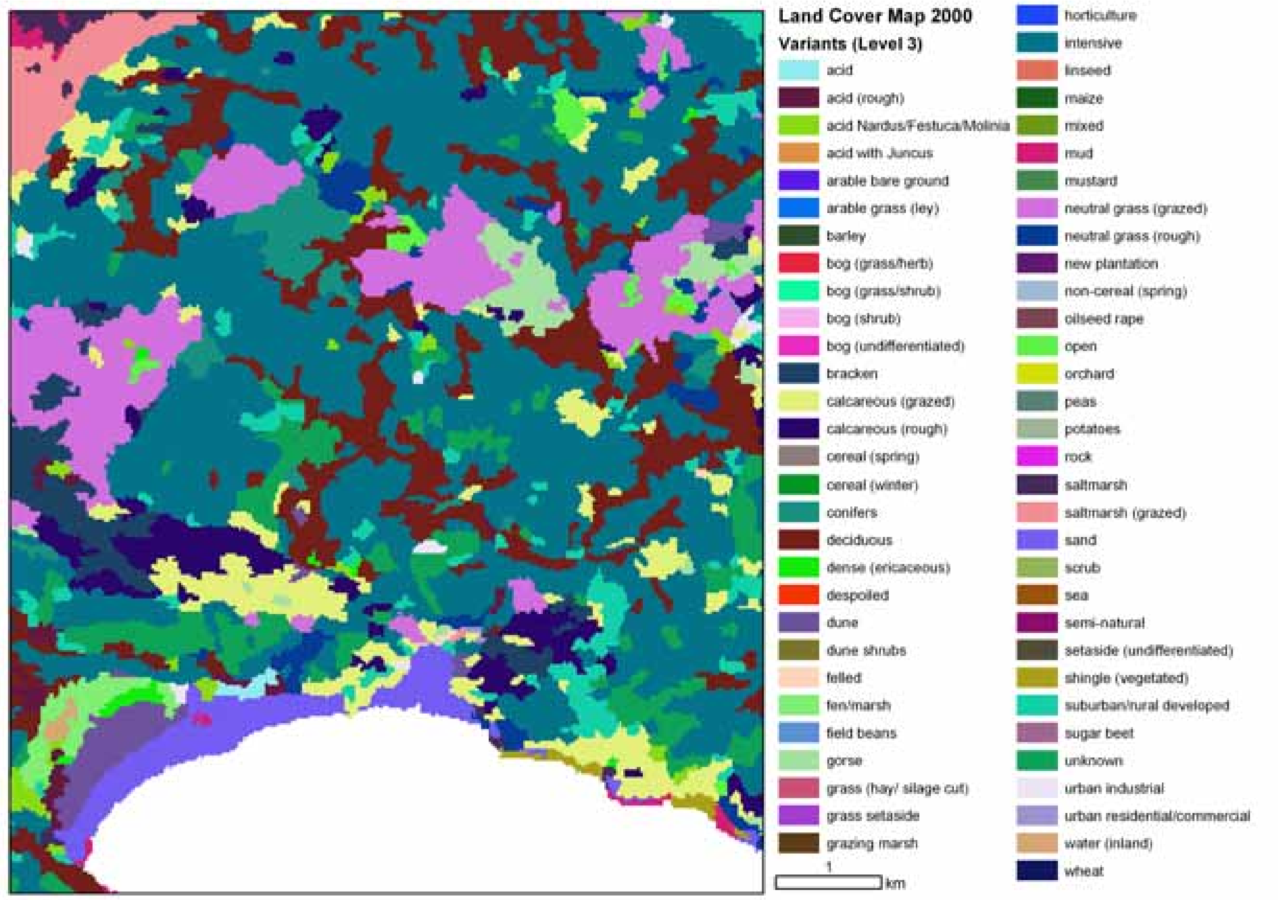


Figure 4-3 – Section of the Land Cover Map 2000

There is also an ***inventory of ancient woodland*** in Wales held by the Countryside Council for Wales. It contains information on woodland naturalness, classifying it as ancient semi-natural woodland (ASNW) or ancient replanted woodland (PAWS - planted ancient woodland sites), as illustrated in Figure 4-4. All ancient woodland blocks larger than 2ha are included in this data set. First edition Ordnance Survey maps were compared to present day maps and field survey to create the data set, although the data set by its nature is provisional.

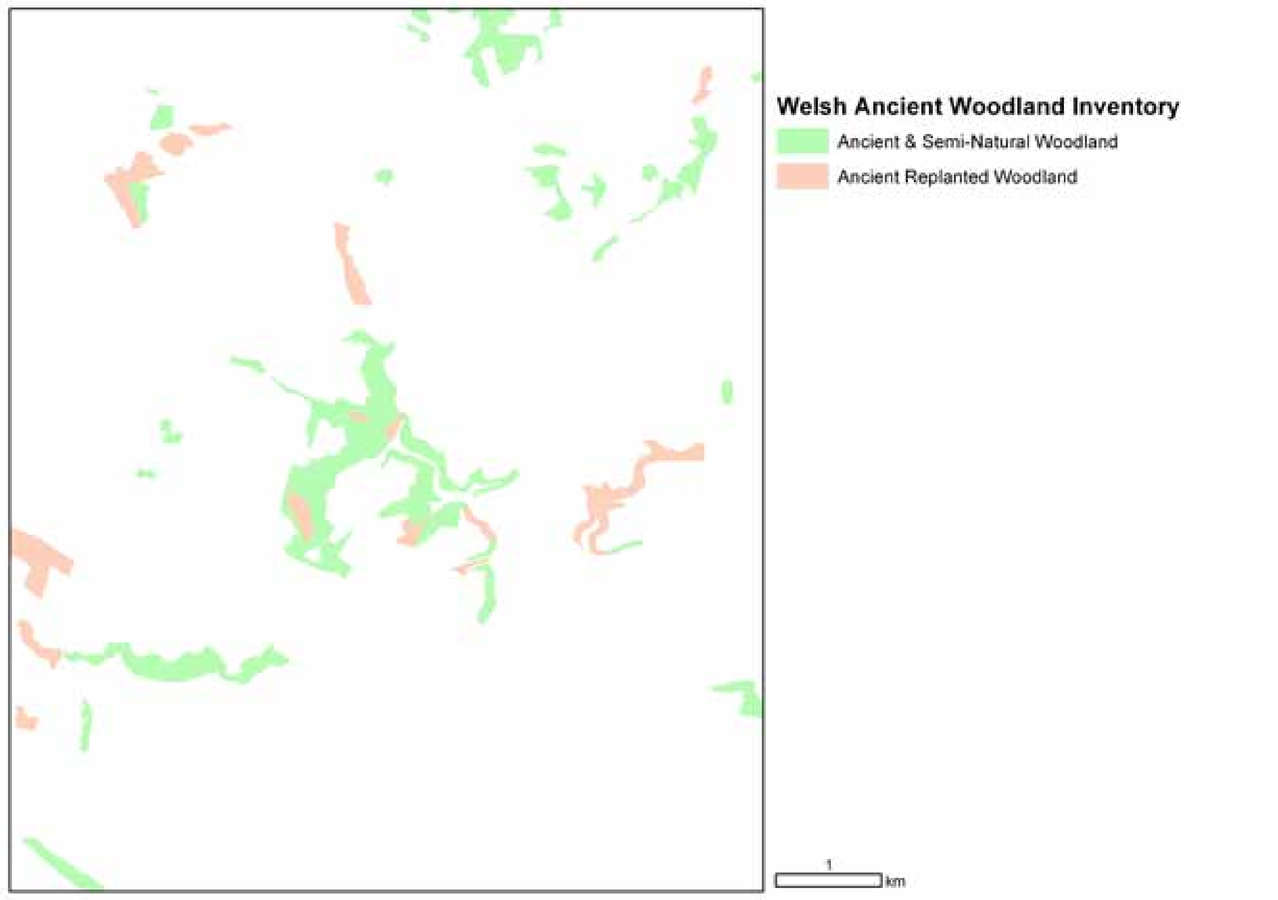


Figure 4-4 – Section of the Welsh inventory of ancient woodland

The impact of ***topography*** is incorporated via the Ordnance Survey Landform PANORAMA data set. This digital elevation model (DEM) is derived from the interpolation of contour data and is available at a 1:50,000 scale. It relies on the 10m vertical intervals of contour data, which have a +/- .03m vertical accuracy.

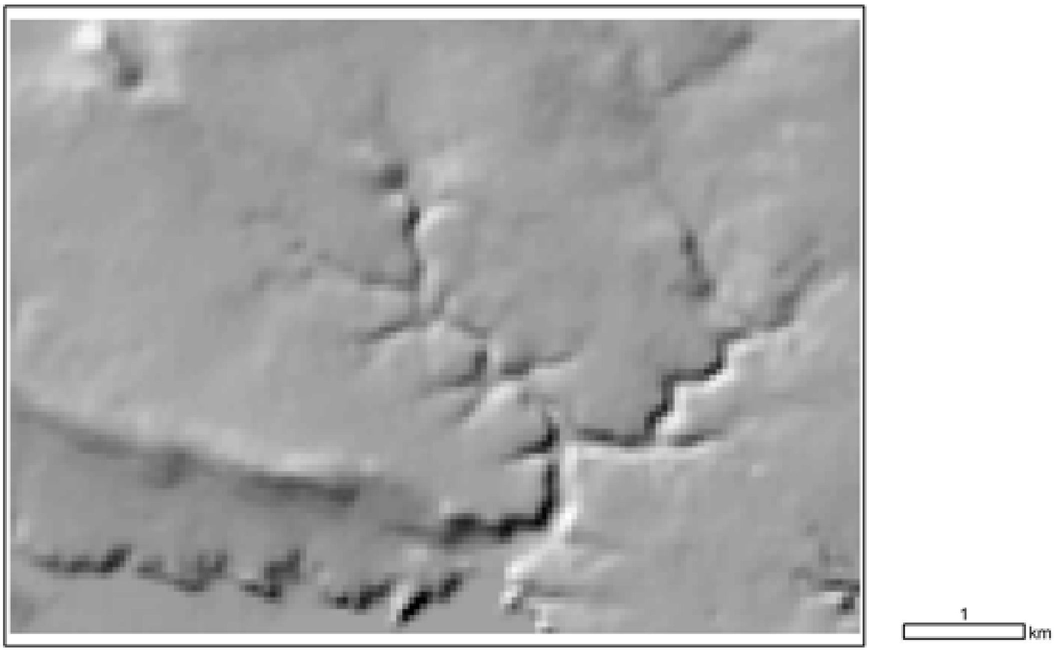
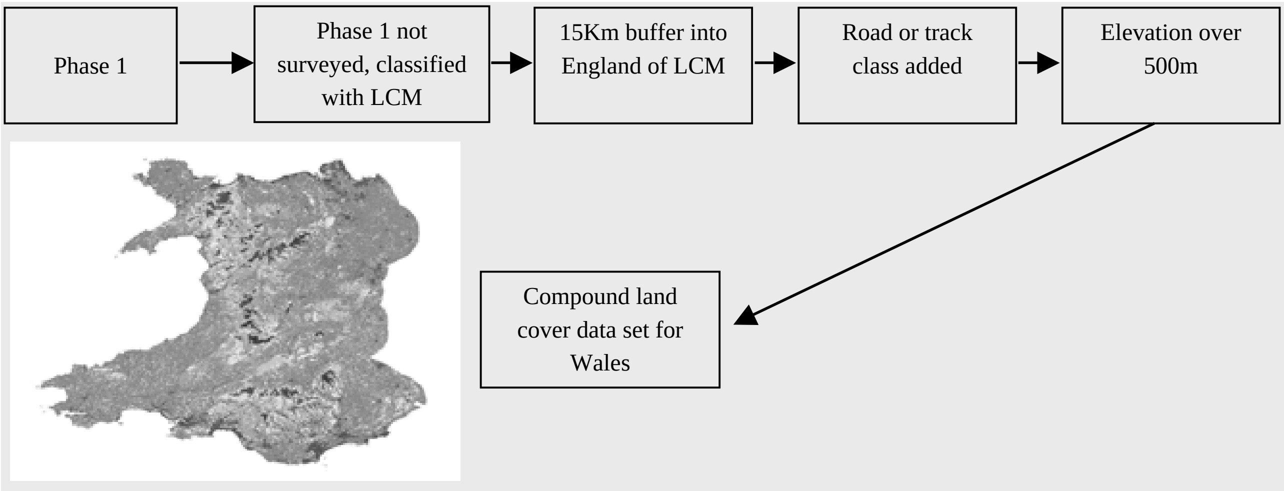


Figure 4-5 – Section of the Panorama digital elevation model (DEM) representing topography as hillshade

The land cover module is implemented once during the modelling process. A simple land cover model integrates data from the land cover data sets with a simple preference hierarchy. The basis of the land cover model is Phase 1, which was used as the primary land cover data set. LCM 2000 was used to provide land cover for a large area (18,000ha) of the CCW Phase 1 which was not surveyed and is classified as 'not accessed land'. LCM data was also needed to classify a 15km buffer of land cover beyond the national boundary of Wales enabling woodland networks to straddle the Wales-England border; ecological processes do not respect national boundaries. As neither data set fully accounted for roads and tracks, a road or track class was added to the data during processing. Elevation was also regarded as a factor in woodland isolation with areas of high elevation above 500m seen as reducing connectivity; this has been interpreted as decreasing the landscape permeability by a factor of ten. The data processing is summarised below:



This module produced a dataset that retained the required features from Phase 1 and LCM. Guided by the study of NLMs (Section 3) at different resolutions, a 10m raster was selected as being appropriate. This is a compromise between processing time and modelling the data in Phase 1 adequately within a raster environment.

4.2.2.2 Focal species module

The use of focal species is central to the BEETLE approach in exploring habitat networks. This module uses a qualitative approach to the creation of focal species profiles. The aim of aiding strategic policy at the Wales scale would not be well served by the analysis of a multitude of species. The selection of multiple species for analysis would also be complex and is inherently subjective. This together with very limited autecological data on the distribution and dispersal of species has led to the use of simulated or Generic Focal Species (GFS), defined to be representative of a number of species groups, priority habitats and key ecological processes. GFS profiles were developed through consultation with the 'woodland habitat network steering group'. These profiles allow an iterative analysis of the landscape for various species, which enables the exploration of the range of potential networks. The parameters that control the focal species module are summarised below:

- **Habitat preference**
- **Habitat area requirements**
- **Land cover permeability or ecological cost** (described further in Section 4.2.2.3)
- **Dispersal distance**

The defined GFS profiles for this study are based around key elements of woodland conservation in Wales, as outlined below:

- **Ancient woodland**, as the key focus of woodland conservation in Wales
- **Broadleaf woodland**, for their biodiversity value and their role in supporting ancient woodland networks
- **All woodland**, to reflect wider conservation concern and the role of all broadleaf and conifer woodlands
- **Semi-natural habitats**, to reflect conservation concerns beyond woodland

The GFS are developed around these basic habitat types, with further variants of high and medium habitat area requirements and dispersal abilities, as outlined in Table 4-1. This table also illustrates the assumed susceptibility to habitat fragmentation, due to habitat area requirements and dispersal ability (Vos *et al.*, 2001). The dispersal element of the model was based around a 50 year timescale, to take account of longer distance dispersal events. This is also considered an appropriate timescale for the effects of climate change (Harrison *et al.*, 2001). The top left cell of the table reflects the species profile which is most sensitive to fragmentation (e.g. extinct species), while the bottom right cell reflects the least sensitive to fragmentation (e.g. pest species). The area of perceived conservation concern is marked with a dashed line. Table 4-2 shows the basic parameters for each of the GFS profiles.

Table 4-1 - Matrix of Generic Focal Species, indicating their sensitivity to fragmentation based on area requirements and dispersal ability

		Dispersal ability		
		Low	**Medium**	**High**
Area requirements	**High**	**e.g. Extinct species** Ancient woodland Broadleaf woodland All woodland Semi-natural	Broadleaf woodland All woodland Semi-natural	
	Medium	Broadleaf woodland All woodland Semi-natural	Ancient woodland Broadleaf woodland All woodland Semi-natural	
	Low			**e.g. Pest species**

- High fragmentation sensitivity
- Medium fragmentation sensitivity
- Low fragmentation sensitivity
- Area of conservation concern

Table 4-2 – Generic Focal Species parameters

Fragmentation sensitivity	Habitat preference	Habitat area requirements	Dispersal preferences (permeability)	Dispersal distance
High Area & Low Dispersal limited - High Sensitivity	Ancient woodland (ASNW & PAWS)	Min 2ha mapping unit	As detailed in Table 4-3	1000m
	Broadleaf woodland All woodland Semi-natural	10ha		
High Area limited – Medium Sensitivity	Broadleaf woodland All woodland Semi-natural	10ha	As detailed in Table 4-3	5000m
Low Dispersal limited – Medium Sensitivity	Broadleaf woodland All woodland Semi-natural	2ha		1000m
Medium Area & Dispersal limited - Low Fragmentation Sensitivity	Ancient woodland (ASNW & PAWS)	Min 2ha mapping unit	As detailed in Table 4-3	5000m
	Broadleaf woodland All woodland Semi-natural	2ha		

4.2.2.3 Connectivity module

Connectivity is modelled as the dispersal ability of a focal species and the ease of movement through the surrounding landscape. The surrounding matrix has a significant impact on connectivity for many woodland species. Semi-natural and extensive habitats are considered to be more conducive, or permeable, to species movement whereas intensive land uses are predicted to be less permeable, thereby reducing connectivity and increasing ecological isolation (e.g. Peterken, 2002; Woodland Trust, 2002). The ease of movement, or permeability, through different land cover types is expressed in terms of 'ecological cost' (see Adriaensen *et al.*, 2003; Chardon *et al.*, 2003; Sutcliffe *et al.*, 2003). The ecological cost is based on the degree of land cover modification and structural diversity, as defined in Table 4-3. These specific costs for woodland related species were established through consultation with the 'woodland habitat network steering group' and associated habitat specialists.

