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Biodiversity Impacts of Development Pressures in Northern Ireland

Evidence Review for Office of Environmental Protection

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Executive Summary

This report has been prepared for the Office of Environmental Protection in response to a brief to review the evidence of the impacts of development pressures on biodiversity in Northern Ireland.

The Report describes how development pressures are defined and explains the methodology used in the review, including the search terms, geographic scope and criteria for inclusion and exclusion used to identify appropriate peer-reviewed research. This resulted in 70 papers being identified as relevant, and while this included individual useful studies that provide valuable evidence on specific forms of impact or on individual species or habitats, it became apparent that there is a lack of robust, systematic evidence on how development is impacting on biodiversity in Northern Ireland.

In the absence of such evidence, the Report goes on to describe engagement with grey literature to identify other insights to assist in appraising the biodiversity impacts of development. Using data from Northern Ireland Government statistics, regulatory data and other sources, three development pressures are identified as most likely resulting in significant biodiversity impacts:

- Land Use Change: Residential Development;
- Land Use Change: Agricultural Development and Intensification;
- Resource Use: Mining and Extraction.

The evidence around each of these is reviewed, accompanied by a discussion of the wider range of other development pressures that may have biodiversity impacts.

The report concludes by reflecting on the challenges in securing robust evidence for evaluating development impacts on biodiversity in Northern Ireland, and makes a number of recommendations on how this could be improved, including: more effective use of existing datasets; research tasks that could identify the impact of specific development pressures; and developing opportunities for ameliorating the impacts of development through the planning system.

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1. Introduction

This report presents a review of evidence of the biodiversity impacts of urban and rural development pressures in Northern Ireland (NI) prepared for the Office for Environmental Protection (OEP). It is one of a series of evidence reviews requested by the OEP to support an assessment of pressures and drivers impacting terrestrial and freshwater biodiversity in NI, intended to inform their statutory response to the NI Environmental Improvement Plan. The report was commissioned in response to a call for proposals to conduct a review of the literature and evidence relating to the drivers and pressures affecting biodiversity across Northern Ireland caused by both urban and rural development, specifically habitat loss and fragmentation. The priority was to identify research completed with the last ten years, although evidence on any timeframes indicating impacts of development was of interest.

An interdisciplinary team of environmental experts from Queen's University Belfast were awarded the tender, involving the Prof. Geraint Ellis of the Environmental and Spatial Governance (ENSGOV) research group in the School of Natural and Built Environment, Prof. Mark Emmerson from the Climate+ Co-Centre based in the School of Biological Sciences, and Dr Amanda Slevin from the Centre for Sustainability, Equality and Climate Action (SECA), based in the School of History, Anthropology, Philosophy and Politics. These were supported by a larger team of researchers that assisted in the systematic review and drafting sections of this report, who are listed on the cover page.

In line with the OEP's brief, the objectives of this research are:

(1) To enable the OEP to reach an informed and evidence-based position on the drivers and pressures affecting terrestrial and freshwater biodiversity across Northern Ireland;
(2) To enable the OEP to reach an informed and evidence-based position on the pressures created by urban and rural development impacting terrestrial and freshwater biodiversity across Northern Ireland.

Following the brief agreed with the OEP, this report explains how a systematic review of peer-reviewed research was undertaken, and summarises its results. It reports that while some useful evidence was identified, this tended to be relatively piecemeal, so this was elaborated from other sources. The report discusses relevant data that can be found in grey literature that also provides evidence on the most significant development pressures in Northern Ireland, and from this, three pressures that are most likely to result in significant impacts on biodiversity are identified. The report concludes with a reflection on the overall evidence base, and identifies a number of recommendations for improving this in the future.

2. Definitional issues

In this report biodiversity in Northern Ireland is regarded as the diversity 'within-species, between-species and of ecosystems', as set out in the UN Convention on Biological Diversity (CBD).

As requested by the OEP, this report has used the IPBES categorisation of indirect and direct drivers (known as pressures) of biodiversity change to organise the review of evidence. Using this categorisation, a series of searches were undertaken based on an understanding of the most likely development pressures operating in NI (e.g. urban and rural development, as well as development related to specific land use change, including industry, infrastructure, renewable energy, extractive industries and developments linked to agricultural intensification). Searches were also undertaken for any evidence of the indirect impacts of urban and rural development on biodiversity. The details of how these searches were undertaken are described in section 3, with detailed search terms in Appendix 1.

In aligning with the categorisation requested by the OEP, the framework used in this report, including the definitions of main terms, is shown in Table 1 below. In this report 'development' is defined as being:

> 'Development' is regarded as being human activities consisting of existing physical works and/or changes to land use, as defined in UK planning law (i.e. related to the '*carrying out of building, engineering, mining or other operations in, on, over or under land, or the making of any material change in the use of any building or other land*'[1]).

This definition of 'development' illustrates clear alignment with IPBES indirect drivers and pressures, particularly the two IPBES pressures ('direct drivers'), Land Use Change and Natural Resource Use and Exploitation (quarrying, deforestation, etc), although some evidence was also identified linking development pressures with climate change and pollution. As outlined in Section 3, search strings were developed to gather evidence on the impacts of development, aligned with the IPBES model of drivers and pressures. **Error! Reference source not found.**1 illustrates alignment of development categories with the IPBES model and demonstrates the overlaps and synergies across pressures (direct drivers) and indirect drivers.

As is discussed in the report, there appears to be a shortage of systematic evidence that robustly highlights the impacts of development on the biodiversity of Northern Ireland, over the long, medium and short term. Because of this, the report emphasises what we know about the development drivers, and less on the impacts and state of related biodiversity.

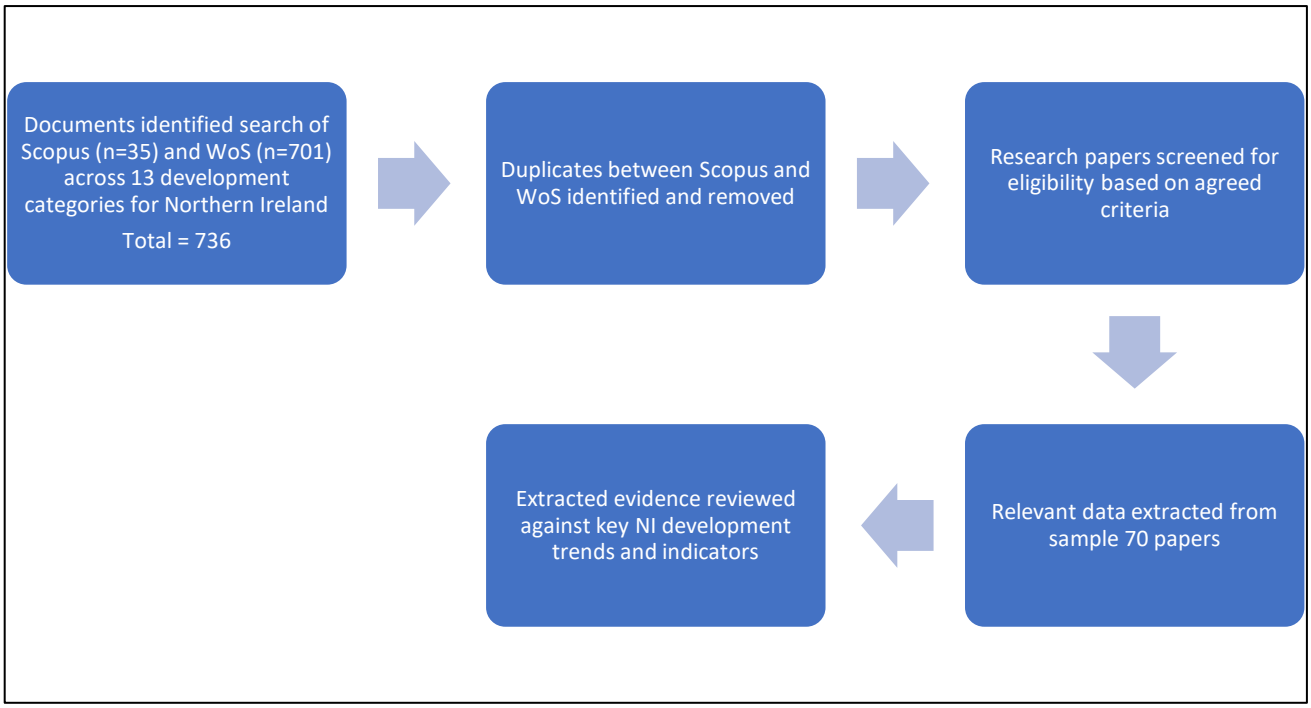
[1] As defined in, for example, s.23 of the NI Planning Act (2011) and s.55.of the Town and Country Planning Act 1990 for England and Wales).

3. Research Design and Search Strategy

3.1. Research Design

This review followed guidance from the Collaboration for Environmental Evidence (CEE, 2022) in that it aims to be comprehensive, systematic, and transparent, to aid replicability. A research protocol was developed and agreed with the OEP focussing on best practice for systematic literature reviews (Xiao and Watson, 2019), based on underpinning research questions, inclusion and exclusion criteria, search strategy, quality assessment criteria and screening, data extraction procedures, data management, reporting. The key elements of the protocol are described below, with the overall process and research papers considered at each stage shown in Figure 1.

Figure 1: Process of identifying and processing relevant evidence



3.2. Search Strategy

The review's search criteria sought to identify the impact of development pressures on biodiversity in Northern Ireland, with an emphasis on land use change and resource use. Given the knowledge of the main forms of development in Northern Ireland, search strings were developed for the following categories of development:

- Urban Development: Direct impacts;
- Urban Development: Indirect impacts;
- Rural Development: Direct Impacts;
- Rural Development: Indirect impacts;
- Housing: Direct Impacts;
- Industry: Direct Impacts;
- Agricultural Development: Direct Impacts;
- Infrastructure: Direct Impacts;
- Renewable Energy: Direct Impacts;
- Mining and Extraction: Direct Impacts;
- Commercial Development: Direct Impacts;
- Recreation Development: Direct Impacts;

- Tourist Development: Direct Impacts;

All the above were then searched using five geographic categories: Northern Ireland; Ireland; Great Britain; United Kingdom; and United Kingdom AND Ireland, although the evidence from Northern Ireland was used as the basis of the evidence review, and research from other jurisdictions only used if this included observations directly relevant to Northern Ireland, or provided supporting evidence for impacts on Northern Ireland.

To develop appropriate search strings to use with the identified bibliographic data sets (see below), we adopted those used by McDonald et al (2020) for identifying peer reviewed research that may contain evidence for the direct and indirect impacts of urban growth on biodiversity, using only environmental science category. In 2020, McDonald et al found that an unrestricted geographic search produced 2431 papers, which the authors screened to 922 papers. When repeated today, the search produced 5695 papers and 8593 when using 'all fields'. A number of slight modifications were made to these strings after reviewing terms used in other reviews, including those by Colsaet et al. (2018) de Barros Ruas et al. (2022) and Wenzel et al. (2020). The search strings and results are shown in Appendix 1, which were not restricted to environmental sciences, and repeated for each of the geographic areas highlighted above.

In line with the 'Gold definition' offered by the Collaboration for Environmental Evidence Synthesis Appraisal Tool (CEESAT) for overviews (2020), the literature search included all agreed search terms, search strings, and Boolean operators ('AND', 'OR', etc). Meetings were convened for the whole team of researchers to evaluate the effectiveness of the searches and to identify any significant gaps or other issues.

3.3. Search sources

The primary searches were undertaken using the first two data sets **of peer reviewed publications**:

- Web of Science
- Science Direct-Scopus
- These were supplemented by further limited reviews using Google Scholar and CABI Digital Library

These were accompanied by searches of **grey literature to identify further sources of evidence, a**nd included searches using the following:

- Environmental Protection Agency (ROI)
- EU publications
- Official government statistical returns (planning, mineral agricultural statistics etc)
- Government department publications, including DAERA, DoC, DoI, DfI in NI

Due to time and resource limitations, the search did not explicitly include PhD theses and other 'non-published' sources, but some were identified while reviewing evidence generated form above searches, and included where relevant.

3.4. Eligibility Screening

In line with OEP guidance, eligibility criteria agreed with the OEP was applied to the research papers identified from the review described above. documents, using defined inclusion and exclusion criteria, and carry out the following steps, recording document retain/discarded at each step.

i) **Screen title and abstract for relevance**: During the initial pilot phase, we implemented a process of double screening during which a junior researcher (PhD researchers) and a more experienced researcher independently searched for literature using common search terms. Researchers then met to review publications and inclusion decisions to ensure quality assurance of the inclusion/exclusion decisions and

help refine the search process. The research team met on a weekly basis when conducting the search to discuss progress, difficulties, inclusion/ exclusion of publications, with decisions documented in an Excel spreadsheet. Each researcher maintained a spreadsheet to document their literature searches, with a Master spreadsheet managed by one of the lead authors.

ii) **Screen main body of text for:**
   - Relevant population
   - Type of exposure/Intervention.
   - Type of comparator (species abundance, habitat quality/are before-after pressure)
   - Type of outcome (e.g. extinction, species decline, species abundance
   - Type of study (e.g. monitoring, experimental, observational)
   - Temporal & Spatial Scale (e.g. multi-year and multi-site)

iii) A short **summary description** of the evidence was prepared for each document reviewed, and recorded on a master spreadsheet.

3.5. Inclusion criteria

Informed by the OEP's brief and CEE (2020), the following inclusion criteria apply:

- ***Population terms** (P)*—any population of relevance to the study, encompassing indigenous flora and fauna species of Northern Ireland.
- ***Exposure** (E) or Intervention (I)* – either a factor to which a ***Population*** is exposed (E) or an intervention (I) that is imposed to provide an environmental outcome. For example, windfarm development, agrochemicals, housing development etc. In relation to planning, consider specific exposure across consented development (e.g. housing, wind farms); development in breach of planning control (e.g. excess pollution from intensive pig farming); permitted development (overgrazing on peatland)
- ***Outcome** (O)*—any change in the population relevant to the study, for example, extinction, species decline, species abundance.
- ***Location** (L)* – Northern Ireland, island of Ireland, UK, etc.

The systematic review focused on empirical research and particularly any available comparative research (e.g. before and after exposure/ intervention). The review started with peer reviewed publications related to NI, widening to the island of Ireland, and possibly extending to other parts of the UK depending on sources.

3.6. Exclusion criteria

- Language: Articles should be in English.
- Location: exclude articles that do not include data from Northern Ireland/ Ireland/ UK.
- Scale: Screen out short studies (e.g. duration of one year or less); avoid very small-scale studies
- Irrelevant to research questions (does not examine drivers/ pressures/impact).
- Timeframe: Start with general search and then narrow in line with findings. If finding substantial literature, include only studies published in the previous ten years.

3.7. Recording literature

Copies of keywords and searches were recorded and stored on an excel spreadsheet to ensure the exact search was replicable by the OEP (see Appendix 2). To ensure consistent application of eligibility criteria, searches were undertaken by at least two researchers working independently with results discussed to inform inclusion/ exclusion of literature.

The total number of articles and number of unique articles found during the searches (after removal of duplicates) were also stored on a master spreadsheet is presented, along with the number excluded at each stage of the screening process (CEE, 2020). We will also the reasons for exclusion of each article/study was also documented. A final list of eligible articles are listed in Appendix 2.

3.8. Quality assurance

As noted above, a process of double screening was used in the pilot phase to ensure quality control and comprehensiveness. Weekly meetings of the QUB research team ensured consistency and transparency at different stages of the literature review, with key decisions recorded in an Excel spreadsheet that will be made available to the OEP, through a shared Microsoft Team. References will be made available to the OEP using Zotero, thus enabling the OEP to undertake their own quality control (double screening and review of 5% of all papers in the original search) and there were regular progress review meetings with the OEP to check any queries that arose.

3.9. Data extraction

The above steps ensured a high quality and comprehensive literature review was undertaken. This was then supported by coding of the identified articles to facilitate ease of referencing when discussing the various development prosses discussed in later sections of this report.

4. Systematic Review of Drivers and Pressures on Biodiversity in Northern Ireland

4.1. Principal drivers and pressures impacting biodiversity in Northern Ireland

Although the systematic search identified 72 peer-reviewed papers that met the inclusion criteria, there were very few that provide specific evidence of impacts on biodiversity from the identified development pressures. This lack of evidence presents a major challenge to evaluate the impacts arising from development pressure on biodiversity in Northern Ireland. Indeed, there are so few academic studies identified by this review that reporting solely on the basis of studies captured by the systematic review poses issues of underrepresentation of those development processes that are clearly occurring in Northern Ireland (as evidenced by, for example planning and economic output statistics) but not formally reported in peer reviewed studies. Conversely due to the small number of papers, extrapolating the evidence found would disproportionately amplify such findings, rather than noting that it reflects that evidence may have been generated from the presence of specific NI research groups or authors specialising in a particular aspect of Northern Ireland biodiversity

To address this potential imbalance, we provide a high level summary of the evidence identified in the systematic review, organised in line with the IPBES's five main pressures ('direct drivers') of biodiversity change. The identified papers are shown below in Table 1, with a brief description of the evidence they contain given in Appendix 2.

Table 1: Summary of included papers in development pressures literature review, organised by IBPES direct drivers of biodiversity change

IPBES direct driver (pressure)	**No. of papers**	**Citations (*in alphabetical order*)**
Land use	46	Anderson et al. (2009); Bateman et al. (2013); Brucet et al. (2013); Butler and Norris (2013); Byrne et al. (2013); Cooper et al. (2003) ; Davies et al. (2012); Dool et al. (2016) ; Douglas et al. (2023); Drinan et al. (2013); Eglington and Pearce-Higgins (2012); Evans et al. (2011); Evans, Gibson and Rossell (2006); Feeney et al. (2023); Finch et al. (2023); Firbank et al. (2013); Franks et al. (2017); Gaston and Evans (2010); Griffith et al. (2012); Hanmer et al. (2022); Hayhow et al. (2013); Henderson et al. (2002); Isermann and Rooney (2014); Lintott et al. (2016); Lundy and Montgomery (2010a); Lundy and Montgomery (2010b); Mathews et al. (2015); McCann et al. (2017); McCarthy et al. (2021); McElarney et al. (2010); McKenzie et al. (2011); Miler et al. (2015); Miller et al. (2017); Milne et al. (2020); Montgomery et al. (2020); O'Mahony (2017); O'Mahony, O'Reilly and Turner (2012); Plummer et al. (2015); Reid et al. (2012); Reid, McDonald and Montgomery (2007); Reid, McDonald and Montgomery (2010); Russ and Montgomery (2002); Thomas et al. (2020); Twining et al. (2020); White et al. (2019); Whitehouse (2006)
Natural resource use and exploitation	13	de Castro et al. (2022); Isaksson et al. (2020); Joy et al. (2018); Le Joncour, et al. (2023); Neat et al. (2014); Nordbeck and Hogl (2024); Searle et al. (2022); Smyth et al. (2016); Smyth, Murphy and O'Brien (2009); Thorstad et al. (2021); Van Denderen et al. (2022); Winfield (2016); Yates and Schoeman (2013)

Climate change	7	Burton et al. (2010); Coll et al. (2016); Helbig et al. (2022); Powney et al. (2010); Reid et al. (2021); Simpson et al. (2011); White, Montgomery and Lennon (2018)
Pollution	4	Dillon et al. (2012); Foy, Lennox and Smith (2001); Morecroft et al. (2009); Sier and Monteith (2016)
Invasive species	0	
Total number of included papers	**70**	

The papers identified for each of the papers are very briefly discussed below.

4.2. Land-use change

The systematic search on development pressures and biodiversity in Northern Ireland found most papers related to Land Use Change category. This included papers indicating general impacts on biodiversity from land-take (e.g. Gaston and Evans 2010) but also those revealing specific and cumulative effects of development upon different habitats and species.

As the much of the new development in NI takes place on greenfield sites (including housing, agricultural development, infrastructure, extraction, etc.) there are indications that the key biodiversity issue is the loss of seminatural Broad Habitat loss (Cooper et al. 2003). Evidence from McKenzie et al. (2011) shows productive agricultural grassland and other habitats were also built over, including broadleaf seminatural woodland and species-rich grassland habitats, specified by the European Habitats Directive as important for their biodiversity. McCann et al. (2017) evidenced hedge loss of 4.6% between 1998 and 2007. Some of the consequences of development pressures on underlying soils are evidenced by Feeney et al. (2023).

Other identified evidence links development pressures directly to specific species, particularly birds. For example, Finch et al. (2023) examine the demography of the Common Swift *Apus apus*, which like many insectivorous birds, is experiencing population declines caused by loss of nesting sites coupled with in the reductions in the abundance and availability of insect prey. Similarly, Miller et al. (2017) explore interactions between weather and land-use in terms of nest success of the common blackbird (*Turdus merula*) finding that blackbirds had higher survival probabilities in human rural habitats, than in urban or countryside habitats. Eglington and Pearce-Higgins (2012) explored how land-use intensity and climate change had influenced declines in a range of bird species in the UK, finding that 'changes in land-use intensification … will continue to be the major driver of population change in these species' (p. 6). Douglas et al. (2023) researched impacts of habitat change on wading birds finding that levels of predators were influenced by land use changes such as forestry and landscape fragmentation for agriculture.

Davies et al. (2012) examined the value of domestic gardens for biodiversity and human-wildlife interactions, across the UK to highlight the role of urbanisation as a direct driver of complex processes of biodiversity change. Evans et al. (2011) also assessed impacts of urban development on birds using data from the National Breeding Bird Survey (BSS), indicating some of the reasons why development may result in species decline. Other indirect impacts of urbanisation on birds were identified by Hanmer et al. (2022) who showed how declines in greenfinch and chaffinch populations may be a result of parasite transmission via human's supplementary feeding. Plummer et al. (2015) note how species such as Eurasian blackcap *Sylvia atricapilla have* changed migratory behaviour due to the reliability of bird food provision in urban gardens.

A number of papers also evidenced impacts on different mammal species. Lintott et al. (2016) and Mathews et al. (2015) provide evidence on how different bat species respond to urban environments, while Russ and Montgomery (2002) and Lundy and Montgomery (2010) show that several bat species in Northern Ireland have

been detrimentally affected by landscape changes such as reductions in inland water, deciduous woodlands, field boundaries and high intensity farming. Dool et al. (2016) highlight the impacts of habitat loss and degradation on woodland-associated bat species.

Several studies on badgers relate to the consequences of increased interaction with bovines due to agricultural intensification and increases in land for livestock (e.g. Byrne et al. 2013, Milne et al. 2020), primarily round issues of bovine tuberculosis (bTB), but also increased badger persecution (Reid et al. 2012).

Reid, McDonald and Montgomery (2010) and Reid et al. (2021), connect widespread declines of hares in agricultural landscapes with habitat loss and agricultural intensification. O'Mahony et al. (2012) offers valuable data on the distribution and abundance of pine martens across Ireland, finding that they are positively associated with the extent of conifer forest landcover types and is negatively associated with open areas, dwarf vegetation areas, and urban areas. Twining et al. (2020) also highlight impacts of landscape modification on the pine marten in Northern Ireland. Land management practices can also have indirect and cumulative effects on aquatic fauna, with Evans et al. (2006) noting impacts on salmon habits in Northern Ireland as a result of bank erosion and drainage maintenance work.

In terms of invertebrates, Cameron et al. (2004) offers a quantitative assessment of spider species across different habitat types in Northern Ireland, showing declines in heath and wood are leading to the loss of rarer and consequently greater value species. Drinan et al. (2013) presents evidence that the impact of conifer plantation forestry on small blanket bog lakes in Ireland threatens threatened aquatic invertebrate species. Whitehouse (2006) noted the role of human activities such as forest clearance on some beetle species.

In relation to plants, McCollin and Geraghty (2015) identified the intensification of agriculture as the most significant driver of floristic change across the island of Ireland, with Isermann and Rooney (2014) noting specific impacts of land use change on Sea Holly and White et al. (2019) provide evidence on Irish vascular plants. Impacts have also been noted on macrofungi (Griffith et al. 2012). McElarney et al. (2010) note that commercial forestry is the second largest land-use category in Northern Ireland with the majority of forests across the island comprising non-native conifer trees, the management of which can lead to eutrophication from elevated phosphorous, with implications for aquatic macrophytes. Cooper et al. (2008) also provide evidence on the long-term impacts of forestry practices on biodiversity.

4.3. Natural Resource Use and Exploitation

The second most significant driver identified in the systematic review related to Natural Resource Use and Exploitation. Some of the identified papers related to marine fishing and consequences for species such as the native oyster (*Ostrea edulis*) in Strangford Lough (Smyth et al. 2016), but also evidence on the threats to wild salmon arising from human activities (Thorstad et al. 2021). There is some evidence on biodiversity threats arising from the expansion of different forms of renewable energy, such as those facing on seabirds (Isakson et al. 2020, Searle et al. 2022), and seals (Joy et al. 2018). No direct papers on impacts of wind turbines on upland ecosystems were found relating to Northern Ireland. Smyth, Murphy and O'Brien (2009) explore the consequences of biofuel cultivation, suggesting that grass could serve as a source of biomethane to fuel Irish cars, without habitat destruction, land use change, new farming practices or annual tilling.

4.4. Climate Change

Peer-reviewed research was also identified that make connections between land use change, resource exploitation, climate change and impacts upon biodiversity. This included Helbig et al. (2022) which examines the impact of climate change on peatlands and Coll et al. (2016) which studied upland heaths in Ireland, noting that new habit formation is unlikely due to current and near-future land use and other conditions. White et al. (2018) describe changes in species distribution through local extinction and colonisation of British birds as a major consequence of climate change. Burton et al. (2010) examined population decline in waterbirds and

seabirds in the Severn Estuary and Bristol Channel, noting a combination of climate change, oil-spills, conflicts with fisheries, and estuarine habitat loss.

4.5. Pollution

A small number of papers were identified relating to pollution arising from development pressures. Morecroft et al. (2009) and Sier and Monteith (2016) explore long term trends from chemical and biological data between 1993 and 2007 at 12 terrestrial sites in the United Kingdom, noting impacts on different species. Foy et al. (2001) examined water quality in the Colebrooke and Upper Bann catchments of Northern Ireland showing the impacts of agricultural practices on aquatic ecosystems.

4.6. Summary of systematic evidence review

As noted from the summary above, while the review of peer-reviewed research identifies some important sources of evidence on the range and potential consequences of different development pressures in Northern Ireland, this is not particularly comprehensive or systematic, and presents substantial challenges for drawing direct conclusions on the most significant biodiversity impacts. It does, however, suggest that overall, the dynamics of land use change offer the most significant source of such pressures, followed by natural resource use and exploitation. These insights are further developed in the next section, which explores additional sources of evidence to consolidate the insights described above.

5. Other Evidence of Development Pressures

5.1 Evaluating evidence from the grey literature

In the absence of comprehensive, up-to date systematic evidence or monitoring data, as noted in the previous section, it is challenging to indicate a robust evidence-based justification for the development pressures that are having the greatest impact on biodiversity in Northern Ireland. However, in order to provide the OEP with additional insights on how different types of development *may* be influencing biodiversity, a search was undertaken of the grey literature, including statistics from planning, other forms of regulatory processes and monitoring information on some forms of economic activity, using the different categories of development used in the search strategy described in section 3 (see Table 1). Where necessary, we have expanded our search criteria to include evidence from the wider island of Ireland for verification (e.g. EPA 2020, Ahrens and Lyons 2019) and other sources (e.g. Gaston and Evans 2010). Our approach provides an overview of a number of development categories, and flags what appears to be the most significant impacts on biodiversity and which could be used as a platform for further investigation.

For each category of development, there is a range of evidence of the level of development and while in some cases information on the broad spatial distribution may exist, it is more difficult to establish long-term development patterns, pressures in relation to specific locations, and the impact on specific species and habitats. It therefore follows that it is even more challenging to then link this with robust evidence on the actual state of environmental quality and biodiversity against defined benchmarks. This is particularly true of cumulative impacts, which appear to be a fundamental gap in evidence. There have however many individual environmental statements prepared for major developments, most of which are hosted in the Planning Portal and which could be used to develop a more robust evidence base. The fact that some species more sensitive to habitat fragmentation (Keinath et al., 2017, Spinozzi et al., 2012, Evans et al., 2006), presents further challenges in understanding the impact of development on biodiversity.

A key source of information in this section has been the use of headline planning statistics[2], which indicate the numbers of applications over time (and thus may act as a proxy for development levels), and which if combined with specific searches of the NI Planning Portal (DFI. n.d) could provide additional insights into the trends of specific forms of planned development. There are other sources of evidence describing overall trends of biodiversity in Northern Ireland, such as the *State of Nature Report for NI* (State of Nature Partnership, 2023) and the National Plant Monitoring Scheme (NPMS, n.d). There is much less accessible evidence that links development trends directly with the impact on and state of, biodiversity in Northern Ireland. The dominant land use across the island of Ireland is agriculture (77% of NI land area and 63% in the Republic of Ireland, and the single largest sector for Greenhouse Gases, DAERA, 2022), and consequently, far more research has explored the impact of land use changes brought about by changing agricultural practices, than building or infrastructural development (e.g. Bateman et al. 2013).

Because of the predominantly rural nature of Northern Ireland, a particularly useful source of evidence for development impacts on biodiversity is the Northern Ireland Countryside Survey[3] (DAERA, n.d), which provides robust, longitudinal evidence of habitat change across the region and links this to trends in some forms of development, such as rural housing. This survey was first undertaken in 1986-1992, and repeated in 2000 and 2007. An additional survey has been commissioned with fieldwork taking place in 2023/24 with a repeat survey of vegetation in 2026/27. The most recent currently available survey data relates to 2007 (Cooper et al. 2009, also McKenzie et al. 2011). Data collected is compatible with the long running Countryside Survey undertaken

[2] Planning Activity Statistics: https://www.infrastructure-ni.gov.uk/articles/planning-activity-statistics Last accessed 31/07/24
[3] The Northern Ireland Countryside Survey: https://www.daera-ni.gov.uk/articles/northern-ireland-countryside-survey last accessed 31/07/24

in GB[4] (UKCEH, n.d.) which was undertaken six times between 1978 and 2019 with an interval of between 6 and 10 years. Since 2019, the GB countryside survey has evolved to become a rolling five-year programme monitoring soils and vegetation across Scotland, England and Wales, led by UKCEH who also now have the contract for the current NI Countryside survey.

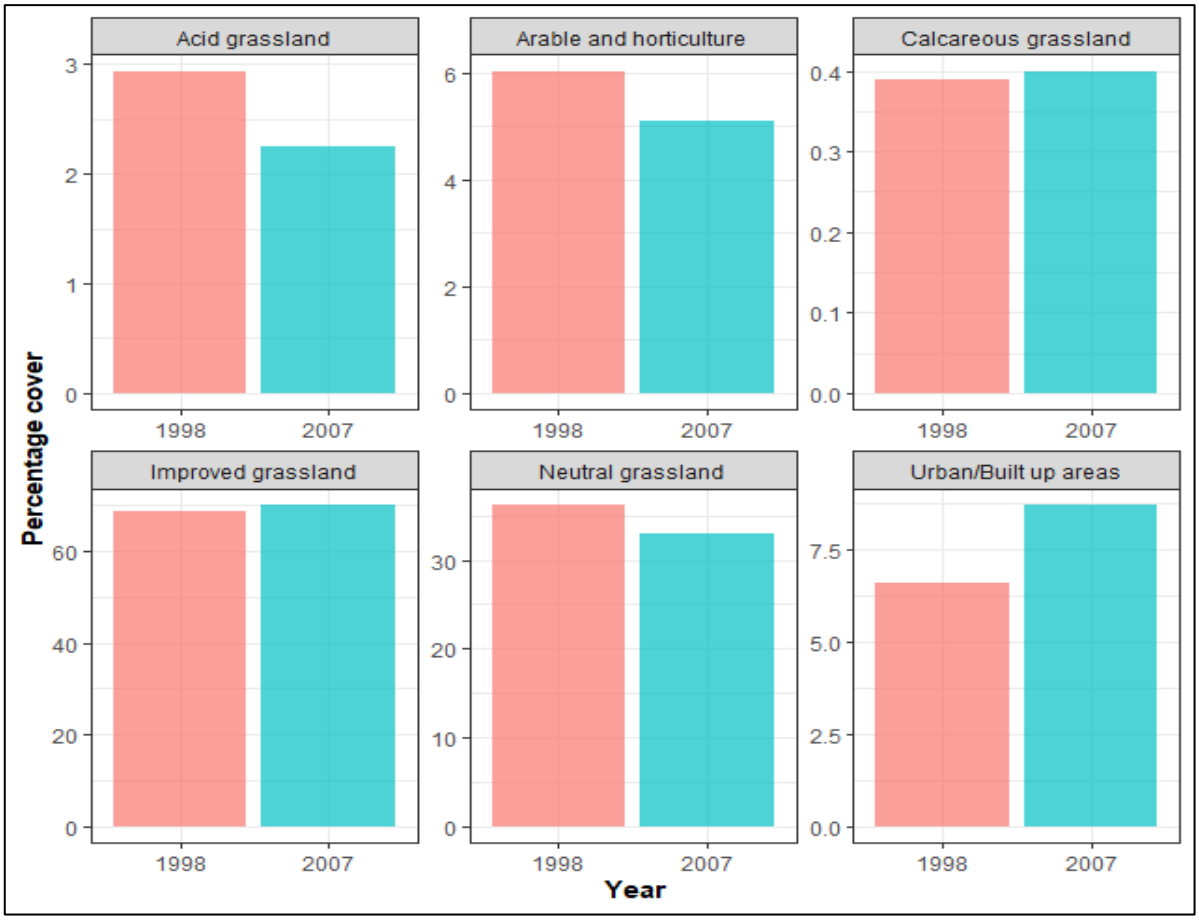
5.2. Identifiable development trends

Using such evidence, combined with the expertise of the research team, a range of development pressures were identified as likely to be having significant impacts on biodiversity in Northern Ireland. As noted above, a key evidence source for the nature, scale and trajectory of development pressures in rural Northern Ireland (77% of the total area) is the Northern Ireland Countryside Survey (DAERA, n.d), discussed above. Evidence from comparing NI Countryside Survey data from 1986 and 2007, indicates long term development pressures arising from housing and related infrastructure such a roads and sewerage treatment works. These pressures appear to have been well established by 1986, but the are other indicators, such as evolving settlement patterns, suggesting these are part of a very long term development trajectory over the entire post-war period.

The 2007 Countryside Survey (Cooper et al., 2009) indicates that between 1998-2007 the main processes of habitat loss were agricultural conversion, rural housing and agricultural building development, continuing trends identified since the first NI Countryside Survey in 1986 (Cooper et al., 1997, see Figure 2)Figure 1. Notably, the increase in rural building reported in 2007 was almost twice that reported in the 1986 survey. This building mostly occurred on grassland and pastoral agriculture (particularly in lowland landscapes) where the area of seminatural habitats is low, and where hedgerows have particular importance in promoting biodiversity.