Ecological cost relates to the ease of movement (*permeability*) through different land cover types

For instance, a broadleaf GFS with limited dispersal could potentially move 1000m thorough a semi-natural habitat which has low ecological cost, but only 50m through a high-cost arable landscape. In this example, the probability for movement through an intensive landscape is 1/20th of the probability of movement through a semi-natural landscape. Figure 4-6 illustrates the resulting ecological cost surface for Wales. These costs were also supplemented by the influence of topography, with an increased cost for areas in excess of 500m altitude.

Table 4-3 - The ecological cost (*permeability*) of land cover types used to determine woodland habitat networks for Wales

	Habitat characteristics (*modification/structure*)	Examples	Ecological cost *(movement as a function of dispersal distance and ecological cost)*
Low ecological cost	Quasi-woodland habitats; relatively unmodified with strong 3-D structure and known to readily accommodate woodland species	Semi-natural scrub, bracken	**1 – high permeability** dispersal distance = **1000** ecological cost = **1** movement 1000/1=**1000m**
Intermediate ecological cost	Unimproved semi-natural habitats; little modification with well developed structure	Heathlands, marshy grassland	**3** dispersal distance = **1000** ecological cost = **3** movement 1000/3= **333m** or 1/3 probability
	Unimproved semi-natural habitats; little modification but with limited structure	Unimproved grasslands, mires	**5** dispersal distance = **1000** ecological cost = **5** movement 1000/5= **200m** or 1/5 probability
	Semi-improved habitats; moderate modification and limited structure	Semi-improved grassland, modified heathland, bogs	**10** dispersal distance = **1000** ecological cost = **10** movement 1000/10= **100m** or 1/10 probability
High ecological cost	Heavily modified habitats with very little structure	Improved grassland, arable, amenity grassland	**20** dispersal distance = **1000** ecological cost = **20** movement 1000/20= **50m** or 1/20 probability
	Artificial and hostile habitats	Water, buildings, roads	**50 – low permeability** dispersal distance = **1000** ecological cost = **50** movement 1000/50= **20m** or 1/50 probability

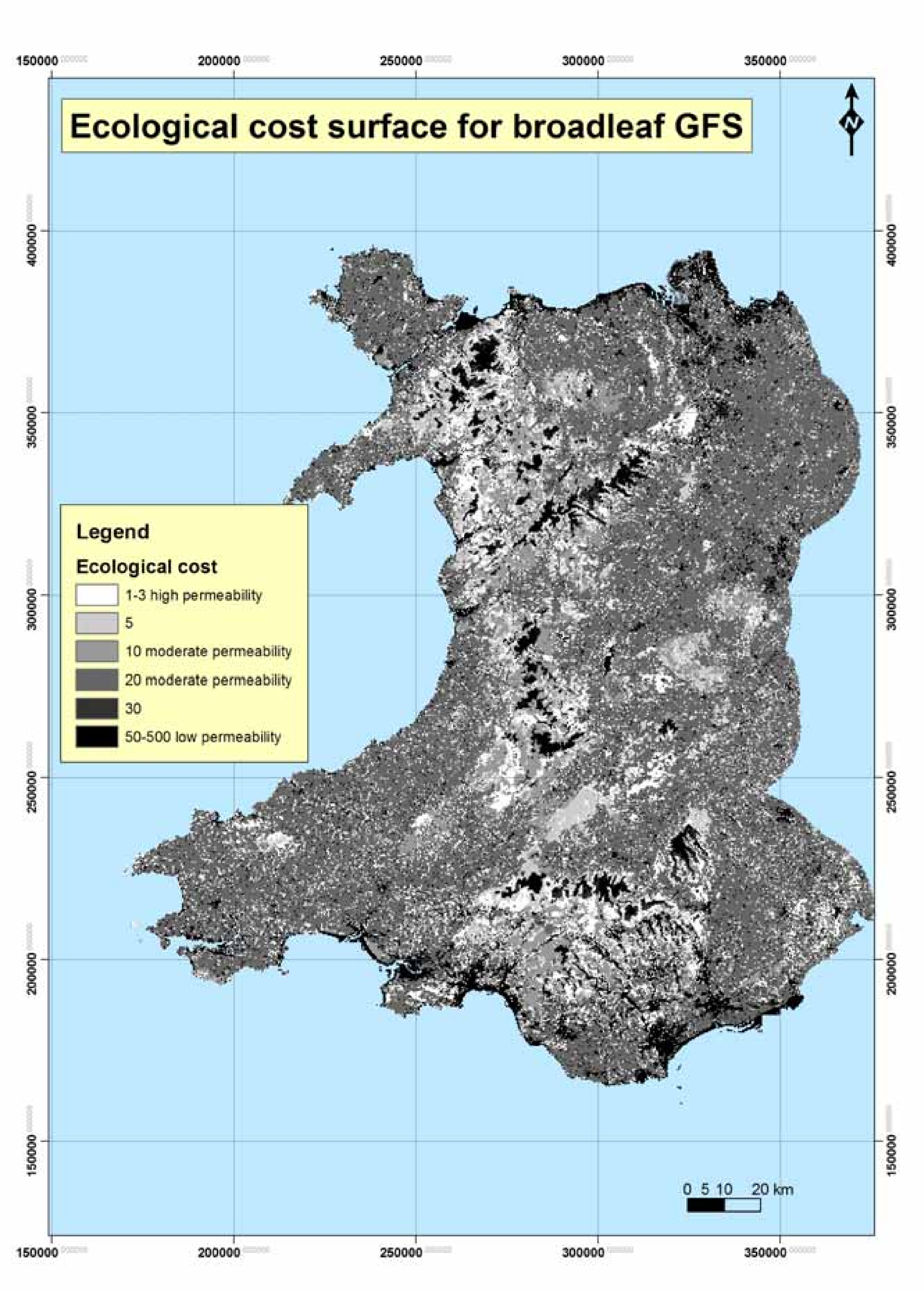


Figure 4-6 – Ecological cost surface for Wales and a 15km buffer into England, depicting the ease of movement, or permeability, for a woodland Generic Focal Species (GFS)

4.2.2.4 Network analysis module

Figure 4-7 illustrates how the various modules are brought together to provide the necessary data for the network analysis module. In this illustration, data from the **land cover module** is represented in figure **(a)**. The **focal species module** is used to define the habitat areas, and in this example broadleaf woodlands are selected **(b)**. This module also provides the necessary data for use in the **connectivity module** to assess landscape permeability, in this example high permeability is illustrated with light colours whilst dark colours signify low permeability **(c)**. This allows the identification of potential networks, defined by different colours, which can be examined within the **network analysis module (d)**.

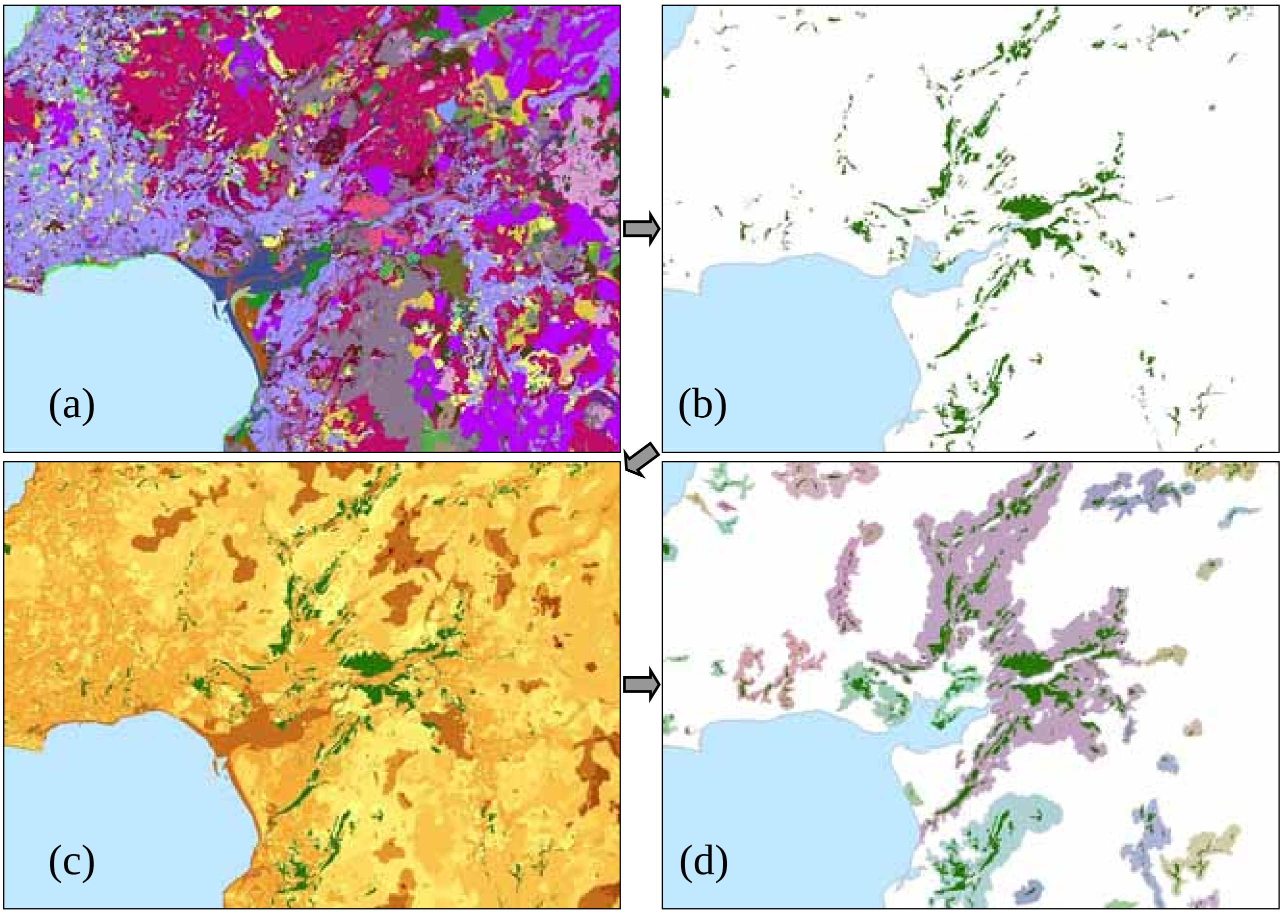


Figure 4-7 – BEETLE modelling sequence

(supporting text above)

The understanding and development of habitat networks is based around the principle of identifying a number of key components within a functional network at a range of scales. The subsequent development of a habitat network and prioritisation for action will be based around these key components.

Core Networks are built up from those generic focal species (GFS) most at risk from habitat fragmentation (green area in Table 4-1), i.e. they have high area requirements and low dispersal ability. Many fragmentation sensitive species, with limited dispersal abilities will be restricted to these Core Networks and will be unlikely to take advantage of recent/future habitat expansion and linkage. Long distance chance dispersal events between Core Networks may be the only means by which less mobile species will be able to survive fragmentation and rapid climate change (Woodland Trust, 2002). Therefore, a high priority is to consolidate these areas and to ensure they are of a high quality.

Focal Networks are built up from these GFS with a lower risk from habitat fragmentation (red area in Table 4-1), with lower area requirements and greater dispersal ability. These Focal Networks will potentially contain a number of discrete Core Networks; enabling the identification of where they may be functionally joined by a variety of management actions. A management priority within Focal Networks will be to improve the ecological permeability of the landscape. The Woodland Trust (2002) has recognised that the wider connectivity of the landscape will be enhanced if there is a reduction in the general intensity of land use in the surrounding area. An understanding of the composition of land cover within the Focal Network can be used to prioritise and target suitable and appropriate management action. For instance, if there is a large component of PAWS within an ancient woodland Focal Network, PAWS restoration may be a priority. However, if a broadleaf Focal Network has no PAWS but large areas of intensive agriculture, extensification measures through agri-environment schemes may be a more effective option.

Large-Scale Linkages are formed by creating a number of alternative pathways between strategic Focal Networks. Here the aim is to prioritise and target action beyond Core Networks and Focal Networks. The identification of potential linkages between networks is seen as key to protect and enhance the sustainability of biodiversity within habitat networks, particularly in the light of the impacts of habitat fragmentation and predictions of climate change. Large-scale linkages are designed to be very aspirational and are intended to give a strategic overview of the multiple connectivity pathways between selected networks. Although the development of Large-Scale Linkages is beyond the scope of this current study, two linkages are presented to illustrate the basic concept within the results section.

The future management actions, as outlined in Table 4-4, will be linked back to these key network components. The actions provide a framework in which to prioritise and target future management, in order to gain the largest ecological benefit. These general management actions reflect the principles proposed by Peterken *et al.* (1995), Hampson and Peterken (1998), McIntyre and Hobbs (1998), The Woodland Trust (2000; 2002) and Peterken (2002); which emphasise the need to expand action from existing Core Networks, into Focal Networks and then into more ambitious Large-Scale Linkages. The framework will be modified during the prioritisation and implementation process by opportunities, stakeholder objectives, constraints, additional environmental, economic and social objectives, etc., as outlined in Section 1.3.1.

Table 4-4 – Future management actions related to the development of Core Networks, Focal Networks and Large-Scale Linkages. Management actions extend from left to right

	Core Networks (HL species)	Focal Networks (LH species)	Large-Scale Linkages
Maintain	▪ Protect habitat		
	▪ Manage habitat		
	▪ Restore habitat		
Improve		▪ Buffer habitat	
		▪ Expand habitat	
		▪ Improve matrix	
Reconstruct			▪ New habitat
			▪ Large-scale linkages

4.3 RESULTS

The aim of this modelling approach was to create a range of habitat networks based upon the GFS outlined in Table 4-1. This range is apparent in Figure 4-8. In this example small Core Networks were created for ancient woodland GFS with high area requirements and low dispersal ability. In contrast, very extensive Focal Networks were created in the case of the semi-natural GFS, with lower area requirements and higher dispersal potential.

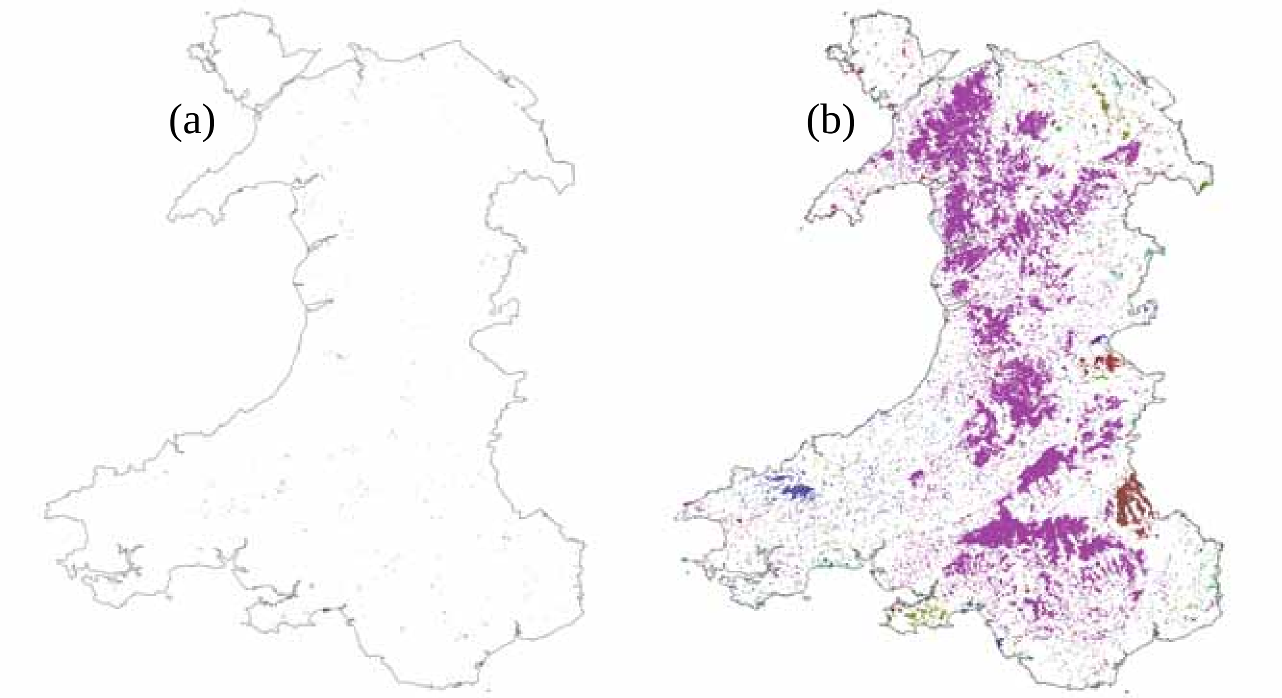


Figure 4-8 – Range of habitat networks for contrasting Generic Focal Species

(a) numerous small networks formed by ancient woodland GFS with high area and low dispersal ability & (b) extensive networks formed by semi-natural GFS with lower area and higher dispersal ability

It was impractical to present the full range of potential networks in the results section. There was a very apparent need to prioritise, and the creation of networks for broadleaf and ancient woodland was seen by the steering group as a key objective for Wales. These networks are likely to contain a significant number of species of conservation concern (examples listed in Table 1-1) and are likely to represent some of the key areas for native woodland habitat action plans.

Therefore, this section presents the Core Networks for broadleaf and ancient woodland; it also identifies Focal Networks for each, including the twenty largest. To further illustrate the concept of Core Networks nested within larger Focal Networks, four discrete Focal Networks (two of broadleaf woodland and two of ancient woodland), which each contain a number of Core Networks, are presented. The results are presented in the form of a basic description, summary statistics, a summary of land cover and an illustrative map.

The summary of the land cover takes the form of a table that shows the land cover classes that represent 95% of a Core Area or Focal Network. This illustrates the most significant land cover without presenting all 171 classes. Table 4-5 illustrates the most extensive categories in the Phase 1 data set for Wales, which account for 95% of the data sets extent. This is useful for comparison with the cover inside the networks we have subsequently identified.

Table 4-5 – Area and percentage contribution from land cover categories which account for 95% of extent of the CCW Phase 1 data set

Land cover	Area (ha)	Percentage Cover
Improved Grassland	1001636	48.6
Planted Coniferous Woodland	167514	8.1
Unimproved Acid Grassland	133126	6.5
Semi-Natural Broadleaf Woodland	86662	4.2
Buildings	77277	3.7
Dry Acid Heath	65268	3.2
Arable	64761	3.1
Bracken	63712	3.1
Marshy Grassland	44829	2.2
Semi-Improved Neutral Grassland	37330	1.8
Intertidal Mud/Sand	33113	1.6
Marshy Grassland Molinia Dominated	27551	1.3
Dry Heath/Acid Grassland Mosaic	26313	1.3
Semi-Improved Acid Grassland	24885	1.2
Blanket Bog	20435	1.0
Not Accessed Land	17748	0.9
Wet Modified Bog	15281	0.7
Dense Scrub	14649	0.7
Acid/Neutral Flush	14463	0.7
Amenity Grassland	10508	0.5
Planted Mixed Woodland	10290	0.5
Wet Heath	10161	0.5

4.3.1 Core Networks

The Core Networks were defined for species with a dispersal ability of 1km and a 10ha minimum patch size for broadleaf woodland, and with no minimum patch size for ancient woodland (see Table 4-1, Table 4-2 & Table 4-3). This created a pattern of small, comparatively compact groups of habitat, that we have termed Core Networks.

4.3.1.1 Broadleaf Woodland Core Networks

Broadleaf woodland Core Networks are present across Wales; their distribution is seen in Figure 4-9. This distribution reflects the location of broadleaf habitat with particular concentrations of broadleaf woodland such as the Lower Wye Valley being apparent. A set of summary statistics for the Core Networks are given below:

Statistic	Broadleaf Woodland Core Networks
Number of Core Networks	1254
Minimum Area (Hectares)	13.7
Maximum Area (Hectares)	947.5
Total Area (Hectares)	86695.0
Mean Area (Hectares)	69.1
Standard Deviation (Hectares)	74.4

The land cover within Broadleaf Woodland Core Networks (Table 4-6) shows marked differences to the distribution of land cover in Wales as a whole (Table 4-5).

Table 4-6 – Area and percentage contribution from land cover categories which account for 95% of extent of the Broadleaf Woodland Core Networks

Land cover Class	Hectares Core Networks	Percentage Core Area Cover
*Semi-Natural Broadleaf Woodland**	*34915*	*40.3*
Improved Grassland	15063	17.4
Bracken	8803	10.2
Planted Mixed Woodland	6319	7.3
Planted Coniferous Woodland	3462	4.0
Marshy Grassland	2520	2.9
Planted Broadleaf Woodland	1936	2.2
Semi-Improved Neutral Grassland	1896	2.2
Dense Scrub	1762	2.0
Unimproved Acid Grassland	1675	1.9
Dry Acid Heath	1290	1.5
Roads Or Background	1060	1.2
Semi-Improved Acid Grassland	877	1.0
Arable	506	0.6
Running Water	427	0.5
Buildings	422	0.5
95% Cover Total	**82934**	**95.7**
Other Classes	3761	4.3
All Classes	**86695**	**100**

*Semi-Natural Broadleaf Woodland is the habitat in this analysis and the majority of this cover is by definition in the network.

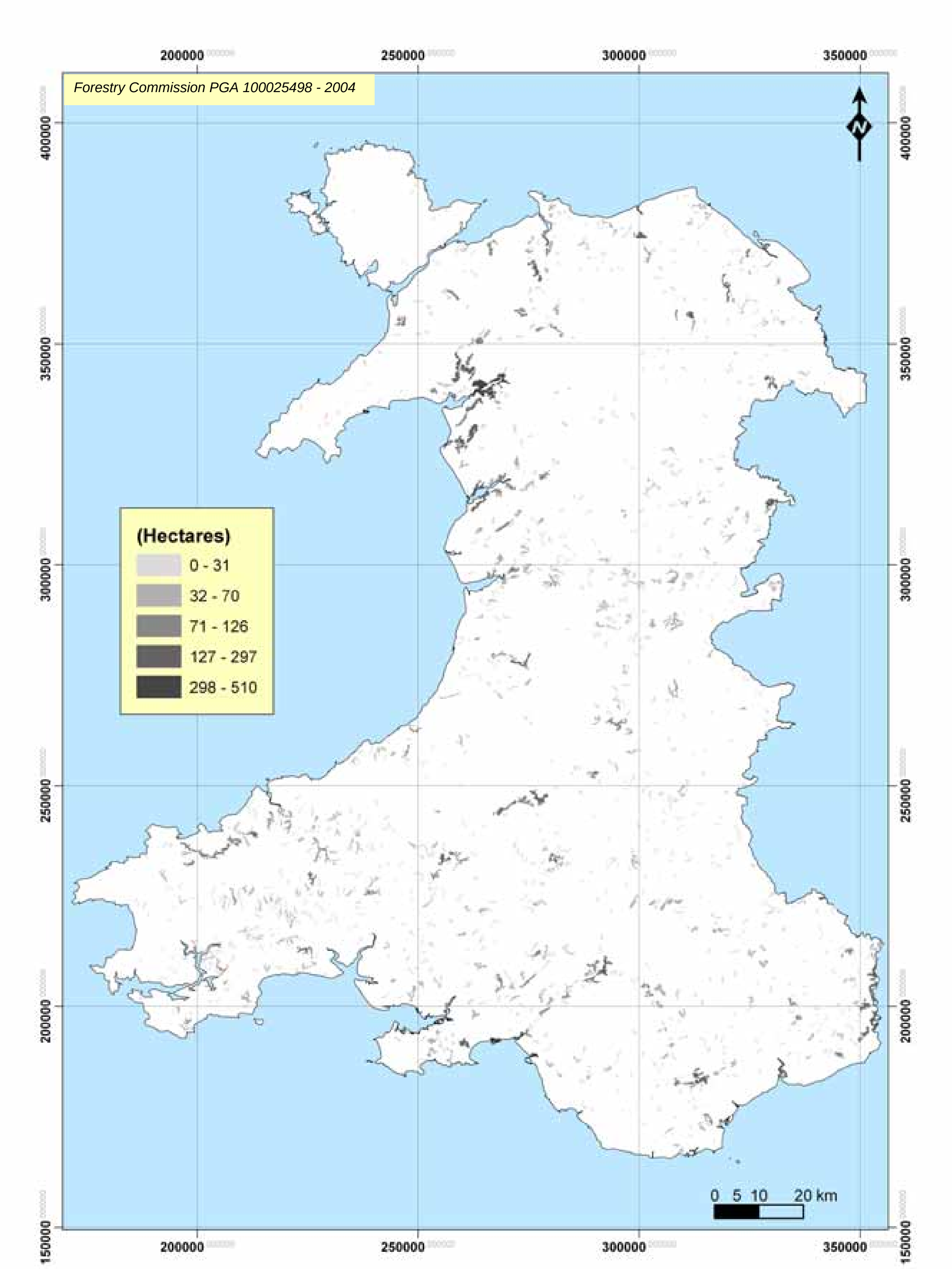


Figure 4-9 – Broadleaf Woodland Core Networks

4.3.1.2 Ancient Woodland Core Networks

The basis of the Ancient Woodland Core Networks in Wales is the ancient woodland inventory for Wales. All ancient woodland (ASNW and PAWS) was included and this has resulted in a more extensive network of Core Networks than that produced for broadleaf woodland (Figure 4-10). The distribution of Core Networks approximates the clusters of ancient woodland seen across Wales.

Statistic	Ancient Woodland Core Networks
Number of Core Networks	3918
Minimum Area (Hectares)	2.0
Maximum Area (Hectares)	2414.9
Total Area (Hectares)	146806.5
Mean Area (Hectares)	37.5
Standard Deviation (Hectares)	79.2

Again the concentrations of land cover listed in Table 4-7 appear to differ from the distribution found across Wales as a whole (Table 4-5).

Table 4-7 – Area and percentage contribution from land cover categories which account for 95% of extent of the Ancient Woodland Core Networks

Land cover Class	Hectares Core Networks	Percentage Core Area Cover
Semi-Natural Broadleaf Woodland*	46764	31.9
Improved Grassland	27604	18.8
Planted Coniferous Woodland*	25411	17.3
Bracken	13474	9.2
Planted Mixed Woodland*	6720	4.6
Marshy Grassland	2849	1.9
Planted Broadleaf Woodland*	2719	1.9
Unimproved Acid Grassland	2579	1.8
Semi-Improved Neutral Grassland	2565	1.7
Dense Scrub	2430	1.7
Roads Or Background	1889	1.3
Dry Acid Heath	1743	1.2
Semi-Improved Acid Grassland	1367	0.9
Arable	967	0.7
Felled Coniferous Woodland	902	0.6
95% Cover Total	**139983**	**95.4**
Other Classes	6824	4.6
All Classes	**146807**	**100**

*These classes may contain habitat data.

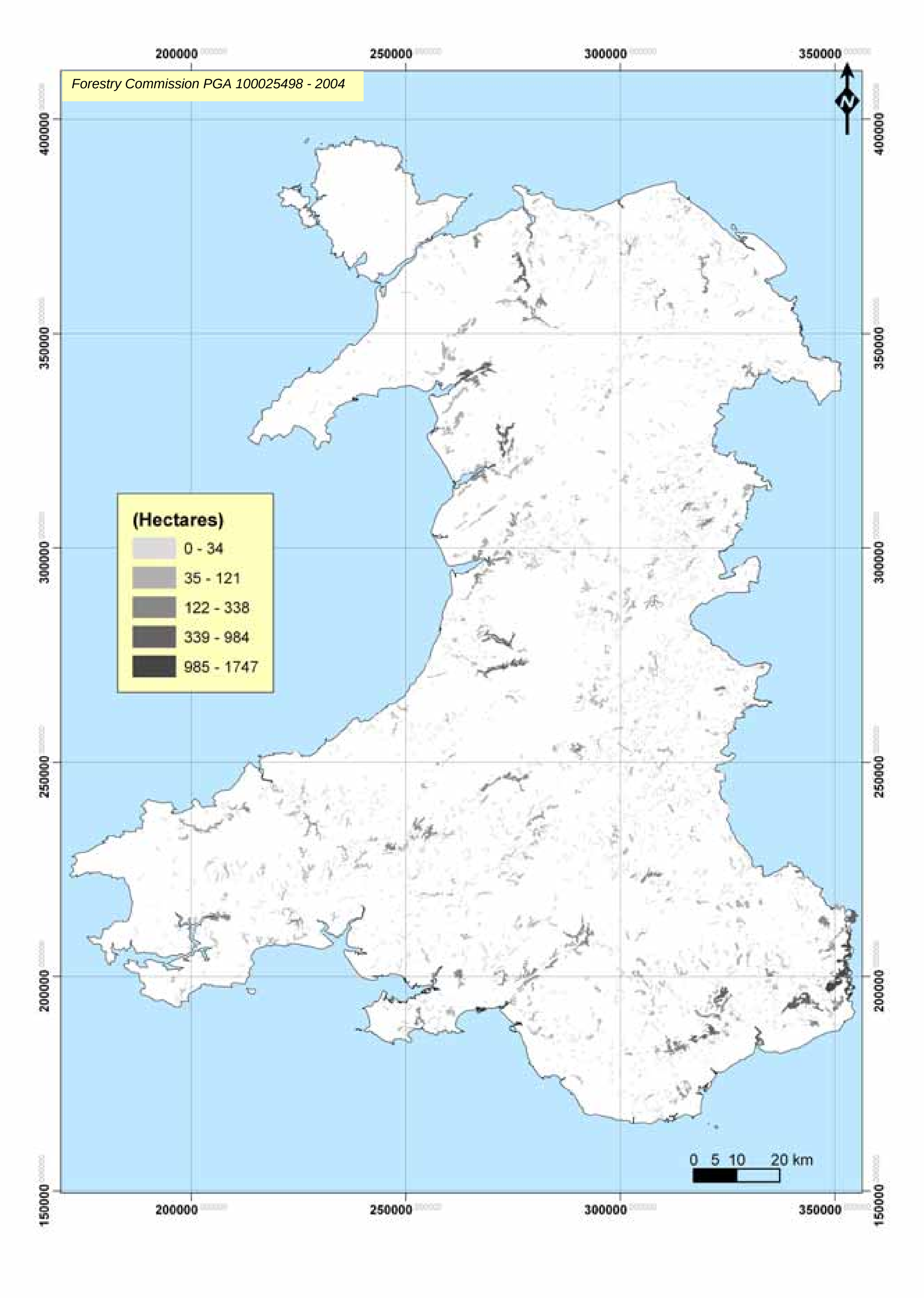


Figure 4-10 – Ancient Woodland Core Networks

4.3.2 Focal Networks

Focal Networks are identified for species with a dispersal ability of 5km and a 2ha minimum patch size (see Table 4-1, Table 4-2 & Table 4-3). This created further links between groups of Core Networks and also identified additional woodland networks.

4.3.2.1 Broadleaf Woodland Focal Network

Broadleaf Woodland Focal Networks are extensive across Wales; their distribution is seen in Figure 4-11. This distribution reflects the distribution of broadleaf woodland in Wales and also begins to illustrate where potentially strategically important networks could be present and how Core Networks could be functionally connected. A set of summary statistics for the functional networks are given below:

Statistic	Broadleaf Woodland Focal Networks
Number of Core Networks	2366
Minimum Area (Hectares)	7.2
Maximum Area (Hectares)	23808.5
Total Area (Hectares)	581619.9
Mean Area (Hectares)	245.8
Standard Deviation (Hectares)	934.7

The land cover found within the Focal Networks is summarised in Table 4-8, which shows the major land cover classes contributing to the Focal Network. By far the largest contribution is made by improved grassland with over 40% of the networks. This is a reflection of the prevalence of improved grassland in Wales, with over 1,000,000ha (Table 4-5).

Table 4-8 – Area and percentage contribution from land cover categories which account for 95% of extent of the Broadleaf Woodland Focal Networks

Land cover Class	Hectares Focal Networks	Percentage Focal Network Cover
Improved Grassland	232681	40.0
Semi-Natural Broadleaf Woodland	76529	13.2
Bracken	44618	7.7
Planted Coniferous Woodland	40155	6.9
Unimproved Acid Grassland	25308	4.4
Dry Acid Heath	20029	3.4
Marshy Grassland	18229	3.1
Semi-Improved Neutral Grassland	15883	2.7
Roads Or Background	11130	1.9
Planted Mixed Woodland	9719	1.7
Arable	9315	1.6
Semi-Improved Acid Grassland	9072	1.6
Dense Scrub	8679	1.5
Buildings	8601	1.5
Dry Heath/Acid Grassland Mosaic	6408	1.1
Planted Broadleaf Woodland	4661	0.8
Marshy Grassland Molinia Dominated	3396	0.6
Wet Heath	3229	0.6
Running Water	2711	0.5
Amenity Grassland	2286	0.4

95% Cover Total	**552638**	**95.0**
Other Classes	28982	4.9
Total All Classes	**581620**	**100**