Figure 2: Changes in percentage land use cover as described in Cooper et al. (2009, Table 5) between 1998 and 2007, for grassland and urban/built up land cover types

[4] UKCEH Countryside Survey: https://www.ceh.ac.uk/our-science/projects/countryside-survey Last accessed 31/07/24



It is likely that many of the trends identified between the 1986 and 2007 surveys will have continued to the present day, but with potential changes in intensity and character, given what is known of economic conditions, policy controls and incentives in the intervening period. While this could be confirmed when the findings of the 2023/24 survey are published, it is likely that development patterns would have reflected prevailing economic and social conditions, with these issues being influential over the last 20 years:

- A more restrictive planning policy for housing in the countryside, expressed in Planning Policy Statements 14 (2006) and 21 (in 2010) which encouraged clustered development and thus potentially less habitat fragmentation. The collapse of the housing market in 2008 is also expected to have influenced the speed and scale of residential development.
- An increase in large scale and intensive farming developments, particularly in poultry and pigs, following the *Going for Growth Strategy* (2013). Agricultural intensification is also strongly associated with increases in improved grassland and decreases in seminatural habitats such as neutral grassland, arable and horticulture, fen, marsh and swamp, bog, and calcareous grassland (Cooper et al., 2003).
- Continued high level of production from extractive industries, especially quarrying, with new exploratory licenses issued for a large area of Northern Ireland.
- There has also been a significant increase in renewable energy developments, both solar and wind, with evidence from other jurisdictions of biodiversity impacts of the latter arising when located on upland areas. (Gasparatos et al., 2017, Rehbien et al., 2020). Other changes in upland habitats, such as transitions from bog to acid grassland and from dwarf shrub heath to acid grassland, and deliberate and accidental burning can lead to reduced heather cover and increased grass cover due to heavy grazing pressure (Cooper et al., 2003), with implications for habitat loss and consequences for species such as ground nesting birds and arthropod communities (McFerran et al., 1994, Kelly et al .,2023).

This scale and pattern of development will have created significant pressures on biodiversity yet has been undertaken in the absence of systematic evaluation of its cumulative impacts, over many decades. While it is challenging to point to direct evidence from different categories of development on biodiversity, the discussion above, coupled with the research team's expertise does allow the key development pressures to be identified, and these are discussed in the next section

5.3. Most Significant Development Pressures

Taking into account the evidence reviewed from the systematic research and the review of the grey literature, the following development categories were identified has being the most likely to have the most significant biodiversity impacts in Northern Ireland:

- *Land Use Change: Residential development,* particularly conversion of greenfield sites to single houses in the countryside, resulting in habitat loss and fragmentation, but also indirect impacts from septic tank leakage and light/noise pollution.
- *Land Use Change: Agricultural development and intensification,* particularly major farm buildings expansion of large-scale pig and poultry units, leading to habitat loss/fragmentation and indirect impacts on water and air quality.
- *Resource Use*: *Mining and Extraction,* with some evidence of continued high level of quarry activity and concerns around their regulation by the NI planning system, while sensitivity of peat extraction, afforestation on peat and potential of restoration of peat also have some significance.

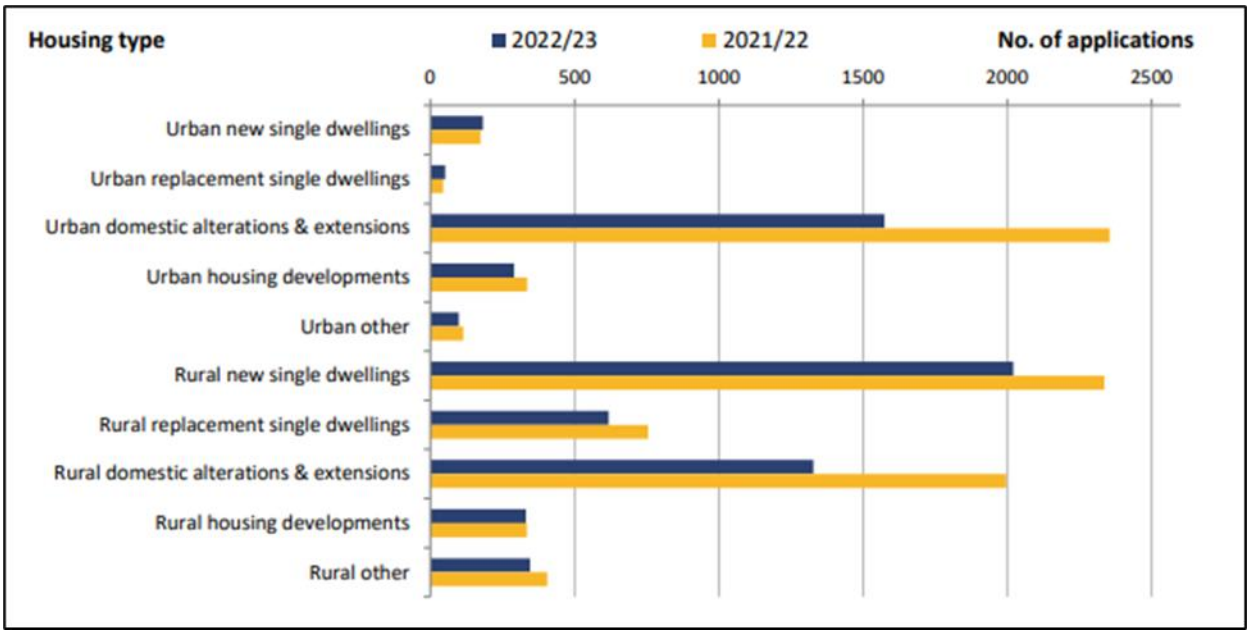
The next sections of the report discussed each of these pressures in turn, followed by a short discussion of other types of development that may be having an impact on biodiversity in Northern Ireland.

Land Use Change: Residential development

Meeting the housing needs of the Northern Ireland population gives rise to significant development activity, with over 100,000 dwellings completed 2008-2023 (average of 7,000 per annum, see Dept of Communities 2023), and housing accounting for a majority (62.5%) of all planning applications, with 95.4% of these being awarded permission. Housing is clearly a major development pressure on the Northern Ireland environment with demand closely aligned with economic prosperity, and housing need aligned with trends in population growth, life expectancy and household formation; projections suggest that the number of NI households will increase by 88,700 between 2016 and 2041 (i.e. 3500 per annum, NISRA 2018) adding to the existing unmet housing need, which included over 45,000 on the social rented sector waiting list (Dept of Communities, 2023), While there are robust and accessible data on the level of planning activity around housing from annual and quarterly NI Planning Activity Statistics[5] and on housing starts and completions in NI Housing Statistics[6], these provide little information into likely impacts on biodiversity, particularly because the statistical returns provide little insight on the spatial distribution of new housing development, its proximity to environmental designations or its impact on habitat fragmentation and destruction. However, Annual Reports of Planning Statistics (Dept of Infrastructure, 2023), indicate broad patterns of the type of housing applications received, with the highest number of these being on greenfield sites, particularly rural single new dwellings, which made up 29.2% of all residential planning applications, and another 23% also on greenfield sites (such as urban extensions etc) (see **Error! Reference source not found.**3).

Figure 3: NI residential applications decided by urban/rural 2021/23 & 2022/23

[5] Planning Activity Statistics: https://www.infrastructure-ni.gov.uk/articles/planning-activity-statistics Last accessed 31/07/24
[6] NI Housing Statistics: https://www.communities-ni.gov.uk/topics/housing-statistics



From: Dept of Infrastructure (2023)

While it is difficult to find robust evidence of the specific biodiversity impact occurring as a result of rural housing, the 2007 NI Countryside Survey (Cooper et al., 2009) indicated the increase in 'Built Up Areas and Gardens' (see bottom right graph in Figure 2) at twice the rate recorded in the previous survey (from 1998), mostly over Neutral and Improved grassland, but also semi-natural habitats in lowland landscapes; Tall herb/ruderal vegetation; Established broadleaf woodland; Transitional seminatural woodland/scrub; and Species-rich dry grassland. Such habitats are also being reduced by agricultural conversion and development, and as there are only small amounts of these habitats in lowland areas, the Survey Report flags this as a key biodiversity issue, without specifying the specific species that may be most affected. There are also likely to be indirect impacts on biodiversity of such development, including that arising from noise and light, potential leaking from septic tanks, induced traffic and further development to meet infrastructure and service demands of the new residential development.

Theses impacts on biodiversity are directly regulated through the planning system, and while regional policy expressed in the Strategic Planning Policy Statement (DfI, 2015) is more restrictive than in previous decades, there is now some variation in policy as District Councils adopt their own Local Development Plans. Haran et al. (2019) note that local council planning departments are 'appreciative' of the extent of such housing development, and the long-term environmental consequences of such patterns of development.

Although the scale of rural housing may be the primary identifiable cause of biodiversity loss by residential development, the Northern Ireland population has undergone long-term urbanisation, so that 60% of the population now living in urban areas, and there has been a growth of second homes since the mid-1990s particularly in high amenity areas, including the Causeway Coast, Newcastle-Dundrum and the Fermanagh Lakelands (Norris et al., 2010, Paris, 2008). Urbanisation processes have been shown to have multiple and complex impacts on biodiversity (some of which are discussed in section 4), such as the long term declines in bats and large moths (State of Nature Partnership, 2023) particularly from habitat loss and a wide range of impacts from pollution and disturbance. Negative impacts of increased urban land cover on native and invasive species have been documented in riparian zones in Northern Ireland (Lundy and Montgomery, 2010). The introduction of domesticated environments and behaviours are also indirect consequences of residential development, leading to bird feeding (Davies et al., 2012), which itself can lead to changes on migration

(Plummer et al., 2015) while domestic cats have been shown to result in large amounts of wildlife mortality (e.g. Loss et al., 2022).

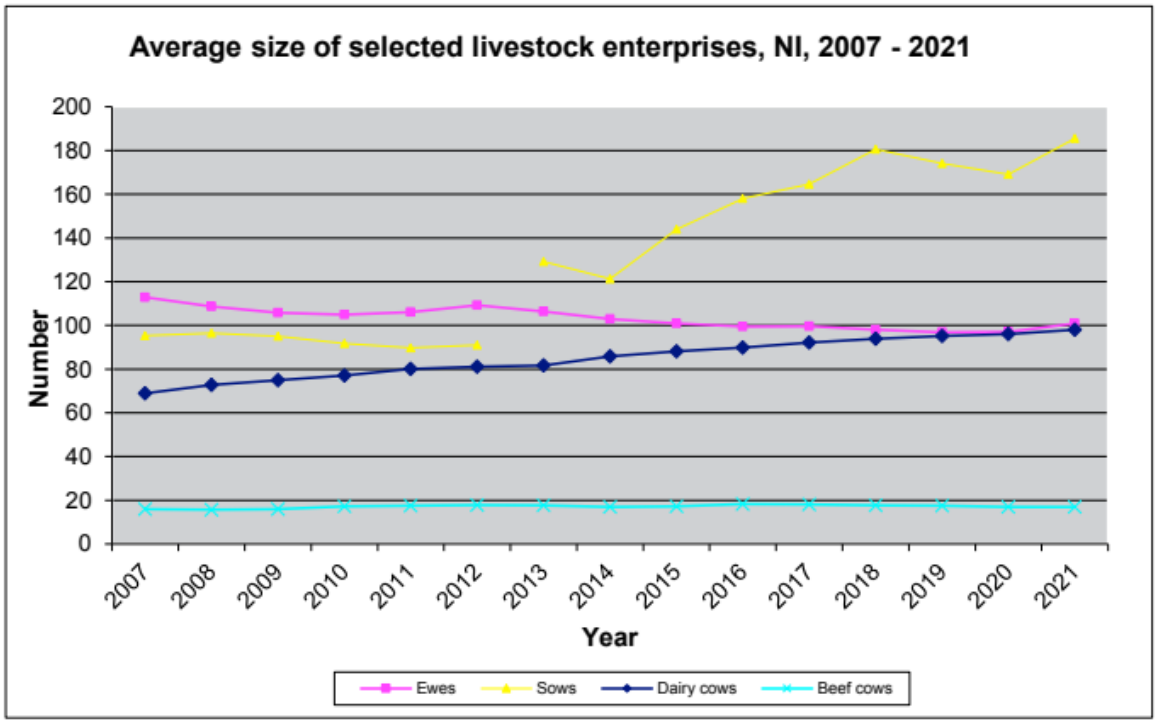
Urban green and blue open spaces can provide opportunities for enhancing local biodiversity (e.g. Lambert et al., 2021) and while there are current statistics for the provision of open space in NI (NI Environment Link, 2023), there does not appear to be any indication of the trend related to both quantity and quality over time. In the absence of NI evidence, we could assume the trends have been broadly the same as other parts of the UK. In England urban green space declined from 63% in 2001 to 55% in 2018 (CCC, 2019), with policies on urban densification being a factor (Dallimer et al., 2011). Species richness has been shown to decline with increasing urban densities and locations, although higher density developments can help meet other sustainability goals, including reducing the land take in greenfield sites (McKinney, 2008). Densification approaches have also been pursued in NI's urban areas, particularly Belfast (e.g. BCC, 2024), mostly focusing on brownfield sites, some of which may be significant for biodiversity themselves (MacGregor et al., 2022, Hunter, 2014, Cox and Rodway-Dyer, 2023).

Land Use Change: Agricultural development and intensification

The second key development pressure that appears to have had a key role in influencing biodiversity in NI is agriculture (State of Nature Partnership 2023). The impact of agriculture is mediated through direct drivers such as land use change/intensification and indirectly through more diffuse water pollution (Foy et al., 2001), particularly nutrients and pesticides, which result in regular fish kills in Northern Ireland (Wood, 2024). As nature friendly farming is the subject of another review by the OEP, agricultural pressures on biodiversity resulting from activities considered 'development' (see Section 2 above), such as the construction of farm buildings and supporting infrastructure, are considered here. As with other development pressures discussed in this report, there is a lack of direct, robust and comprehensive data on the extent and trends related to this form of development, particularly as many types of agricultural buildings are regarded as 'permitted development', as highlighted in the Strategic Planning Policy Statement (DfI, 2015) and specified in Part 7 of the Planning (General Permitted Development) Order (Northern Ireland) 2015.

Routine reporting of those agricultural developments that need planning permission are not included in planning statistics, although they could potentially be extracted from the NI Planning portal to provide insights on the distribution and scale of the physical development. The key trends of the main types of agricultural development can be surmised from NI Agricultural statistics (e.g. DAERA 2023), including the development pressures resulting from the growth of multiple agri-food sectors, facilitated by the *Going for Growth Strategy* (DAERA, 2017), which has been linked to deteriorating water quality (e.g. Doody et al., 2020, Manley, 2024). A number of trends are apparent, including a significant increase in the size of enterprises rearing sows, (see Figure 4), increases in dairy cattle (DAERA 2023, see Figure 5) and a doubling of the number of poultry reared in Northern Ireland since 1990 (DAERA, 2021), particularly in eastern areas. These will have resulted in development pressures as they usually involved the construction of extensive housing facilities, supporting infrastructure and waste disposal arrangements that are regulated in the first instance by the planning system (and hence recognisably 'development'). The recently published *Lough Neagh Report* (DEARA, 2024) focusses primarily on issues of enforcement, rather than the effectiveness of the development management system, which has been shown to have major failings when considering environmental impacts of intensive farming developments (NIAO, 2024).