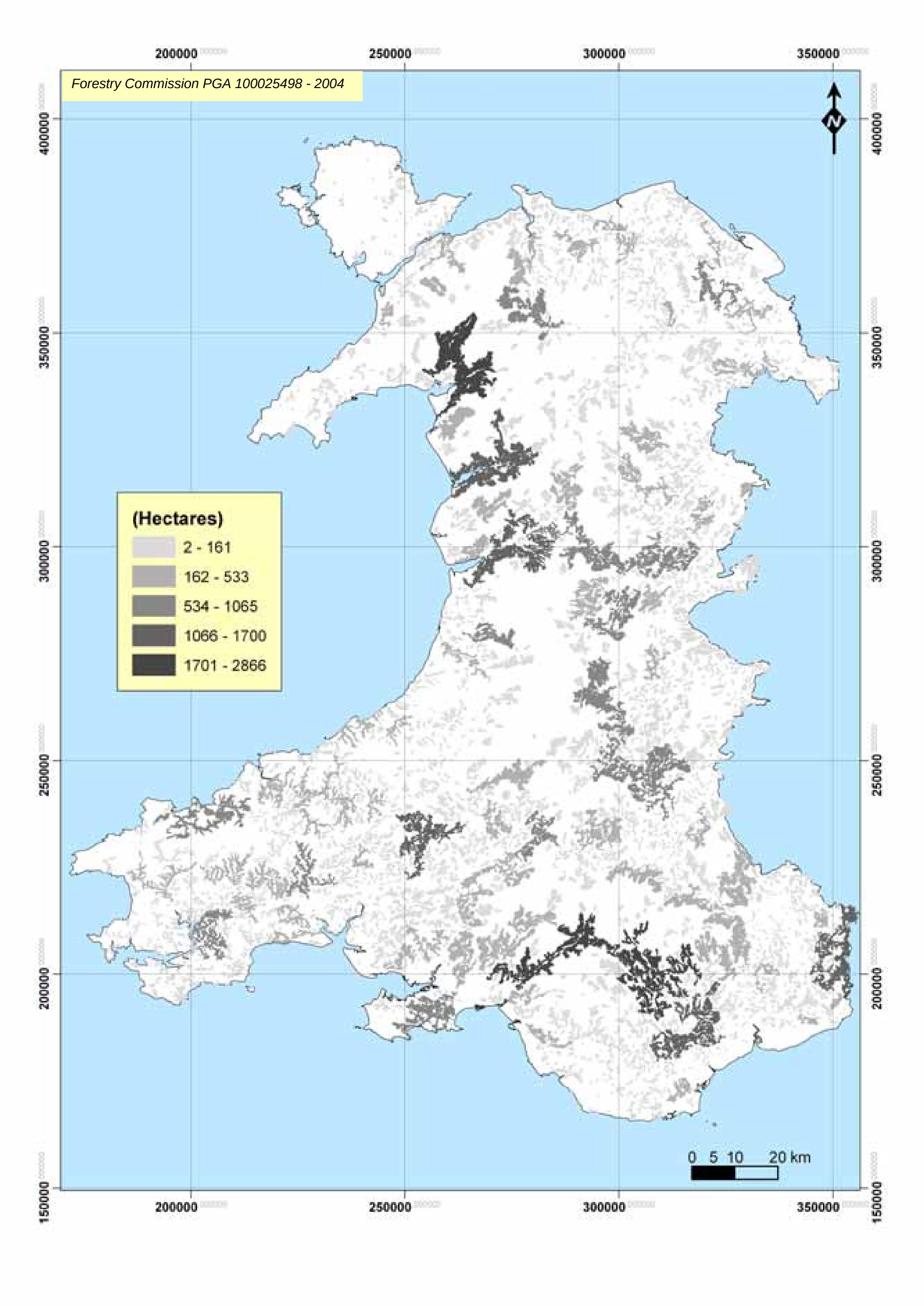


Figure 4-11 – Broadleaf Woodland Focal Networks

4.3.2.2 Ancient Woodland Focal Networks

Ancient Woodland Focal Networks have a similar distribution to broadleaf woodland across Wales; their distribution is seen in Figure 4-12. This distribution reflects the distribution of ancient woodland in Wales. Concentrations such as the Merionydd Oak Woods are apparent and the potential for consolidating Core Networks can also be seen. A summary of the Focal Networks is given below:

Statistic	Ancient Woodland Focal Networks
Number of Core Networks	1655
Minimum Area (Hectares)	3.8
Maximum Area (Hectares)	11097.9
Total Area (Hectares)	447968.4
Mean Area (Hectares)	270.7
Standard Deviation (Hectares)	803.2

The land cover found within the Focal Networks is summarised in Table 4-9. This identifies the major land cover classes that contribute to the potential network; the largest contribution is made by improved grassland.

Table 4-9 – Area and percentage contribution from land cover categories which account for 95% of extent of the Ancient Woodland Focal Networks

Land cover Class	Hectares Focal Networks	Percentage Focal Network Cover
Improved Grassland	168553	37.6
Semi-Natural Broadleaf Woodland	63103	14.1
Planted Coniferous Woodland	46546	10.4
Bracken	37828	8.4
Unimproved Acid Grassland	18587	4.1
Dry Acid Heath	15023	3.4
Marshy Grassland	10858	2.4
Semi-Improved Neutral Grassland	10222	2.3
Planted Mixed Woodland	7901	1.8
Roads Or Background	7743	1.7
Semi-Improved Acid Grassland	6684	1.5
Arable	6381	1.4
Dense Scrub	5918	1.3
Buildings	5308	1.2
Dry Heath/Acid Grassland Mosaic	4779	1.1
Planted Broadleaf Woodland	3530	0.8
Marshy Grassland Molinia Dominated	2419	0.5
Wet Heath	2175	0.5
Running Water	2057	0.5
95% Cover Total	**425615**	**95.0**
Other Classes	22353	5.0
All Classes	**447968**	**100**

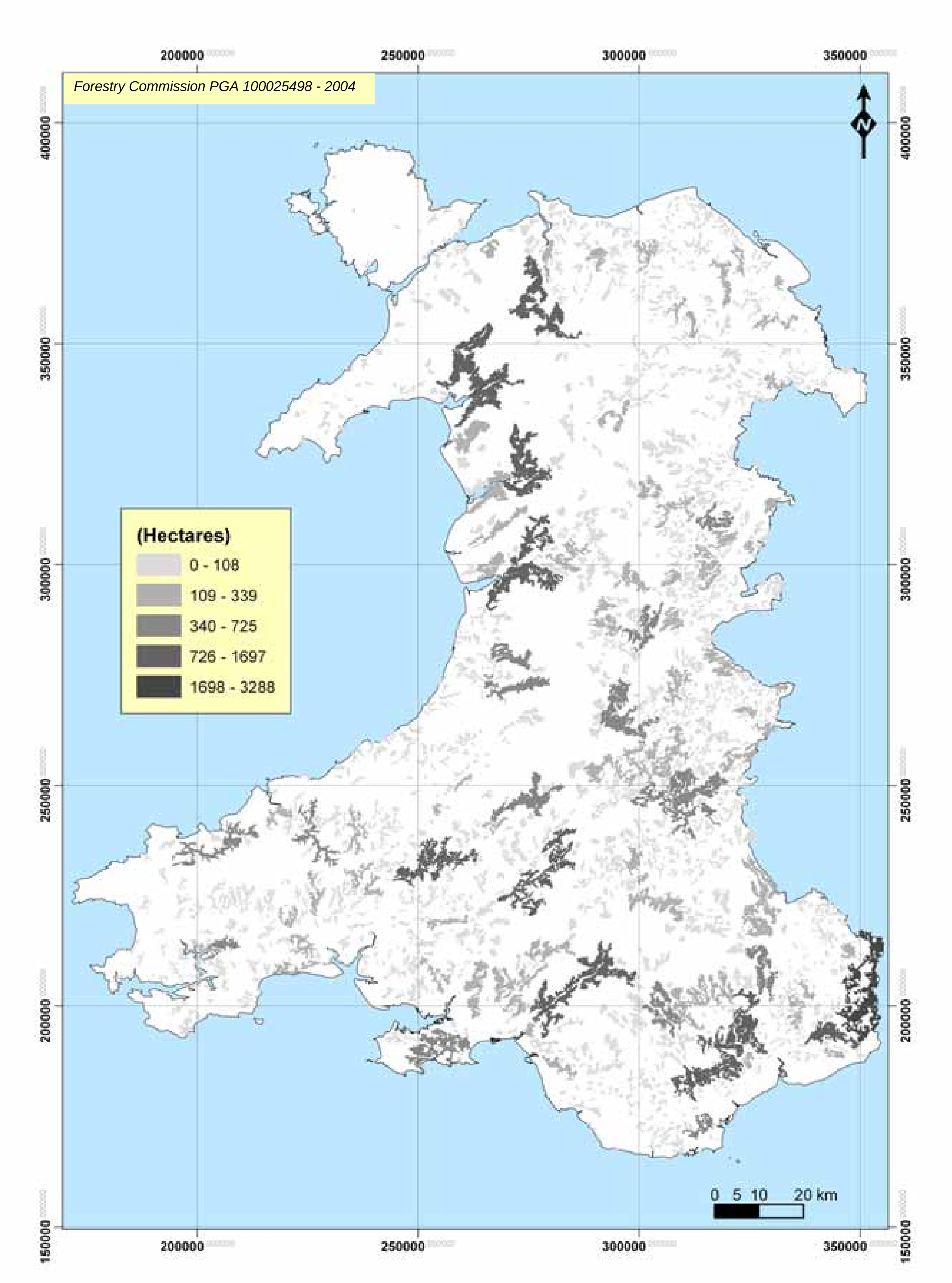


Figure 4-12 – Ancient Woodland Focal Networks

4.3.3 Large Focal Networks

Broadleaf and Ancient Woodland Focal Networks were ranked according to their quantity of habitat. This is another way of viewing the networks and it may aid the identification of the largest and possibly strategic networks. The top twenty largest broadleaf and ancient woodland networks are presented in Figure 4-13 and Figure 4-14 respectively; and their relative size is described below.

Network Rank	Broadleaf Woodland Habitat in Focal Network (ha)	Ancient Woodland Habitat in Focal Network (ha)*
1	2866	3288
2	2414	1697
3	1700	1430
4	1649	1400
5	1511	1282
6	1395	1279
7	1199	1180
8	1065	1173
9	1001	1123
10	946	1091
11	833	979
12	826	725
13	768	675
14	754	665
15	727	659
16	646	559
17	635	497
18	617	495
19	580	494
20	559	473

* includes ASNW and PAWS

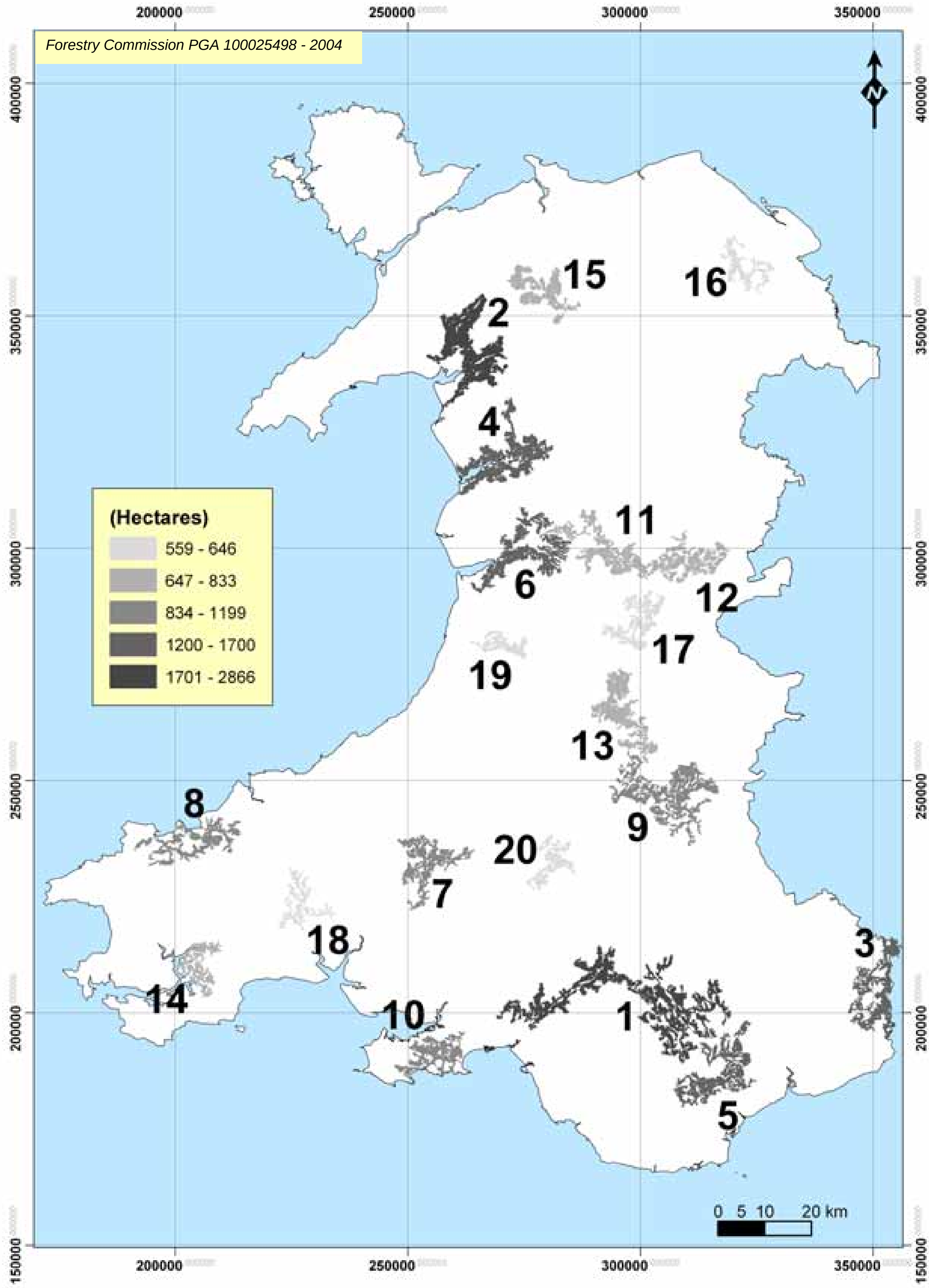


Figure 4-13 – The twenty largest Broadleaf Woodland Focal Networks

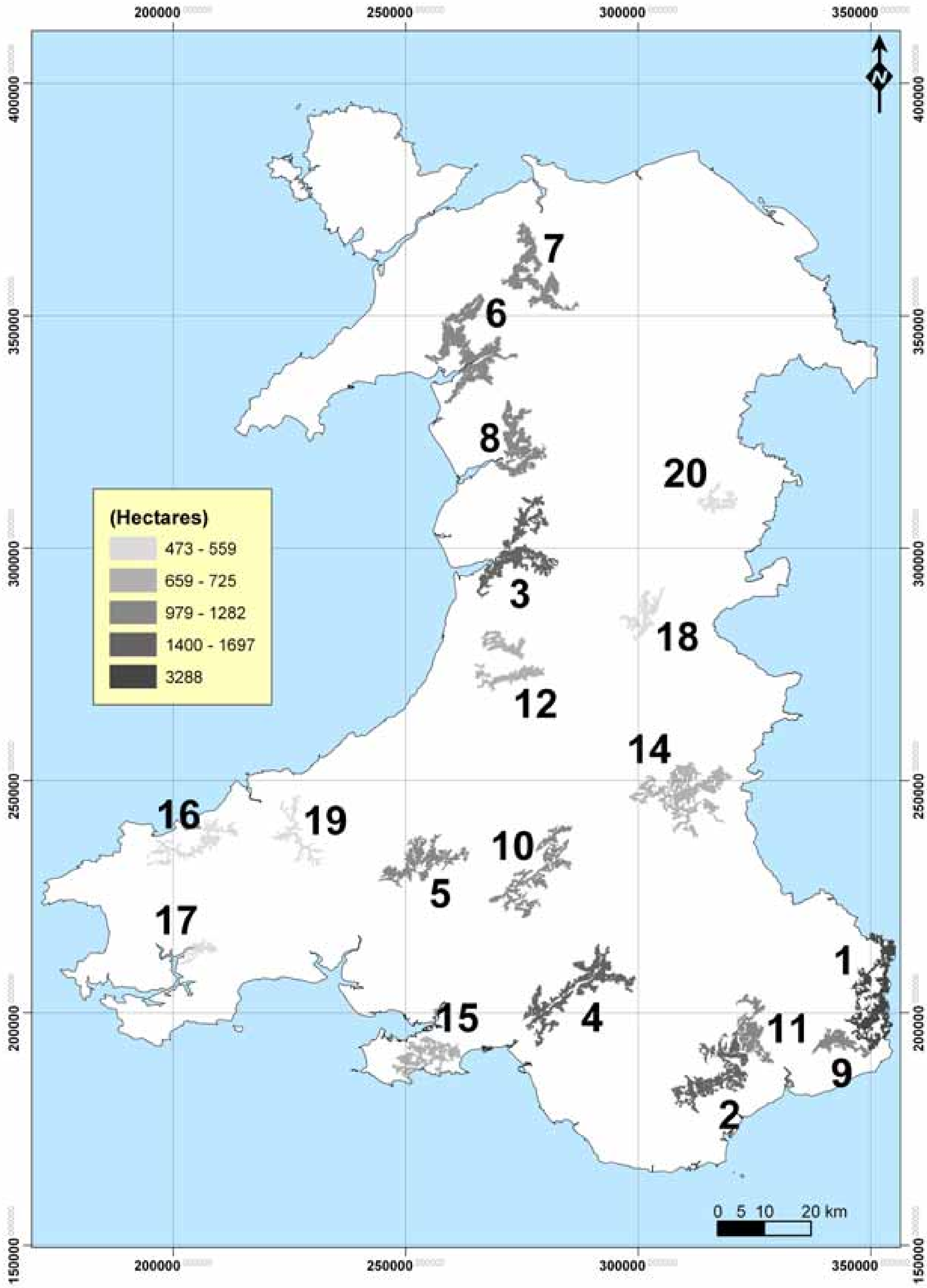


Figure 4-14 – The twenty largest Ancient Woodland Focal Networks

4.3.4 Core Networks nested within Focal Networks

To further illustrate the concept of Core Networks nested within larger Focal Networks, four discrete Focal Networks are presented. Figure 4-15 illustrates the location of the four Focal Networks; two broadleaf woodland and two ancient woodland. The results are presented in the form of a basic description, a summary of land cover and an illustrative map. Such an approach may be useful to aid the implementation of this strategy at a more local scale (See Section 1.3.1).

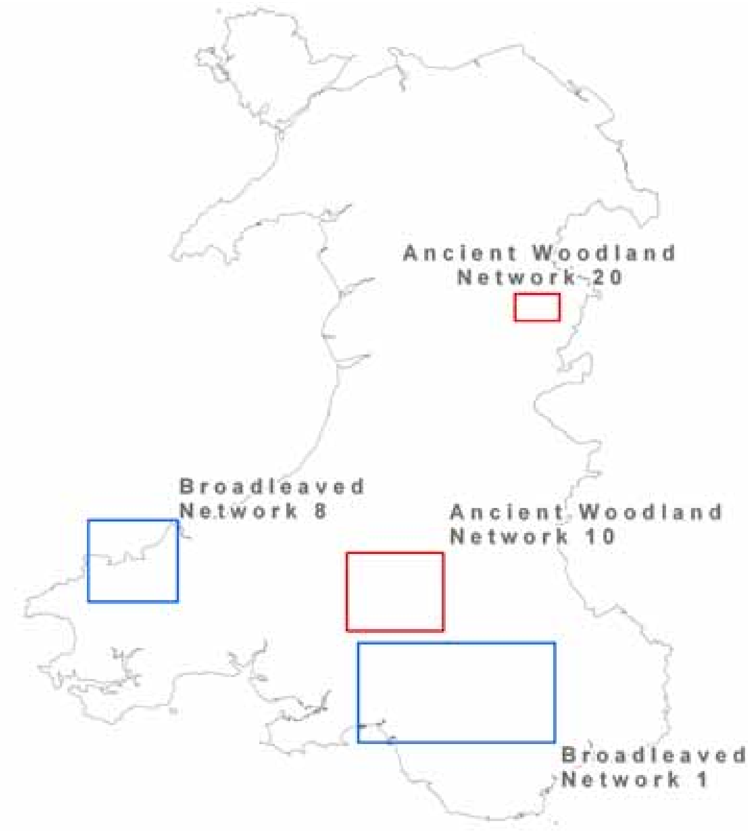


Figure 4-15 – Location of four Focal Networks used to illustrate the concept of Core Networks nested within Focal Networks

4.3.4.1 Nested Networks Example 1 - Broadleaf Focal Network 1

Network description

This is by far the largest broadleaf network in Wales (Figure 4-16). It is formed by a number of groups of Core Networks. One group is based on the woodlands of the Vale of Neath with further groups in the central South Wales Valleys. The scale, extent and character of network is governed by the topography of the region. Woodlands are concentrated on valley sides with a mixture of broadleaf and conifer woodland. In a number of places these focal areas are connected across open semi-natural habitats, which often provide connectivity across watersheds. This linking can be seen clearly around Hirwaun, where the woodland is connected from the Vale of Neath into the Cynon Valley.

AWI summary

	Focal Network (ha) and (% of network)	Core Networks (ha) and (% of core area)
ASNW	1403 (5.9%)	822 (20%)
PAWS	837 (3.5%)	306 (7.5%)

Reflecting its extensive and well wooded nature this Focal Network has large areas of ASNW and PAWS, containing 4% and 3% of the Welsh total area respectively. Much of the ASNW is not within Core Networks possibly offering the opportunity for expansion. There may also be opportunities for PAWS restoration.

Land cover summary

There were 82 land cover classes in the Focal Network and 56 in the Core Networks. 95% of the area of the Focal Network and the Core Networks were accounted for by 20 and 16 classes respectively. The contribution of these classes is summarised for the Focal Network in Table 4-10 and the Core Networks in Table 4-11.

Table 4-10 – Area and percentage contribution from land cover categories which account for 95% of extent of the Broadleaf Focal Network 1

Land cover Class	Area Hectares	Percentage of Network
Improved Grassland	4527	19.0
Semi-Natural Broadleaf Woodland*	3257	13.7
Planted Coniferous Woodland	3171	13.3
Bracken	2347	9.9
Semi-Improved Neutral Grassland	1439	6.0
Marshy Grassland	1365	5.7
Semi-Improved Acid Grassland	896	3.8
Unimproved Acid Grassland	862	3.6
Roads or Background	786	3.3
Buildings	772	3.2
Dry Acid Heath	692	2.9
Spoil	524	2.2
Dense Scrub	415	1.7
Dry Heath/Acid Grassland Mosaic	366	1.5
Planted Broadleaf Woodland	256	1.1
Amenity Grassland	246	1.0
Planted Mixed Woodland	219	0.9
Running Water	206	0.9

Wet Heath/Acid Grassland Mosaic	162	0.7
Quarry	128	0.5
95% Cover Total	**22635**	**95.1**
Other Classes	1173	4.9
All Classes	**23809**	**100**

Table 4-11 – Area and percentage contribution from land cover categories which account for 95% of extent of the Core Networks with Broadleaf Focal Network 1

Land cover Class	Area Hectares	Percentage of Core Area
Semi-Natural Broadleaf Woodland*	1572	38.5
Bracken	495	12.1
Marshy Grassland	315	7.7
Planted Coniferous Woodland	300	7.3
Improved Grassland	229	5.6
Semi-Improved Neutral Grassland	185	4.5
Planted Mixed Woodland	158	3.9
Semi-Improved Acid Grassland	109	2.7
Unimproved Acid Grassland	104	2.5
Planted Broadleaf Woodland	81	2.0
Dry Acid Heath	69	1.7
Dense Scrub	65	1.6
Roads or Background	64	1.6
Spoil	63	1.6
Running water	42	1.0
Buildings	41	1.0
95% Cover Total	**3890**	**95.3**
Other Classes	191	4.7
All Classes	**4081**	**100**

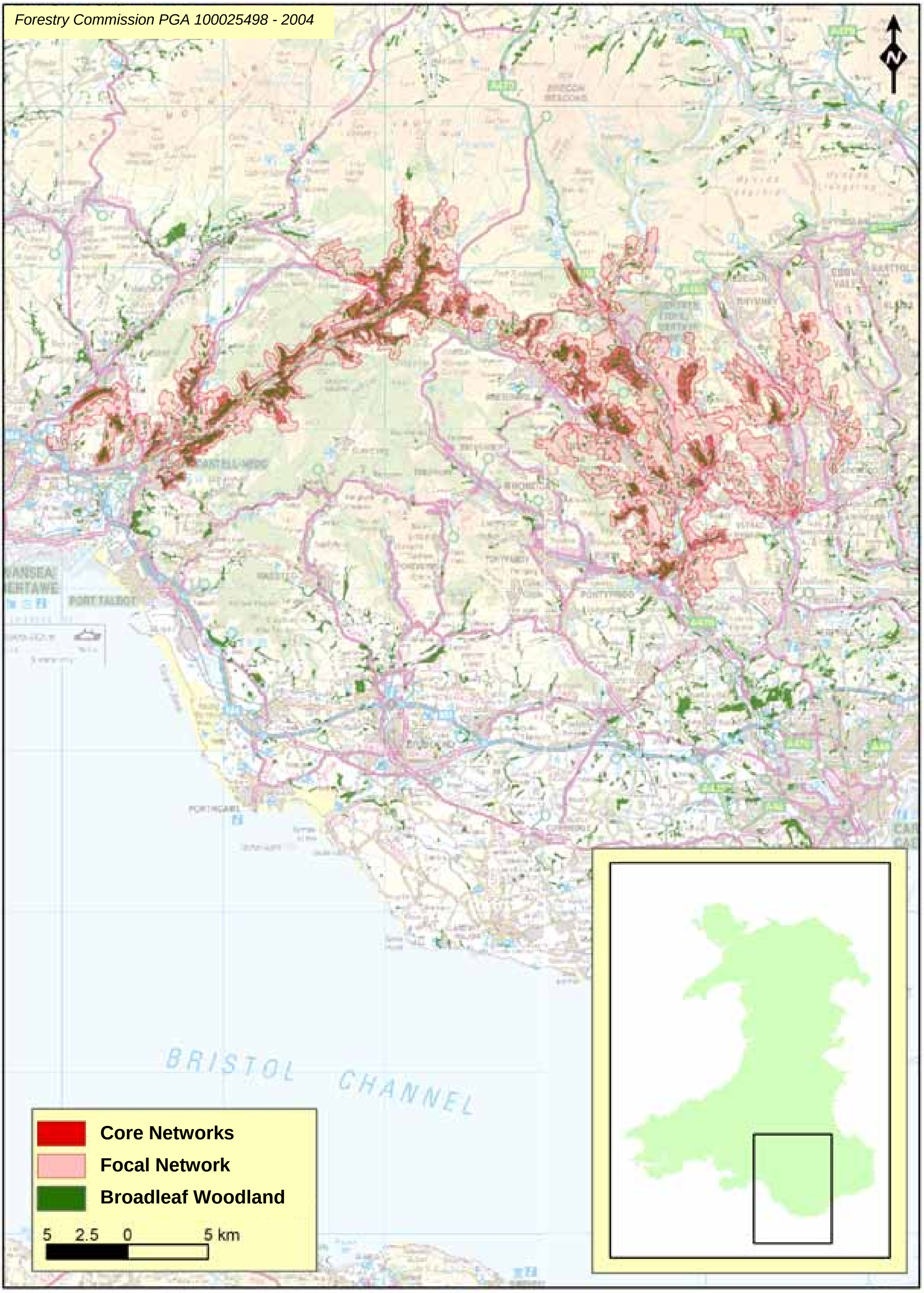


Figure 4-16 – Broadleaf Woodland Core Networks nested within Focal Network 1

4.3.4.2 Nested Networks Example 2 - Broadleaf Focal Network 8

Network description

This network, which is the eighth largest in Wales, is formed from wooded valleys that extend from the towns of Fishguard and Newport (Figure 4-17). Core Networks are concentrated in these wooded areas along the Gwaun Valley from Fishguard and forest areas around the Nyfer Valley. These account for the concentrations of woodland within this network and there are also extensions of this network through open habitats out onto Dinas Head.

AWI summary

	Focal Network (ha) and (% of network)	Core Networks (ha) and (% of core area)
ASNW	512.5 (7.8%)	473.4 (25%)
PAWS	78.0 (1.2%)	53.6 (2.8%)

Land cover summary

95% of the area of the Focal Network and the Core Networks were accounted for by 14 and 11 classes respectively. The contribution of these classes is summarised for the Focal Network in Table 4-12 and the Core Networks in Table 4-13.

Table 4-12 – Area and percentage contribution from land cover categories which account for 95% of extent of the Broadleaf Focal Network 8

Land cover Class	Area Hectares	Percentage of Network
Improved Grassland	2806	42.5
Semi-Natural Broadleaf Woodland	1132	17.1
Bracken	527	8.0
Dense Scrub	315	4.8
Dry Acid Heath	295	4.5
Marshy Grassland	243	3.7
Planted Coniferous Woodland	203	3.1
Semi-Improved Neutral Grassland	184	2.8
Arable	162	2.5
Wet Heath	131	2.0
Buildings	117	1.8
Roads Or Background	116	1.8
Planted Broadleaf Woodland	30	0.4
Semi-Improved Acid Grassland	26	0.4
95% Cover Total	**6286**	**95.1**
Other Classes	321	4.9
All Classes	**6607**	**100**

Table 4-13 – Area and percentage contribution from land cover categories which account for 95% of extent of the Core Networks within Broadleaf Focal Network 8

Land cover Class	Area Hectares	Percentage of Network
Semi-Natural Broadleaf Woodland	907	48.5
Improved Grassland	371	19.9
Bracken	127	6.8
Dense Scrub	110	5.9
Semi-Improved Neutral Grassland	76	4.1
Marshy Grassland	75	4.0

Planted Coniferous Woodland	52	2.8
Planted Broadleaf Woodland	21	1.1
Roads Or Background	17	0.9
Dry Acid Heath	17	0.9
Planted Mixed Woodland	14	0.7
95% Cover Total	**1786**	**95.5**
Other Classes	84	4.5
All Classes	**1870**	**100**

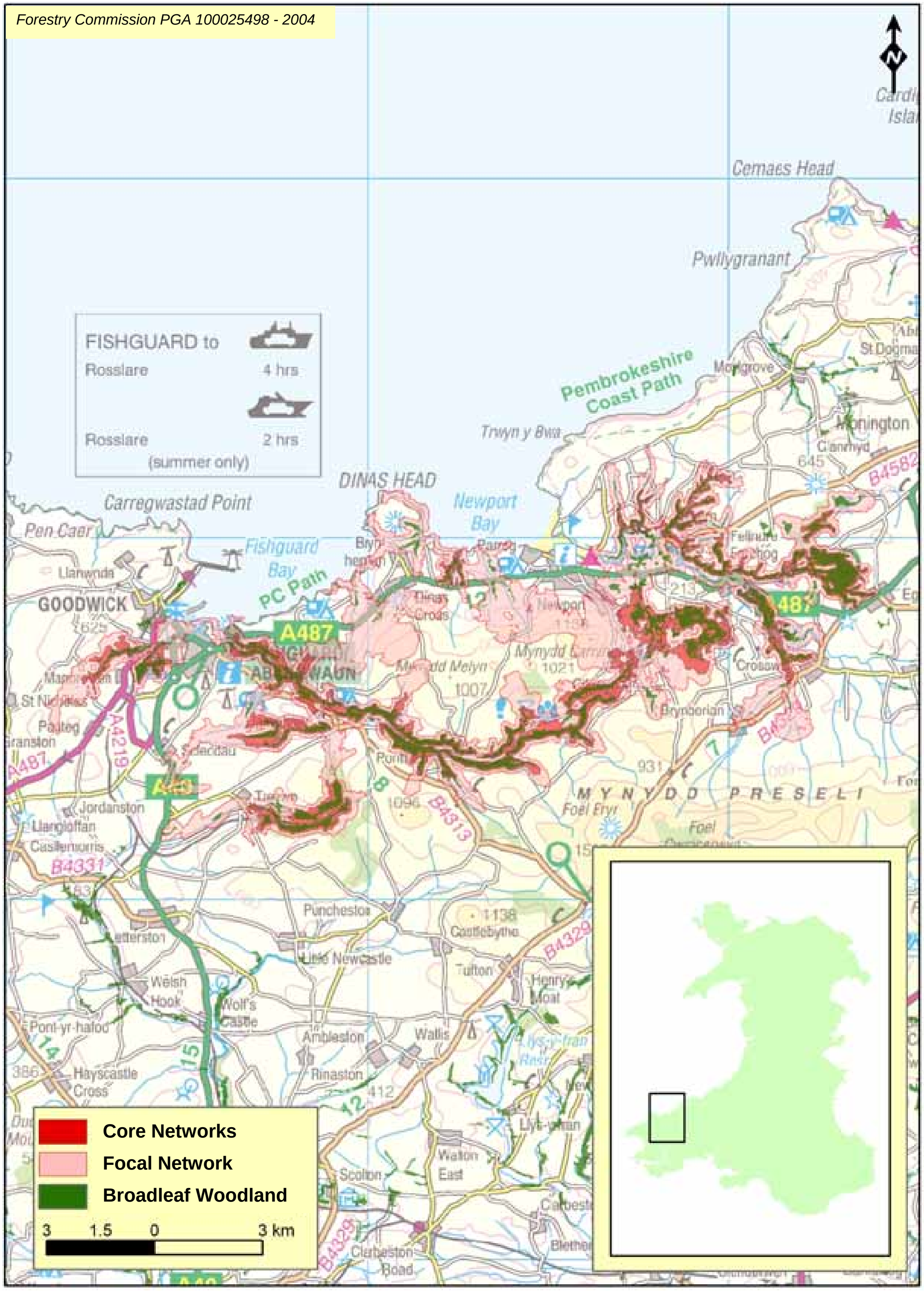


Figure 4-17 – Broadleaf Woodland Core Networks nested within Focal Network 8

4.3.4.3 Nested Networks Example 3 - Ancient Woodland Focal Network 10

Network description

This network forms an arc from the north east through to the south west of Llandovery (Figure 4-18). Lying on the west side of the Tywi before the upland Black Mountain areas; this ancient woodland network was identified as the 10th largest in Wales. It contains 1091 hectares considered to be current habitat.

AWI summary

	Area (ha)
ASNW	694 (9.9% Focal Network, 28.7% Core Networks)
PAWS	397 (5.7% Focal Network, 16.4% Core Networks)

Land cover summary

95% of the area of the Focal Network and the Core Networks were accounted for by 10 and 8 classes respectively. The contribution of these classes is summarised for the Focal Network in Table 4-14 and the Core Networks in Table 4-15.