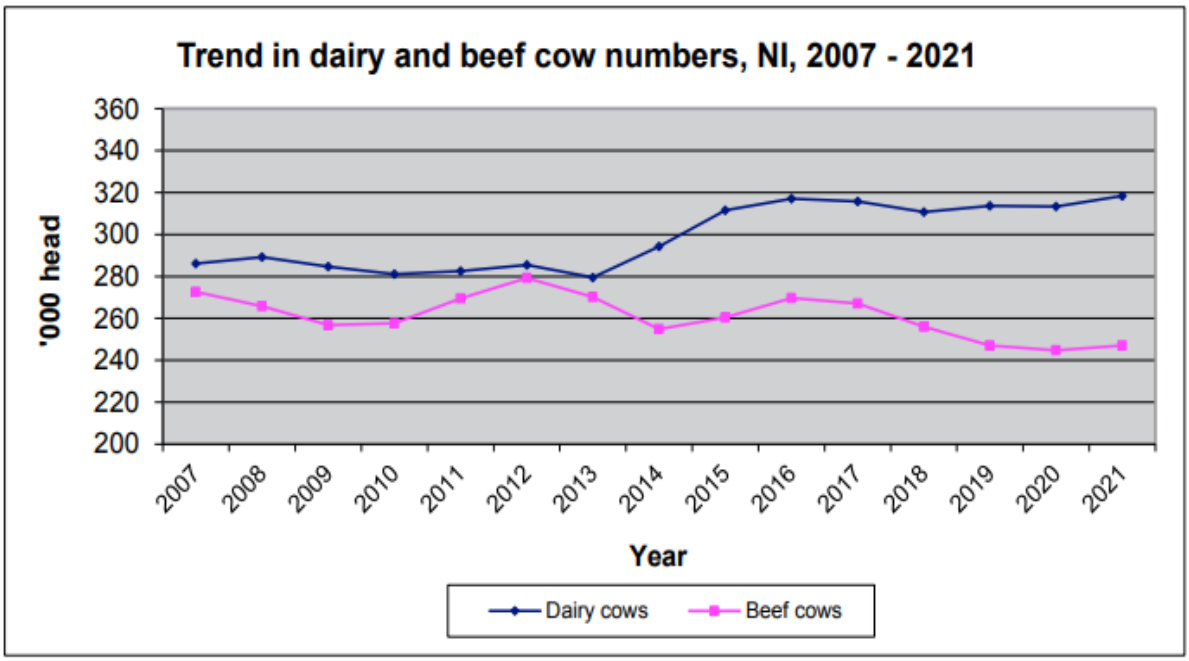
Figure 4: Average size of selected livestock enterprises, NI, 2007-2021



Note: From 2013 onwards, pig figures derived from the Northern Ireland Annual Inventory of Pigs

From: DEARA (2023)

Figure 5: Trends in dairy and beef cow numbers, NI, 2007-2021



From: DEARA (2023)

Resource Use: Mining and Extraction

A further development category in Northern Ireland that appears to have significant biodiversity impacts, primarily because of its land take, and thus habitat loss and fragmentation, is mining and extraction, particularly quarrying. This is another sector where there is a lack of available, comprehensive and robust evidence on which to fully evaluate the sector's impact on biodiversity in Northern Ireland. However, there is indicative data on the sector from the Department of the Economy (2022a), indicated that there are approximately 186 quarries and sandpits in Northern Ireland, which reported over 14 million tonnes of extracted minerals in 2022 (Department of the Economy 2022a), although half of the identified quarries did not submit a return. The fact that 25% of Northern Ireland is covered by mining concessions (Department of the Economy 2022b), compared to 7.7% in Scotland, 6.4% in Wales and 0.2% in England (Greene, 2022), indicated the potential scale of this sector, which can, depending on location, result in major habitat loss, fragmentation and other impacts on biodiversity. Although new mining and quarrying proposals are subject to planning controls, and therefore cumulative impacts can potentially tracked from NI Planning Portal data, active and inactive sites may be subject to extant consents, that may have been awarded prior to any robust regime of environmental assessment, which makes a full evaluation problematic, in the absence of comprehensive site surveys.

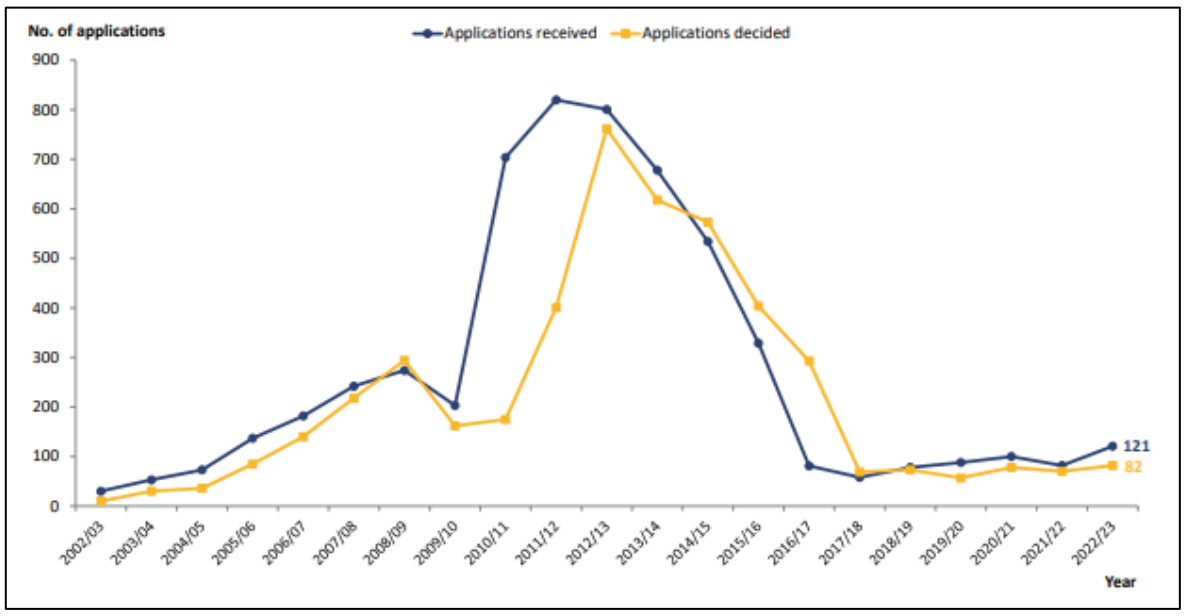
A further development pressure from the mining sector is a recent emergence of proposals for gold mining in Northern Ireland, with the Cavanacaw mine in Omagh (Galantas Gold, (n.d) consented and in development, and a further major proposal at Curraghinalt in County Tyrone (within the Sperrins Area of Outstanding Natural Beauty) currently in the planning process (PAC, 2024). While much of the operation for these mines may be underground, the mine in development at Cavanacaw has significant supporting infrastructure related to water treatment, access roads and waste treatment, and the operator owns 220 acres of the surrounding land, so potential impacts are substantial. It is unlikely that Northern Ireland will attract many more of these proposals, but given the location and scale of operations, combined with other pressures coming from extractive industries, it does represent a significant development pressure whose cumulative impact on biodiversity needs further investigation.

Other development pressures

While the three development pressures discussed above are likely to be most significant in relation to biodiversity impacts in Northern Ireland, there are other economic sectors that rely on physical development and land take, and this potentially result in environmental impacts, and some of the evidence on the trends and scope of these are discussed in this section. The decarbonisation of the energy system, and the targets under the NI Climate Change Act 2022 requires a shift to renewable forms of energy generation, and thus the development of renewable energy projects, with wind turbines being the cheapest form of energy generation, but which normally requires rural locations. The development of such projects can be tracked in the Department of Infrastructure Planning Statistics (DfI, 2024), as shown in figures 6 and 7). This activity could increase substantially once a new Renewable Electricity Support Scheme is established (DfE, 2023).

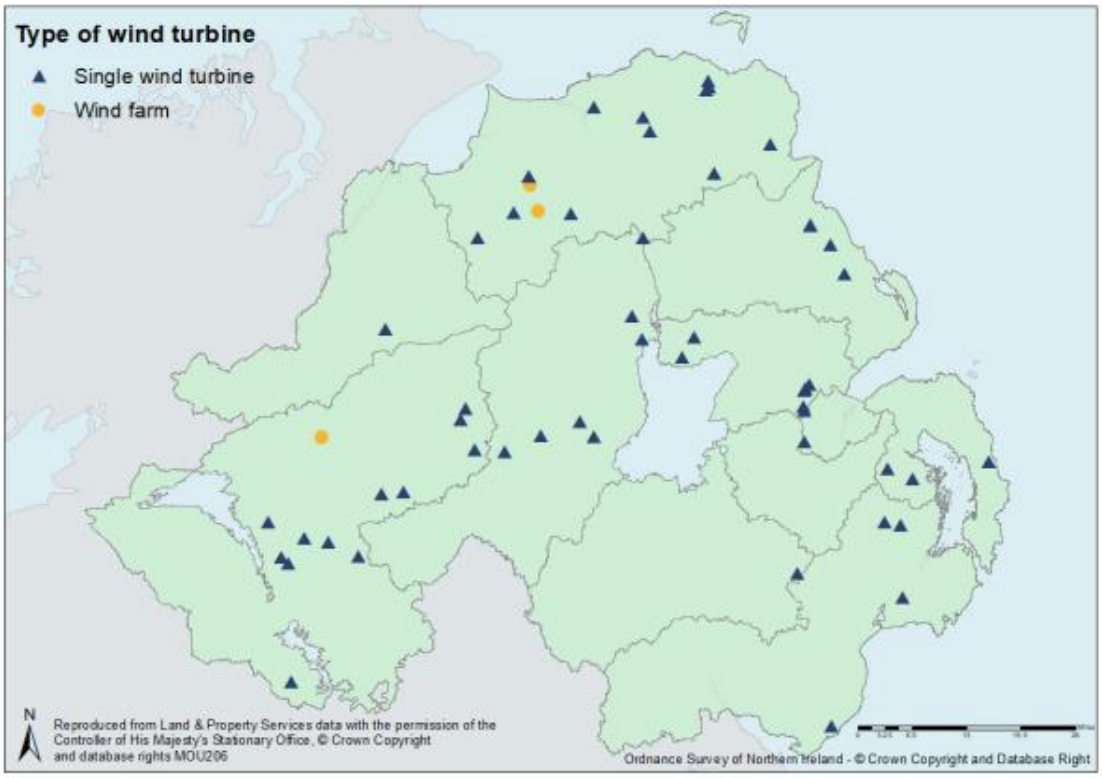
Given the rich wind resource of Northern Ireland, wind turbines are found in most areas (other than Areas of Outstanding Natural Beauty, although there are proposals for such developments in the planning process) with many single turbines on rural lowlands and most larger scale arrays in more upland areas, with potential impacts on blanket bogs and peatlands, including habitat and species loss (Detrey, 2023, Cryan and Barclay 2009). Although there is little direct evidence from Northern Ireland on the biodiversity impacts of such developments. Ruddock and Reid (2010) reviewed available literature to recommend specific guidance for developers in Northern Ireland, and there is some evidence from the island of Ireland to suggest that wind turbines can result in lower bird densities (Fernandez-Bellon et al., 2019), irreversible damage to peatland habitats (Renou-Wilson and Farrel, 2009) and influence the behaviour of bats (Russ and Montgomery, 2002, Cryan and Barclay, 2009), with the impacts on blanket bogs being of particular concern (Chico et al., 2023). Project location and design influence the biodiversity impacts of wind energy projects (Ruddock and Reid, 2010), and in Northern Ireland these are governed by a criteria-based policy in the Strategic Planning Policy Statement (SPPS, DfI 2015) rather than spatial zoning (which tends to be the approach in Scotland, Wales and the Republic of Ireland). Consequently, there are implications for strategic assessment of overall impacts, the evaluation of individual projects and monitoring of impacts over time. The SPPS notes that a 'cautious approach' will apply in sensitive landscapes such as Area of Outstanding Natural Beauty (para 6.223, DfI 2015) and proposals will not be allowed where they result in an unacceptable adverse impact on biodiversity. This policy is currently under review (DfI, 2021).

Figure 6: 6 Renewable energy applications, annually 2002/03 to 2022/23



From: Dept of Infrastructure (2023)

Figure 7: 7 Location of approved wind energy applications by council, 2022/23



From: Dept of Infrastructure (2023)

In the last ten years there has also been several large-scale solar farm developments in Northern Ireland, and while relatively rare, they can extend over several hectares and have been shown to have biodiversity impacts on bats (Tinsley et al., 2023) and birds (Visser et al., 2019), although there does not appear to be evidence from the island of Ireland. As noted above such developments could become more significant in the future, especially if a NI renewable energy support scheme is established. Northern Ireland has also witnessed the development of biogas digesters, which may have localised direct biodiversity impacts and more indirect impacts from operations and supply chains, although there appears to be no evidence on this in Northern Ireland.

In addition to renewable energy, infrastructure is another development pressure for biodiversity (e.g. Torres et al., 2016), particularly road building (Benítez-López et al., 2010). It is notable that Northern Ireland has a total road network of 25,858km (more than double the road length per person compared to GB[7]). Furthermore, the road network in NI has increased by 1034km or 4% since 2003 (DfI 2023, DRD, 2003), compared to an increase of 0.8% in Great Britain during the same period (Dept of Transport, 2024). Although there does not appear to be direct evidence to indicate the biodiversity impacts of road development in NI, it does result in a range of detrimental consequences including habitat fragmentation, road kill and behavioural influences (Bennett, 2017, Gaughran et al., 2021). The greater road density in NI implies that these impacts maybe more significant here than in other regions of the UK.

Finally, while this report has reported significant challenges in securing evidence of biodiversity impacts arising from the major forms of development discussed above, all of which are, to different degrees, regulated by government primarily through the planning system, there are even more significant challenges when considering the those pressures that are not regulated, either because they are regarded as permitted

[7] NI has 0.014km roads per person, GB has 0.006km person – figures derived from DFI 2023, DoT 2024 and relevant census data.

development in planning law[8] or in some cases may require planning permission but for various reasons (including illegality), remain outside regulatory control. Two examples of this which have been shown to have poor regulatory compliance and significant environmental impacts are illegal dumping (Brennan, 2016, Mills 2013) or sand and gravel extraction (MacCauley, 2020).

[8] This includes minor or temporary development, some changes of land use and some agricultural activities, see The Planning (General Permitted Development) Order (Northern Ireland) 2015

6. Reflections and Limitations

The review of evidence on the development pressures that may be resulting in impacts on biodiversity in Northern Ireland has faced a number of limitations. The primarily limitation has been a significant lack of available systematic and comprehensive evidence upon which to base such an assessment. This deficit is apparent in both the searched academic literature, and the monitoring data collected, compiled and/or made readily available by government agencies in Northern Ireland. In relation to relevant academic research, this faces significant limitations from the capacity and scope of the academic community compared to many of the other UK Regions (with only two universities), and unavailability of dedicated and consistent funding programmes to allow the development of longitudinal data sets, although the NIEA Countryside Survey is an exception to this, as noted above.

This lack of robust systematic data has generated other limitations to the study in that the assessment of evidence was reliant on available data, and in its absence, it is extremely challenging to comment on baseline conditions or trends over time of some of the development pressures that have been identified. The systematic search of academic literature was also undertaken within a limited timescale and this mean that certain parameters were placed on searches, which were focussed on the last decade of research and primarily focussed on studies with a major Northern Ireland component. With more time or resources available, it may be possible to extrapolate further evidence from studies from other parts of the UK and Ireland, and examine more historical research studies. While every effort was made to locate relevant sources of data from grey literature, it is more challenging to be systematic in such searches, so some evidence may have been overlooked. A further limitation has been a lack of capacity to comment on the range of potential indirect impacts on biodiversity as a consequence of the development pressures discussed in this report. This partly stems from the lack of robust evidence on the scale and location of the development pressures identified, and thus a poor picture of the direct impacts, from which indirect impacts could be derived. While there is evidence on how different types of human activity and development can disrupt animal and plant behaviour, or alter ecosystem conditions, as a result of some of the pathways that may be considered as indirect impacts of development pressures, such as noise, light, water and air quality etc., these have only been mentioned when direct evidence was identified. Taking into account such complex interactions clearly would provide a more accurate, and extensive, assessment of resulting biodiversity impacts.

Nevertheless, although not systematic nor comprehensive, the evidence highlighted here the ways in which different development pressures can impact on biodiversity in Northern Ireland. The review has also identified the key development patterns that generate the pressures, with some indication of how these may continue to evolve.

However, it does appear that although there are potential sources of evidence for linking development pressure with the state of the environment in Northern Ireland, these are not currently being adequately exploited to provide cumulative and monitoring data on biodiversity or other environmental consequences of development. An example of this identified in this review is an opportunity to associate the findings of the commissioned 2023-26 Countryside Survey (DEARA n.d.) with spatial data from the NI Planning Portal, which would not have been available for previous iterations of the Countryside Survey. This could provide opportunities to identify the specific spatial location and extent of land use change, and sampling could help identify the impact on specific habitat types. Indeed, the NI Planning Portal, includes submitted Environmental Statements of major development proposals, which could be a significant source of evidence of the environmental consequences of development, could be used more effectively to establish cumulative trends and impacts of development. If aligned with a range of other spatial data (such as on designated sites or distribution of habitats and species) Environmental Statements could yield very important evidence on the issues discussed in this report. However, the data on the Planning Portal only relates to forms of development that require planning permission (see

Section 2 above), meaning significant data gaps would remain related to permitted development (particularly some agricultural activities exempted from planning control and the resumption of long-standing extractive/quarrying licenses) and development that is in breach of planning control (for example illegal waste disposal, e.g. Mills, 2013).

Throughout the report comment has been made in relation to the planning system as a both a source of evidence on development pressures and as the primary regulatory mechanism for limiting and ameliorating development impacts on biodiversity. However, the capacity of the planning system to effectively undertake this function has been called into question in a series of highly critical reports on its effectiveness. Most comprehensively, reports from the NI Audit Office (NIAO, 2002, 2024) and the Assembly Public Accounts Committee (2022) have drawn attention to very major short-comings of the planning system. Some of the findings of these reports are very relevant to the issues discussed in this report.

The 2022 reports by NI Audit Office (2022) and the NI Public Accounts Committee Report (2022) highlight a range of fundamental weaknesses in the planning system, which would have to be addressed to establish an effective evidence-based process of regulation of development pressures that assesses and limits the impacts on biodiversity. The nature of this challenge is highlighted by comments by the NIAO (2022) noting that:

'*Ultimately, as it currently operates, the system doesn't deliver for customers, communities or the environment'* (para 4.12)

Similarly, the Public Accounts Committee recommended that:

'Issues with quality at all stages of the planning process are pervasive, affecting applications, statutory consultation, plan-making and the appeals system. The Committee is concerned about the long-term, cumulative effect of widespread quality issues. A planning system that allows poor quality applications risks poor quality development, which will only lead to further issues and additional costs for the future'. (para 4, p 6)

and

'It is the Committee's strong view that the problems presented are symptomatic of a planning system that is beset by more fundamental issues.' (para 5, p6)

Leading to the Committee's recommendation that:

'The planning system in Northern Ireland is not working. The Committee recommends that a Commission is established to undertake a fundamental review to ascertain the long-term, strategic changes that are needed to make the system fit for purpose. This should be led by someone independent from the Department (recommendation 1, para 13, p9)

Both the Public Accounts Committee and the NIAO commented on other issues that can affect how development pressures are balanced with biodiversity, including the poor coverage of up-to date local development plans, a lack of funding of key public agencies involved in the planning process and badly fragmented decision-making.

Specifically in relation to the evidence base required to monitor the impact of development on biodiversity, these reviews highlighted that:

'*there is no publicly available information demonstrating how planning decisions have translated into built development, improved or enhanced the built or natural environment, benefitted communities or contributed to the economy*.' (NIAO 2022, para 4.31)

and that:

'Broader long-term impacts are not being routinely captured and demonstrated' and that *'The cumulative effects of planning are not being measured and that this could lead to negative outcomes with impacts for the public purse.'* (NIAO 2022, para 4.32)

The Public Accounts Committee also noted that:

'*The Committee recommends that planning authorities regularly review past decisions to understand their real-world outcomes, impact on communities and the quality of the completed development. (*Recommendation *10 para 24, p.13)*

The NIAO report also highlights two other specific issues that are relevant to this evidence review, namely that Shared Environmental Service (SES), the specialist service for providing support and guidance to local planning authorities faces significant resourcing challenges (NIAO 2022, para 5.8); and that '*the planning system is struggling to progress some complex planning applications which can include environmental impact assessments*' (para.5.34). In respect to this last issue, the NIAO has particular concerns around ammonia emissions, potential inadequacies in screening processes, the objective scientific evidence used and how cumulative evidence is taken into account. The Public Accounts Committee also highlighted inconsistencies in the planning system for rural housing (Recommendation 7, para 21, p 11) which is linked to one of key development pressures highlighted in this report.

The nature of these reports would suggest that there is an urgent need for a far-reaching programme planning reform, and a Interim Planning Commission has been formed to consider this (DfI, 2023). While the efficiency of the system is the most often citied priority for reform, it should also consider the effectiveness of how development impacts biodiversity. The Commission has been taking evidence from key stakeholders, to advice its deliberations, and the OEP should consider approaching them to discuss the range of issues raised in this report.

7. Recommendations

This Report has highlighted significant issues in relation to the evidence base for understanding how proposed and existing development impacts on biodiversity over time. A result of that is that it is not possible to make substantive recommendations in relation to specific biodiversity impacts occurring in Northern Ireland, but rather highlight opportunities for improving the evidence base, which will be necessary for any long term effective monitoring, intervention and policy reform.

Three broad areas are highlighted for consideration by the OEP:

Recommendation 1: Creating a more systematic evidence base on development pressures and impacts on biodiversity in Northern Ireland.

a) This report has clearly highlighted difficulties in establishing a systematic, robust and accessible evidence base that can be used to evaluate the impacts on biodiversity, arising from a range of development pressures. However, there are many existing datasets that could be integrated, at relatively little cost, which would allow the creation of valuable baselines, indicators and sensitivity assessments of past patterns of development. The official statistics referred to in this report (including Planning, Agricultural and Mineral Statistics), all contain much of the key evidence, including detailed spatial data. It is expected that such records are now held electronically so that merging of datasets and alignment with existing data on species, habitats and environmental designations would facilitate a relatively effective way to indicate key environmental risks and existing biodiversity loss as a result of past development pressures. An initial scoping exercise involving the research and statistics representatives of key government departments would be a pragmatic first step in exploring the potential of this.

b) A second area would be to explore the potential of regular reporting from data held on the Planning Portal, which holds information on past planning applications and permissions, and current planning activity. This is an extremely underused resource for monitoring the trends, scale and spatial distribution of development pressure. Regular reporting on specific development categories, its proximity to species and habitat distribution and environmental designations would provide the basis for ongoing monitoring of potential biodiversity impacts.

c) As noted in the report, the Planning Portal also acts as a repository of many Environmental Statements prepared under The Planning (Environmental Impact Assessment) Regulations (Northern Ireland) 2017, which is mandatory for certain categories of major development proposals. Such statements necessitate a variety of ecological surveys, and this can be seen as a potential repository of valuable biodiversity data. While extracting such evidence may entail a more labour-intensive process that analysing the electronically held data on the Planning Portal, this would provide detailed and accurate biodiversity information, in key sites where development has been proposed, and this would provide specific evidence on the type of threats and impacts that accompany key development pressures.

d) Finally, under this section, the report has noted that Northern Ireland has a relatively low capacity of researchers working in areas that can help contribute to this evidence base, and there appears to be a lack of regular funding programmes that could help create longitudinal data sets and specifically develop research capacity in this area. A high level assessment of the research capacity of government, agencies and the region's universities could provide important insights on how this could be addressed. Deployment of research funds from DEARA, and strategic use of doctoral studentships supported by DfE could offer mechanisms for addressing this.

Recommendations 2: Review of the impact of specific development pressures

a) This report has identified the development pressures that appear to be the most significant in terms of their impacts on biodiversity (residential development, agricultural development and mining and

quarrying). These have been identified in terms of development trends and expert opinion, but there is a lack of robust evidence for this. It is suggested that as these development categories appear to have the greatest biodiversity impacts, specific investigations are undertaken of each sector, using some of the methods indicated above; extraction of planning data from planning portal, combining with existing government statistics and spatial data on species and habitats. The NI Countryside Survey offers a particular opportunity here as all three development categories have greatest impacts in rural areas, the past and ongoing survey data can be integrated with planning data to provide a relatively robust indication of the ecological risk associated with each. This could be consolidated with expert interviews and focus groups to identify potential improvement in monitoring, legislation, policy and guidance for each development category to reduce potential impacts.

Recommendation 3: **Identifying opportunities for amelioration of the impacts of development pressures including planning reform**

a) Subject to the development of a more robust evidence base as discussed throughout this report, existing regulatory processes offer opportunities to reduce the impacts of biodiversity arising from development pressures. One prominent mechanism for doing this could be the introduction of regulations around Biodiversity Net Gain, as existing in England, or more modest proposals for exploring opportunities for biodiversity sensitive urban design (e.g. Garrard et al., 2018) or pollinator schemes (O'Sullivan et al., 2017). In any case, as highlighted in section 7, the current NI Planning System has been shown to be failing in in its core functions, including effective environmental protection. As a consequence, there are demands for far reaching planning reform, which has been entrusted to an Interim Planning Commission, and it is suggested that the OEP engage with this Commission to explore the opportunities for integrating biodiversity protection within the programme of reform. Acknowledging that agricultural land use is a potentially politically sensitive topic in Northern Ireland, and that that there are growing and potentially conflicting demands on a limited land resource from priorities that include housing, decarbonisation, agriculture and biodiversity, there is merit in exploring the value of a land use framework in Northern Ireland, similar to the Scottish Land Use Strategy, which would allow strategic priorities to be defined and then used to inform local development plans.

8. Conclusion

This review of the available evidence on development pressures and impacts on biodiversity that relates directly to Northern Ireland, suggests that there is insufficient evidence to draw high confidence conclusions on how different forms of development pressures are directly linked to different dynamics of biodiversity change and decline in Northern Ireland. The report identified the following current key development pressures in relation to biodiversity:

- Land Use Change: Residential development
- Land use Change: Agricultural development and intensification
- Resource Use: Mining and Extraction

Key recommendations relate to the need to establish more rigorous monitoring of cumulative impacts of planned development, more effective development management in support of biodiversity objectives, and opportunities to more effectively assess of past trends, using existing uncoordinated data sources.

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*References that relate directly to Northern Ireland evidence is indicated in **bold**

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Appendix 1: Search Terms used in Systematic Review

The basis for the search terms were those used in McDonald et al (2020), we used their partial search strings listed in their Supplementary Information S2 for the direct and indirect impacts of urban growth on biodiversity, using only environmental science category. In 2020 the unrestricted geographic search produced 2431 papers, which the authors screened to 922 papers. When repeated today, the search produced 5695 papers and 8593 when using 'all fields'. We some slight modifications to their search terms after reviewing terms used in other reviews, such as Colsaet et al (2018) de Barros Ruas and Wenzel et al (2020). Combining these terms with 'Northern Ireland', 'Ireland' and 'United Kingdom', using 'all fields', and not restricted to environmental sciences produces the following results.

SEARCH STRINGS

Urban Development: Direct impacts

'all fields'=(impact* OR threat OR decline OR effect OR decrease OR loss OR disturbance OR change*) AND 'all fields'=(urban* OR city OR cities OR sprawl) AND 'all fields' = (biodiversity OR vertebrates OR invertebrates OR richness OR "number of species" diversity OR "taxonomic diversity" OR "habitat") AND 'all fields'= (Northern Ireland/ Ireland/ Great Britain/ United Kingdom: United Kingdom AND Ireland)
In Scopus 'all fields' = Article title, Abstract, Keywords

Web of Science

Northern Ireland:65
https://www.webofscience.com/wos/woscc/summary/22ce9ede-afc8-447d-9b71-2412fcda44c0-cc826d02/relevance/1
Ireland: 419
https://www.webofscience.com/wos/woscc/summary/c128a442-774b-4e38-809d-936c59e3318b-cc829dd6/relevance/1
Great Britain:80
https://www.webofscience.com/wos/woscc/summary/0fd8905c-742f-4a76-93bd-76c47ab83000-cc82ce92/relevance/1
United Kingdom: 211
https://www.webofscience.com/wos/woscc/summary/a090a661-8914-4cd5-92c5-b404b7606362-cc82d7f4/relevance/1
United Kingdom AND Ireland: 15
https://www.webofscience.com/wos/woscc/summary/f194b8c5-04ce-4aa2-9648-20e8b820fd98-cc82dd96/relevance/1

Scopus

Northern Ireland: 7
Ireland: 21

Urban Development: Indirect impacts

'all fields'=(urban* OR city OR cities) AND 'all fields'=(teleconnection OR telecoupling OR footprint OR consumption OR "supply chains" OR "indirect impact" OR "indirect impacts") AND 'all fields'=(= (biodiversity OR vertebrates OR invertebrates OR richness OR "number of species" OR diversity OR "taxonomic diversity" OR "habitat")) AND 'all fields'= (Northern Ireland/ Ireland/ Great Britain/ United Kingdom: United Kingdom AND Ireland)

Northern Ireland: 1
https://www.webofscience.com/wos/woscc/summary/46cc93aa-c093-49b3-962f-14f64ffea6fb-cc8723cd/relevance/1
Ireland: 11
https://www.webofscience.com/wos/woscc/summary/ce567c81-ad2b-4150-a576-83c5320ad827-cc872071/relevance/1

Great Britain: no hits
United Kingdom: 13
https://www.webofscience.com/wos/woscc/summary/192227af-3b0a-40ad-b1af-e9a467e06ffc-cc871838/relevance/1
United Kingdom AND Ireland: 1
https://www.webofscience.com/wos/woscc/summary/3ec82825-a005-4b07-a31d-2b46f102722d-cc871485/relevance/1

Scopus
Northern Ireland: 1
Ireland: 1

Rural Development: Direct impacts
'all fields'=(impact* OR threat OR decline OR effect OR decrease OR loss OR disturbance OR change*) AND 'all fields'=(rural* OR countryside OR landscape) AND 'all fields' = (biodiversity OR vertebrates OR invertebrates OR richness OR "number of species" diversity OR "taxonomic diversity" OR "habitat")) AND 'all fields'= (Northern Ireland/ Ireland/ Great Britain/ United Kingdom: United Kingdom AND Ireland)
Northern Ireland: 254
https://www.webofscience.com/wos/woscc/summary/d8bc92e8-5ea7-4b3a-bcd3-c5ca486a5c19-cc85012a/relevance/1
Ireland: 914
https://www.webofscience.com/wos/woscc/summary/4862a752-294a-497a-9c58-1ce3c608c21e-cc84fd51/relevance/1
Great Britain: 358
https://www.webofscience.com/wos/woscc/summary/5bc5688a-cbc4-4588-bbe3-f7c1716078f2-cc84bc6c/relevance/1
United Kingdom: 412
https://www.webofscience.com/wos/woscc/summary/d7feedfc-765d-4de0-9711-ae8fe32b4929-cc84b8f2/levance/1
United Kingdom AND Ireland: 44
https://www.webofscience.com/wos/woscc/summary/c5a3d089-3d2e-429b-a462-9748b8f897eb-cc84b4fb/relevance/1

Scopus
Northern Ireland: 10
Ireland: 90

Rural Development: Indirect impacts
'all fields'=(rural* OR countryside OR landscape) AND 'all fields'=(teleconnection OR telecoupling OR footprint OR consumption OR "supply chains" OR "indirect impact" OR "indirect impacts") AND 'all fields'=(= (biodiversity OR vertebrates OR invertebrates OR richness OR "number of species" OR diversity OR "taxonomic diversity" OR "habitat")) AND 'all fields'= (Northern Ireland/ Ireland/ Great Britain/ United Kingdom: United Kingdom AND Ireland)
Northern Ireland: 7
https://www.webofscience.com/wos/woscc/summary/a5b03dcc-a389-435f-80fb-060601a3b1d9-cc872bbe/relevance/1
Ireland: 26
https://www.webofscience.com/wos/woscc/summary/ad3d6806-939c-439d-803b-cb4af1c7e7b8-cc8737c7/relevance/1
Great Britain: 2

https://www.webofscience.com/wos/woscc/summary/189c60a4-140e-4032-8415-0ad09921b8d7-cc873a74/relevance/1
United Kingdom: 12
https://www.webofscience.com/wos/woscc/summary/60c47a9d-413f-47ff-8e92-bf9e691bb55f-cc873c8e/relevance/1
United Kingdom AND Ireland: 1
https://www.webofscience.com/wos/woscc/summary/b5995947-b89e-4edc-9683-1700bc9d69f3-cc873ea3/relevance/1

Scopus
Northern Ireland: 1
Ireland: 2

Housing: Direct impacts
'all fields'=(impact* OR threat OR decline OR effect OR decrease OR loss OR disturbance OR change*) AND 'all fields'=(housing OR houses OR residential development) AND 'all fields' = (biodiversity OR vertebrates OR invertebrates OR richness OR "number of species" diversity OR "taxonomic diversity" OR "habitat")) AND 'all fields'= (Northern Ireland/ Ireland/ Great Britain/ United Kingdom: United Kingdom AND Ireland)
Northern Ireland: 12
https://www.webofscience.com/wos/woscc/summary/cb53fbe7-6c97-48cc-baee-b588042f3e32-cc866f07/relevance/1
Ireland: 62
https://www.webofscience.com/wos/woscc/summary/db222d57-ebc9-4fa4-8394-c6a98ef352cc-cc866c89/relevance/1
Great Britain: 25
https://www.webofscience.com/wos/woscc/summary/144af28f-89a7-4094-9343-a47c317fa9eb-cc86691e/relevance/1
United Kingdom: 29
https://www.webofscience.com/wos/woscc/summary/daf15678-82bd-467f-a4f3-53e8b689d581-cc866608/relevance/1
United Kingdom AND Ireland: 3
https://www.webofscience.com/wos/woscc/summary/04441f2c-4289-48d4-9607-5cdbccb6a333-cc8663ce/relevance/1

Scopus
Northern Ireland: no hits
Ireland: 1

Industry: Direct impacts
'all fields'=(impact* OR threat OR decline OR effect OR decrease OR loss OR disturbance OR change*) AND 'all fields'=(industry* OR manufactur* OR production) AND 'all fields' = (biodiversity OR vertebrates OR invertebrates OR richness OR "number of species" diversity OR "taxonomic diversity" OR "habitat")) AND 'all fields'= (Northern Ireland/ Ireland/ Great Britain/ United Kingdom: United Kingdom AND Ireland)
Northern Ireland: 76
https://www.webofscience.com/wos/woscc/summary/f51bfc1c-601d-409b-b904-bb2ab1f6c864-cc8543c9/relevance/1
Ireland: 584
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Great Britain: 77

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United Kingdom: 217
https://www.webofscience.com/wos/woscc/summary/a0156160-62b0-424c-b838-101500c99688-cc8561d4/relevance/1
United Kingdom AND Ireland: 21
https://www.webofscience.com/wos/woscc/summary/0bdf1c25-2c67-4d6c-af59-98af040584be-cc85662b/relevance/1

Scopus
Northern Ireland: 5
Ireland: 42

Agricultural Development: Direct impacts
'all fields'=(impact* OR threat OR decline OR effect OR decrease OR loss OR disturbance OR change*) AND 'all fields'=(farm* OR agricult*) AND 'all fields'=(construction OR development) AND 'all fields' = (biodiversity OR vertebrates OR invertebrates OR richness OR "number of species" diversity OR "taxonomic diversity" OR "habitat")) AND 'all fields'= (Northern Ireland/ Ireland/ Great Britain/ United Kingdom: United Kingdom AND Ireland)
Northern Ireland: 94
https://www.webofscience.com/wos/woscc/summary/449fd186-797b-40b1-b0fd-04fb7057e290-cc857ec4/relevance/1
Ireland:405
https://www.webofscience.com/wos/woscc/summary/aa23253b-d93d-475c-9f3c-352f8ecf4269-cc857b69/relevance/1
Great Britain: 67
https://www.webofscience.com/wos/woscc/summary/76e11cb5-6f4e-430f-8f37-f857d8e6af04-cc85778c/relevance/1
United Kingdom: 130
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United Kingdom AND Ireland: 21
https://www.webofscience.com/wos/woscc/summary/68f65ec1-0efb-46b2-abc9-68560775b4f4-cc857118/relevance/1