Table 4-14 – Area and percentage contribution from land cover categories which account for 95% of extent of the Ancient Woodland Focal Network 10

Land cover Class	Area Hectares	Percentage of Focal Network
Improved Grassland	3226	45.9
Planted Coniferous Woodland	1119	15.9
Semi-Natural Broadleaf Woodland	1082	15.4
Bracken	444	6.3
Unimproved Acid Grassland	301	4.3
Marshy Grassland	158	2.3
Marshy Grassland Molinia Dominated	151	2.2
Roads Or Background	88	1.2
Dry Heath/Acid Grassland Mosaic	64	0.9
Felled Coniferous Woodland	54	0.8
95% Cover Total	**6687**	**95.3**
Other Classes	333	4.7
All Classes	**7020**	**100**

Table 4-15 – Area and percentage contribution from land cover categories which account for 95% of extent of the Core Networks within Ancient Woodland Focal Network 10

Land cover Class	Area Hectares	Percentage of Core Area
Semi-Natural Broadleaf Woodland	819	33.9
Planted Coniferous Woodland	606	25.0
Improved Grassland	598	24.7
Bracken	146	6.0
Marshy Grassland	65	2.7
Planted Broadleaf Woodland	26	1.1
Roads Or Background	23	1.0
Unimproved Acid Grassland	19	0.8
95% Cover Total	**2303**	**95.2**
Other Classes	117	4.8
All Classes	**2420**	**100**

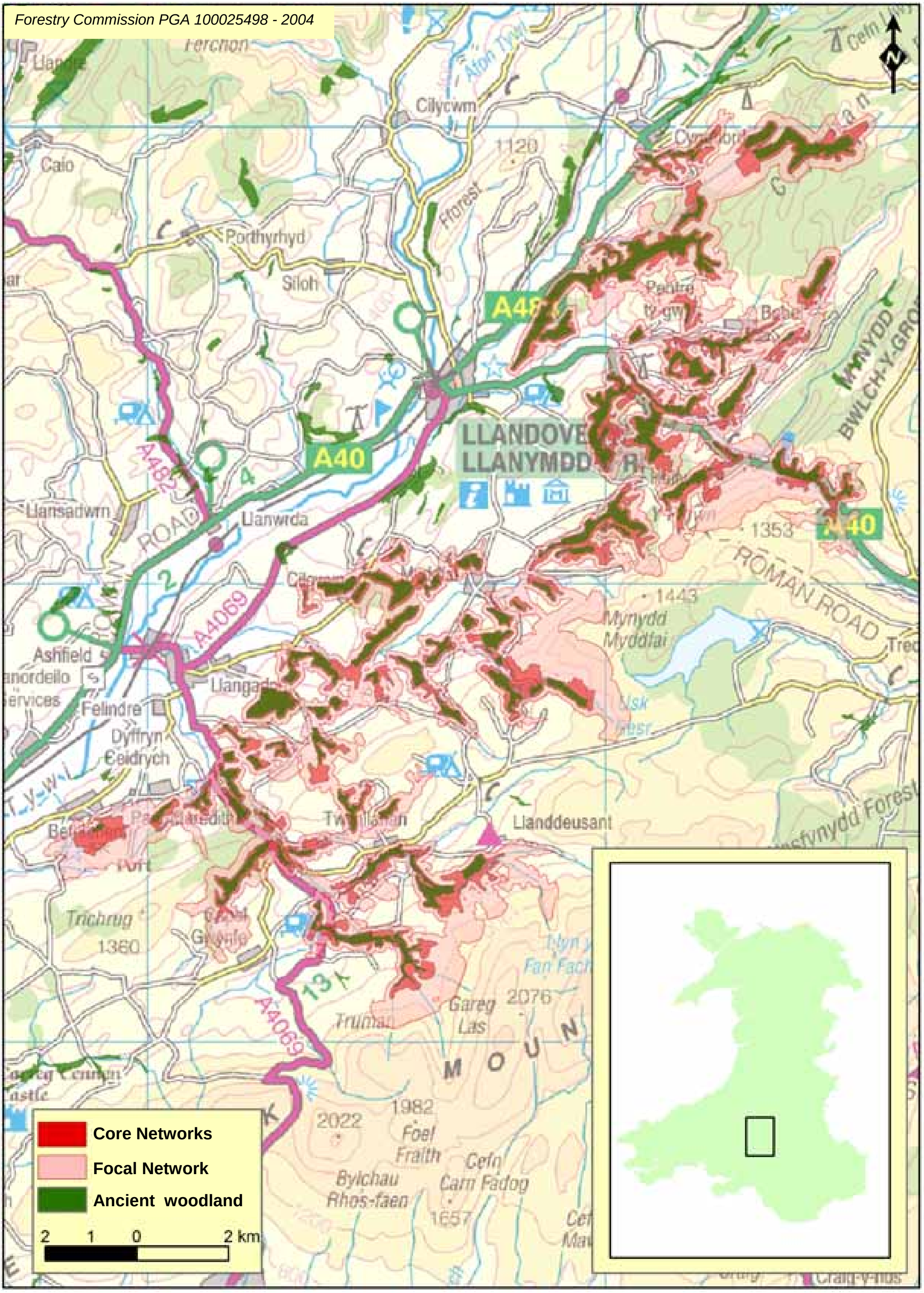


Figure 4-18 – Ancient Woodland Core Networks nested within Focal Network 10

4.3.4.4 Nested Networks Example 4 - Ancient Woodland Focal Network 20

Network description

A group of woodlands lying to the north west of Welshpool form this network (Figure 4-19). Classified by quantity of habitat it is the 20th largest ancient woodland network in Wales. It has 473 hectares considered to be habitat.

AWI summary

	Area (ha)
ASNW	203 (9.9% Focal Network, 23.1% Core Networks)
PAWS	270 (13.2% Focal Network, 30.7% Core Networks)

Land cover summary

95% of the area of the Focal Network and the Core Networks were accounted for by 8 and 7 classes respectively. The contribution of these classes is summarised for the Focal Network in Table 4-16 and the Core Networks in Table 4-17.

Table 4-16 – Area and percentage contribution from land cover categories which account for 95% of extent of the Ancient Woodland Focal Network 20

Land cover Class	Area Hectares	Percentage of Focal Network
Improved Grassland	1238	60.4
Semi-Natural Broadleaf Woodland	312	15.2
Planted Coniferous Woodland	281	13.7
Bracken	38	1.8
Arable	30	1.5
Planted Mixed Woodland	25	1.2
Roads Or Background	22	1.1
Felled Coniferous Woodland	22	1.1
95% Cover Total	**1968**	**96**
Other Classes	82	4
Total All Classes	**2050**	**100**

Table 4-17 – Area and percentage contribution from land cover categories which account for 95% of extent of the Core Networks within Ancient Woodland Focal Network 20

Land cover Class	Area Hectares	Percentage of Core Area
Improved Grassland	280	31.8
Semi-Natural Broadleaf Woodland	255	29.0
Planted Coniferous Woodland	235	26.7
Planted Mixed Woodland	25	2.9
Felled Coniferous Woodland	19	2.2
Planted Broadleaf Woodland	17	1.9
Bracken	15	1.7
95% Cover Total	**845**	**96.2**
Other classes	34	3.8
Total All Classes	**879**	**100**

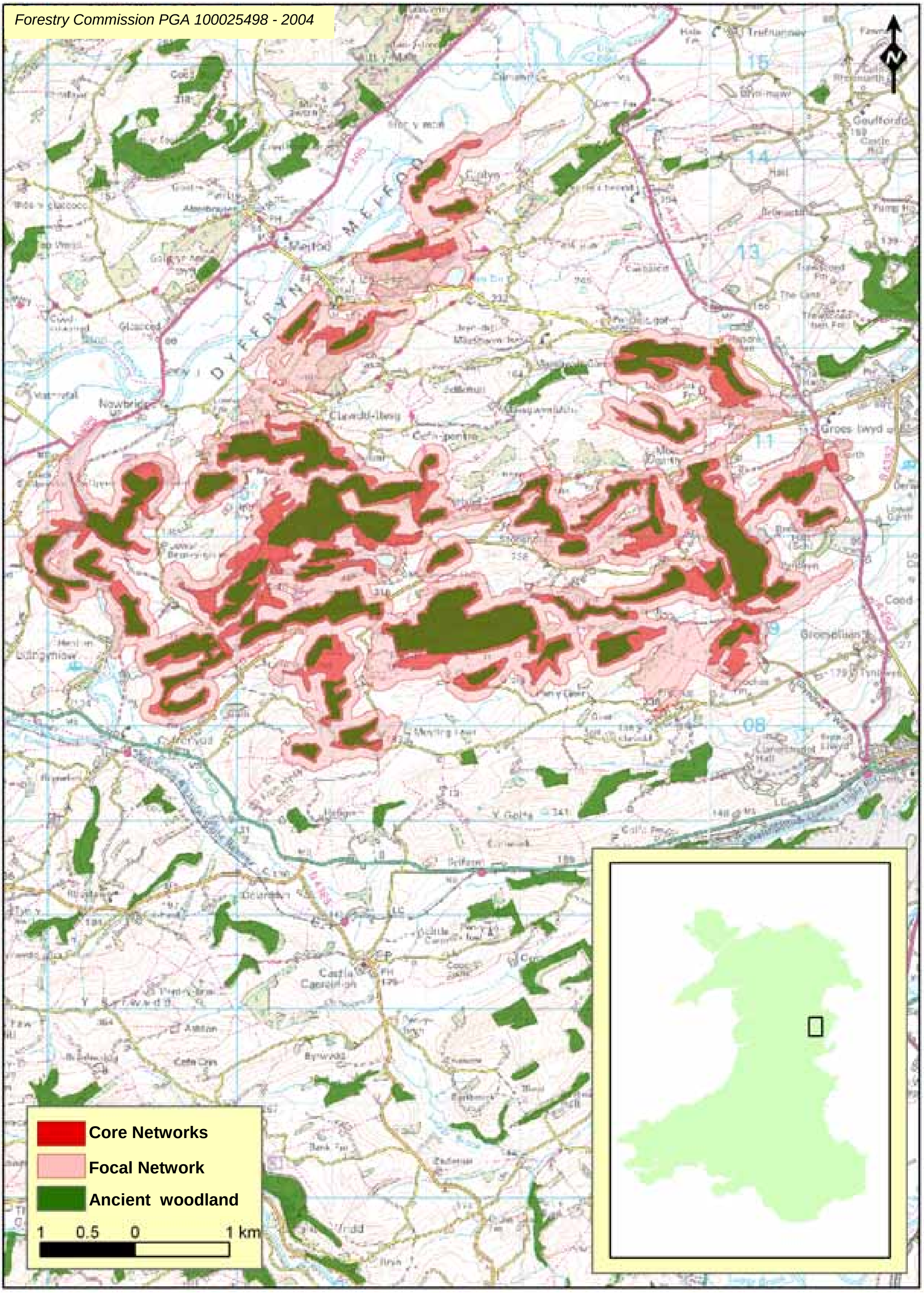


Figure 4-19 – Ancient Woodland Core Networks nested within Focal Network 20

4.3.5 Large-Scale Linkages

Large-Scale Linkages are formed by creating a number of alternative pathways between strategic Focal Networks. Their aim is to prioritise and target action beyond Core Networks and Focal Networks. These aspirational linkages are seen as a strategic approach to enhance the sustainability of biodiversity within habitat networks, particularly in the light of the impacts of habitat fragmentation and predictions of climate change.

Although the detailed development of Large-Scale Linkages is beyond the scope of this current study, two examples of large-scale linkages are presented in Figure 4-20 and Figure 4-21 to illustrate the basic concept. The examples run from the south-east to the north-west and the south-west to the north-east, respectively, and are considered important for the steering group to mitigate the potential impacts of climate change. For illustration purposes, these linkages were based on a 50m resolution rather than the previous 10m.

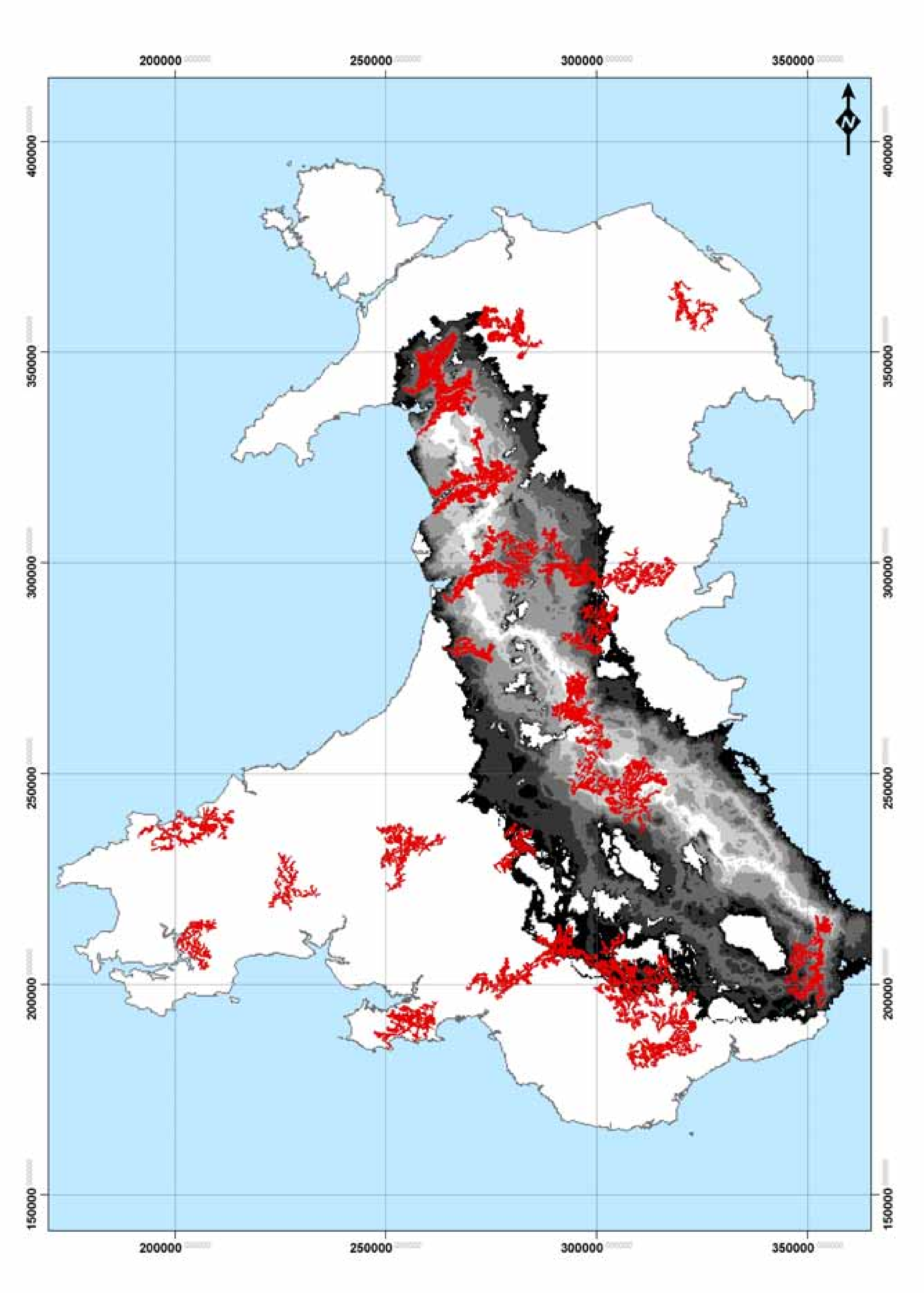


Figure 4-20 – Indicative Large Scale Linkage from south-east to north-west Wales

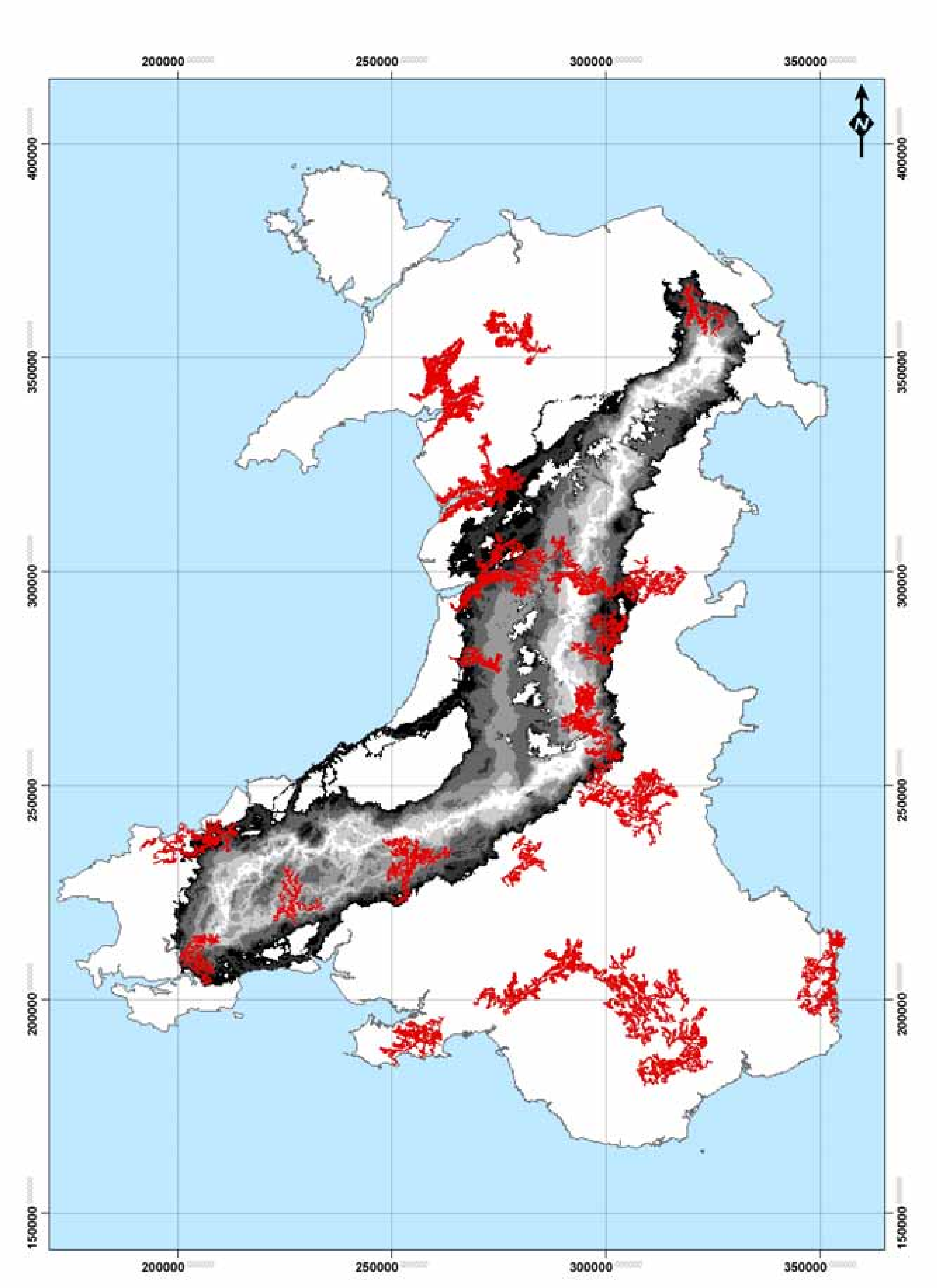


Figure 4-21 – Indicative Large Scale Linkage from south-west to north-east Wales

4.4 DISCUSSION AND CONCLUSIONS

4.4.1 Network approach

The approach adopted here to define a habitat network is based on the principle of providing a strategic, spatially-explicit tool to aid the effective management of landscapes for biodiversity. It is designed to be an adaptive tool which aims to support and assist the effective targeting and prioritisation of limited management and resources. It is based on the concept of improving connectivity for woodland biodiversity in general, rather than a tool to predict the dispersal and viability of actual woodland species. The tool is also designed to avoid the use and implementation of simple land cover thresholds.