Scopus
Northern Ireland: 3
Ireland: 17
Infrastructure: Direct impacts
'all fields'=(impact* OR threat OR decline OR effect OR decrease OR loss OR disturbance OR change*) AND 'all fields'=(infrastruct* OR transport* OR network* OR road* OR rail*) AND 'all fields' = (biodiversity OR vertebrates OR invertebrates OR richness OR "number of species" diversity OR "taxonomic diversity" OR "habitat")) AND 'all fields'= (Northern Ireland/ Ireland/ Great Britain/ United Kingdom: United Kingdom AND Ireland)
Northern Ireland:123
https://www.webofscience.com/wos/woscc/summary/56374662-adc6-4f64-8de3-e55e38a94774-cc85c6f9/relevance/1
Ireland:735
https://www.webofscience.com/wos/woscc/summary/390befcb-806f-4709-83e2-1ad5a0cf6658-cc85d61d/relevance/1
Great Britain:128

https://www.webofscience.com/wos/woscc/summary/390befcb-806f-4709-83e2-1ad5a0cf6658-cc85d61d/relevance/1
United Kingdom: 350
https://www.webofscience.com/wos/woscc/summary/cda07436-2038-4e8a-9e4d-47492a3d9b93-cc85de52/relevance/1
United Kingdom AND Ireland: 35
https://www.webofscience.com/wos/woscc/summary/96c42d49-c7c2-41fa-92f7-5b1e67a67f76-cc85e18f/relevance/1

Scopus
Northern Ireland: 6
Ireland: 55

Renewable energy: Direct impacts
'all fields'=(impact* OR threat OR decline OR effect OR decrease OR loss OR disturbance OR change*) AND 'all fields'=(renewable energy OR wind energy OR solar energy OR turbine OR anaerobic digester) AND 'all fields' = (biodiversity OR vertebrates OR invertebrates OR richness OR "number of species" diversity OR "taxonomic diversity" OR "habitat")) AND 'all fields'= (Northern Ireland/ Ireland/ Great Britain/ United Kingdom: United Kingdom AND Ireland)
Northern Ireland: 20
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Ireland: 80
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Great Britain: 8
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United Kingdom: 31
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United Kingdom AND Ireland: 3
https://www.webofscience.com/wos/woscc/summary/a9afdce9-6239-4731-a61f-7fbcae132e0d-cc85fc5d/relevance/1

Scopus
Northern Ireland: No hits
Ireland: 6

Mining and extraction: Direct impacts
'all fields'=(impact* OR threat OR decline OR effect OR decrease OR loss OR disturbance OR change*) AND 'all fields'=(mining* OR quarry* OR extract*) AND 'all fields' = (biodiversity OR vertebrates OR invertebrates OR richness OR "number of species" diversity OR "taxonomic diversity" OR "habitat") AND 'all fields'= (Northern Ireland/ Ireland/ Great Britain/ United Kingdom: United Kingdom AND Ireland)
Northern Ireland: 30
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Ireland: 235
https://www.webofscience.com/wos/woscc/summary/08ef3b5e-534f-49e7-8301-ac4ab034ac83-cc864be2/relevance/1
Great Britain: 19

https://www.webofscience.com/wos/woscc/summary/f19ed8c2-eee2-4a32-b96a-ff7e78dcbbe8-cc864e3e/relevance/1
United Kingdom: 88
https://www.webofscience.com/wos/woscc/summary/7f991ca3-26c0-4a05-8f6b-7de50ce8f92f-cc86506e/relevance/1
United Kingdom AND Ireland: 5
https://www.webofscience.com/wos/woscc/summary/47006d34-3863-45c0-b620-9f35caaf18b8-cc865341/relevance/1

Scopus
Northern Ireland: 2
Ireland: 25

Commercial Development: Direct impacts
'all fields'=(impact* OR threat OR decline OR effect OR decrease OR loss OR disturbance OR change*) AND 'all fields'=(commercial OR offices) AND 'all fields'=(construction OR development) AND 'all fields' = (biodiversity OR vertebrates OR invertebrates OR richness OR "number of species" diversity OR "taxonomic diversity" OR "habitat")) AND 'all fields'= (Northern Ireland/ Ireland/ Great Britain/ United Kingdom: United Kingdom AND Ireland)
Northern Ireland: 11
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Ireland: 58
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Great Britain: 1
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United Kingdom: 26
https://www.webofscience.com/wos/woscc/summary/afe11c6c-53bd-4874-bc5f-7e62b93713f9-cc86c24b/relevance/1
United Kingdom AND Ireland: 3
https://www.webofscience.com/wos/woscc/summary/ada5f7b4-9ad4-499c-9971-737511e39690-cc86c496/relevance/1

Scopus
Northern Ireland: no hits
Ireland: 4

Recreation development: direct impacts
'all fields'=(impact* OR threat OR decline OR effect OR decrease OR loss OR disturbance OR change*) AND 'all fields'=(recreation OR leisure OR golf) AND 'all fields'=(construction OR development) AND 'all fields' = (biodiversity OR vertebrates OR invertebrates OR richness OR "number of species" diversity OR "taxonomic diversity" OR "habitat")) AND 'all fields'= (Northern Ireland/ Ireland/ Great Britain/ United Kingdom: United Kingdom AND Ireland)
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Ireland:10
https://www.webofscience.com/wos/woscc/summary/47b96358-ca23-4c65-b4af-808b50270278-cc86ceab/relevance/1

Great Britain: 2
https://www.webofscience.com/wos/woscc/summary/19295cf5-083b-4896-8aa5-3cfe79d47906-cc86cc93/relevance/1
United Kingdom: 9
https://www.webofscience.com/wos/woscc/summary/7c843212-d0ee-4138-aed0-5e1a80780342-cc86cabb/relevance/1
United Kingdom AND Ireland: 1
https://www.webofscience.com/wos/woscc/summary/219b525e-6cf4-4e85-9079-bc3d9de0018c-cc86c907/relevance/1

Scopus
Northern Ireland: no hits
Ireland: no hits

Tourist development: Direct impacts
'all fields'=(impact* OR threat OR decline OR effect OR decrease OR loss OR disturbance OR change*) AND 'all fields'=(hotel OR tourism Or attraction OR travel) AND 'all fields'=(construction OR development) AND 'all fields' = (biodiversity OR vertebrates OR invertebrates OR richness OR "number of species" diversity OR "taxonomic diversity" OR "habitat")) AND 'all fields'= (Northern Ireland/ Ireland/ Great Britain/ United Kingdom: United Kingdom AND Ireland)
Northern Ireland: 7
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Ireland:49
https://www.webofscience.com/wos/woscc/summary/a95f2267-b68e-4ab6-bed5-5104ac2223bf-cc86e012/relevance/1
Great Britain: 4
https://www.webofscience.com/wos/woscc/summary/906322a4-1842-431a-8854-e7ccb8bc081f-cc86e2b9/relevance/1
United Kingdom: 25
https://www.webofscience.com/wos/woscc/summary/f2eda93d-fdc7-415c-9c75-25b464eab953-cc86e57e/relevance/1
United Kingdom AND Ireland: 2
https://www.webofscience.com/wos/woscc/summary/ec44ddd5-aa3d-4b8d-9f8c-9d99c8169669-cc86e7be/relevance/1

Scopus
Northern Ireland: no hits
Ireland: 2

Summary of paper identified across all search strings:

Development pressure	Jurisdictions	WoS	Scopus
Direct Urban Development	Northern Ireland	65	7
	Ireland	419	21
	Great Britain	80	N/A
	United Kingdom	211	
	United Kingdom AND Ireland	15	
Indirect Urban Development	Northern Ireland	1	1
	Ireland	11	1
	Great Britain	0	
	United Kingdom	13	
	United Kingdom AND Ireland	1	
Direct Rural Development	Northern Ireland	254	10
	Ireland	914	90
	Great Britain	358	
	United Kingdom	412	
	United Kingdom AND Ireland	44	
Indirect Rural Development	Northern Ireland	7	1
	Ireland	26	2
	Great Britain	2	
	United Kingdom	12	
	United Kingdom AND Ireland	1	
Housing	Northern Ireland	12	0
	Ireland	62	1
	Great Britain	25	
	United Kingdom	29	
	United Kingdom AND Ireland	3	
Industry	Northern Ireland	76	5
	Ireland	584	42
	Great Britain	77	
	United Kingdom	217	
	United Kingdom AND Ireland	21	
Agricultural Development	Northern Ireland	94	3
	Ireland	405	17
	Great Britain	67	
	United Kingdom	130	
	United Kingdom AND Ireland	21	
Infrastructure	Northern Ireland	123	6
	Ireland	735	55
	Great Britain	128	
	United Kingdom	350	
	United Kingdom AND Ireland	35	
Renewable energy	Northern Ireland	20	0

	Ireland	80	6
	Great Britain	8	
	United Kingdom	31	
	United Kingdom AND Ireland	3	
Mining and extraction:	Northern Ireland	30	2
	Ireland	235	25
	Great Britain	19	
	United Kingdom	88	
	United Kingdom AND Ireland	5	
Commercial development	Northern Ireland	11	0
	Ireland	58	4
	Great Britain	1	
	United Kingdom	26	
	United Kingdom AND Ireland	3	
Recreation	Northern Ireland	1	0
	Ireland	10	0
	Great Britain	2	
	United Kingdom	9	
	United Kingdom AND Ireland	1	
Tourism	Northern Ireland	7	0
	Ireland	49	2
	Great Britain	4	
	United Kingdom	25	
	United Kingdom AND Ireland	2	

Appendix 2: Identified Evidence

IPBES direct driver	Citations (in alphabetical order)	Summary of research
Land use	1. Anderson et al. (2009)	Research develops models to explain and predict Hen Harrier (*Circus cyaneus*, a species of conservation importance) distribution based on climate, habitat, and gamekeepers activity. It finds a direct link between hen harrier distribution and human interference and persecution, arguing that gamekeeper activity may be keeping hen harriers out of the most climatically suitable areas or keeping the population numbers too low and isolated for the natural re-expansion of the species. It notes that Hen Harriers are less dense in areas of human interference, even when habitats in those areas may be more suitable, and argues 'our paper provides further support for the view that illegal killing on grouse moors continues to be a major obstacle to improving the conservation status of the hen harrier in the UK' (p. 497).
	2. Bateman et al. (2013)	Builds on the UK National Ecosystem Assessment to examine land use change scenarios and consider multiple benefits of ecosystem services. To consider optimal land-use and the integration of ecosystem services within economic decision-making, Bateman et al. (2013) modelled several ecosystem service-related goods (agricultural production, greenhouse gas emissions and sequestration, recreation, urban green space, and wild-bird species diversity). Authors emphasise that 'land use in the UK is dominated by agriculture', which at the time of writing accounted for … '74.8% of the total surface area and includes not only cropland but also the majority of grassland, mountain, moor, and heathland habits' (p. 46). They found that 'land-use decisions based on market prices alone can reduce the overall value of the sum of agricultural and monetizable ecosystem services at the national scale' (p. 48) and argue that prioritising agricultural market values reduces overall values. Targeted planning, which incorporates all potential ecosystem services and their values can produce major gains and help conserve wild-species biodiversity. They proceed to outline principles for future land-use analysis and planning, which include a need for assessments to consider spatial and temporal variations in tandem with synergistic impacts like those between climate and land-use change. They conclude by advocating for ecosystem services to be placed on a level playing field with 'market-priced good' to contribute to sustainable use of the 'Earth's limited resources' (pp. 49-50).
	3. Brucet et al. (2013)	According to Brucet et al. (2013), freshwater ecosystems incorporate around 12% of the world's animal species, yet the biodiversity of such habitats is rapidly declining due to anthropogenic activities. They assess anthropogenic and natural factors that impact upon freshwater fish diversity, across 1632 lakes from 11 European countries (including NI, ROI and UK). Anthropogenic pressures like eutrophication were assessed by total phosphorus, land use (percentage of natural and agricultural land

		cover), and population density. Results from the study include a finding of decreased fish body size in lakes with enhanced eutrophication; results confirm that fish density is sensitive to some anthropogenic pressures, which are best assessed at local, rather than at a macroecological scales. At a macroecological scale, the strong effect of environmental temperature on most components of fish diversity suggests future changes in fish diversity as a consequence of climate change.
	4. Butler and Norris (2013)	Being cognisant of the intensity of global biodiversity loss and associations with agricultural changes that have driven biodiversity losses across Europe (where agriculture occupies around 50% of the land surface), Butler and Norris (2013) trialled a novel approach for understanding local biodiversity changes to better inform conservation strategies. Focused on the UK, they explored functional space composition as a method for understanding links between land-use, resource availability and population dynamics of 19 farmland bird species. They found that local population dynamics 'vary substantially between species', articulate positive and negative impacts, and emphasise the utility of examining the context-specific nature of land-use and species population (pp. 203-6).
	5. Byrne et al. (2013)	Refers to the implication of badgers *Meles meles* in the epidemiology of bTB in cattle populations with badgers being subsequently killed through culling regimes in areas with chronic histories of bTB cattle herd breakdowns. They examined the impacts of culling on the relative abundance of badgers and found 'significant reductions in badger density' and increases in dormant setts in areas where culling occurred.
	6. Cameron et al. (2004)	Provide a quantitative assessment of spider species across different habitat types in Northern Ireland. The loss of heath and wood leads to the loss of rarer and consequently greater value species. The potential diversity loss is associated with the conversion of natural or semi-natural habitats to agricultural land (species-poor grassland).
	7. Cooper et al. (2003)	This study by Cooper et al. (2003) examined broad habitat changes in Northern Ireland and found the greatest net area decreases were in Neutral Grassland (-32%), Arable and Horticulture (-25%), Fen, Marsh and Swamp (-19%), Bog (-8%) and Calcareous Grassland (-7%). From their perspective, the key biodiversity issue is the loss of seminatural Broad Habitat loss, which they attribute to agriculture, public and private forestry, building construction and peat cutting for fuel.
	8. Cooper et al. (2005)	Cooper et al (2005) shows biodiversity changes in abandoned peat cuttings in Northern Ireland, focusing on the Montiaghs Moss bog. The research found that when drain management ceased, it led to several significant changes in the habitat: a) increased surface acidification, b) reduction in open water habitats, and c) poor fen development. These habitat changes are particularly important for beetle species diversity, which experienced declines under the altered condition
	9. Cooper et al. (2008)	Examined vegetation development in second rotation Irish conifer plantations, offering insights into the long-term impacts of forestry practices on biodiversity. High density of native broadleaf trees (ash and

		sycamore) was recorded, mostly regenerated prior to first rotation harvesting. Large numbers of birch were found, mostly regenerated after harvesting. Several non-native broadleaf and conifer tree species had also regenerated. The abundance of ground flora species typical of Irish broadleaf woodlands declined with time from first rotation felling. Causes of ground flora decline included the clear-fell process, tree crop canopy development, and second rotation plantation restructuring. While this study was not conducted specifically in Northern Ireland, its findings are likely relevant due to similar forestry practices and ecological conditions across Ireland. Maintaining continuity of open-canopy tree crops is key for retaining biodiversity gains from the first rotation, especially for sites with established broadleaf woodland ground flora. Strategic forest planning decisions are crucial for achieving biodiversity conservation in managed forests.
	10. Davies et al. (2012)	Davies et al. (2012) signal a need for conservation management strategies to be extended to urban centres in order to preserve species, particularly as, globally, greater numbers of human populations settle in cities. Recognising the value of domestic gardens for biodiversity and human-wildlife interactions, their UK study examined socio-economic and demographic factors that influence whether or not households feed wild birds. They found that just 29% of households provided food once a week and, while they outline some benefits of bird feeding, they point to potentially detrimental effects like the spread of disease, loss of natural foraging behaviours and increased predation risk. In doing so, they illustrate a confluence of forces like urbanisation as a direct driver and indirect drivers associated with culture, income and age, which impact upon biodiversity change.
	11. Dool et al. (2016)	For woodland-associated bat species, such as *Rhinolophus hipposideros*, reduced gene flow is observed due to the impact of woodland fragmentation in Ireland. There are also risks of long-term isolation for small populations, including reduced genetic diversity, increased population differentiation, inbreeding, reduced population size, and predicted eventual extinction. The study highlights that habitat loss and degradation pose the most immediate threat to many biota among anthropogenic modifications to ecosystems.
	12. Douglas et al. (2023)	Douglas et al. (2023) examined how breeding waders like the Eurasian Curlew *Numenius arquata* respond to manipulation of habitat and predators. Recognising that loss and degradation of breeding habitat, along with predation, drives low Curlew breeding success, the authors trialled interventions at six sites across the UK, including Antrim in NI, and compared responses with reference site. They found positive responses for Lapwing but less so for Curlew or Snipe populations and they argue for landscape-scale intervention and policy changes to aid recovery of wader populations. They suggest a focus on anthropogenic causes of high mesopredator densities which impact wader populations, including forestry, landscape fragmentation for agriculture, livestock farming, and the extirpation of most apex predators.