There are inherent assumptions within this modelling approach, such as habitat preference, area requirements, dispersal distance and matrix permeability. These assumptions are based on sound ecological theories and principles which have been developed through consultation with the 'woodland habitat network steering group' and are explicit within the modelling approach. Although this approach is not intended to model and predict actual species dispersal and viability, it could undoubtedly be validated and refined with species-specific studies, improved species profiles and data, and improved habitat and land cover data.

4.4.2 Data limitations

The use of Generic Focal Species is an attempt to move the focus from the conservation of individual species to wider groups of species and ecological processes. It arose from the recognition that there is very limited species data, particularly in terms of their dispersal ability and their use of the surrounding matrix. Additional species-specific studies will provide an opportunity to validate some of the assumptions within this networks approach and further refine the focal species profiles.

The CCW Phase 1 survey represents an unprecedented high quality land cover data set for the whole of Wales. However, this data set only provides an historical snapshot of the Welsh landscape, and such landscapes exhibit complex temporal dynamics. The Survey also has limited value in assessing habitat quality and particular landscape features are omitted, such as hedgerows. Improved spatial data sets at a range of scales could start to capture the dynamics of landscapes and provide useful information on habitat quality.

4.4.3 Promoting sustainability through woodland habitat networks

The woodland networks investigated in this study are based on ecological principles and aim to provide insights into biodiversity conservation planning. However, it is acknowledged that habitat networks are set within the wider context of sustainable development. In addition to ecological benefits, networks can yield wider environmental, economic and social benefits.

Developing and implementing woodland habitat networks has the potential to profoundly alter the Welsh landscape. The key to successfully managing any landscape change is the integration of woodland networks into the wider sustainable development agenda.

The implementation of woodland habitat networks is likely to promote the strategic protection, management, restoration and expansion of woodland habitats, in addition to the alteration to the intervening landscape matrix and the creation of new woodland. Were this approach to be pursued, there would be associated implications and opportunities for the sustainability of the landscape. To fully exploit the potential of habitat networks, a closer analysis of its effects on a full range of socio-economic and environmental objectives would be required. Some of the key issues relating to these objectives are introduced in Table 4-18 and Table 4-19. Many of these associated, non-ecological, issues and benefits may considerably strengthen the case for habitat networks (Dover, 2000).

Table 4-18 – Examples of potential implications and opportunities of woodland habitat networks for selected environmental issues

Environmental issue	Linking in with a habitat network
Water Quality: Forest operations can increase water turbidity and siltation. There are also implications due to fertiliser applications, enhanced capture of acid deposition and its potential effect on groundwater quality.	Within the EU Water Framework directive catchment scale planning is promoted. Any woodland network development should sit within this framework, particularly where woodland management may impact on water quality.
Water Resources: Water resources may also be an issue with the expansion of woodland having impact on groundwater supplies and summer river flows. Research has also noted that woodland has potential in flood alleviation where woodland acts to reduce peak flow.	Networks need to be created and maintained so that they do not adversely affect drinking water resources. They could also be designed to reduce potential flood risk where appropriate.
Air pollution and critical loads: Critical loads reflect the sensitivity of an ecosystem to nitrogen and sulphur pollution.	Air pollution effects could be integrated through the use of critical load mapping. These may give an idea of the potential for woodland expansion and management in different parts of Wales. This could be used to enhance the implementation of a woodland habitat network.
Non-woodland biodiversity: The focus on woodland networks may have both positive and negative impacts on other biodiversity interests, particularly open/ non-woodland habitat networks.	Networks should be assessed for a range of woodland and non-woodland focal species, to ensure conflicts are avoided and an optimal landscape is maintained for the widest biodiversity.
Invasive species and pests: the development of networks, particularly large-scale national networks may aid the dispersal of invasive species such as grey squirrels or deer.	There are potential problems from invasive species in Wales with or without a habitat network. A woodland network has the potential to facilitate or hinder the spread of invasive species, and provide insights into their strategic management.

Table 4-19 – Examples of potential implications and opportunities of woodland habitat networks for selected social and economic issues

Socio-economic issue	Linking in with a habitat network
Public and stakeholder objectives and perception: Understanding the societal implications of a woodland habitat network is key to its successful implementation. Work on stakeholders objectives and public perception of a woodland network is obviously important.	This would require the application of social research techniques. The objectives of stakeholders and public perception can be used to implement an effective habitat network.
Recreation and the benefits for human health of woodlands: There maybe potential for increased recreation activities within a woodland habitat network.	This requires an understanding of why some areas of woodland are more important than others for recreation and human health. If this understanding can be developed then woodlands can be planned that achieve these benefits together with biodiversity objectives.
Landscape character, aesthetics, heritage and archaeology: The effect of woodland habitat networks on landscape character maybe acute and it could fundamentally change landscape aesthetics. Integrating this work with projects designed to understand landscape character would be a priority. Through this understanding any perceived negative effects on the character of the landscape could be mitigated.	Work is being conducted on assessing the landscape character of Wales, based on the landscape description unit methodology. This may offer the opportunity to prioritise the implementation of woodland networks using this as a basis.
Production of woodland products: This factor incorporates the direct economic production of woodland within a network.	The balancing of economic and biodiversity objectives, is essential to the viability of a woodland network strategy. Simple quantitative measures are unlikely to achieve this balance and it should be addressed through a landscape planning process. Research would be needed on how networks could be optimised for harvesting, their benefits to local economies and how they can help produce for new markets such as biofuels.

4.4.4 The next step - implementing habitat networks

This strategic approach to habitat networks provides a sound basis for their implementation at a more local scale. This is the appropriate stage at which to bring in additional stakeholder objectives and wider environmental and socio-economic interests introduced in Table 4-18 and Table 4-19. A recent study by Watts and Selman (2004) highlighted the importance of spatially-explicit plans and partnerships with wider stakeholders to aid the effective implementation of conservation strategies at the landscape scale. At a finer scale, it may also be possible to improve the quality of the land cover and habitat data and use real species to validate some of the inherent assumptions within this approach.

It is widely recognised that there are considerable challenges in translating landscape scale plans, such as habitat networks, into effective action on the ground (Watts, 2001; Watts and Selman, 2004). In the light of limited statutory planning mechanisms, successful implementation is heavily dependent upon formal and informal partnerships between land managers, non-governmental organisations and public sector organisations. According to Gilg (1996), planning of action at the landscape scale will primarily depend on voluntarism and cooperation. In light of limited statutory control, action must rely on broadly 'neutral' voluntary methods and more positive incentives as outlined in Table 4-20.

Table 4-20 - The Gilg/Selman spectrum of planning options

Positive ◄———	**Neutral**	———► **Negative**
Public ownership or management of land via long-term leases	Voluntary methods based upon exhortation, advice, and demonstration, but often backed up with the threat or promise of one of the other methods	Regulatory controls, mainly negative, for example, planning permission
Financial incentives to encourage production and/or desirable uses		Monetary disincentives to discourage production and/or undesirable uses

Source: Adapted from (Gilg, 1996)

To conclude, Figure 4-22 illustrates how this strategic approach can be taken forward through its application in local scale case studies. This example indicates the potential for the development of woodland habitat networks in the Gower Peninsula, taking into account the broad management options listed in Table 4-4 and the associated issues introduced in Table 4-18 and Table 4-19. At this scale, it would be possible for forest/land managers to assess the appropriateness of habitat networks, and make informed choices along with other stakeholder interests and associated environmental and socio-economic factors, in order to provide multiple-purpose sustainable landscapes.

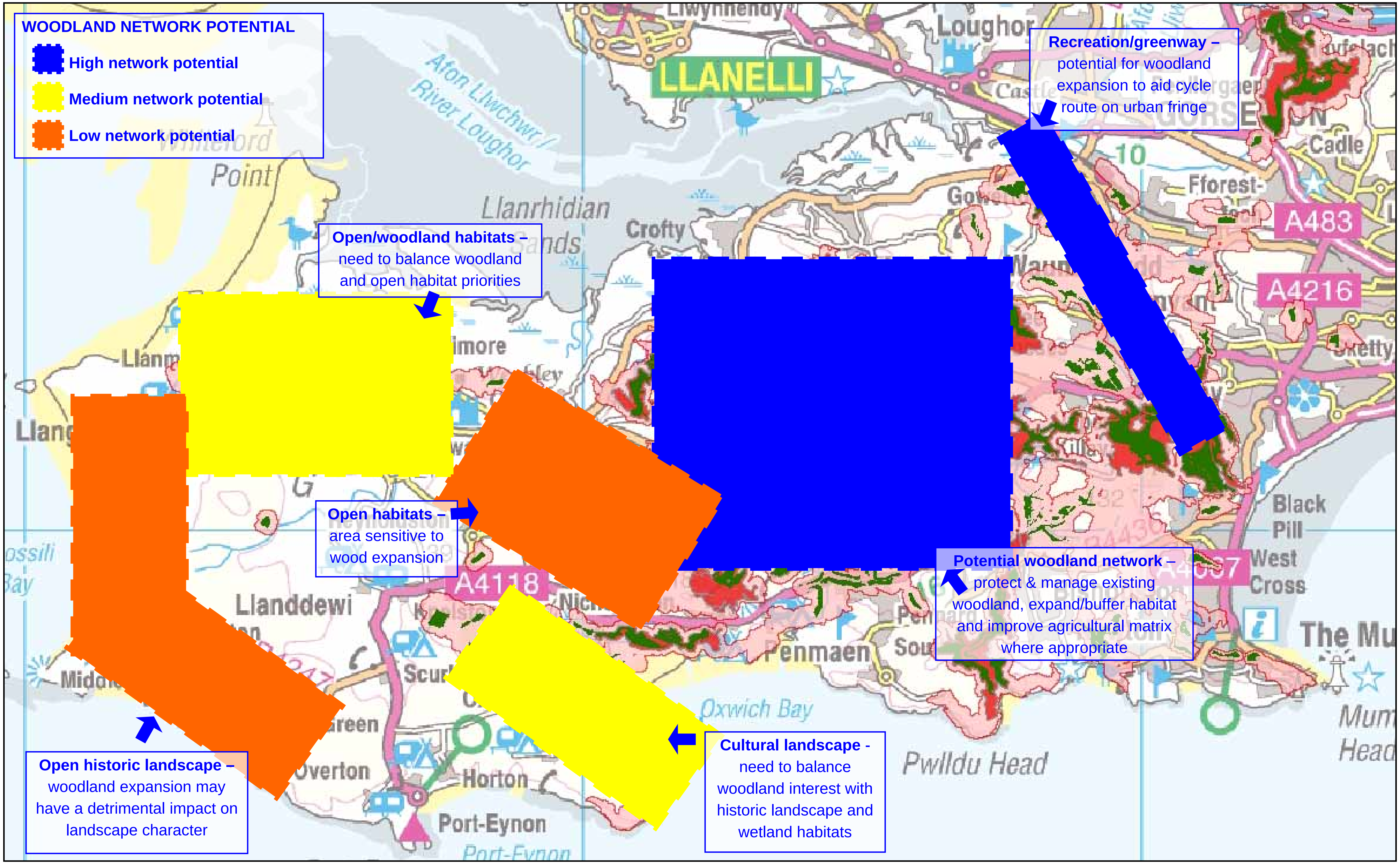


Figure 4-22 – Illustration of the potential for the development of woodland habitat networks in the Gower Peninsula, taking into account other environmental, economic and social priorities

5 GLOSSARY

ASNW	Ancient semi-natural woodland
BEETLE	Biological and Environmental Evaluation Tools for Landscape Ecology – *suite of evaluation tools being developed by Forest Research*
Connectedness	A physical attribute of the landscape based on physical distance
Connectivity	A functional attribute of the landscape related to ecological processes
Core Network	A limited habitat network for a species with high habitat area requirements and low dispersal ability (*see Focal Network*)
DEM	Digital Elevation Model
Focal Network	An extensive habitat network for a species with medium habitat area requirements and medium dispersal ability (*see Core Network*)
GFS	Generic Focal Species - *defined to be representative of a number of species groups, priority habitats and key ecological processes*
LCM	Land Cover Map 2000
NLM	Neutral Landscape Model
PAWS	Plantation on ancient woodland site
Phase 1	Countryside Council for Wales Phase 1 Survey

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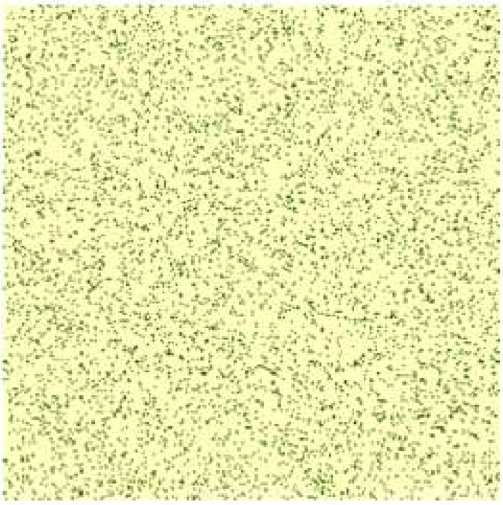
APPENDICES

APPENDIX I – NEUTRAL LANDSCAPE MODELS

10% NLMs



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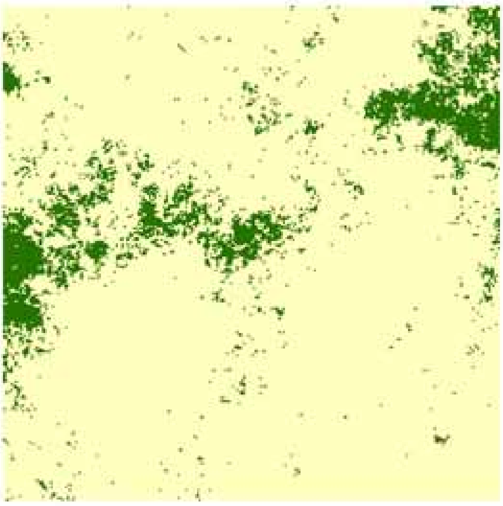
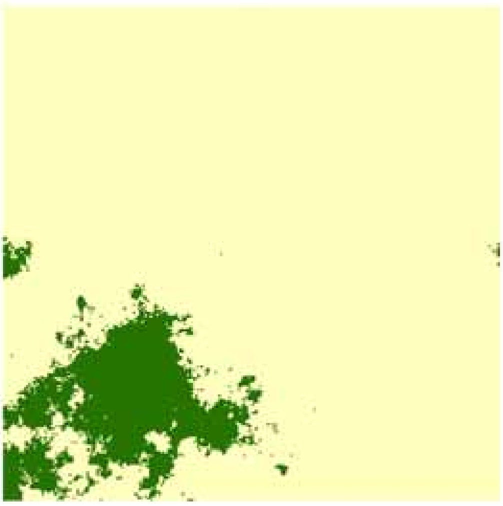
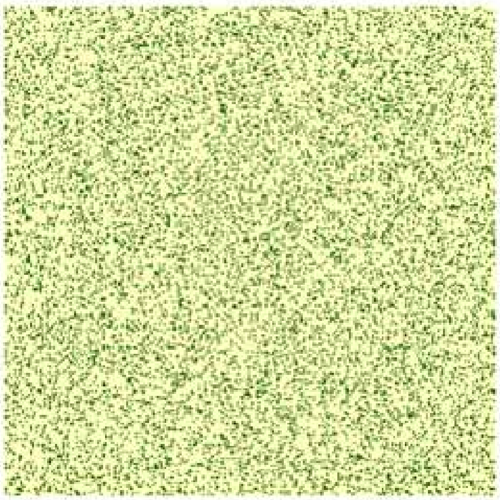


LOW SPATIAL-CORRELATION



HIGH SPATIAL-CORRELATION

20% NLMs



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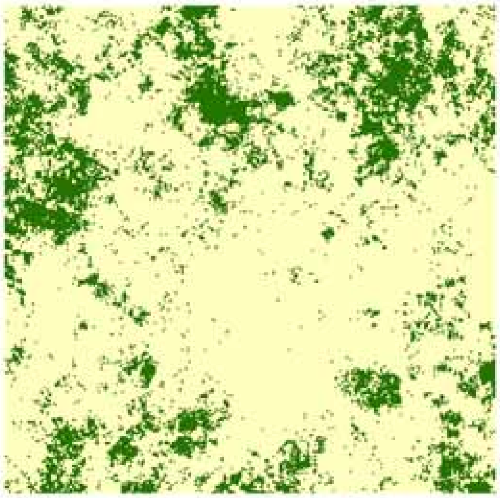

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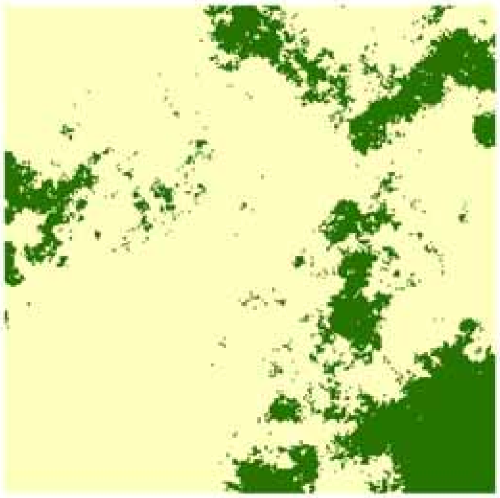
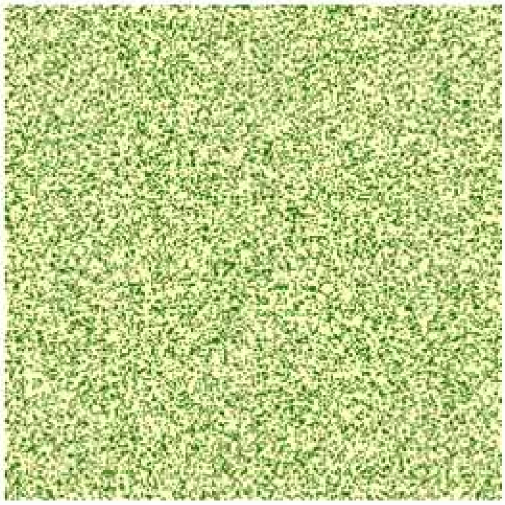