	13. Drinan et al. (2013)	Explores macroinvertebrate assemblages of peatland lakes in order to assess conservation value with respect to anthropogenic land-cover change. Points to effects of conifer plantation forestry on small blanket bog lakes in Ireland; these lakes can harbour many rare and threatened aquatic invertebrate species. However, their conservation value is threatened by peat extraction and conifer afforestation.
	14. Eglington and Pearce-Higgins (2012)	Recognising how biodiversity pressures caused by habitat destruction and management intensification are 'responsible for substantial population declines, range contractions and species' extinctions' (p. 1) and are likely to worsen and be exacerbated by anthropogenic climate change, Eglington and Pearce-Higgins (2012) explored **land-use intensity** and **climate change** as drivers of species population declines in the UK. Drawing on forty-year time-series of national trends on the abundance of 18 farmland birds, land-use data, weather data (for Lancashire, London and Bristol), and species-specific models, they sought to disentangle the relative importance of land-use intensity and climate change as drivers of species population decline. The authors examined the annual estimates of abundance (1966–2008) for the grey partridge *Perdix perdix*, common kestrel *Falco tinnunculus*, northern lapwing *Vanellus vanellus*, stock dove *Columba oenas*, common wood pigeon *Columba palumbus*, European turtle dove *Streptopelia turtur*, western jackdaw *Corvus monedula*, skylark *Alauda arvensis*, common whitethroat *Sylvia communis*, common starling *Sturnus vulgaris*, Eurasian tree sparrow *Passer montanus*, yellow wagtail *Motacilla flava*, European greenfinch *Carduelis chloris*, European goldfinch *Carduelis carduelis*, common linnet *Carduelis cannabina*, yellowhammer *Emberiza citrinella*, common reed bunting *Emberiza schoeniclus* and corn bunting *Emberiza calandra*. They found that farmland bird populations have fluctuated due to annual variations in both land-use intensity and weather. Annual changes in 10 of the 18 species were significantly correlated with at least one of the three land-use variables (cereal yield, cattle herd, sheep herd); annual changes in populations of 9 species were significantly related to weather variables, of which minimum temperature was the most important. While the authors state there is increasing evidence of climate change impacting bird populations (positively and negatively)' 'changes in land-use intensification … will continue to be the major driver of population change in these species' (p. 6). They also conclude that improving land-use practices for bird populations can help counter negative climate change impacts and contribute to 'effective climate change adaptation for biodiversity' (*ibid*.)

	15. Evans et al. (2011)	Concentrated on urban birds, assessing impacts of urban development which they posit as a 'major threat to biodiversity' (p. 32). Illustrating connections between indirect and direct drivers of biodiversity change, including human population growth, socio-economic factors that prompt people to move from rural to urban areas, increasing numbers of single person households, and growing demand for low-density housing, the authors articulate three key reasons why increased urban development has negative impacts on biodiversity, as follows. (1) urbanisation tends to occur in areas with large numbers of people, contributing to conservation conflicts because human population density is correlated with species richness; (2) land used for housing development tends to be more 'ecologically valuable than undeveloped areas'; (3) fewer native species are found in developed urban areas than in the rural areas replaced by urban areas, even if such species are present in nearby rural areas (*ibid.*). Using data from sources like the National Breeding Bird Survey (BSS), a comprehensive dataset of avian densities in rural and urban areas, the research examined how different bird species are affected by urbanisation. Similar to Gaston and Evans (2010), their finding included: specialist bird species had lower urban densities than more generalist bird species; ground-nesting birds had lower urban densities than birds that do not nest on or close to the ground, likely due to higher predation rates experienced by ground nesting birds; urbanisation favours species that feed on plant resources and nest above the ground. They concluded that habitat management, encouraging provision of a wide range of supplementary foods, and improving the suitability of urban areas for ground-nesting species (including both habitat creation and management of predation risk by species such as domestic cats) can increase urban avian biodiversity.
	16. Evans, Gibson and Rossell (2006)	There are indirect and cumulative effects of various land management practices on biodiversity, particularly for sensitive species like salmon, in Northern Ireland. Sediment loads in the river Bush, a prime salmon habitat in Northern Ireland, demonstrates the significant impacts of bank erosion and drainage maintenance work, accounting for 90% of the sediment load (60% and 30% respectively) (Evans et al. 2006). In addition, forest clearfell and ploughed land contributes to the annual suspended sediment and bed load. This implies that increased sediment load can have severe impacts on aquatic ecosystems, particularly for sensitive species that require clean gravel beds for spawning.
	17. Feeney et al. (2023)	Land use and the provision of countless ecosystem services and goods are ultimately underpinned by soils, which are under 'unprecedented threat' due to global challenges like climate change and increasing production and consumption of food, fibre and fuel (Feeney et al. 2023, p. 2). Involving researchers from the UK Centre for Ecology and Hydrology and the Environment Agency, Feeney et al. (2023) suggest that around 60-70% of Europe's soils are unhealthy and they describe their endeavours to establish soil health benchmarks for managed and semi-natural landscapes in GB (excluding NI), across a breadth of soils and land uses. The authors outlined benchmarks that encompass 'physical, chemical and biological aspects' of soil health, including measures of soil organic matter, pH levels,

		bulk density, and earthworm abundance. They illustrate marked variations in soil health across 'habitat, soil type and rainfall', revealing that 'habitat was the single most important control on soil properties', followed by soil then mean annual rainfall (pp. 4-11). Soil bulk density and pH tended to decrease in proportion to management intensity (agriculture > semi-natural grasslands > woodlands > heathlands > wetlands) and earthworm abundance, deployed as a measure of biodiversity, was higher when land-use shifts to less intense forms (e.g. EA was higher in modified/improved grassland above arable and horticulture). In other words, soil health tended to be poorer in areas with intensive agriculture, with the caveat that the study did not include urban and built-up areas, coastal ecosystems, heavily industrial soils and deep peats. Nevertheless, this study is valuable because soil health is recognised as 'the continued capacity of the soil to function as a vital living ecosystem that sustains plants and animals, environmental quality and human needs' (p. 2) and it establishes novel benchmarks to assess soil health while demonstrating key interconnections between biodiversity, patterns of land use, and climate change.
	18. Finch et al. (2023)	Finch et al. (2023) examine the demography of the Common Swift *Apus apus*, which like many insectivorous birds, is experiencing population declines (there was an estimated 57% reduction in abundance of swifts between 1995 and 2017 in the UK). The loss of nesting sites, in tandem with reductions in the reductions in the abundance and availability of insect prey, are held as some factors driving population decreases and Finch et al. studied demographic and environmental drivers, with a particular focus on weather and aphid biomass. Their data suggested that falling first-year survival of Swifts is connected with increased precipitation, and associated impacts such as smaller brood size and higher nest failure, thus driving population decline. They recommend that conservation efforts focus on ensuring provision of safe and productive nesting sites and they advocate for further research on habitat and land management practices that offer foraging resources, particularly during inclement weather.
	19. Firbank et al. (2013)	Firbank et al. (2013) considered whether 'sustainable intensification' of food production might be an appropriate response to food shortages and ongoing environmental degradation. Using data on a mix of farms (arable, dairy, mixed, upland) gathered between 2006-2011, Firbank et al. found that several farms increased both food production and other ecosystems services through actions like using resources more efficiently and/or enhancing biodiversity, sometimes reducing livestock numbers and increasing cropping. However, farmers who increased meat or milk production did not achieve 'sustainable intensification' and the authors point to the need for correct drivers to influence individual farmers.
	20. Franks et al. (2017)	Examined the Eurasian Curlew *Numenius arquata,* considering environmental factors that impact upon the species' breeding abundance and population change in Britain. Utilising data from 1995 – 2011, they found negative associations between arable farming, woodland cover and Curlew abundance and population declines and argue that improved

		breeding habitat quality and effective site protection may be important conservation measures.
	21. Gaston and Evans (2010)	A peer-reviewed book chapter by Gaston and Evans (2010) illustrated dramatic demographic shifts over 50 years in the UK which contributed to, at the time of writing, over 90% of the British population living in urban areas that were estimated to account for 7-10% of the UK's total land use surface. As Britain became more urbanised, green space within urban areas declined and became more fragmented. Acknowledging the complexity of consequences for wildlife, they highlight how substantial areas of natural and semi-natural habitats were lost, and that the richness and abundance, particularly of more specialist and previously narrowly distributed species associated with these habitats, declined. They refer to significant declines in some bird populations (Starling, House Sparrow, Blackbird, Robin and Swift), large moths and bats, yet recognise that some species benefitted from urban environments, including Peregrines, *Falco peregrinus*, the Collared Dove, *Streptopelia decaocto* and invasive species like Harlequin Ladybird, *Harmonia axyridis* and the Grey Squirrel*, Sciurus carolinensis.* Their research illuminates ecological challenges presented by urbanisation and recognise that 'many species will undergo marked declines', while also acknowledging how patterns of human settlement inherent to urbanisation can be more beneficial in terms of lower per capita demands on resources.
	22. Griffith et al. (2012)	Argues that the loss of semi-natural grasslands in Europe, mainly through ploughing, reseeding and inputs of synthetic fertilisers, has contributed to a 'severe reduction in the diversity and abundance of grassland macrofungi.' They conducted a field experiment at a grassland site known to contain diverse populations (>50 species) of grassland fungi and tested the effect of sward height on macrofungal fruiting. They trialled different sward management techniques to aid species richness and fruitbody numbers and subsequently advocated for leaving areas initially uncut, followed by haycutting. then maintenance of a short sward, a regime that would benefit diversity of other grassland plans and invertebrates.
	23. Hanmer et al. (2022)	Hanmer et al. (2022) warn about some unanticipated consequences of supplementary feedback of wild birds due to the spread of the protozoan parasite, *Trichomonas gallinae*, from columbids to finches, which has led to epidemic finch trichomonosis and a rapid population decline of greenfinch (*Chloris chloris*). Chaffinch (*Fringilla coelebs*) numbers have also declined markedly from the second to fifth most common bird in Britain. Based on citizen science data and post-mortem examinations, Hanmer et al. uncover declines in both greenfinch and chaffinch populations with the greatest declines occurring in peri-domestic habitats where birds are often given additional food by humans. Indeed, their research shows increases in chaffinch trichomonosis cases proportional to its population decline and they argue that their research provides evidence that supplementary feeding can contribute to parasite transmission, thereby necessitating disease mitigation strategies to ensure that any benefits offered through supplementary feeding are not outweighed by risks such as *T.gallinae* infection.

	24. Hayhow et al. (2013)	Changes in habitat use are thought to impact hen harrier populations in Northern Ireland, which showed a marginal decline (less than 10%) between 2004 and 2010. However, there was a major change in habitat use by hen harrier. In 2004, 33% were found on heather moor and 37% in mature conifer plantations. While 33% were still on heather moor in 2010, 55% were found in young plantations, with only one record in mature plantation (Hayhow et al 2013).
	25. Henderson et al. (2002)	Henderson et al. (2002) who looked at population estimates, trends and habitat associations of breeding Lapwing *Vanellus vanellus*, Curlew *Numenius arquata* and Snipe *Gallinago gallinago* in Northern Ireland in 1999. Their work demonstrates how successful conservation requires a countryside-wide approach, not just attention at key sites, and they warn that intensive pastoral farming in upland and lowland areas, along with activities like peat extraction and drainage, further reduces the suitability of open habitats for those vulnerable wader species.
	26. Isermann and Rooney (2014)	Presents an account of Sea Holly *Eryngium maritimum* and states that it is one of the most threatened and rarest plants, largely due to habitat loss and land-use changes.
	27. Lintott et al. (2016)	Offers insights into impacts of urbanisation on bat species in Great Britain. Two cryptic bat species, *Pipistrellus pipistrellus* and *Pipistrellus pygmaeus*, respond differently to urban environments despite both being generally well-adapted to human-modified landscapes. While this study is not specific to Northern Ireland, this finding suggests the need for species-specific consideration in urban planning and conservation efforts.
	28. Lundy and Montgomery (2010a)	Lundy and Montgomery undertook a multi-scale analysis of habitat associations of the European Otter and American Mink, focused on the riparian environment along fifty hydrologically independent rivers, randomly selected across Northern Ireland's seven major basins. Both species, Otter (*Lutra lutra*) and Mink (*Neovison vison*), were positively associated with increased habitat diversity, the provision of natural land cover and a reduced level of urbanisation. Interested in establishing relationships between species occurrence and environmental variables, the authors found that habitat improvements were seen more quickly in Mink, a non-native pest species, rather than the native Otter, and they conclude by emphasising the importance of scale in animal ecology and consideration of specific pest species monitoring and management within effective conservation schemes.
	29. Lundy and Montgomery (2010b)	Highlighted how agricultural intensification has occurred at the expense of biodiversity, the authors explore features which promote bat feeding in agricultural riparian areas (agriculture estimated to constitute 75.7% of total land area, with permanent grassland representing 81.6% of agricultural land use). Focusing on Nathusius' pipistrelle (*Pipistrellus nathusii*), common pipistrelle (*Pipistrellus pipistrellus*), soprano pipistrelle (*Pipistrellus pygmaeus*), Leisler's bat (*Nyctalus leisleri*), and Myotis species (*Myotis sp*.), Lundy and Montgomery 2010b found that feeding activity of bat species was positively associated with lower levels of agricultural intensity, the provision of natural land cover, and riparian hedgerow

		abundance; feeding activity was negatively affected by high-intensity farming.
	30. Mathews et al. (2015)	Demonstrates species-specific responses to urban environments, such as artificial night-lighting, in Ireland. While *Nyctalus leisleri* shows a positive association with street lighting, contrasting with the general trend, *Pipistrellus pipistrellus* exhibits a negative association with the amount of built environment.
	31. McCann et al. (2017)	Examines drivers of change for hedge habitats, emphasising that agricultural intensification, increased rural building and variation in hedge management are the main drivers of change. They make a direct connection between building construction and hedgerow habitats, evidenced by hedge loss of 4.6% between 1998 and 2007 that occurred alongside a building increase of 30.35% in the sampled area. Indirect effects of development on biodiversity include the introduction of non-native species into hedgerows.
	32. McCarthy et al. (2021)	The authors focused on the landscape and temporal influences on the winter diet of the Hen Harrie*r Circus cyaneus,* a threatened diurnal raptor. The common snipe is an important component of hen harrier diet, particularly in lowland inland and upland areas. This implies that protecting and maintaining wet, open habitats is crucial for preserving suitable conditions for both hen harriers and their prey species.
	33. McCollin and Geraghty (2015)	A comprehensive all-island study also identified the intensification of agriculture as the most significant driver of floristic change across the island of Ireland. This agricultural intensification has led to a notable decline in archaeophytes and species typical of nutrient-poor soils. The general trend indicates the intensification and specialisation in land use across the island.
	34. McElarney et al. (2010)	According to McElarney et al. (2010), commercial forestry is the second largest land-use category in Northern Ireland with the majority of forests across the island comprising non-native conifer trees. Management of commercial forests produces elevated concentrations of phosphorous (P) in lakes, beginning with P fertilisation during planning, P-loss at felling, and the poor P-binding capacity of upland peat soils, which can contribute to eutrophication (McElarney et al, 2010). Their study concentrated on aquatic macrophytes in twelve lakes across NI that had different levels of catchment to commercial forests. They found that macrophyte species richness and abundance declined in lakes with trees harvested in their catchment and imply that the isoetid flora of softwater Northern Irish lakes is declining, specifically *Littorella uniflora* a species vulnerable to eutrophication and acidification.
	35. McKenzie et al. (2011)	Looked at some consequences of agricultural development, specifically the ecological impacts of rural buildings on habitats within agricultural settings in Northern Ireland. Between 1998 and 2007, rural buildings increased by 30.4% to encompass 5.2% of NI whilst the number, area and edge density of building patches also increased. They found that building was mainly on productive agricultural grassland yet other habitats were also built over,

		including broadleaf seminatural woodland and species-rich grassland habitats, specified by the European Habitats Directive as important for their biodiversity. The authors concluded that land use planning policy and practice does not sufficiently protect habitats and they call for a consistent rural development strategy that would facilitate habitat protection and associated ecosystem services.
	36. Miler et al. (2015)	Considered human lake shore alterations and their impacts upon macroinvertebrates in 51 lakes across 7 countries and 4 geographical regions of Europe (Northern, Western, Southern and Central Europe), offering a method to assess hydro-morphological pressures upon lakes to aid conservation of invertebrate communities.
	37. Miller et al. (2017)	Explores interactions between weather and land-use in terms of nest success of the common blackbird (*Turdus merula*). Using data from a large citizen science dataset, the authors explore the impact of laying dates, weather conditions, conserved soil moisture, soil carbon, habitat type and urbanisation on nest failure rates. They found that daily blackbird survival probabilities were higher in human rural habitats, than in urban or countryside habitats, and suggest that such intermediate habitats offer a balance between low food availability in urban areas and higher predation rates in the wider countryside. They also point to evolving impacts of climate change which may alter interconnections between breeding success and habitat.
	38. Milne et al. (2020)	The impacts of land use change upon badgers transcend direct and indirect drivers of biodiversity change and is a contentious matter. Due to agricultural intensification and use of land for livestock, the native Eurasian badger *Meles meles* has come into greater contact with bovines. Badgers are frequently perceived, by some agricultural stakeholders, as being a primary host and reservoir of bovine tuberculosis (bTB), which is caused by the bacterium *Mycobacterium bovis*. In turn, badgers are often persecuted and blamed for transmission of bTB to cattle, despite some research to the contrary. Milne et al. (2020) examined bTB in cattle herds, specifically those impacted by prolonged breakdowns despite controls on herds with positive bTB results. The authors undertook a retrospective observational study to better understand the factors associated with breakdown duration and found six explanatory variables that were important predictors of breakdown length; herd size, the number of reactors testing positive, the presence of a lesioned animal at routine slaughter, the count of *M. bovis* genotypes during the breakdown, the local herd-level bTB prevalence, and the presence of herds linked via management factors (associated herds). The count of genotypes (MLVA richness variable) was a 'particularly important predictor of breakdown duration' and the authors contended that the variable represented a proxy for beef fattening herds, which despite trading restrictions, can entail the purchase of cattle and sale of animals straight to slaughter. They found that in other herd types, prolonged breakdowns can be due to residual infection within the herd and infection from the environment (e.g. infected wildlife, contiguous herds

		and/or a contaminated environment), however, the contribution of badgers to prolonged breakdowns was not clear in the study.
	39. Montgomery et al. (2020)	Revealing the many functions of hedgerows in rural and urban settings, Montgomery et al. (2020) describe hedgerows as ecosystems with above- and below- ground components and identify key functions related to biodiversity, soil and water conservation, carbon sequestration. They highlights issues like hedgerow removal due to agricultural intensification and argue for the establishment of a minimum hedge width and longer intervals between hedge cutting that would aid biosecurity, promote carbon sequestration and help biodiversity.
	40. O'Mahony (2017)	Found that pine marten distribution is positively associated with the extent of conifer forest landcover types and is negatively associated with open areas, dwarf vegetation areas, and urban areas. The key finding suggests the importance of evaluating the availability of denning sites in carnivore conservation and provide valuable management considerations, key to mitigating human-wildlife conflict as carnivores continue to recover and recolonise the area.
	41. O'Mahony, O'Reilly and Turner (2012)	This cross-jurisdictional study offers insights into the distribution and abundance of pine martens across Ireland, including specific findings for Northern Ireland. Pine martens in Ireland exist at the western edge of their global range, in Europe's least forested region. The research found an occupancy rate of 56.7% in Northern Ireland and relative population density in western areas. Little or no evidence of recent expansion from core population areas (18% of land area) was found, despite increases in forest cover and full legal protection. The population abundance was estimated at approximately 320 individuals and the authors concluded that the pine marten is one of the rarest wildlife species in Ireland, hence it has greater conservation value.
	42. Plummer et al. (2015)	Centring on links between supplementary feeding and evolutionary change, Plummer et al. (2015) provide intriguing evidence about how one bird species has responded to climate change and food availability. Opening with a statement about how human activities are driving rapid, global environmental change, the author state that urbanisation is responsible for extreme human-altered habitats and contribute to evolutionary change. They focus on the Eurasian blackcap *Sylvia atricapilla*, which have been wintering in urban areas of Britain with increasing frequency over the past 60years, rather than migrating south to the Mediterranean. The researchers utilise a long-term national scale data set and illustrate how, over a 12 year period, blackcaps are increasing associated with supplementary food provision in urban gardens and that the reliability of bird food influences their winter distribution, nationally. Furthermore, local climate conditions also determine blackcap wintering patterns and they conclude that a new wintering population of blackcaps has been established due to the synergistic effects of increased garden bird food availability and climate change, presenting evidence on the role of human activities in evolutionary change.

	43. Reid et al. (2012)	Explored changes in the prevalence of badger persecution in Northern Ireland, pointing to historically high levels of badger persecution in NI than GB, despite legislative protection for the species. The found that over a 14-18 year period (1990-1993, 2007-2008), the rate of disturbance of badger setts in NI (which suggests illegal persecution) had declined yet the overall badger population remained stable, compared with growing populations in GB. They suggest that the prevalence of persecution may not be the only factor impacting badger population dynamics and they identify other potential factors, like climate, habitat composition and structure, farming practices or food availability, that can affect population trajectories and explain greater badger abundance in GB compared to NI.
	44. Reid, McDonald and Montgomery (2007)	Focusing on agri-environment schemes (AES) designed to foster land-scape improvements in biodiversity, Reid, McDonald and Montgomery (2007) evaluated NI's Environmentally Sensitive Area (ESA) scheme through a survey of the relative abundance of three mammal species, Irish hare *Lepus timidus hibernicus*, European rabbit *Oryctolagus cuniculus* and red fox *Vulpes vulpes*. Of the three species, the hare is considered a priority species for conservation action while the rabbit and fox are often regarded as agricultural pests. The ESA scheme did not target the landscape and habitat variables associated with hares and had no demonstratable effect on the abundance of the species. In contrast, the abundance of foxes and rabbits increased, suggesting that AESs may benefit common species but not rarer species like the Irish Hare.
	45. Reid, McDonald and Montgomery (2010)	The authors connect widespread declines of hares in agricultural landscape with habitat loss and agricultural intensification. They examine the habitat heterogeneity of the Irish hare (*Lepus timidus hibernicus*) in a pastoral landscape, finding that hares occupy a heterogeneous mix of rough pasture and improved grassland during the autumn, winter and spring. However, in summer, hares tend to use improved grassland more frequently which could function as a risky habitat for the species as their peak birthing period occurred during silage harvesting season, thereby illustrating how such a homogenous habitat could function as an ecological trap for the species at a critical time of year.
	46. Russ and Montgomery (2002)	Argues that agricultural intensification in Northern Ireland has had a detrimental effect on biodiversity due to large-scale changes to the landscape. Their research centred on several species and species groups of bats, including *Pipistrellus pipistrellus*, *Pipistrellus pygmaeus, Nyctalus leisleri*, and *Myotis* species (considered as a single group in the research). They found that bats strongly selected water bodies with bankside vegetation, treelines, and deciduous and mixed woodland edge, and avoided open areas like upland/unimproved grassland and improved grassland. In their view, bat populations are likely to be affected by reductions in area, quality of inland water, deciduous woodlands and field boundaries and they argue that habitat management should focus on improving those habitats elected by bats and include the maintenance and enhancement of connecting linear habitats.

	47. Thomas et al. (2020)	The UK Countryside Survey (CS) is a national long-term survey of soils and vegetation that spans three decades (1978–2007), which the authors use to examine changes in topsoil organic carbon (tSOC) resulting from land use change, and construct mixed models to describe the impact of indirect drivers where land use has been constant. Where it occurs, land use change is a strong driver of SOC change, with largest changes in tSOC for transitions involving SOC-rich soils in upland and bog systems. Afforestation did not always increase tSOC, and the effect of transitions involving woodland w.as dependent on the other vegetation type. The overall national spatial pattern of tSOC concentration where land use has been constant is most strongly related to vegetation type and topsoil pH, with contributions from climate variables, deposition and geology. Comparisons of models for tSOC across time periods suggest that declining SO4 deposition has allowed recovery of topsoils from acidification, but that this has not resulted in the increased decomposition rates and loss of tSOC which might be expected. As a result, the relationship between pH and tSOC in UK topsoils has changed significantly between 1978 and 2007. The contributions of other indirect drivers in the models suggest negative relationships to seasonal temperature metrics and positive relationships to seasonal precipitation at the dry end of the scale. The results suggest that the CS approach of long-term collection of co-located vegetation and soil biophysical data provides essential tools both for identifying trends in tSOC at national and habitat levels, and for identifying areas of risk or areas with opportunities for managing topsoil SOC and vegetation change.
	48. Twining et al. (2020)	Evidence of the impacts of landscape modification on the pine marten in Northern Ireland is provided in this article, which demonstrates landscape change-induced differences in behaviour and population structure of the pine marten in two contrasting landscapes: a) a semi-natural wooded landscape and b) a human-modified landscape with limited forest cover, composed mainly of conifer plantation.
	49. White et al. (2019)	Used a variety of research methods to examine the impacts of human modified landscapes (pasture-dominated, heterogeneous, and non-pasture-dominated) upon Irish vascular plants. They found that species richness decreases with increasing productivity, especially at higher productivity levels.
	50. Whitehouse (2006)	Examined the colonisation, dispersal and decline of ancient beetle species in GB and Ireland, referring to the local extirpation of up to 40 species in Britain and 15 species in Ireland and the role of human activities such as forest clearance and wood rafting.
Resource use and exploitation	1. de Castro et al. (2022)	Examined fishing and how trawling effects the spatial distribution of certain fish and influences their ranging behaviour. The findings suggest that fishing leads to micro-evolution of species and that if fishing is consistently correlated with (heterogeneous) habitat quality and fish differ in a heritable ranging trait, fishing may create an evolutionary selection pressure favouring fish with more sedentary ranging behaviour.
	2. Isaksson et al. (2020)	Isakson et al. (2020) outlines tensions between protecting marine wildlife, including seabirds, when seeking to increase ‘green energy’ through tidal

		stream renewable energy. They offer a conceptual framework to assess the effect of tidal steam energy devices on seabirds.
	3. Joy et al. (2018)	Exploring marine renewable energy from underwater tidal turbines, Joy et al. (2018) examined the SeaGen tidal turbine in NI and researched risks for harbour seals, taking into account turbine characteristics, tidal state and seal behaviour. They found 68% spatial evidence by harbour seals with 200m of the turbine and when they accounted for variation across depth and tidal flows, there was a 90% reduction in collision risk for seals.
	4. Le Joncour, et al. (2023)	Found that some sensitive species like sea pens were indicators of areas with less trawling disturbance, while mobile species like fish and Nephrops were associated with heavily trawled areas. The results highlight how fishing can shape benthic community composition and influence the distribution of vulnerable marine ecosystems versus commercially harvested species in these soft-sediment habitats.
	5. Neat et al. (2014)	Warns that commercial fisheries unintentionally risk depletion of local fish populations, such as Atlantic Cod *Gadus morhua*, a species that has historically been overexploited around the British Isles. Their research shows variations among cod from different offshore areas and highlight how differences in thermal experiences (living in colder and less variable waters) contributed to variations in physiology, growth rate, and the ability of the species to respond to climate change. Such variations need to be considered to avoid future exploitation of cod stocks around the British Isles.
	6. Nordbeck and Hogl (2024)	Nordbeck and Hogl (2024) outlined key aspects and challenges associated with peatland strategies in Austria, England, Germany, Finland, Ireland, Northern Ireland, Scotland, and Wales. They emphasise growing commitment to sustainable peatland management in Europe because of wider recognition that peatlands are globally important ecosystems with ramifications for climate change and biodiversity loss. Nevertheless, they identify ongoing challenges surrounding cross-sectoral policy integration.
	7. Searle et al. (2022)	Drawing attention to threats to seabirds posed by climate change and marine renewable energy development, Searle et al. (2022) reveal tensions between legal obligations to increase renewable energy juxtaposed with detrimental impacts on wildlife, especially species already experience climate change related declines. They argue that climate change will have significant ramifications for future seabirds breeding success of in the North Sea, an area which is experiencing rapid offshore renewable energy development, and they recommend methods to consider impacts of climate change and seabird breeding success within assessments for offshore renewable developments
	8. Smyth et al. (2016)	Smyth et al. (2016) examined different methods to help conservation and recovery of the overexploited native oyster (*Ostrea edulis*) in Strangford Lough, finding that strategic site selection for the re-introduction of important shellfish species can significantly accelerate their recovery and restoration.

	9. Smyth, Murphy and O'Brien (2009)	Smyth, Murphy and O'Brien (2009) set the context for their discussion on biofuels by referring to links between habitat destruction and biofuel generation in other countries. They suggest that grass could serve as a source of biomethane to fuel Irish cars, without habitat destruction, land use change, new farming practices or annual tilling. However, no attention is paid to the ecological consequences of continued or enhanced growing of a mono-culture for such purposes.
	10. Thomas et al. (2020)	Illuminates complex interactions between land use change, climate and pollution through a study of topsoil organic carbon in different habitat types. Drawing on data from the UK Countryside Survey (1978-2007), they found that land use change is a strong driver of soil organic carbon change, particularly in upland and bog systems, afforestation may not increase topsoil organic carbon, and vegetation types in woodland affect transitions.
	10. Thorstad et al. (2021)	Makes clear how most of the threats to wild salmon arise from human activities. They illustrate the decline in Atlantic salmon populations and argue that strategies to promote strong, healthy and resilient wild populations should entail the highest number of wild smolts leaving from rivers and coast areas, with improved water quality and habitats, to the ocean. They add that increased marine survival entails reduction of human activities and impacts of aquaculture.
	11. Van Denderen et al. (2022)	Acknowledging how vulnerable marine ecosystems are very susceptible to bottom-fishing, due to being easily disturbed and slow to recover, Van Denderen et al. (2022) propose a policy-based framework to help protect those ecosystems.
	12. Winfield (2016)	Winfield (2016) offers an alternative view on fishing by virtue of attention to the natural capital and ecosystem services associated with recreational fishing. Threats to recreational fisheries include overfishing, physical habitat modification, acidification, chemical pollution, eutrophication, endocrine disrupters, nanoparticles, species introductions, and climate change, yet Winfield also suggests grounds for optimism in the future.
	13. Yates and Schoeman (2013)	Proposes methods of participatory mapping with stakeholders like the fishing community to improve marine management and accommodate conflicting needs, referring to a positive case in Northern Ireland that involved over 100 fishers.
Climate change	1. Burton et al. (2010)	Examines population declines in waterbirds and seabirds in the Severn Estuary and Briston Channel and outline a series of issues that have impacted the area's bird populations. Factors include climate change, the legacy of the Sea Empress oil-spill, conflicts related to cockle and mussel fisheries, and estuarine habitat loss; they also discussed potential impacts of the construction of a tidal power scheme on the Severn Estuary.
	2. Coll et al. (2016)	Modelled projected climate change impacts on upland heaths in Ireland, noting that heathland habitats across the island are mainly within oceanic settings strongly influenced by climate change. They suggested that new habit formation is unlikely due to current and near-future land use and other conditions.

	3. Helbig et al. (2022)	Focuses on peatlands and recognises their importance as carbon dioxide sinks and for global climate cooling effects. However, rapid warming at Northern latitudes can disturb peatlands' sink function and their research on 20 northern peatlands shows complex net CO_2 sink responses that vary across seasons; variations which are important to understand future global warming and carbon sequestration capabilities
	4. Powney et al. (2010)	Using three butterfly species (*Maniola jurtina, Pyronia tithonus* and *Aphantopus hyperantus*), the authors investigated the effects of habitat similarity and range position on population synchrony (defined as correlated fluctuations in the density of separate populations), after accounting for the effects of distance and climate. Concludes that habitat modification and climate change have the capacity to drive changes in population synchrony that could make species more vulnerable to extinction.
	5. Reid et al. (2021)	Outlined the impacts of historical climate and agricultural change on populations of *Lepus timidus hibernicus*, outlining distinct regime shifts across the 20th Century. They warn that increasing effects of climate change and possible agricultural expansion could disrupt these populations and impact ecosystem functioning.
	6. Simpson et al. (2011)	Assessed the impacts of climate change, specifically warming seas, on the commercially important European continental shelf fish assemblage using a data-driven Eulerian (grid-based) approach that accommodated spatial heterogeneity in ecological and environmental conditions. Analysis highlights the importance of focusing on changes in species. abundance in established local communities to assess the full consequences of climate change for commercial fisheries and food security.
	7. White, Montgomery and Lennon (2018)	Describes changes in species distribution through local extinction and colonisation of British birds as a major consequence of climate change. Their research suggest that different species traits account for varying impacts and the results help deepen knowledge of mechanisms underpinning change in species occupancy due to climate change.
Pollution	1. Dillon et al. (2012)	Assesses the application of entomopathogenic nematodes (EPN) to coniferous tree stumps in a forest ecosystem in which pine weevils *Hylobius abietis* breed, as way a mechanism to reduce the pest without use of chemical pesticides. Finds EPN can suppress *H. abietis* populations with 'negligible' risks to non-target beetles.
	2. Foy, Lennox and Smith (2001)	Examined water quality in 42 streams in the Colebrooke and Upper Bann catchments in Northern Ireland from 1990 to 1998, showing the impacts of agricultural practices on aquatic ecosystems. The research assessed the effectiveness of regulatory controls on farm pollution using chemical and biological indices of water quality and pollution statistics. Despite ongoing pollution control measures, biological water quality, as measured by the invertebrate average score per taxon (ASPT) index, did not improve over the study period. There was no appreciable decline in recorded farm

		pollution incidents. Chemical water quality showed some improvements, suggesting a decline in point-source farm pollution after 1990. The lack of improvement in biological indicators may reflect the limited time scale for biological recovery. The high pollution capacity of manures and silage effluent means that even reduced numbers of farm pollution incidents can severely disturb stream ecosystems. The intractable nature of farm pollution suggests the need for an interactive approach to problem resolution involving both farmers and regulators.
	3. Morecroft et al. (2009)	Review identified major trends in physical, chemical and biological data between 1993 and 2007 at 12 terrestrial sites in the United Kingdom Environmental Change Network (ECN) and assessed the effectiveness of the programme. Temperature and precipitation increased and sulphur (S) deposition decreased across the network. There were also significant local trends in nitrogen (N) deposition. The decreasing S deposition was associated with increasing pH of rainfall and soils and there was widespread evidence of soil pH showing recovery from acidification. Warm-adapted butterfly species tended to increase at northern, upland sites, consistent with an effect of increasing temperatures. In contrast, carabid beetle species associated with cooler northern and upland areas showed declining populations. The increasing trend in precipitation may account for a decline in ruderal plant species in the lowlands, reversing an increase associated with drought in the early part of the time series. There was no general shift in the composition of plant communities which might reflect rising soil pH. This may reflect the slow dynamics of plant community processes or a distinction between pH trends at the surface and lower soil horizons.
	4. Sier and Monteith (2016)	Provided a brief history of the UK Environmental Change Network (ECN), as a set of sites at which sustained observations relevant to a range of ecological indicators and environmental parameters could be made. They state that, in its first two decades of operation, the ECN has accumulated a robust set of baseline data that describe environmental and biological variability across a range of habitats in unprecedented detail. With appropriate, informed development, these should prove invaluable in discerning the causes and consequences of environmental change for decades to come.