HIGH SPATIAL-CORRELATION

30% NLMs | **40% NLMs**



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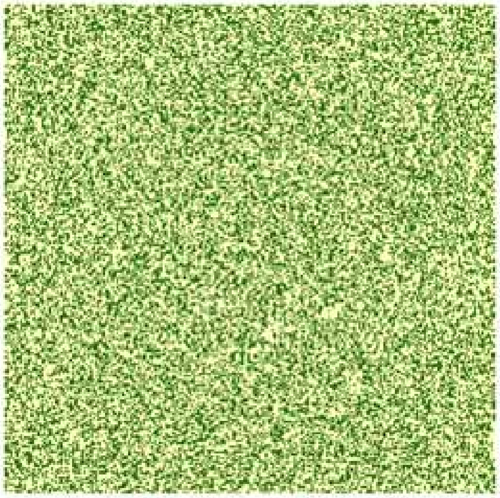

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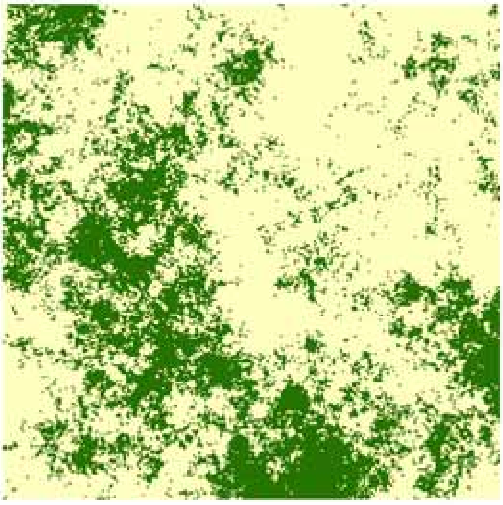

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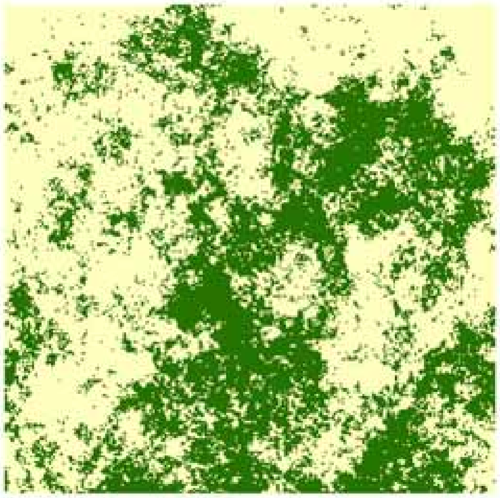
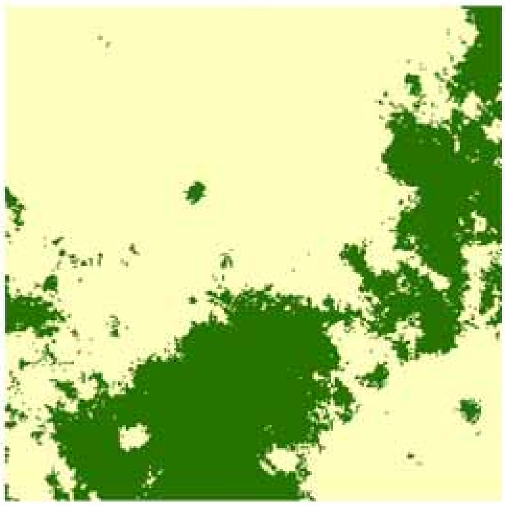
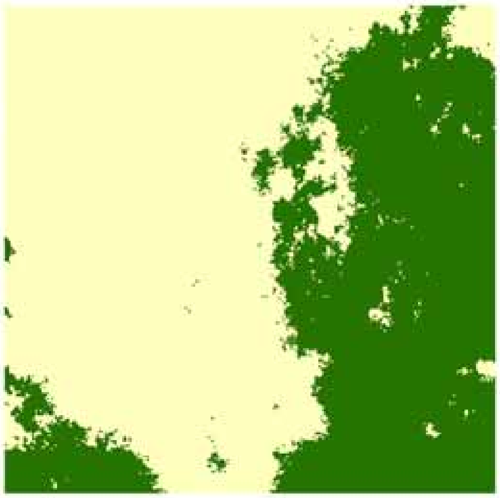


LOW SPATIAL-CORRELATION

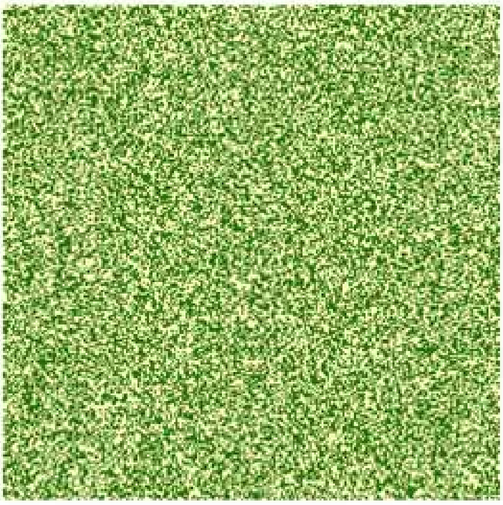


HIGH SPATIAL-CORRELATION



HIGH SPATIAL-CORRELATION

50% NLMs | **60% NLMs**



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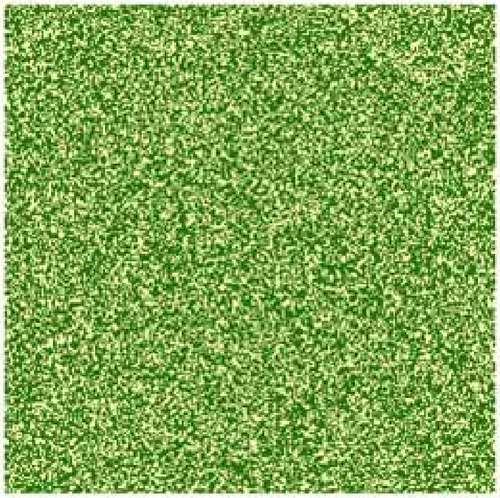

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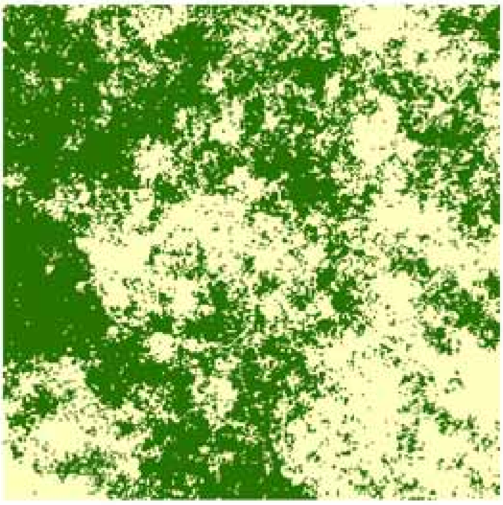

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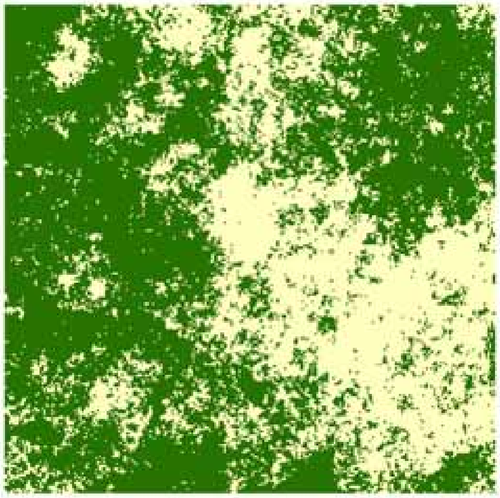

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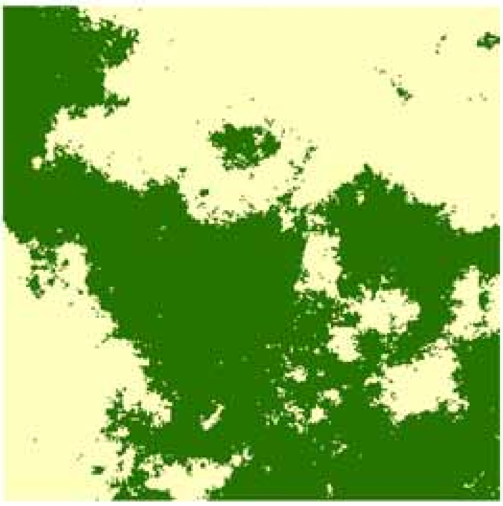

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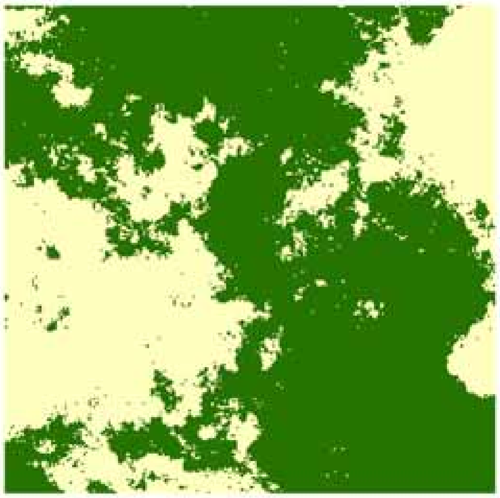
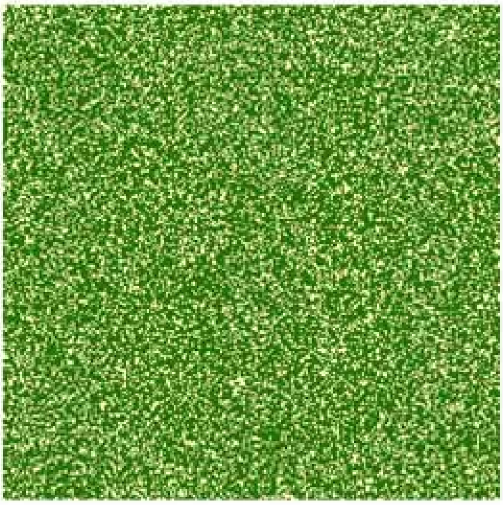


HIGH SPATIAL-CORRELATION

70% NLMs **80% NLMs**



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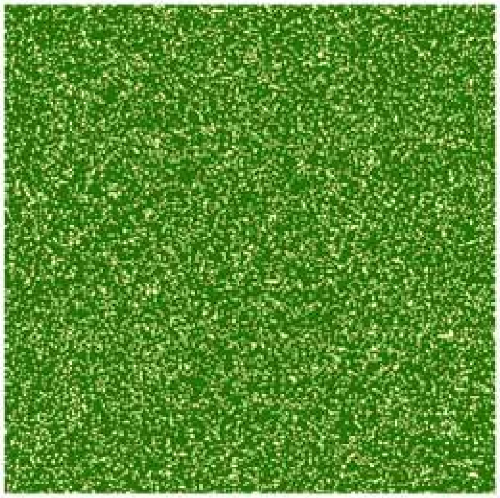

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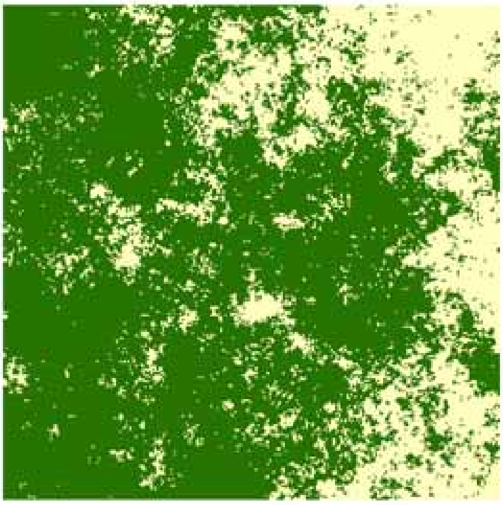

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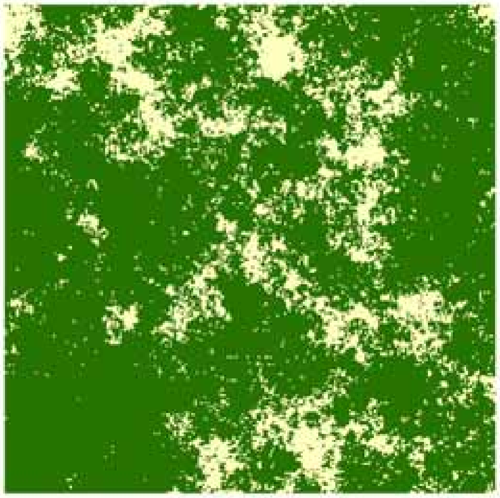

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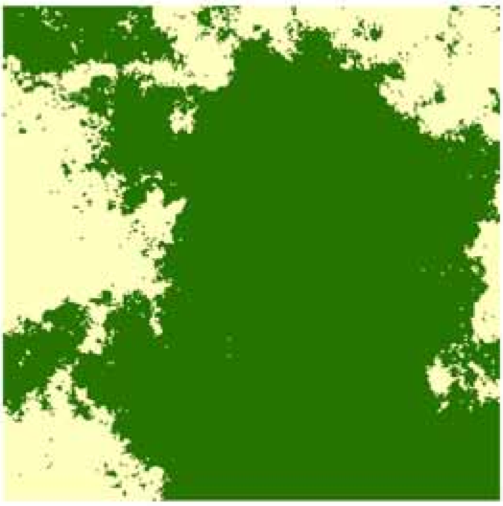

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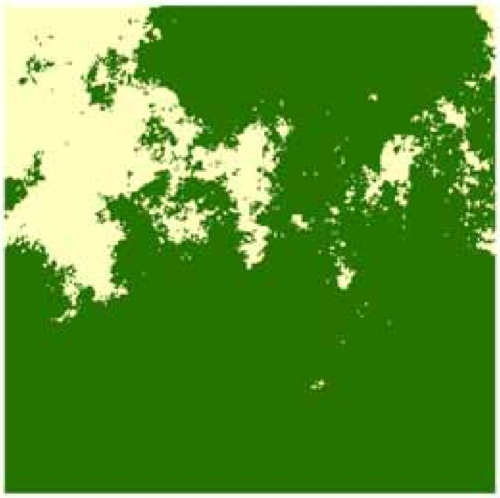
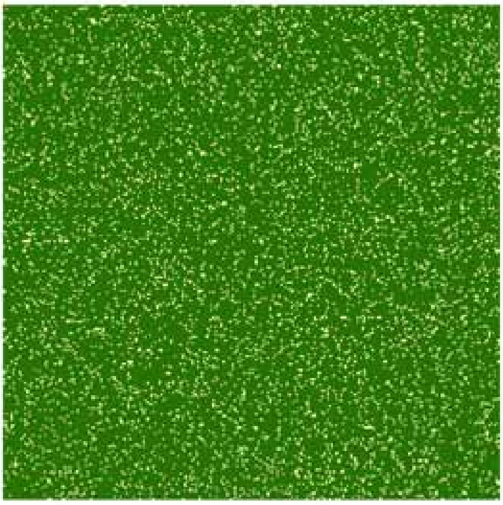


HIGH SPATIAL-CORRELATION

90% NLMs



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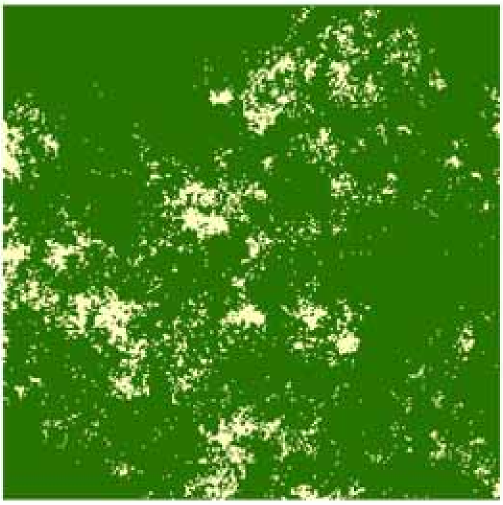

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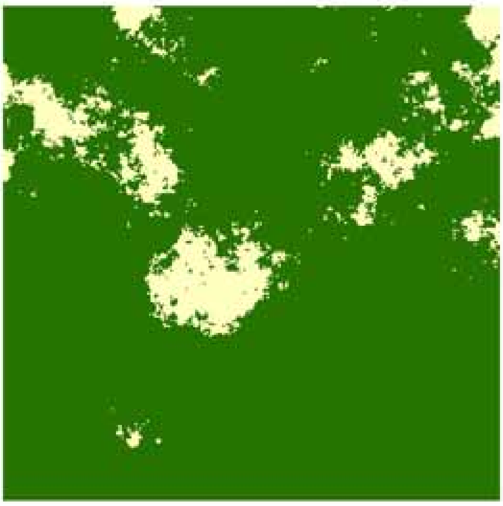

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